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НАУКА, ТЕХНОЛОГИИ И БИЗНЕС

IV МЕЖВУЗОВСКАЯ КОНФЕРЕНЦИЯ АСПИРАНТОВ, СОИСКАТЕЛЕЙ И МОЛОДЫХ УЧЕНЫХ

Москва, 27–28 апреля 2022 г.

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В сборник вошли тезисы докладов и сообщений на английском, немецком и русском языках, сделанные на IV Межвузовской конференции аспирантов, соискателей и молодых ученых, состоявшейся 27–28 апреля 2022 г. Обсуждаются вопросы, связанные с научными исследованиями, проектно-конструкторскими и методическими разработками, экспериментальными работами в области биомедицинских и машиностроительных технологий, радиоэлектроники и лазерной техники, специального машиностроения, робототехники и автоматики, информатики, систем управления, инженерного бизнеса и менеджмента, а также прикладной лингвистики.

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Регистратор физиологических параметров служебной собаки

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Расчетные и экспериментальные исследования технического проекта регистратора физиологических параметров служебной собаки для выявления «ложных посадок» собаки в процессе поисковой деятельности с помощью регистратора электрокардиограммы (ЭКГ) и импеданса с единой тетраполярной электродной системы. Работа устройства основана на синхронном детектировании сигналов на аналогово-цифровом преобразователе. Это позволяет разделять ЭКГ-сигнал и импедансный сигнал непосредственно на аналогово-цифровом преобразователе без использования детектора, что минимизирует габариты устройства.

Ключевые слова: *поисковая деятельность, импеданс, служебная собака, дыхание, электрокардиограмма*

Recorder of Physiological Parameters of a Service Dog

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Computational and experimental studies of the technical design of the registrar of physiological parameters of a service dog to identify "false landings" of a dog in the process of search activity using an electrocardiogram recorder (ECG) and impedance with a single tetrapolar electrode system. The operation of the device is based on synchronous detection of signals to an analog-to-digital converter. This allows you to separate the ECG signal and the impedance signal directly to the analog-to-digital converter without using a detector, which minimizes the dimensions of the device.

Keywords: *search activity, service dog, impedance, respiration, electrocardiogram*

Most traditional aviation security systems are designed only to detect alarms and collect information about events; another distinguishing feature of such systems is their permanent placement at airport facilities. The above circumstances affect the degree of objects protection and increase their vulnerability due to the short response time to alarms. In addition, permanently located security facilities, as well as their technical characteristics known to a wide range of people, make it much easier for trained criminals to overcome the defense lines. One of the methods of strengthening existing aviation security systems is the use of canine groups with police dogs trained to detect explosives. Among all 200 civil airports in our country, only 10 have a cynological service, and the largest of them is that of Aeroflot.

But the use of dogs is hindered by a number of circumstances that reduce the effectiveness of their work, in particular, the dependence of the quality of the work of dogs on environmental conditions, the limitation of continuous work of the dog to only 20 minutes, and a lack of an objective control of the results of its work. The worst thing that can happen is a “false dog sitting”. When the dog is tired of looking, it can “trick” the dog handler and falsely identify explosives. In case of just one event like this you have to cordon off the entire airport terminal [1].

The optimal solution is to combine the unique olfactory qualities of a service dog with the capabilities of modern technical means by integrating them technologically into a biotechnical system. To date, attempts to integrate technical means with the olfactory abilities of a dog have led to the creation of a system that records 4 channels of an electroencephalogram and 1 channel of an ECG. But the inconvenience of attaching a helmet to the dog's head sharply reduces the quality of search activity [2, 3].

The novelty of the development lies in the registration of the activity of the heart and breathing of the dog a system of 4 electrodes is placed on the dog’s chest and sewn into a vest with an electronic unit attached to it, which significantly increases the detector dog’s mobility and improves the reliability of detecting substances by the dog and reduces the time for screening at the airport.

Practical studies (Vayne, 1982; Chomskaya 1972, Sudakov 2000) show that the cardiovascular and respiratory systems in dogs are highly sensitive to olfactory stimuli. The fact is that the sensory olfactory system is connected with the vegetative centers through the reticular formation. The simplest analysis of the dog's heart rate variability shows a short-term increase in heart rate during the “found-settlement” period. Also, under the influence of various odors, the frequency and depth of breathing changes. Therefore, it is important to develop an ECG and respiration recorder consisting of a single electrode system built into a dog vest [4].

For this, the method of electrical impedance cardiography was used, in which it is necessary to place 4 electrodes (2 current and 2 potential) on the dog's chest. As a result, the bioamplifier will amplify the sum of the ECG signal and the electrical impedance, and the ADC, using synchronous detection, will be able to separate one signal from the other. The obtained digitized data is transmitted via a Bluetooth wireless channel to the dog handler-operator's tablet for further analysis.

In the experimental part of this work, an ECG was taken and the frequency heart rate using a tetrapolar electrode system: two measuring two current electrodes. One measuring and one current electrode are located on the right-hand side of the dog's sternum, the other two — symmetrically on the left (Fig. 1) [5].

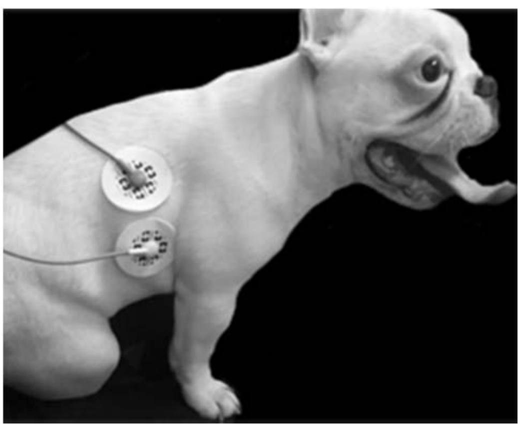

Fig. 1. Application of electrodes during the experiment

As a result of the experiment, ECG signals and heart rate were obtained. The experimental data obtained clearly demonstrate the possibility of taking and filtering the ECG and heart rate from the chest of a dog, as well as the possibility of respiration extraction due to clearly visible respiratory waves. The electrical impedance signals coming from the instrument are noisy with pulsed interference that has a continuous spectrum (Fig. 2, 3) [6].

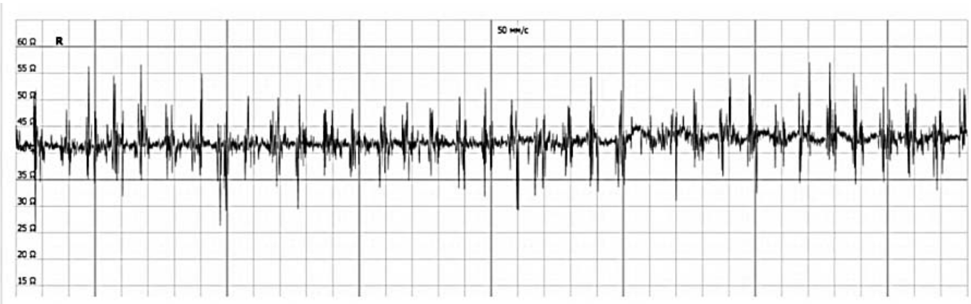

Fig. 2. Initial noisy electrical impedance signal

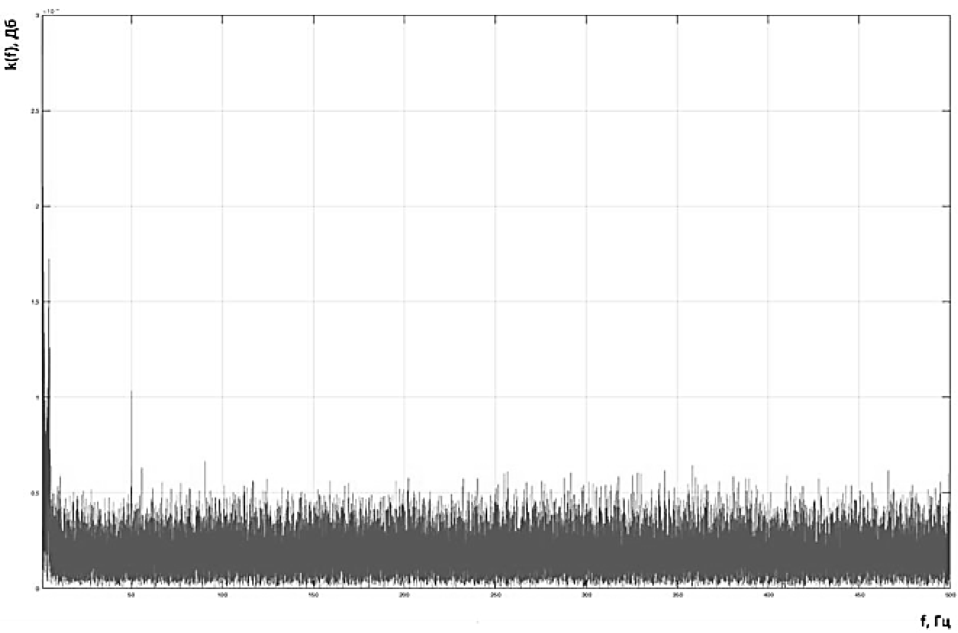

Fig. 3. Spectrum of a noisy electrical impedance signal

Without the use of special analog or digital processing, it is difficult to obtain stable and repeatable measurement results. The impulse noise smoothing technique, originally developed to detect changes in microamp currents at milliamp currents, uses a smoothing algorithm that improves the robustness of accurate measurements in the presence of impulse noise.

Practical noise reduction techniques often involve averaging over large number of samples (block averaging) of the sequence of measured values $x(n)$ to calculate N-samples of the arithmetic mean $M(q)$. In this case, the sequence of block-averaged values $M(q)$ is defined as:

$$M(q) = \sum_{k=qN}^{(q+1)N-1} X\,(n),$$

where the time index of the averaging process takes the values $q = 0,1,2,3$, etc. At $N = 10$, for example, in the first block of data ($q = 0$), the samples $x(0)$ — $x(9)$ are averaged and the sample $M(0)$ is obtained. In the second data block ($q = 1$), the samples from $x(10)$ to $x(19)$ are averaged and the sample $M(1)$ is calculated, and so on.

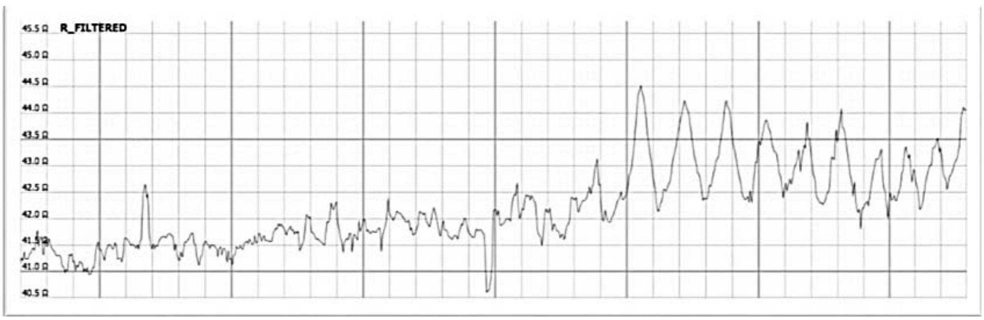

Fig. 4. Filtered electrical impedance signal

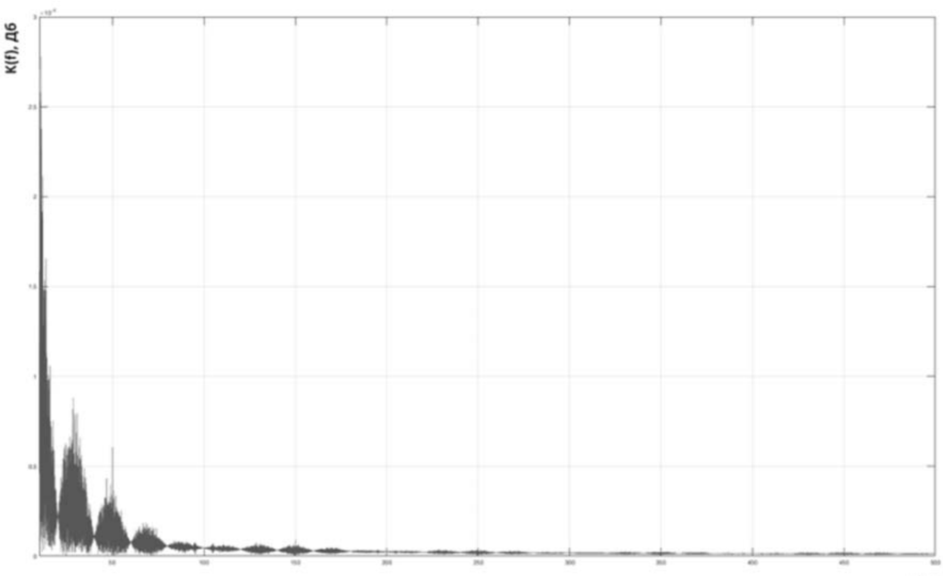

Fig. 5. Spectrum of the filtered electrical impedance signal

The impulse noise smoothing algorithm processes a block of samples obtained from using periodic sampling, and the number of samples N can vary according to individual needs and available resources. The processing of one block of N samples is performed as follows: it is necessary to accumulate $N + 2$ samples of the $x(n)$ sequence, discard the maximum (the largest positive) and minimum (the largest negative) samples, after which a data block of N samples remains, and calculate the average arithmetic $M(q)$ of the remaining N samples. Each sample in the block is then compared to the average. The number of samples that exceed the arithmetic mean and the number of samples that turned out to be less than the arithmetic mean are counted, as well as the sum of the modules of deviations of the values of the samples from the arithmetic mean in one direction (which, according to the definition of the mean, is equal to the sum of the modules of deviations from the mean in the other direction).

In order to improve the quality of the recorded signals and attenuate common mode interference, the instrumental amplifier is assembled according to the scheme on 3 operational amplifiers. A 32-bit microcontroller controls synchronously a 24-bit ADC and a current source assembled on a single chip according to the Holland scheme. Analog and digital power is organized from 2 replaceable finger batteries through stabilizers [7].

Experimental studies on a French bulldog breed dog using the equipment of the BMT-2 department showed a high level of impulse noise in the recorded electrical impedance signal. Because of them, the respiratory waves are not visible at all. Signal averaging does not solve this problem; therefore, an average correction algorithm was applied, considering the number of positive and negative outliers. As a result, impulse noise was completely eliminated (Fig. 4, 5).

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Гуманитарные науки

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Особенности функционирования и эффективности криптовалют

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Рассмотрены особенности возникновения, функционирования и эффективности криптовалют как виртуальных денег, в частности биткойна. Несмотря на то что данный вид валюты выполняет функции денег, т. е. используется как средство платежа, способ накопления и мера стоимости, в его основе лежит альтернативный гарант номинальной стоимости с абсолютной разницей в технология внешнего вида. Показана разница в создании криптовалюты по сравнению с фиатными деньгами с указанием основных особенностей и ограничений ее использования. Приведена оценка эффективности криптовалют с использованием инструментов разработчика корпоративного уровня CoinMetrics API и Nomics API. Получена взаимосвязь между рассматриваемыми показателями и дан ответ относительно необходимости разграничения рыночных и внутренних факторов блокчейна.

Ключевые слова: *биткоин, криптовалюта, электронные деньги, цифровые деньги, майнинг, блокчейн*

Cryptocurrencies Features and Effectiveness

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The features of the emergence, functioning and effectiveness of cryptocurrencies as virtual money, in particular bitcoin, are examined. Although this type of currency fulfils the functions of money, i.e. it is used as a means of payment, a means of accumulation and a measure of value, it is based on an alternative guarantor of nominal value with an absolute difference in the technology of appearance. The difference in the creation of cryptocurrency compared to fiat money is shown, indicating the main features and limitations of its use. The efficiency of cryptocurrencies is evaluated using enterprise-level developer tools Coinmetrics API and Nomics API. The relationship between the indicators under consideration is derived and an answer is given regarding the need to distinguish between market and internal blockchain factors.

Keywords: *bitcoin, cryptocurrency, electronic cash, digital money, mining, blockchain*

Introduction

Cryptocurrency is a relatively new type of digital currency, which is created and controlled by cryptographic methods. This term appeared in 2011 after the publication of an article in Forbes magazine, however, it should be noted that the creator of Bitcoin himself defines this type of money as electronic cash. At the beginning of 2009, one bitcoin was worth only a few thousandths of 1 US dollar, in 2010 the first purchase paid for in bitcoins was made, and by the end of 2013, one bitcoin would cost 800 US dollars. The real excitement around the cryptocurrency began in 2017, when the bitcoin rate slowly but surely crept up to 20 thousand US dollars. The trend has continued to this day

At the moment, there is a boom in the cryptocurrency market, which experts compare with an investment bubble, since in 2021 crypto startups have already attracted $15 billion of capital, which is 5 times more than in the whole of 2020. For example, 12 cryptocurrencies were born in the 3rd quarter. unicorns worth over $1bn, which is a record, and NFT funding totaled $2bn this year, up from $31m in 2020. In turn, ⅘ of deals were closed in the early stages of financing, and investors from the mainstream financial sector like Andreessen Horowitz and SoftBank has helped raise 15 rounds over the past three months for more than $100 million, representing ⅔ of the total VC money invested. Despite increasing public attention, the scientific community only began to research the behavior of the cryptocurrency market trying to identify how the cryptocurrency is working, main features and drawbacks of cryptocurrency market, key factors that determine the profitability of the cryptocurrency [1].

History of cryptocurrency

The first who proposed and described the concept of using electronic money, which was revolutionary for 1983, were Stefan Brands and David Chaum. Adam Bakov was the next who contributed to the development of digital currencies in 1997 and proposed the HashCash system to repel Dos attacks and counteract the sending of spam messages. This system formed the basis for creating blocks in the blockchain chain, and therefore gave the opportunity to work with the world's first cryptocurrency [2].

The next idea, which can be considered as a big step in developing of electronic money, was put forward in 1998 by Nick Szabo and Wei Dai almost simultaneously. So, Dai put forward the concept of his cryptocurrency “b-money” for sending cypherpunks [3], almost at the same time, Nick Szabo had a similar idea, which he gave the name “bit-gold”. In addition, he also described a decentralized system enabling the control of inflation, which later became known as the “Byzantine Generals' Task”. Also an important contribution and a prerequisite for the future creation of cryptocurrency was made by Hal Finney, who created the hash block chains for HashCash.

The first cryptocurrency created in 2007 (began work on a future coin, according to its creator) was Bitcoin, when someone under the pseudonym Satoshi Nakamoto published the book “Bitcoin: A Peer-to-Peer Electronic Cash System” online, containing a detailed description of the work of the new unique payment system. Later, in 2009, the first version of Bitcoin was launched and the first 50 coins were generated, and the first transaction was made using them. Subsequently, the developers regularly released new, improved versions, and in 2011 Namecoin appeared, which became an improved version of the cryptocurrency. The result was an open source system in which any person, or rather several persons, could potentially be involved in confirming transactions, namely the blockchain, on the basis of which a fundamentally new currency, bitcoin, functioned.

Main features and drawbacks of cryptocurrency

The main feature of cryptocurrencies is the impossibility of influencing transactions and controlling them by banks, tax authorities, courts, and the state. This feature illustrates the tendency for money to leave the jurisdiction of one specific country and the formation of a single economic space in which most of the exchange of goods takes place via the

Internet. The emergence of cryptocurrencies forces states to become involved in the rapidly developing trends of social progress in the international currency market, establish legal regulation of cryptocurrencies and develop international standards to address related issues

Cryptocurrencies were invented as an alternative to fiat money, as their main feature was the ability to create and transfer assets without the intervention of some third party. The process of issuing ordinary money is obvious: a financial institution that has a monopoly on issuing money into circulation just increases the money supply. When one person wants to perform a transaction, he/she generates a request to a conditional bank to transfer funds stored in his account. This request is processed by the bank, after which it is the bank that transfers the funds, as a third party, which controls the assets. Having no other alternatives, the person needs to trust the institution or just have the money in cash only [4]. During the usage of cryptocurrency there are only two participants: the sender and the recipient of funds. Cryptographic encryption helps keep both personal data private. There is also no single issuer — there is only a protocol, which is a list of algorithms that determine the rules for the functioning of the system.

The existence of a unit of cryptocurrency begins with mining — literally, with the extraction of this unit. The computer is always the miner, today special machines are used, whose main and only task is cryptocurrency mining. The goal of each miner is to pick up a number that solves the equation compiled by the system. This number is called a hash sum. The machine that finds it forms a new block in a chain of transactions called the blockchain. Blockchain does not have a single definition, but the etymology of the word itself answers the question about the essence of this phenomenon. The word blockchain combines two others: block (English block) and chain (English chain), thus forming a concept that literally means “block chain” [5]. Each new block is added by different persons and contains information about the completed transaction and all previous ones. Each block refers to the block that preceded it. In fact, the blockchain is an open ledger of transactions, a copy of which is stored on several computers at the same time. After a new block is added to the blockchain, it, as well as the blocks before it, are checked by several other miners, confirming that the new version of the blockchain matches the previous one (no code errors).

At the moment when the hash sum is matched, the successful miner becomes like a bank, but not for long: as soon as someone else's computer picks up the hash sum, the role of the bank will be transferred by the system to another person. It should also be noted that, strictly speaking, it does not matter who the “bank” is at any given time, because this status in this scheme does not give its holder any advantages. Unlike the issuer of fiat money, the miner does not need to have a license or other authority to produce new monetary units — a computer will be enough. For the selected hash sum, the system pays the lucky miner a reward in cryptocurrency. This is how new units of cryptocurrency appear. As you can see, their “mining” is just a by-product of the system.

New units of cryptocurrency received by miners as a reward for their work do not rotate abstractly on the Internet, they are stored in a wallet — some kind of program created for this purpose. Each wallet has a unique address consisting of approximately 33 alphanumeric characters. When creating a wallet, the owner receives a public and private keys. The public key is something like a bank account number, while the private key allows the owner to access the funds stored in the wallet. Since the blockchain does not contain a list of all existing wallets, it is impossible to find out the owner of the wallet, but it is possible to transfer funds to a non-existent wallet by simply typing the address. The secret key is the only way to verify the rights to the contents of the wallet. If it is lost or illegally passed into the possession of another person, then nothing can be done about it: the identity of the “real” owner is not recorded in the blockchain in any way.

Cryptocurrencies (Bitcoin, in particular) were created as a means of payment. According to the author's idea, their direct purpose is to pay for goods and services. Some also use cryptocurrencies as a form of investment and earn on exchange rate fluctuations. Any transaction is carried out thanks to a smart contract — an algorithm that determines the obligations of the parties and immediately executes them. A smart contract cannot be changed or invalidated, in this sense it is not at all like a regular contract. Information about any operation, that is, all smart contracts, are entered into the blockchain and confirmed by the miners in exchange for a fee from the parties for the transaction. This process is automated, the owners of computers themselves do not make any declarations of will that could be of interest in the framework of a legal discussion.

Part of cryptocurrency transactions takes place with the participation of trading platforms, cryptocurrency exchange services, such as BinFinex, Binance, LocalBitcoins and some others. The legitimization of cryptocurrencies and the development of their regulation has led to the fact that these services can only be used by persons who have confirmed their identity with a relevant document. The system has information about all users, moreover, the transfer of cryptocurrency within the site occurs by forming a requirement for the site to transfer the specified funds to another crypto wallet, indicating its public key. If the transaction is not made, the parties can submit requirements for its execution to the system. Also, such sites store information about the owners of the wallet and personal data of the participants in the turnover. We can say that the mentioned services, in fact, act as a bank, carrying out operations within the site without the participation of miners. However, if tokens are transferred from a wallet registered on such an exchange to a wallet registered outside it, confirmation by the miners will again be required. One way or another, the participation of cryptocurrency exchanges in operations violates the peer-to-peer scheme, but makes the use of cryptocurrencies much safer for all participants.

Study description and analysis

At the moment, the cryptocurrency market is poorly analyzed, its effectiveness has not been proven, and investors continue to use cryptocurrency for short-term profits with its high volatility. For example, Yukun Liu and Aleh Tsyvinski found that there is no relationship between the volatility of stock markets and macroeconomic indicators and the volatility of cryptocurrencies [6]. On the other hand, Weiyi Liu et. al. [7] showed that market factor and size factor can be considered as valid determinants of cryptocurrency market efficiency. After that Aleh Tsyvinski and Xi Wu [8] introduced the approach of Weiyi Liu [7] and applied it to a broader set of cryptocurrency data — the authors constructed 25 anomaly variables based on 1707 cryptocurrencies. The paper shows that cross-section of returns of all 25 variables can be explained by three risk factors — crypto market return, size and momentum.

But what if risk of a cryptocurrency is allocated not only in market factors but also in the blockchain-based factors? The idea behind this lay in the nature of cryptocurrencies who ate based on the same technology and whose main goal is to introduce safe and easy way of transactions between people in different countries without intermediaries. To answer this question, I decided to takie as the base the 3-factor model mentioned above and to introduce 3 additional blockchain-based factors that can influence the return of the cryptocurrency and got a multiple regression. As Aleh Tsyvinski and Xi Wu [8] were using three-factor model risk model invented by Fama-French in 1993, I should outline that my model is also based on their approach.

1. *First hypothesis* of the research is that the size of particular cryptocurrency usage will affect the amount of returns of the particular currency as It will show the level of trust of people to this currency. This can be tested based on the number of accounts of the currency.

2. *The second hypothesis* is that the level of the transaction will affects the return of the currency. From one side, I think that stable and world-known currency will not have small amounts of fees. From the other side, high amount of fees and reduces the amount of accounts.

3. *The third hypothesis* is that the existence of Github account has positive correlation with cryptocurrency returns. Github is a we-site where the source code is published, which means that any person can observe how the currency is created. It helps to track the development progress of a developers project. Since the cryptocurrency world is open, every action will be displayed. So, the new blockchain-based factors that I introduced are number of accounts of a particular cryptocurrency, transaction fee and Github account existence.

I collected both market and blockchain-specific data for 21 cryptocurrencies on a daily basis from the 1st January 2017 to the 1st January 2022. The crypto data was collected from Coinmetrics API and Nomics API. The risk-free rate was as the one-month U.S. Treasury bill rate from Bloomberg.com. As cryptocurrency market factor I used a CCI30 index — index of the thirty largest cryptocurrencies from cci30.com. Momentum factor is based on the three week returns, since three-week momentum generated the largest long-short spread in the research of [8]. SMB factor is the market capitalization of cryptocurrencies.

As a result I got a multiple regression:

$$R = 0{,}04 + 0.45 \cdot M + 0.98 \cdot SMB(t) - 0.09 \cdot MOM(t) + \\ + 0.05 \cdot NUM + 0.04 \cdot FEE + 0.06 \cdot GIT,$$

where R is return of cryptocurrency calculated as [Ri (t) - rf (risk-free rate)] ; M is market value calculated as $[Rm(t) - rf]$; SMB is size effect (small — big), where size is based on a company's market capitalization; MOM is momentum factor; NUM us number of accounts; FEE is mean transaction fee in USD; GIT us dummy variable of Github account existence.

Having the F-statistics equal to 2.83 and the intercept is significant, we can conclude that the whole regression is significant at 5 % level, meaning that the standard three-factor risk model is unable to explain the return. But only NUM and GIT are significant among the variables with the t-test equal 5 and 3 respectively at 5 % level. This means that H2 (hypothesis 2) is rejected, while H1(hypothesis 1) and H3 (hypothesis 3) are not rejected. Making the last analysis I also check the correlation between market and blockchain-specific factors. As a result I got that Factor ACC is highly correlated with SMB, which may imply multicollinearity issues. FEE and ACC are slightly correlated (r = 0.18).

Conclusion

Cryptocurrency is a form of reward that miners receive for solving mathematical equations. Its turnover is protected by cryptographic encryption to ensure security and anonymity, transactions are carried out by an automated system. Cryptocurrencies are a decentralized institution, that is, their release and circulation is carried out by a large number of persons independent of each other. Bitcoin is the first and most widely used cryptocurrency, but far from the only one — new payment tokens have been and are being developed on the basis of blockchain, however, it was the first means of payment that solved the problem of double spending — selling the same funds several times, re-transactions.

My research showed that cryptocurrency market depends not only on market factors but also on the blockchain-based factors. While one hypothesis was rejected, two factors — number of account and existence of Github profile — should be considered as relevant determinants of cryptocurrency efficiency. Results of the research can be applied for further investigation of the crypto-currency market and construction of risk-factor models.

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УДК 801.733

Герменевтика как способ реконструкции реальности в период пандемии коронавируса

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Рассмотрен герменевтический метод реконструкции реальности. Установлена связь между текстом и социальной реальности. Определена практическая ценность герменевтики. Указаны ее достоинства и недостатки. При исследовании использовался метод «герменевтического круга» и метод сплошной выборки. Оценена эффективность герменевтических методов при анализе неологизмов, возникших в период пандемии. Был очерчен круг проблем, с которыми столкнулись при анализе данных исследования.

Ключевые слова: *герменевтика, реконструкция реальности, неологизмы, пандемия коронавируса, герменевтический круг*

Hermeneutics as a Way of Reality Reconstruction during the Coronavirus Pandemic

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This author considers the hermeneutic method of reality reconstruction. The practical value of hermeneutics is determined. Its advantages and disadvantages are indicated. The hermeneutic circle method and the continuous sampling method were used.The effectiveness of hermeneutic methods in the analysis of neologisms that arose during the pandemic are evaluated. The problems are identified during the study.

Keywords: *hermeneutics, reality reconstruction, neologisms, coronavirus pandemic, hermeneutic circle*

In the contemporary society there are many problems, some of which are immanent precisely for this stage of social development, for example, the strongest Internet addiction of its members. Other problems could be surveyed throughout the history of the development of society, such problems, for example, include pandemics. Of course, our communities possess not only temporal differences, but also territorial ones. Each country has its own endemic problems, but due to the process of globalization, national differences become more evened out. To achieve true knowledge about the processes taking place in reality is of extremely importance now. One way of mastering such knowledge is the method of reality reconstructing. The object of such research, fixed in time and space, is the so-called textual reality. The instrument for analyzing any textual source is hermeneutics. In this case, the hermeneutic analysis of the texts of newspaper articles is a way to obtain information about the processes in society during the coronavirus pandemic. It is hermeneutics that allows a researcher to dismiss all superfluous and comprehend the deep meanings contained in words, which means obtaining of true knowledge about the surrounding reality.

Since ancient times, many philosophers have dealt with the problem of hermeneutic practice. In the 20th century Hans-Georg Gadamer assigned hermeneutics a universal philosophical status [1, p. 281]. Subsequently many thinkers returned to the problem of determining the status of hermeneutics and its functions. Thus, Gaetano Chiurazzi develops the idea of Gadamer and considers hermeneutics as an unlimited field of study [2]. Michael Carter adheres to the same concept. He tries to use the hermeneutical method for the analysis of mass media texts [3]. Matthew Forest also considers hermeneutics to be a practical philosophy [4]. Nicholas Davey bases his ideas on the theory of Chiurazzi, while inverting the definition and talking about hermeneutics as a field open to its study [5]. John Artos says that in the modern world, in the absence of methods for achieving truth, hermeneutics is the most important means of analysis [6]. At the same time, David Cooper focuses his attention on the hermeneutical analysis of moral discourse [7].

All these studies were devoted to determining the status and functions of hermeneutics as a philosophical discipline. However, the points of view presented in these works are sharply diametrical.

1. On the one hand, there are works in which hermeneutics is regarded as an ideal method. First of all, this is how it looks in the concept of Gadamer. He argues that hermeneutics is philosophy. The same ideal hermeneutics appears in the works of Chiurazzi and Carter. These philosophers believe that with the help of hermeneutic analysis it is possible to uncover all questions concerning social reality.

2. On the other hand, in a number of works there is a sharp criticism of hermeneutics. Forest and Cooper blame hermeneutics for inaction. An evident disadvantage of such concepts is the one-sided perception of hermeneutics.

In this study, hermeneutics is considered from the point of view of its advantages and disadvantages.

1. The practical value of hermeneutics is determined.

2. The possibility of hermeneutical methods for the reconstruction of social reality is also being studied.

3. The degree of truth of the obtained results is analyzed.

4. Textual reality is singled out as an object of study.

5. In addition, a possible distortion of reality, which is a drawback of the hermeneutic method, is being studied. Initially reality can be distorted by the author of the text.

Subsequently the reader may also erroneously interpret the received text. At the same time, criticism of hermeneutics should be constructive. The deconstructive criticism of hermeneutics that it cannot reach the truth is dangerous because it distorts and removes everything important that contributes to the creation of the conditions that make possible the emergence of hermeneutic truths.

To determine the research method it is necessary to determine how the text and social reality are related. The consciousness of the individual is influenced by the social reality surrounding him, the so-called situation “here and now”. At the same time, each person perceives this reality in a different way, which has a different impact on each specific person of a given society, which is reflected directly in the consciousness of this individual. On one hand, all people living in the same society, belonging to the same space-time continuum, have a common single reality with their own problems. On the other hand, the shades of this reality are different for everyone and differ from each other under the influence of personal perception. It is impossible to say unequivocally which perception of social reality is true and which vision is obviously erroneous. The fact is obvious that reality is directly connected with the speech-thinking activity of a person and is manifested through language. In fact, a person transposes the reality surrounding him into a sound-letter form. At the same time, it is practically impossible to convey objectively social reality; in the process of transposition, its inevitable subjectivities occur, associated with the personality of the interpreter of this reality and its addressee. Social reality is almost always subjective; it cannot exist without the actual or mental action of a person, in contrast to objective and physical reality.

Since social reality and text are directly connected, hermeneutic methods are needed to analyze such textual reality. The most common method is the hermeneutical circle method. It is based on the fact that it is impossible to immediately understand the meaning of the entire text (whole). It is necessary to return to its smaller fragments (parts) to search for understanding within the framework of a specific component of the text, then again turn to the whole. The procedure for such appeals — iterations should be carried out until the entire text, as well as all its parts, is fully understood. For successful interpretation and understanding, it is essentially to use all known methods of hermeneutics: rational analytical historical-grammatical and psychological comparison and divinational research and understanding of the author's personality. Having reached understanding, the “hermeneutic circle” should be broken. The task is not only to reveal the surface meanings, but also the deep hidden meanings of words. In this paper, specific lexemes, namely, pandemic neologisms will be subjected to such an analysis. The material of the study is the neologisms that were included in the corpus of the dictionary of the Spanish Royal Academy during the pandemic [8]. To chose them we use the method of a complete sample.

Using the “hermeneutic circle” method, one can determine the deep meanings of words that are the addition of two different words, as well as the result of a pun. For example, in the meaning of *coronavirus*, the neologism *coronillavirus* is found. In this case, we are talking about a word-composition based on a pun for the purpose of creating a comic effect, in which the first component is *coronilla* (*crown of the head*). With the help of further analysis of this neologism using the “hermeneutic circle” method, we determine all the deep meanings of this lexeme. *Coronilla* is also a truncation of the whole phrase *estar hasta la coronilla* (*to be fed up*). All the neologisms given in the table were analyzed in a similar way. The results of this work are presented as a translation of Spanish neological units into English in the Table 1.

Table 1

The Results of the Hermeneutical Analysis of Pandemic Neologisms

No.	Spanish neologisms	English explanation
1	Coronabicho/Covicho	Coronavirus (bicho — a beast)
2	Coronillavirus	Coronavirus (coronilla — a crown of the head)
3	Coronabebé	A child born in a pandemic
4	Coronaboda	A wedding during a pandemic
5	Coronacoma	Economic crisis (bono — securities)
6	Coronabulo	False information about coronavirus (bulo — a false rumor, a pseudo event)
7	Coronachivato	Violator of restrictive measures (chivato — a scoundrel)

End of tabs

No.	Spanish neologisms	English explanation
8	Coronacompra	Shopping during a pandemic at inflated prices
9	Coronacionalismo	Aggravation of the manifestation of nationalism during a pandemic (for example, closing borders)
10	Coronadivorcio	Divorce during a pandemic
11	Coronadiccionario /Lengua /Lenguaje	Words created during a pandemic
12	Coronafiesta	Holidays during a pandemic
13	Coronafobia/manía	fear of contracting coronavirus
14	Coronahisteria	Anxiety, panic during a pandemic
15	Coronaplauso	Thanks to employees for their work in coronavirus, for example, doctors
16	Coronapositivo	A person with a positive test for coronavirus
17	Coronámbulo	Corona + somnámbulo — a person suffering from insomnia from -for coronavirus
18	Coronasutra	instead of the Kamasutra — sexual poses to avoid face contact

It is possible to determine those areas of social reality in which they appeared by using hermeneutic methods to study the neologisms included in the corpus of the dictionary of the Spanish Royal Academy. As we can see from the Table 2, the areas most subjected to word formation are the social sphere, human activity, emotions. The following problem can be identified during the study. Many interesting neologisms from the point of view of their meanings are not included in the corpus of this dictionary, for example, *convinamiento* — an isolation with alcohol. As a result, without being recorded in writing, they will eventually be forgotten and will not be able to serve as a source for subsequent hermeneutical analysis in order to reconstruct reality.

Table 2

Distribution of Neologisms by Areas of their Application

No.	Social phenomenon	No.	Human activity	No.	Emotions	No.	Attitude towards coronavirus
1	Coronabebé	1	Coronachivato	1	Coronafobia	1	Coronabicho
2	Coronaboda	2	Coronapositio	2	Coronahisteria	2	coronillavirus
3	Coronacoma	3	Coronámbulo	3	Coronaplauso		
4	Coronabulo						
5	Coronacompra						
6	Coronacionalismo						
7	Coronadivorcio						
8	Coronalengua						
9	Coronafiesta						
10	Coronasutra						

Since a greater number of neologisms are associated precisely with the social phenomena of pandemic reality, hermeneutic methods of analysis are used to correctly interpret them. The above methods allow you to find the deep meanings of the data. This proves the practical value of hermeneutics in the modern world. Since not all meanings could be unambiguously translated into English, not all meanings could be reflected, this proves that along with obvious advantages, there are also disadvantages in the hermeneutic methods of analyzing and conveying meaning. Hermeneutics helps to reconstruct reality, but does it with distortions. It is the distortion that is the reason why there is a certain skepticism among scientists regarding the hermeneutical method of research. With a hermeneutic analysis of neologisms, we can conclude that the coronavirus has been in society for a long time and its consequences are really difficult for society. Also, by the large number of neologisms that appeared, it can be concluded that people in self-isolation had so much free time that the principle of economy of language was violated, and new words began to be intensively artificially created. Our social reality is nothing but a potential past for our future. Our descendants, analyzing texts by the hermeneutical method, will be able, albeit with some distortion, to reconstruct for themselves the past, which is the present for us.

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Угрожающее требование как категоричная форма требования с отличительными особенностями на уровне просодии

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Близкие по своему функциональному назначению речевые (иллокутивные) акты могут вызывать некорректное восприятие адресатом в ходе устной коммуникации ввиду своей схожести. Таковыми речевыми актами являются требование и угрожающее требование. Под требованием понимается крайне решительное желание добиться определенного действия от адресата. Угрожающее требование представляет собой тоже самое требование, однако с признаками угрозы. Предложено рассматривать угрожающее требование как категоричную форму требования. Несмотря на очевидные схожести двух речевых актов предполагается, что существуют и различия между ними. Для выявления отличительных особенностей данных речевых актов было проведено экспериментально-фонетическое исследование на основе современного немецкого языка, где частота основного тона, интенсивность и длительность выступали главными дифференцирующими параметрами.

Ключевые слова: *требование, угрожающее требование, директив, просодия, экспериментально-фонетическое исследование*

Threatening Demand as a Categorical form of a Demand with Distinguishing Features at the Prosodic level

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Speech (illocutionary) acts that are close in their functional purpose can cause incorrect perception by the addressee in the course of oral communication due to their similarity. These speech acts include a demand and a threatening demand. In this article, a demand is understood as an extremely determined desire to achieve a certain action from the addressee. A threatening demand is the same demand, however, with signs of a threat. In this regard, it is proposed to consider a threatening demand as a categorical form of a demand. Despite the obvious similarities between the two speech acts, it is assumed that there are differences between them. In order to identify the distinctive features of these speech acts, an experimental and phonetic study was carried out based on the modern German language, where the fundamental tone frequency, intensity and duration were the main differentiating parameters.

Keywords: *demand, threatening demand, directives, prosody, experimental and phonetic research*

Introduction

It is a well-known fact that any oral statement is aimed at achieving a certain communicative goal. The absence of a sign of a pragmatic beginning is an exception to the rule. Achievement of the communicative goal directly depends on certain actions of both participants in communication. The speaker must clearly formulate their intention and correctly express it. The listener, in turn, must understand the communicative intention and only then accept it. The listener needs to imagine intentions in their head and understand:

1) whether they have a semantic content;
2) whether they are understandable;
3) whether they correspond to social situations;
4) whether they are executable [1, p. 4].

The success of the ongoing interaction depends on the observance of these conditions, since a direct dependence arises here: the fewer conditions are met, the more likely it is to say that the goal has not been achieved, which means that the communication process can be called unsuccessful.

In addition, the success of communication may be hampered by incorrect perception of speech (illocutionary) acts due to the great similarity of illocutionary acts in their functional purpose. In other words, it is extremely difficult to correctly perceive statements that, by the nature of their manifestation, belong to the same group of speech acts and are based on the same speech act that absorbs shades of another illocution. These illocutions include a demand and a threatening demand. A demand is understood as a desire expressed in an extremely resolute, categorical form [2]. The basis of this speech act is the reluctance of the addressee to perform the causal action, which necessarily leads to negative consequences. A threatening demand is also the most categorical desire, however, containing implicit or explicit forms of threats for non-fulfillment of this requirement or refusal. Thus, by the nature of their manifestation, both speech acts can be attributed to directives, i.e. statements (often authoritarian), which include an attempt to get the addressee to perform some action [3, p. 182]. Due to the fact that a threatening demand is based on the demand itself, but it incorporates the signs of a threat, it can be assumed that the threatening demand is an extreme form of the demand.

As an extreme form of a demand, evidently, a threatening demand has many points of contact with an ordinary demand. Despite this it is assumed that the two speech acts have significant distinctive features. It is preferable to identify the distinctive features of the speech acts at the level of prosody, since “even slight changes in prosodic characteristics allow native speakers to distinguish them by the type of action performed” [4, p. 60]. Such changes primarily occur at the level of fundamental tone frequency, intensity and duration, perceived by ear as melody, loudness and tempo, respectively. A large number of experimental and phonetic studies (E.I. Grigor’ev, T.M. Nadeina, N.B. Ershova, L.G. Karandeeva, A.K. Derkach, O.E. Burashnikova, L.N. Belenikina and others) showed that fundamental tone frequency, intensity and duration are the main parameters that make it possible to identify the differentiating features of speech acts. Thus, in order to identify the distinctive features of the two speech acts, an experimental and phonetic study was carried out.

Materials and methods of research

The material is processed according to the methodology adopted in the experimental and phonetic studies of Moscow State Institute of International Relations. The method is a complex analysis: auditory, acoustic and mathematical-statistical. Native German speakers are offered situations in which a demand and a threatening demand are realized. The situations are reproduced twice. Subsequently, the obtained samples are presented to two groups of auditors: native speakers of the German language and Russian teachers-phoneticians of the German language. The task of the first group is to establish the authenticity of the situation of communication and confirm the correctness of pronunciation norms of the subjects. The second group needs to place stresses, pauses and tone movements in phrases. The next step includes the implementation of phonemic-syllabic decoding of phrases using a special speech signal processing program (Praat), which makes it possible to measure and analyze the acoustic parameters of the fundamental tone frequency, intensity and duration of the studied phrases. In order to obtain an objective assessment of the data, using the SPSS computer program, a mathematical and statistical analysis of the results of the study is carried out, which is the detection of the degree of randomness and regularity of the facts observed in speech. It is the mathematical and statistical calculations that serve as the foundation for further interpretation of the experimental material.

The study analyzed 55 phrases reproduced by 5 native German speakers: 3 men and 2 women, all aged 23 to 26 years old, permanently residing in Germany in the state of Bavaria. The total number of syllables was 990.

Results

In view of the fact that a threatening demand is regarded as an extreme form of a demand, it is obvious that these speech acts will inevitably have many similar features. However, the study also revealed a number of differences.

In the course of the experimental and phonetic study, two models were obtained — M-1 is a demand and M-2 is a threatening demand in terms of the parameters of fundamental tone frequency (Fig. 1), intensity (Fig. 2) and duration (Fig. 3).

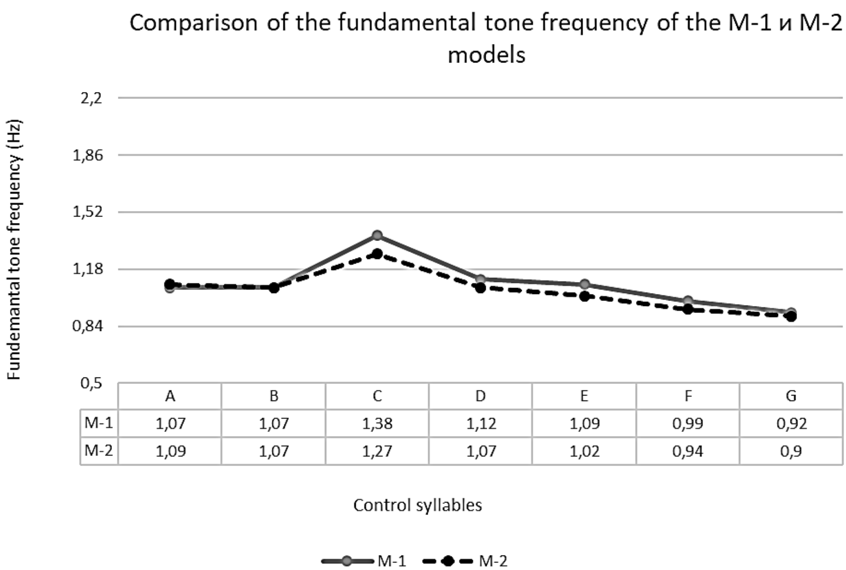

Fig. 1. Comparison of fundamental tone frequency

Comparison of the general averaged values of the fundamental tone frequency of the M-1 and M-2 models showed that the two illocutionary acts do not differ significantly on this basis at the statistically specified level (90 %). T-test is < 1.

The tone range of M-1 is higher than the parameter of this feature of the M-2 model by 1.24 times (0.46/0.37), which is an insignificant difference. Both models are located on the second and third levels. The identity of the models is also observed in the location of the maximum (point C) and minimum indicators (point G) (Fig. 1).

Both models represent a unimodal curve which, having reached its peak in the first stressed syllable (point C), gradually declines until the end of phonation. An identical movement of the curves is observed, whose numerical indicators are practically equal. This is especially visualized in the pre-beat and post-beat. However, the tone of the M-1 is slightly higher than the M-2.

Thus, we can say that the parameter of the fundamental tone frequency is not a feature that allows differentiating a demand and a threatening demand.

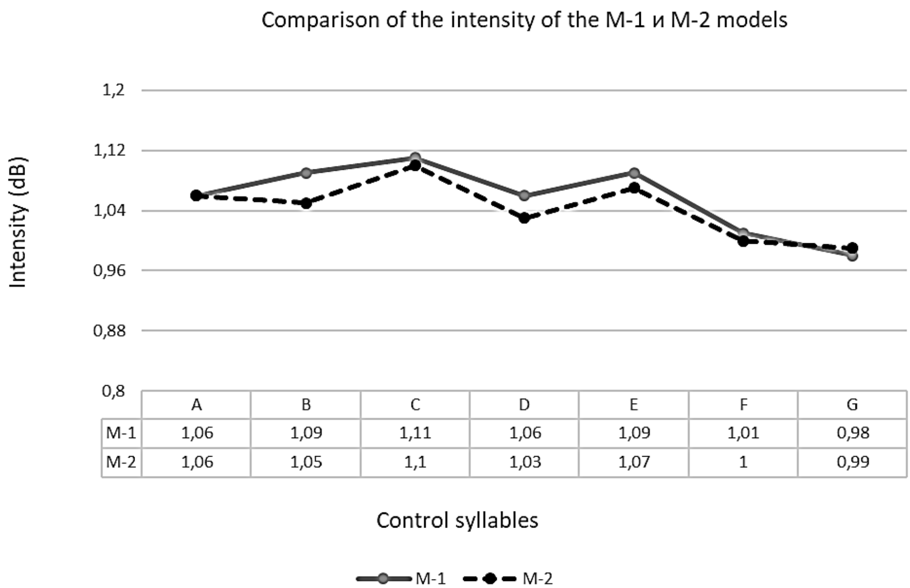

Fig. 2. Comparison of intensity

Comparison of the general averaged intensity values of M-1 and M-2 models shows that these illocutionary acts differ in this feature at a statistically specified level (90 %). T-test score is 5.15.

The loudness range of the M-1 and M-2 models is almost identical. The M-1 is only 1.18 times higher than the parameter of this feature of the M-2 model (0.13/0.11). The loudness range of both models develops at the third and fourth levels. The maximum of both illocutions falls on the rhythmic corpus at point C. The minimum indicator of the two models is fixed at the post-beat — point G (Fig. 2).

M-1 and M-2 models, which are two-vertex curves, show similar features to each other. In the zone of the rhythmic corpus and the post-beat, an absolutely identical contour of the feature is observed, however, the M-1 is located a little higher. As for the pre-beat, from the very beginning of M-1 phonation there is a steep rise of the curve to the first stressed syllable (point C), where the M-2, in turn, slightly decreases from point A and only then rises sharply, reaching point C.

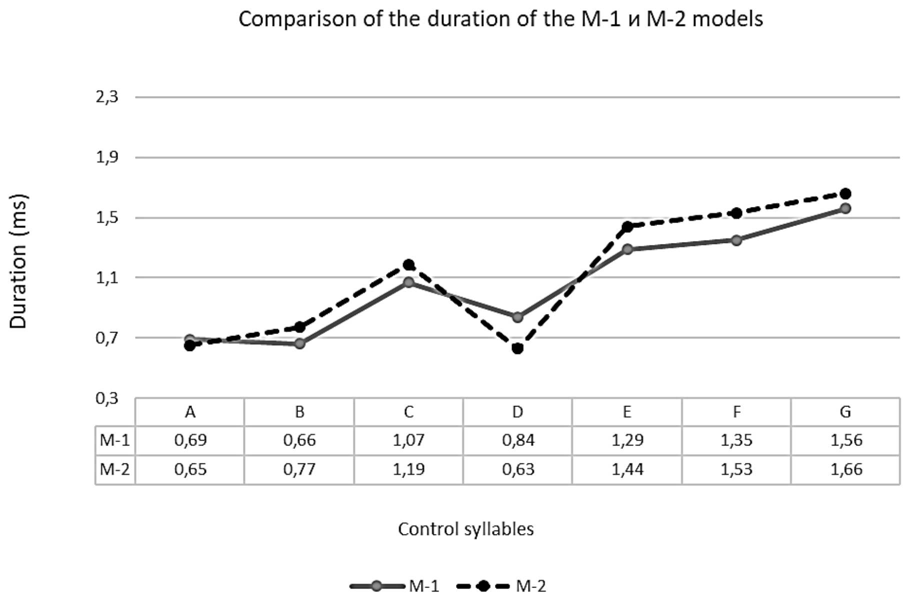

Fig. 3. Comparison of duration

Comparison of the general averaged values of M-1 and M-2 models does not show differences at a statistically significant level (90 %). However, there is a steady trend towards differentiation. It is assumed that the probability of differences in speech acts on this basis will be higher with an increase in the amount of the studied material.

The range of the M-1 model is only 1.14 times narrower than the M-2 model (0.90/103), which is a minor difference. Both models cross four levels at once — from the first to the fourth. The maximum indicator of the M-1 and M-2 is fixed at the same point — point G, but with a slight difference in numerical values. There is no consensus on the minimum positions: M-1 is in the pre-beat (point B), M-2 is in the rhythmic corpus (point D) (Fig. 3).

M-1 and M-2 models have a similar feature — they are zigzag curves indicating an increase in the feature by the end of the phrase. Having similarities in the contours of movement, these models have differences in the sharpness of the drops. Compared to the M-2, the M-1 model is characterized by smoother changes in the duration parameter. In addition, the M-1 model contrasts with the M-2 as follows: at the beginning of phonation the curves begin to move along a downward trajectory, while the M-2, in turn, fixes an ascent up to the first stressed syllable.

Discussion

In both illocutions there is a uniform distribution of tone throughout the entire phrase. The exception is the first stressed syllable where the maximum value of the feature is fixed.

The rise in tone in the rhythmic corpus is explained by the presence of the main meaning of the utterance in this section. In addition, the first syllable of the rhythmic corpus is the area where there is a discrepancy between the demand and the threatening demand. However, it can be fully argued that the development of the fundamental tone frequency is synchronous in both models.

Emphasizing the meaning at point C by tone correlates with indicators at the intensity level. In both models, two peaks are noted falling on the first stressed (point C) and nuclear (point E) syllables. On the contrary, the pre-beat and post-beat are not pronounced loudly. This is especially clearly seen in the example of the post-beat where the curve of the demand, on reaching the main-stressed syllable, is rapidly declining. Thus, emphasizing the loudness of key syllables underlines the paramount importance of conveying to the addressee the meaning of the entire utterance. This could be done for a more intimidating effect where, on the one hand, loudly emphasized key words collide in contrast with words expressed extremely calmly, on the other hand.

Despite the similar features of the speech acts such as the two-vertex contour, the identity of the curve movement, and the location on the same levels, they have distinctive features. Since the demand started unfolding, it has gradually been rising, reaching the first point of the rhythmic corpus, while the threatening demand in this segment is characterized by the opposite situation. In the pre-beat the curve of the threatening demand gradually decreases, after that it sharply moves up to the first stressed syllable. In addition, the threatening demand represents a less loud utterance, as it is located below the demand on the dynamic scale. A similar feature is also observed when comparing the fundamental tone frequency of the two models. The threatening demand on a tonal basis is lower than the demand.

The demand and threatening demand have almost an identical movement of the curve, which makes it extremely difficult to differentiate them on a temporal basis. The peculiarity is only that sharper drops are inherent in the threatening demand. Moreover, the phonation speed of the threatening demand is slower than the corresponding sign of the demand. Both speech acts are characterized by slowing down and speeding up the tempo throughout the entire utterance. This indicates that the speaker, slowing down the process of phonation, highlights key moments, and speeding up, omits secondary ones. The emphasis is on meaning-forming syllables — points C and E. This feature correlates with the parameters of fundamental tone frequency and intensity. The pre-beat in the case of both illocutionary acts fixes the slowing down of the tempo. This is directly related to the gradual completion of phonation and the completion of thought.

Conclusion

As a result of the experimental and phonetic study, it was possible to establish that the threatening demand differs at the prosodic level from the usual demand solely on a dynamic basis. However, the duration tends to be different. Probably, with an increase in the amount of the studied material, these speech acts will be differentiated at a given statistical level in terms of duration and, possibly, fundamental tone frequency.

Due to the extremely similar features of the two illocutionary acts, on the one hand, and the presence of distinctive features, on the other hand, a threatening demand can be considered as an extreme form of a demand. The threatening demand, as it turned out, mostly has similar features. However, there were also distinguishing features. Thus, when compared with an ordinary demand, the tone of threat inherent in a threatening demand is mainly expressed in the following: in a less pronounced tone, less loudness and a slower pace. It is assumed that such characteristics increase the chances of achieving the set communicative goal.

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Об оценке результатов незавершенных научно-исследовательских проектов в России

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Оценка завершенных и незавершенных результатов научных исследований и разработок является крайне актуальной в России. Несмотря на то, что оценка завершенных результатов достаточно состоятельна и ясна на сегодняшний день, особой проработки, тщательного изучения и, вероятно, модернизации требует вопрос оценки незавершенных результатов в текущей ситуации. Рассмотрена оценка результативности научных исследований и разработок, уделено наибольшее внимание оценке результативности незавершенных научных исследований с помощью наукометрических инструментов. По итогам проведенного исследования был сделан следующий вывод: в настоящее время имеющихся ресурсов для оценки незавершенных результатов научных исследований и разработок недостаточно, в связи с этим необходимо создать новые системы, которые будут целостны, надежны, а также смогут функционировать по принципам научной этики.

Ключевые слова: *индексация, исследование, Scopus, Web of science, рецензирование, наукометрия*

On Evaluation of Unfinished Results of Research and Development Projects in Russia

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Evaluation of the results of finished and unfinished research and development (R&D) projects is a very relevant problem for Russia. On the one hand, the framework for the evaluation of the finished results is comprehensive and clear nowadays. On the other hand, *the task of evaluation of the unfinished R&D results is currently requiring special attention and careful consideration, even modernization. This paper considers the evaluation of scientific R&D results and devotes special attention to the evaluation of the unfinished scientific R&Ds efficacy using science metrics tools. Based on the research conducted, we draw the conclusion that currently there is a lack of resources for the evaluation of the unfinished R&D projects results. Thus, new systems having integrity, reliability and capable of functioning according to the principles of science ethics have to be created.*

Keywords: *indexing, research, Scopus, Web of science, peer-review, scientometrics*

Introduction

Over the past decades, the evaluation of scientific research has changed with respect to the scale, methods, purpose, motivation and complexity. In some countries, these changes have stemmed from attempts to direct, regulate and control the research plans and priorities, not only in terms of funding, but also in terms of intentions to influence what is happening within the science system. For many years, the evaluation of government-funded research programs worth billions of dollars and distributed worldwide has been discussed. The existing methods of assessment do not meet the current needs, and an empirical assessment of the merits and value of specific methodologies, models and mechanisms used worldwide to evaluate publicly funded research is needed [1].

The future of higher education and scientific research rests on two pillars: peer review and ranking. It is important to pursue the goal of having the informed peer review system combining these two functions. However, the politicized use of figures (citations, impact factors, funding, etc.) seems inevitable [2].

The quality and quantity of scientific publications can be assessed using a set of statistical and mathematical indicators called science metrics indicators. These indicators are either quantitative, measuring the productivity of a researcher, or qualitative performance indicators that evaluate the quality of publications. Science metrics indicators are important for individual researchers, organizations, and journals for the purpose of comparative performance analysis. Financing and staff decisions are often based on science metrics indicators. This review article describes some of the systems for evaluating the unfinished R&D results using science metrics indicators in Russia today [3].

Materails and methods

There are various principles of evaluation criteria [4]. First of all, the principles comprise impartiality (i.e. objectivity, independence, fairness), competence, responsibility and openness [5]. Also, for evaluating scientific research, the simplicity of evaluation, the consistency of the criterion over time and its globality are important as well.

When we pass over to R&D, we should introduce some definitions.

Scientific research and development (R&D) is a systematic creative activity aimed at increasing the volume of knowledge and searching for new application areas for this knowledge [6]. Within scientific research and development, fundamental and applied research, as well as experimental developments can be distinguished [7].

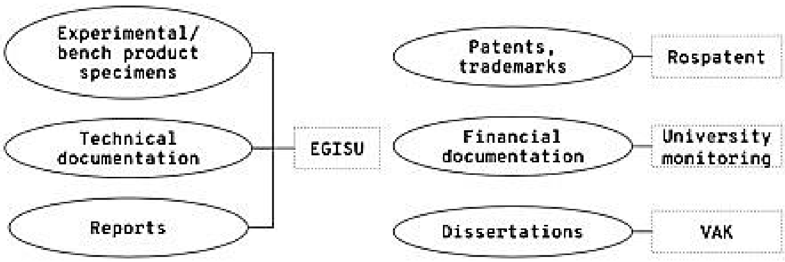
Fundamental research is an experimental and theoretical research aimed at obtaining new knowledge, but without a specific application purpose.

Applied research is an original work aimed at obtaining new knowledge for solving specific practical problems.

Experimental developments are the works aimed at creating new materials, products and devices, introducing new processes, systems and services, or significantly improving those already produced or put into operation, as well as creating prototypes and testing them.

The R&D results can either be finished or unfinished. We stress that the unique feature of the unfinished results is that they need approbation.

The results of the finished R&D include experimental, mock-up, experimental samples; technical documentation; reports; patents, trademarks; economic documentation; dissertations. Figure shows the systems currently used to evaluate and monitor similar results in Russia [8].



Systems for evaluating the results of the finished R&D projects

The results of the unfinished R&D work comprise scientific publications and reports at scientific conferences [9]. These results are evaluated with science metrics tools, first of all, using abstracting databases [10].

To date, there are many abstracting databases. There are local and international databases, domain-specific and universal databases, they can have a low or high entry threshold. Among the many existing abstracting databases, we as Russian scientometrists will single out the following: international databases — Scopus [11], Web of Science (hereinafter — WoS) [12], Google Scholar [13], Lens [14], Dimensions [15], Semantic Scholar [16]; local — Russian Science Citation Index (RSCI) [17]; highly domain-specific — PubMed [18].

Evaluation of the unfinished R&D results using indicators of abstracting databases can be done at the author, organization, or the country level [19]. In addition, the publication platform — the scientific journal — is directly subject to evaluation.

Scientific publications, whether journal articles or conference proceedings, can be evaluated using various indicators at each level, which will consist of quantitative indicators (including the rhythm of publications) and qualitative (first of all, citations).

However, the choice of the abstracting database precedes the evaluation of scientific publications. Therefore, at this stage it is necessary to evaluate the abstracting database itself.

The evaluation of the abstracting database should comprise:

• scope of scientific journals and publishing houses;
• indexing entry threshold;
• multidisciplinary or domain-specific content;
• the languages of content;
• the international or local profile;
• governmental or commercial profile;
• adherence to the principles of science ethics;

• information and analytics tools for working with content;

• capability of work at the level of an individual author, organization, the country or the journal with the main science metrics indicators;

• type of access to the database.

It should be noted that various evaluation aspects of abstracting databases may contradict each other, for example, the aspects 1 and 2 from the above-mentioned list. The number of indexed publication sites is essential for evaluating the citation of publications, on the one hand, the wider the coverage of the abstract base, the better. But at the same time, this situation compromises the quality indicator. Thus, the Web of Science citation index will be much lower than the one at to the RSCI, but it will hold much more value.

Results and discussion

The results of this study will be based on the effectiveness of local and international abstracting databases most common in Russia. Their assessment will be based on the quality of the tools and the level of reliability. Table 1 compares abstracting databases vital for the day-to-day administration of science in Russia by several evaluation criteria.

Table 1

Comparison of the abstracting databases currently used in Russia

International databases	Access type	International/ local profile	Governmental /Commercial profile	Entry threshold	Journal and publisher scope	Multidisciplinarity or domain-orientedness
Scopus	Mixed	International	Commercial	High	41.5K+	Multidisciplinary
WoS	Subscription-based	International	Commercial	High	24 838	Multidisciplinary
Google Scholar	Open	International	Commercial	Low	The widest scope, exact scope is hard to evaluate	Multidisciplinary
RSCI	Open	Local	Commercial	Low	5618	Multidisciplinary
PubMed	Open	International	Governmental	Special	30,000	Medicine-oriented

Based on the data from Table 1, it is clear that RSCI coverage is critically low due to its local nature. On the contrary, Google Scholar has an immeasurably large coverage. In addition, they are ineffective for evaluating scientific publications, since they have a low level of the input threshold for indexing the publication.

Now we consider the accessibility and reliability of science metrics indicators of the considered abstracting databases.

We believe that the essential science metrics indicators are:

• number of publications and their rhythm;

• citation level and quality of citations;

• co-authorship — academic and international;

• FWCI (Field-Weighted Citation Impact);

• h-index;
• m-index;
• journal quartile.

Based on the data from Tables 1 and 2, several databases will be excluded from the list as unsuitable for monitoring publication activities and evaluating the results of the unfinished R&D in organizations.

Table 2

Comparison of the abstracting databases used in Russia

International databases	Number of publications	Citations	Citation quality	Publication citations	FWCI	h-index	m-index	Journal quartile	International co-authorship
Scopus	+	+	–	+	+	+	–	+	+
WoS	+	+	–	+	–	+	–	+	+
Google Scholar	–	±	–	–	–	+	+	–	–
RSCI	+	+	–	–	–	+	–	–	+
PubMed	+	+	+	–	–	+	–	–	–

We believe that RSCI is an unsuitable abstracting database because of the small coverage and, consequently, not representative citation information, as well as a low entry threshold and local profile. It is also impractical to use Google Scholar, since its coverage is immeasurably wide, and there is practically no entry threshold. In addition, Google Scholar lacks the ability to evaluate using scientometrics for organizations. And the third abstract database, which is not applicable for evaluating the results of scientific research and development, is PubMed. Of course, PubMed is a unique and extremely valuable reference base, but only for medicine specialists, but for technical, humanitarian and other organizations, PubMed data will be of little practical value.

Thus, Scopus and WoS remain among the widely applicable abstract databases in Russia. The tools of these databases currently allow us to qualitatively assess the scientometric indicators of any organization at the international level. However, at the same time, Scopus and WoS are much less suitable for low-budget local organizations or those unable to carry out research at the international level. Consequently, to evaluate the results of the unfinished R&D of prestigious, global organizations, it seems appropriate to use scientometric data and information and analytical tools Scopus and WoS, and for local — RSCI.

At the same time, in order to evaluate the unfinished R&D results of prestigious, global organizations, it is necessary to work with data from commercial abstracting databases that are country-independent and base their activities solely on scientific ethics and business rules. Unfortunately, today the world of scientific publications is strongly influenced by the international political agenda. For example, the resources of Clarivete, the owner of the Web of Science abstracting database and the InCites information and analytical resource, stopped operations in Russia due to the influence of non-scientific factors [20]. In the light of all described above, it seems logical to develop new methods and tools for evaluating incomplete results of scientific research and development using scientometry, valid for scientists from different countries, and this area will be covered in the following works.

Conclusion

This paper considered the evaluation of finished and unfinished R&D results in Russia. For the evaluation of the finished results, there is a plenty of tools, but they have to be studied in greater detail. To evaluate the results of the unfinished R&D of local and low-priority organizations, RSCI should be used. However, for the results of the international and high-ranked organizations, international abstracting databases should be used. The existing common abstracting databases have serious issues related to reliability and integrity. So, further research will consider the feasibility of creating new systems with high integrity, reliability, which function according to the principles of science ethics.

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Базовый шаблон многоязычной словарной статьи предметной онтологии на основе корпуса научно-технических текстов

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Рассмотрены аспекты разработки шаблона многоязычной словарной статьи предметной онтологии. В частности, представлен шаблон многоязычной словарной статьи лингвистической онтологии предметной области на основе корпуса научно-технических текстов для русского и английского языков. Шаблон может быть использован для решения задач автоматической обработки естественного языка. Базовый шаблон многоязычной словарной статьи лингвистической онтологии в предметной области на основе научно-технических корпусов быть полезна для решения проблем, связанных с задачами обработки естественного языка научно-технических текстов.

Ключевые слова: *лингвистические онтологии, терминология, параллельный корпус, словарная статья, научно-технический текст*

Multilingual Word Template for Ontology Based on Scientific and Techical Text Corpus

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The aspects of the development of a template of multilingual dictionary article of the subject ontology are considered. In particular, the template of multilingual dictionary article of linguistic ontology of the subject area based on the corpus of scientific and technical texts for Russian and English languages is presented. The template can be used to solve problems of automatic natural language processing. The basic template of a multilingual dictionary article of linguistic ontology in the subject area based on scientific and technical corpora be useful for solving problems associated with the tasks of natural language processing of scientific and technical texts.

Keywords: *word template, linguistic ontologies, terminology, text corpus, technical text*

Introduction

Currently, ontologies are becoming increasingly popular as one field of artificial intelligence science. Ontologies can help processing texts and solving problems with information retrieval. In order to make them beneficial it is necessary to correlate them with the concepts of ontology and a set of linguistic expressions (words and phrases) with which concepts can be expressed in the text. The procedure for comparing the concepts of ontologies and linguistic expressions can be carried out in various ways. So, it is essential to design ontologies in various subject areas.

This paper is based on the works of such researchers as N.V. Lukashevich [1], B.V. Dobrov [2], T.A. Gavrilova [3], L.V. Nayhanova [4] who laid the foundation of linguistic ontologies for automatic text processing. Also, there are such scientists who made research dealing with linguistic ontologies earlier, they were Corcho, Gómez-Pérez, Tsujii, Ananiadou et al. [5]. Oscar Corcho and Asunción Gómez-Pérez published their research of a new set of ontology specification languages, based on new web standards for indentifying factors to choose among a set of languages when building a domain ontology for an application in 2004. In 2005, Junichi Tsujii and Sophia Ananiadou described significance of ontologies as important tools for effective and efficient information sharing, extraction and text mining.

All these studies laid the foundation for current research. In this paper, we consider the theoretical material concerning ontologies and their types, provide the definition of the concept of ontology, types and properties. We gave examples of using ontologies in the assisting with problems of automatic natural language processing. We analyzed the structure of an ontology dictionary entry and terms as a means of naming special entities in otology. It is important develop multilingual dictionary entries of linguistic ontologies of the subject area, which can later be used to solve lots of problems in automatic processing of a natural language.

Methods

To investigate terminological units and contexts of their usage in parallel texts of scientific articles in English and Russian languages in subject area, it is necessary to use the various research methods. In our research we use such methods as sampling, modelling and analysis. Continuous sampling of terminological units and their contexts are based on the vocabulary entries of the linguistic ontology in the subject area. The method of modelling helps to create a basic template of the vocabulary entries of the linguistic ontology in the subject area and the method of semantic analysis helps to determine the semantic relations between terminological units within a certain subject area. These methods are used to create a multilingual vocabulary of linguistic ontologies in the subject area, which can solve a lot of automatic and natural language problems.

Results

The ability to create a domain ontology automatically is provided by extracting knowledge from quality terminological and/or explanatory dictionaries. In this case, terminosystem created on the basis of knowledge extracted from dictionaries, is the core of the ontology of the domain. The final version of the ontology should be created by combining several kernels of ontologies, built on the basis of different terminological dictionaries. Naihanova [4] notes that terminological dictionaries intended to create a domain ontology selected by an expert in the field of knowledge under consideration. To create a complete ontology in the subject area, it is necessary to construct the nomenclatures, which are constructed by extracting knowledge from scientific texts such as monographs, textbooks, articles and others. Then, the term system and the nomenclatures are to be connected.

During the research, a specific template for dictionary entry in a subject ontology was created (Table). The Dictionary entry template in a subject ontology contains the following criteria: Dictionary article ID, Concept ID, Definition, A — H criteria, semantic cases, verbs, word combinations and context. These criteria are helpful for analysing a term in a subject ontology.

Dictionary entry template in a subject ontology

Criteria	Russian language	English language
Dictionary article ID		
Concept ID		
Definition		
A = {A1, A2}		
B = {B1, B2, B3, ...}		
C = {C1, C2, C3, C4}		
D = {D1, D2}		
E = {E1, E2, E3, ...}		
F = {F1, F2, F3, ...}		
G = {G1, G2, G3, ...}		
H = {H1, H2}		
Semantic cases		
Verbs		
Word combinations		
Context		

Each A — H criterion has its own explanation:

1. A = {A1, A2} — concept designation, where A1-unique concept name or dictionary entry name; A2 — concept sign corresponding to frame identifier.

2. B = {B1, B2, B3, ...} — is a set of concept definitions. There can be multiple definitions for a single concept.

3. C = <C1, C2, C3, C4> is the set of described types of conceptual objects, in which four types are distinguished according to Dahlberg:

• C1— essence: tangible and intangible objects, ways of looking at them;
• C2 — properties: quantitative, qualitative, relational (relations);
• C3 — actions: operations, processes, states;
• C4 — values (dimensions): time, position, space.

4. D = {D1, D2} — a pair of sets of properties of a concept, where D1 — set of qualitative properties; D2 — set of quantitative properties.

5. E = {E1, E2, E3, ...} — a set of concepts describing methods/functions peculiar to a given concept and reflecting pragmatics associated with a given concept.

6. F = {F1, F2, F3, ...} — the set of synonyms of concepts, or, in other words, the set of concepts having quantitative relations (identity relation) with a given concept.

7. G = {G1, G2, G3, ...} — the set of correlates, or, in other words, the set of concepts having an opposition relation to a given concept.

8. H = {H1, H2} is a pair of sets of concepts having qualitative relations with a given concept, where:

• H1 is the set of concepts that form a generalization relation with the data {H11, H12, H11} — generic concepts, H12 — set of species concepts;

• H2 — set of concepts forming aggregation relation with data {H21, H22}, H21 — concept which is "whole" in relation to described, H22 — set of concepts which are a part of described [6].

Description of a term using these criteria helps to obtain the necessary information in a subject ontology.

Discussion

One of the factors influencing the relevance information of search results is the multivalence of a search query. Polysemy is expressed by lexical means of a natural language. It is noted that almost every word in natural language, except for strictly unambiguous terms, is polysemous. The multiple meanings of a word depend on the context in which the word is used. The plurivalence of a lexical unit is manifested at the stage of the search query. It is substantiated that ontologies allow to convey the semantic component of the data related in the subject area. The proposed method of lexical multivariant resolution can be applied for a search query to the input of the search engine. The search engine is connected with the ontology library to find the user's search query. If the lexical item from the search query is multi-valued, the search engine offers the user a list of subject areas in which the lexical item from the search query is found. Often the user searches for a result from a specific subject area. When a subject area is defined, the search engine identifies the nearest items in the ontology structure, and the system is guided by their presence or absence when ranking search results. The usage of ontologies also allows synonyms and acronyms to be added for a search query to mean the same concept by different lexical means.

Conclusion

Modern approaches consider natural language lexicon as one part of the ontological model components. Applying ontology for automatic texts processing, in particular, solves information retrieval problems. It is necessary to match ontological concepts with a set of language expressions which concepts can be expressed in the text. Implementing the natural language processing tasks of scientific and technical texts and the construction of ontologies, we have created a basic template for a multilingual dictionary entry of a linguistic ontology in a subject area based on scientific and technical corpora. This multilingual dictionary entry of a linguistic ontology in a subject area can be useful to solve problems with the natural language processing tasks of scientific and technical texts.

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Уровень правосознания студентов, обучающихся по специальностям, связанной с компьютерной безопасностью

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Рассмотрен вопрос роста количества внутренних нарушителей в коммерческих организациях. Проанализирован уровень сформированности правосознания у студентов, обучающихся по специальности, связанной с компьютерной безопасностью, ведь именно они в будущем могут стать защитниками информации и потенциально наиболее опасными инсайдерами. Выполнен поиск различий по уровню сформированности сферы правосознания у студентов различных курсов, а также сделан вывод о наличии связей между уровнем развития данной сферы и их личностными ценностями.

Ключевые слова: *правосознание, информационная безопасность, студенты, внутренние нарушители, защита информации, личностные ценности студентов, современное образование*

Level of Legal Perception Among Students of Information Security

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The article raises the issue of the growing number of internal violators in commercial organizations. The authors analyzed the level of formation of legal perception of students in the specialty related to computer security. Because in the future they may become the protectors of information and the most dangerous potential insiders. Authors searched for differences in the level of formation of legal consciousness among students of different years of study at the university, and also made a conclusion about the presence of correlations between the level of development of this sphere and their personal values.

Keywords: *legal perception, information security, students, internal perpetrators, information protection, personal values of students, modern education*

Introduction

The widespread use and development of information technology makes information susceptible to extremely many factors. The number of unauthorized attacks on information systems and leaks of confidential information increases annually [1]. The most dangerous risk associated with information leaks is its uncontrolled transmission by an internal perpetrator — a human. Statistically, the largest number of information leaks occurs through insider channels, i.e. when employees of organizations deliberately steal information and transfer it to third parties [2].

If the current recruitment procedure is evaluated, the following can be observed: companies and banks focus only on determining the level of professional knowledge of future candidates [3]. This level is determined by formal attributes: education, work experience [4]. And only few companies pay attention to the personal qualities of future job seekers [5]. In today's environment, every employee may be of interest to competitors or criminal groups. That is why employers have higher requirements for personal qualities of candidates for one or another position: as a rule, the risk of information leakage through technical channels is lower than through channels with human factor [6].

The aim of the study was to determine the level of legal awareness of students studying for a degree in computer security.

Hypotheses of the study:

1. The level of legal consciousness of the majority of students is at least average, as they have chosen information protection as their future speciality.

2. There are no differences in the level and its components of legal awareness between students studying in different years of study at the university (first and second, third, fourth — together).

3. There is no correlation between the level of legal awareness and the personal values of the students.

The empirical material of the study was conducted at Bauman Moscow State Technical University since September 2021 till February 2022. The research involved 133 students: 19 girls and 114 boys, studying at the 1st, 2nd, 3rd and 4th years in the specialties 10.05.01 — “Computer Security” and 10.05.03 — “Information Security of Automated Systems”. The average age of the subjects was 18 years old.

Research methods:

• study of everyday legal consciousness (L.A. Yasyukova) [8];
• analysis of legal consciousness components (R.R. Muslumov) [9];
• portrait Values Questionnaire-Revised (PVQ-R2) [10].

Discussion of the results

According to R.R. Muslumov's method “Analysis of Legal Awareness Components”, the median value of the “Knowledge of Law” scale is 71, which corresponds to a high level of development of this component. This means that the respondents have a sufficiently well-developed outlook on legal knowledge. They are familiar with basic laws and legal norms. The medians of all other scales “Legal System”, “Legal Institutions”, “Legal Attitudes”, “Legal Activity”, “Open-mindedness” correspond to an average level of development of the components.

On the percentiles, it is shown that only about 30 % of students have a high level of development of all components of legal awareness.

In the results of L.A. Yasyukova's methodology the median value of the scale General level of development of legal consciousness is 16, which means that most students have the basics of legal consciousness. It is established that only about 10 % of students scored higher than 19 (a good level of formation).

The median values of the spheres of legal awareness: the domestic sphere and legal knowledge show a good level of formation, the business and civil spheres show an average level.

According to R.R. Muslumov's methodology, the first hypothesis is confirmed: on the Knowledge of Law scale, the median value of the entire sample corresponds to a high level of development of this component. The remaining five scales correspond to an average level of development.

To determine whether there are differences in the level of formation of legal consciousness components between the first year and senior students (the 2nd, 3rd, 4th years) the U-Mann-Whitney test will be used (Table 1).

According to R.R. Muslumov's methodology, the hypothesis is accepted only for the scale corresponding to students' legal attitudes. For the remaining five scales the null hypothesis is accepted, that is, there are no differences between students of different years of study at the university. Note that all hypotheses were tested at the significance level of 0.05.

Table 1

U-Mann-Whitney test for components of legal awareness

Hypothesis	Significance level, alpha	Result
H0: no differences for different courses on the scale "Knowledge of the law"	0.470	The H_0 hypothesis is accepted
H0: no differences for different courses on the scale "Attitudes towards the law in general"	0.212	The H_0 hypothesis is accepted
H0: no differences for different courses on the scale "Attitudes towards legal institutions"	0.183	The H_0 hypothesis is accepted
H0: no differences for different courses on the scale "Legal attitudes"	< 0.001	The H_0 hypothesis is rejected
H0: no differences for different courses on the scale "Legal activism"	0.271	The H_0 hypothesis is accepted
H0: no differences for different courses on the scale "Open-mindedness"	0.832	The H_0 hypothesis is accepted

Thus, it is the level of pro-social legal attitudes that differs among respondents of different ages.

The results obtained with the help of L.A. Yasyukova's methodology compare whether there are differences in the levels of legal consciousness between the first year and the senior students.

For the general level of legal awareness, the null hypothesis is accepted, so there are no differences. There are differences only in the civil sphere. It is related to the self-identification of the examinees as a citizen of the state.

To summarize the testing of the second hypothesis: according to R.R. Muslumov's methodology, there are differences only on the scale of legal attitudes. According to remaining five scales (knowledge of law, legal system, institutions of law, legal activity, open-mindedness) it is evaluated that there are no differences between students of different years of study. According to L.A. Yasyukova's methodology, there are no differences in the general level. There are differences only in the civil sphere.

For testing the third hypothesis, which is that there is no relationship between the components and level of legal consciousness and the personal values of the subjects, Spearman's rank correlation coefficient ρ is used.

A weak positive or weakly negative relationship is discovered between legal awareness and personal values (Table 2). Note that the Schwartz PVQ-R2 meta-value “Retention” is usually characterised by a weak positive relationship. While the meta-value “Self-affirmation” is characterised by a weak negative correlation with right-consciousness.

Table 2

Correlation analysis of the links between the sphere of legal consciousness and the personal values of the subjects

Personal value / Component of the sphere of legal consciousness	Self-determination	Self-affirmation	Openness to change	Preservation
Knowledge of the law	Weak negative correlation	Weak negative correlation	Weak negative correlation	Weak negative correlation
Attitudes towards the law in general	Weak negative correlation	Weak negative correlation	Weak negative correlation	Weak positive correlation
Attitudes towards legal institutions	Weak negative correlation	Weak negative correlation	Weak negative correlation	Weak positive correlation
Legal attitudes	Weak positive correlation	Weak negative correlation	Weak negative correlation	Weak positive correlation
Legal activism	Weak positive correlation	Weak negative correlation	Weak positive correlation	Weak positive correlation
Open-mindedness	Weak negative correlation	Weak negative correlation	Weak negative correlation	Weak negative correlation

Based on the data obtained, it is shown that there is a certain tendency that, with regard to the sphere of legal consciousness, the respondents hold conservative views. That is, they are in favour of preserving established cultural and legal values, traditions and laws. At the same time, the respondents recognise the fact that legal norms may restrict their freedom of action. These norms in their minds are associated with rigidity, lack of mobility and lack of sensual pleasure. This is supported by a weak positive relationship with the meta-value “Preservation” and a weak negative relationship with the meta-value “Openness to change”.

Summarise

To summarise, it can be noted that students have an average level of legal consciousness according to both R.R. Muslumov's and L.A. Yasyukova's methodologies. The correlation analysis of the right sphere and value orientations showed only weak links between personal values and components of legal consciousness.

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УДК 81

Функциональные особенности фразовых глаголов

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Проанализированы функциональные особенности фразовых глаголов в английском языке. Методом сплошной выборки были отобраны английские фразовые глаголы с постпозитивами out, up, off, on, in, down, представленные в словарях неологизмов и англоязычной прессе. Материалом исследования послужили работы ученых в данной области, словари неологизмов UNWORDS, Rice University New Words Database, Wordspy, а также материалы Британского Национального Корпуса. Учет функциональных особенностей фразовых глаголов позволил выделить коммуникативную, номинативную, информативную и эффективную функции. Все функции фразовых глаголов взаимодействуют между собой, создавая необходимую характеристику определенной языковой номинации. Теоретическая и практическая значимость заключается в определенном вкладе, которое проведенное исследование вносит в изучение функциональных особенностей фразовых глаголов и может быть использовано на занятиях английского языка.

Ключевые слова: *фразовый глагол, фразеологическая единица, смысловое значение, речь, система английского языка, языковая картина мира*

Functional Features of Phrasal Verbs

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The functional features of phrasal verbs in English were analyzed. English phrasal verbs with postpositions out, up, off, on, in, down, presented in dictionaries of neologisms and the English-language press were selected by the method of continuous sampling. The material of the study was the works of scholars in the field, UNWORDS dictionaries of neologisms, Rice University New Words Database, Wordspy, as well as the materials of the British National Corpus. Consideration of the functional features of phrasal verbs allowed us to distinguish communicative, nominative, informative and effective functions. All functions of phrasal verbs interact with each other, creating the necessary characteristic of a certain linguistic nomination. Theoretical and practical significance lies in the certain contribution the study makes to the study of the functional features of phrasal verbs and can be used in English classes.

Keywords: *phrasal verb, phraseological unit, semantic meaning, speech, English language system, linguistic view of the world*

Phrasal verbs are complex constructions, represented by a verb and a preposition, an adverb, a preposition and an adverb. Moreover, all the listed parts are perceived as a unified whole, united by a common meaning. In other words, a phrasal verb must be considered as an integral, inseparable phraseological unit, the general semantic meaning of which differs from the meaning of its individual components.

Phrasal verbs arose in the language as a result of the need to express a more detailed attitude to the actions being performed, to clarify the spatial orientation within which the described action takes place.

For the first time in linguistics, the term “phrasal verb” was mentioned in 1925 by L. Smith [1]. Other names of this term are the concepts of “verb group and particles”, “two-word verb”, “three-word verb”, “multi-word verb”. In the Russian language, the term “phrasal verb” appeared somewhat later in 1986. It was first recorded in the English-Russian dictionary of combinations [2].

To date, there are a huge number of phrasal verbs in English, at that this number is steadily arising. The remarkable thing is that there is not only the appearance of new phrasal verbs, but also an increase in the frequency of use of existing units. Phrasal verbs attach speech a special expressiveness and they are used not only in colloquial speech, but also in official business texts. All of listed above reasons have determined the relevance of this study.

The aim of the article is the analysis of the functional features of phrasal verbs in English.

Many domestic and foreign researchers studied phrasal verbs (as S.Y. Bogdanova, G.E. Belaya, O.S. Akhmanova, E.E. Golubkova, S.Y. Tarabrina, A.S. Harris, J. Povey, etc.).

One of the specific characteristics of phrasal verbs is the degree of the formality. Despite the fact that they are less formal than ordinary verbs, such units can occur not only in an informal setting, but also in the texts of official publications. Moreover, phrasal verbs are often found in the mass media and other sources of information transmission. However, the use of phrasal verbs in papers of more serious content is considered inappropriate. Such usage cannot be considered as a strict rule but it can be considered as a strict tendency that characterizes language norms.

For the semantics of understanding in the English language system, great importance is given to the actually existing linguistic view of the world. Phrasal verbs in this case are focused on creating alternatives ways of communication and interaction. In modern linguistics, it is customary to talk about the specifics of the mechanisms of influence of semantic phraseological components. It is common to talk about the specifics of the mechanisms of influence of semantic phraseological components. The distinctive characteristic of phrasal verbs is that they can create restrictions in the appropriate context based on a combination of a number of strictly defined components. This process leads to the integration of all the presented component elements of the phrasal verb into a unified whole.

The use of phrasal verbs in speech at various semantic levels has always been a great deal of interests to researchers. Therefore, three problems of their use were identified, the solution of which is not clearly defined to date. Such problems include:

• definition of the essence and extent of the concept of phrasal verbs. The problem is largely related to the fact that phrasal verbs can vary depending on the number and level of components. The compatibility of component elements of such verbs determines their essence;

• system-semantic organization of phrasal verbs. The problem correlates with the fact that certain postverbs used to create phrasal verbs have a specific nominative function. The meaning of the same verb largely depends on which postverb accompanies it;

• classification of phrasal verbs. The problem is also very complex, since it is related to the typology of phrasal verbs. Thereby, researchers face a very difficult task, which consists of which criterion it is necessary to carry out classification.

Phrasal verbs used both in everyday communication and in fictional or other literature have stability. The essence of the stability lies in the specific reproducibility of combination of lexical components obtained in the final version. Such phrasal verbs are characterized by so-called external signs. Despite the fewness of external sings, they play a significant role for understanding and interpretation.

Phrasal verbs arise mainly in oral speech, which indicates that the main sphere of the application is everyday communication. Since phrasal verbs are designed to make the speaker's speech more vivid, emotional and diverse, we can speak about the relevance of their use in films, songs and fictional literature.

The functioning of phrasal verbs in speech is also related to a number of difficulties. First,, one of the difficulties is a semantic function, since incorrect use of the verb can lead to complete distortion of the meaning of the expression.

Furthermore, the semantic meaning of a phrasal verb can be adequately defined only if there is an appropriate context. For example, the expression "*go out*" can be translated as "*to leave a room or building*". For example, "*He goes out of this café every day*". However, if there is an appropriate context, we can note the possibility of translating the expression in the meaning of "*to leave a room or building in order to do something for entertainment*". For example, "*I often go out with my friends*". Although the specific characteristic of phrasal verbs also consists of the fact that the same verb can be translated in different ways depending on the different context. For example, the same verb "*go out*" can be translated as "*to have a romantic relationship*". For example, "*Michael goes out with Ann*". Any of the phrasal verbs available in the English language system can change the semantic meaning. Such a change in the semantic load of lexical units leads to the arising of phrasal neologisms in speech, i.e. new lexical units, the meaning of which can be understood only based on the specific content of the provided information.

One of the features of phrasal verbs is idiomaticity, i.e. the combination of semantic components in the expression, the individual meaning of which does not correspond to the general meaning of the expression. According to this, we can say that the polysemantics of phrasal verbs lead to the fact that it can be possible to perceive them both literally and idiomatically [3].

In the work of N.V. Avdevich, devoted to the issue of cognitive-discursive features of polysemous phrasal verbs in modern English, it is said that phrasal verbs in English can be considered from the perspective of two variants: British and American [4]. Four groups of lexical units were identified in the work:

• identical meanings, different verbs, different particles. For example, *ace out* (AE) and *beat off* (BE).

The lexical units have identical meaning, but different structures: they are based on different verbs *"act"* and *"beat"*, as well as different postpositions *"out"* and *"off"*;

• identical meaning, different verbs, identical particles. For example, *check off (AE) and tick off (BE).*

The phrasal verbs have equivalent meanings, same particles *"off"*, but the verbs *"check"* and *"tick"* are different;

• identical meanings, identical verbs, different particles. For example, *beat on (AE) and beat up (BE).*

The verbs are identical both in meaning and partially in structure, the difference lies only in the particles *"on"* and *"up"*;

• different meanings, identical verbs and particles. For example, *hang on (AE) and hang on (BE).*

The forms of phrasal verbs are identical: in the American and British versions, the same verb and particle, but the meanings are different: *"hang on"* (AE) — "hold on to something, wait"; *"hang on"* (BE) — "persevere, hang on the phone".

From the point of view of the functional features of phrasal verbs, it is also necessary to note a number of their distinctive features:

• the possibility of replacing a phrasal verb with a simple verb, the meaning of which corresponds to the context and the situation in which it is used according to the chosen situation;

• idiomaticity of a phrasal verb, which, accordingly, consists in the presence of a common semantic meaning characteristic of the whole phrase as a whole, and not for a number of individual components;

• the ability to form passive constructions, which leads to the fact that lexical units, forming set expressions, cannot be modified without losing their semantic connotation [5].

Phrasal verbs used in everyday communication have four functions: communicative, nominative, informative and effective. Moreover, it is significant that all listed functions work together. So, in the process of using a phrasal verb in speech, the communicative function is realized automatically in the process of communication. At the same time, the nominative function of a phrasal verb is to name the action in question. The essence of the informative function consists of transferring the necessary data in order to carry out further communication. The essence of the effective function is to have an appropriate effect on the listener or reader, achieving a certain level of psycho-emotional impact exerted on the opponent.

The use of phrasal verbs by non-native speakers can correspond to a number of mistakes and difficulties [6]. Such mistakes and difficulties include:

• desire not to use phrasal verbs in everyday communication;

• stylistic incompetence, manifested in the lack of ability to feel the difference between formal and informal styles, as a result, inappropriate use of phrasal verbs;

• misunderstanding of the meanings of phrasal verbs, as a result, inappropriate use of a particle or a verb;

• ignorance of the compatibility of words, collocation illiteracy, manifested in the wrong choice of the word in the formation of phrases;

• the use of so-called "individual", "unique" phrasal verbs, which the speaker creates by analogy with existing ones, trying to fill the gap in language knowledge. The error often leads to the arising of new types of phrasal verbs or neologisms in the language;

• syntactic errors, manifested in the incorrect use of transitive and intransitive phrasal verbs and in violation of the word order.

Accordingly, a number of the listed mistakes suggests that the use of phrasal verbs in speech assumes that the speaker has a comparative large linguistic experience that could allow him or her to correctly carry out the corresponding language activity.

As follows from the presented examples, phrasal verbs can be used in different linguistic spheres. Phrasal verbs have both generally accepted and narrowly professional semantic load, they can reflect general and particular concepts.

When studying the functional features of phrasal verbs, it was found that this is a unique linguistic form in its structure and application. Phrasal verbs are characteristic not only for everyday colloquial speech, but also are a full part of the language of professional communication. The high frequency of the use of phrasal verbs is explained by their semantic compactness and informativeness, i.e. they can act as a highly productive means of linguistic economy. The functioning of phrasal verbs in the language of professional communication is directly related to the mobility of these language combinations, their ability to acquire new and transform existing meanings to extend them to new concepts and phenomena.

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УДК 81

Современные средства обучения китайской письму

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Рассмотрены основные особенности современного обучения китайскому языку и преимущества обучения с использованием веб-приложений. Смешанное обучение с использованием веб-приложений является продуктивным на начальных этапах изучения китайской письменности, а в дальнейшем может использоваться как вспомогательное средство. На данный момент существует множество веб-приложений для изучения китайского языка, но отечественные разработки занимают малую долю подобных учебных материалов.

Ключевые слова: *китайский язык, изучение иностранного языка, обучение иностранному языку, китайские иероглифы, веб-приложение, учебные материалы*

Modern tools for Learning Chinese Characters

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The article deals with the main approaches to modern Chinese language teaching and the advantages of teaching with web applications. The main idea of the article is that blended learning with the use of web applications is efficient at the initial stages of learning Chinese writing, and later it can be used as an auxiliary tool. At the moment there are many web applications for learning Chinese, but Russian developments occupy a small share of such learning web applications.

Keywords: *Chinese language, foreign language learning, foreign language teaching, Chinese characters, web applications, learning materials*

The increasing development of e-learing and using web applications directly demonstrate the changes in language teaching methods. Applying technologies in the educational process is positive since a technology brings interactivity and improves the effectiveness of the learning process. Digital strategies in education contribute to improving the quality of knowledge acquisition and shaping professional skills. Despite the fact that digital globalization has significantly changed the speed of obtaining information in various area, face-to-face education is still the main form of education in schools and universities. The Internet technologies are used as additional tools for students to communicate and work together. Thus, in the near future the introduction of digital technologies into the educational process will have a major impact on the choice of teaching strategies, teaching methods, and will substantially change the quality of knowledge obtained. Blended classes with the use of technologies should become a part of the curriculum.

The number of Chinese language learners increases every year. According to [1], learning Chinese characters depends on the degree of learners perception skills. The learners gradually shape their perception system, which implies complication of the learning material starting from recognition and understanding the schemes of graphic organization of characters including radicals, to recognition and understanding of complex characters. The schemes of the graphic structure of a hieroglyphic sign, the position of radicals-determinatives in a hieroglyph, and the form of the key elements are used as categorical features [1]. The use of computer technologies in the process of learning Chinese writing allows us to solve important didactic tasks, which can include the following:

• developing skills in recognizing and memorizing characters and their constituent parts;

• improvement of text reading skills;

• forming motivation for learning Chinese.

Due to the difficulties of learning isolated languages the process of teaching Chinese characters writing involves the use of various techniques. The difficulty in learning to write primarily depends on the lack of phonetic reference points in the character. Students have to to memorize and should be able to highlight the basic elements of a character (features, graphemes, radicals) in order to form correct writing skills. The process of learning characters should be structured so that studying characters the student should fix its phonetic and lexical images. Memorizing hieroglyphics vs memorizing characters of alphabetic writing is provided by a set of more complex brain operations including associative links. In the learning process it is necessary to develop a holistic perception of a character, the ability to analyze not only the relationship between writing, meaning and sounding the character, but also to understand a degree of compatibility of all its constituent elements. Currently, teaching a foreign language requires the simultaneous acquisition of both oral and written speech, i.e. students simultaneously master the skills of speaking, listening, writing, and reading. This principle of teaching allows students to form a more complete picture of the language, contributes to a better memorization of hieroglyphic signs. At the initial stages of teaching hieroglyphics it is possible to use game technologies represented by a large group of techniques. With the help of game technologies it is easier to form and maintain an interest in the Chinese language (a motivational component), students memorize graphic images of characters better, they learn the training programs more successfully, they are less exposed to psychological stress when memorizing a large amount of a material. This approach is time-consuming for teachers, as it implies more thorough preparation of a considerable amount of a teaching material for classes due to the need for frequent changes of students activities [2, 3].

Blended learning is currently the most promising in education. This approach makes it possible to change not only the students' activity, but also to influence the block of students' independent work. To date, the use of interactive exercises helps students to form their skills and abilities not only in the classroom with a teacher, but also to study independently in their spare time and at any place [4]. Some of the most common tasks for studying Chinese writing are filling in the blanks of features, radicals or characters, matching the written translation, sound or graphic organization of a character, determining the correct sequence of writing of a character, etc.

The use of computer technologies, such as web applications, interactive posters helps students to accelerate the assimilation of the material and not to lose their motivation due to interactivity. There are following examples:

• “Great Wall Chinese” application (an interactive Chinese language learning mode based on multimedia technology) that allows learners to monitor their progress;

• “Hello Chinese” application (game-based learning);

• “Memrise” application, which includes video materials, game tests, multimedia cards and practical phrases, allows learners to monitor their progress;

• “Train Chinese” application (Chinese dictionary with multimedia cards);

• “Chinese Writer” application (teaching Chinese writing in the form of a game — more than 5600 characters).

These applications can be divided according to learning approaches. Some educators rely on game-based learning information as the main teaching methodology, while others use multimedia cards to memorize hieroglyphics. Also they are shared by ability to monitor learning progress. The further development of the use of web applications in teaching Chinese writing is promising as more and more people are interested in learning languages. The rapid pace of technology development allows for a qualitative improvement in learning. It is also worth noting that at present there are few domestic web applications. Thus, this area is open for technical and linguistic development.

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Отношение человек — техника в современном обществе

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Рассмотрены актуальные проблемы человека в условиях тенденции широкого использования человеком современных технологий. Указаны выявленные проблемы в отношении системы человек — техника. Сделан вывод о том, что необходимо разработать подход должного формирования культуры гуманизма для повышения общественной ответственности с использованием информационно-коммуникационных технологий в условиях социально-виртуальной среды.

Ключевые слова: *социально-виртуальная среда, технический прогресс, гуманистический идеал, система «человек — техника», культура гуманизма*

The Human-Machine Relation in the Modern Society

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The article considers actual problems of man in the conditions of modern reality in the context of the modern technologies' widespread use trend. The paper indicates identified problems concerning the human-machine system. The authors conclude the necessity to develop an approach to the proper formation of a culture of humanism to increase public responsibility using information and communication technologies in a socio-virtual environment.

Keywords: *socio-virtual environment, humanistic ideal, technological progress, human-machine system, culture of humanism*

The study of scientific publications [1–3] revealed trends in the widespread use of modern technologies by humans. For example, today the use of information and communication technologies (ICT) by society largely influences the changes in various social processes, which transforms each of its participants in the conditions of a socio-virtual environment (SVE). In our opinion, all this is relevant for the study.

Indeed, it is difficult to imagine our life without the use of various gadgets and other electronic devices. They have become an integral part of human life in various spheres of society. That has led to the fact that it has become possible to significantly improve the quality of life.

Therefore, the purpose of our study is to consider the relationship between human and technology. To achieve this goal, the following tasks should be solved:

• to identify the main factors that affect a person's personality and his life in the conditions of SVE;

• to determine the degree of influence of identified problems;to make an attempt to

• identify ways to solve the identified problems.

The first factor is technological progress and the widespread use of ICT in the conditions of SVE, which is gaining global significance due to the change in preferences of interactions in the man-tech mode. That is influenced by the gradual transformation of ICT from a tool of life into the very purpose of life, where their dependence is visible. This is confirmed by the author of the work [1], where, as an illustration, the author points out that the use of modern technologies by people (for example, ICT) causes dependence that, in some cases, can lead to mental disorders.

In our opinion, this is due to the free dissemination (movement) of information, knowledge, and technology through space and time. Moreover, the constant growth of information and the need for its processing have led to the need to create not powerful computers but new technologies for storing large amounts of data. It is essential to mention the partially and in some cases completely removed information asymmetry between the participants of the SVE.

In addition, as society integrates into the SVE, it is crucial to mention the factor associated with freedom in the SVE, which implies the synthesis of different cultures. That may affect the fact that many cultural traditions are forgotten, and national values are replaced or destroyed. Therefore, we agree with the conclusions of K. Lorenz [4, 5] that life in modern society is not a competition of creative personalities, it is a struggle for a place in the social structure. There is no place for a person who still has a soul with eternal values in such a society. In this case, today there is a gap between the development and non-development of SVE, which can be called a digital chasm and which represents a virtual inequality between many participants.

In addition to moral and ethical problems, the widespread use of ICT leads to environmental problems [3]. Technology represents the external freedom of man, and engineering education is aimed at expanding the boundaries of this external freedom. Therefore, society should see the danger of expanding these boundaries because without ecologization engineering is destructive. The main negative consequence is the formation of the human consumer cult.

In conclusion, we point out that the current level of technological progress is changing the relationship between human and technology. Social ideas are being transformed under the influence of the widespread use of ICT in the conditions of the SVE. Today, there is a danger that this may contribute to a change in traditional values. The humanistic ideal imposes certain restrictions on technical development, but these restrictions are a necessary condition for the existence and development of both man himself and modern technologies.

In our opinion, in the considering conditions, the prospects for the development of man and humanity may depend on the proper formation of a culture of humanism based on some of the provisions indicated in work [6]. Thus, it is necessary to develop an appropriate approach to the solution of problems noted above, which can contribute to the increasing public responsibility and determination with the use of ICTs in the conditions of the SVE.

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Использование цифровой среды при обучении иностранному языку в средней школе

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Рассмотрены слабые и сильные стороны цифровизации при дистанционном обучении. Особое внимание уделено образовательной платформе — проекту «Московская электронная школа», который обеспечивает прогрессивные методики обучения. На примере одного из интерактивных уроков по английскому языку, разработанных автором, продемонстрированы особенности реализации современных цифровых технологий в образовании и их эффективность.

Ключевые слова: *цифровая среда, Московская электронная школа, интерактивный урок, современные технологии, методика обучения*

The Use of Digital Environment in Teaching a Foreign Language in Secondary School

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The present report discusses the strengths and weaknesses of digitalization in distance learning. Particular attention is paid to the educational platform – Moscow Electronic School (MES), which organises progressive teaching methods. The features of the implementation of modern digital technologies in education and their effectiveness are demonstrated on the example of one of the interactive English lessons developed by the author.

Keywords: *digital environment, Moscow E-School, interactive lesson, modern technologies, teaching methodology*

Introduction

Nowadays digital technologies play a decisive role in the strategic development of the socio-economic sector of the state. Having penetrated into the sphere of education, they led to the emergence of new forms of interaction, changing the forms of control and evaluation, the nature of obtaining information and the content of the material [1, 2]. Their rapid development in the economy, culture, art and other fields has recently made their impact in education as well, making it more convenient and accessible. Digitalization in this case does not exclude live communication between a student and a teacher, but it greatly facilitates the learning process. Let's take a look at its advantages and disadvantages [3]. The advantages are that all the information we need is always at hand; there is no need in printed products (books, tutorials, notebooks); students can study anywhere at any time, and the use of gaming techniques and information technologies make the lessons more interesting and varied. There may be singled out the following disadvantages: it takes more effort to create digital lessons than traditional learning; prolonged use of gadgets leads to visual impairment; sitting in front of a monitor for a long time slows down mental and physical development, as it requires less activity for the brain and body. The electronic devices negatively impact children's communication skills and serve as an obstacle to live communication [4].

Purpose

The purpose of this report is to show the effectiveness of the use of some modern technologies and teaching methods. Particular attention is paid to the presentation of the educational platform — Moscow Electronic School, or just MES, which organises progressive teaching methods.

Having penetrated into the sphere of education, digital technologies led to the emergence of new forms of interaction, changing the forms of the nature of obtaining information and the content of the material. Digitalization in this case does not exclude live communication between a student and a teacher, but it greatly facilitates the learning process.

The education system does not stand still. Ultra-modern educational institutions are provided with high-speed Internet, a controlled access system for schools, interactive panels, devices, an electronic journal and diary; and a library of electronic educational resources have been introduced. Lockdown contributed to the formation of a new digital environment with great opportunities for testing and controlling knowledge [5]. The integration of disciplines, which unites a number of subjects together, has become especially relevant. Their collaboration establishes a connection, ensures cooperation, solves a range of educational and developmental tasks. Specifically, to improve vocabulary, expand knowledge about regional studies, culture and Art, activate the cognitive activity of students. It is possible to integrate a foreign language with other disciplines, like Art, history, literature, geography, which contributes to the development of communication skills and interpersonal skills [6].

Method

Since 2016, the Moscow Department of Education has been implementing the Moscow Electronic School (MES) project — a unified educational platform that helps a child to learn, a teacher to teach, and parents to control the educational process. At any time, students can check the lesson schedule, find out their homework, chat with teachers and keep abreast of school news. Parents not only know when their children entered and left the school, the menu at the school canteen, the topics of the lessons, but also the grades.

Over the past few years, a number of Moscow teachers have developed thousands of digital lessons using video and audio fragments, text and table materials, test tasks, interactive applications with a self-test function. All this makes learning process interactive, entertaining and productive. It encourages schoolchildren to switch their attention from one type of activity to another. It helps them digest the material and get less tired throughout the lessons.

The author conducted a survey among secondary school students to identify their readiness to use digital technologies in the study of a foreign language. According to the results: more than 70 % of the students used Internet resources in their daily learning activities, more than a half considered the resources useful in learning a foreign language, and the vast majority of students would like to include additional activities using digital technologies in the classroom [7].

Nowadays a teacher is an assistant who guides their students in the digital space, organises independent cognitive activity of students. A teacher chooses or creates the interactive tasks for their lesson. At the same time, students can study the material independently using the materials from the electronic educational library of MES. Almost all of the schools in Moscow are connected to MES, it is used by 2.8 million users. Schools are equipped with 21,000 high-tech classrooms, more than 49,000 wi-fi points and 21,800 interactive panels, 44,000 laptops are provided for teachers [8]. It is evident that the difference between a traditional English lesson and an interactive one. A teacher selects video and audio files for the lesson, prepares printouts and pictures for assignments, which requires a lot of time. The MES library allows you to find a suitable interactive lesson for each topic for a particular class. The most important thing here is that such tasks are interspersed with various gaming elements, for example, solving a crossword puzzle, arranging the answers for the questions in the correct order on an interactive panel. Working with several students at the same time allows a teacher to organise group and pair work.

Conclusion

There are some other educational platforms. For example, many regional schools use the materials from the Russian Electronic School (RES) library, as the Moscow Electronic School (MES), where there is the most itemized list of topics. But still, the main part of the RES library mostly consists of educational videos and training tasks, while the MES library has interactive lessons that help teachers in full-time and distance learning: apps, tests, video lessons, audio materials, electronic textbooks and even electronic educational tutorials.

Thanks to the digitalization of education, the current paper work of teachers has also been simplified.

Thus, it can be concluded that the competent use of the MES educational platform allows teachers to organise a modern process of teaching foreign languages in secondary school. After all, the use of digital environment not only makes the educational process easier and more efficient, but also expands future opportunities for students.

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Готовность преподавателей иностранного языка технического вуза к оцениванию компетентностных результатов обучения в цифровой среде

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Рассмотрена проблема оценочной компетентности преподавателей ESP применительно к цифровой среде технического вуза. Методологические аспекты формирующего оценивания проанализированы в ракурсе компетентностного подхода. Поставлен вопрос о понимании преподавателями ESP сущности формирующего оценивания, а также об их способности использовать цифровые инструменты для оценивания иноязычной профессиональной коммуникативной компетенции студентов инженерных специальностей. Приведены результаты опроса 47 действующих преподавателей ESP МГТУ им. Н.Э. Баумана, направленного на определение восприятия преподавателями собственной оценочной деятельности. Опрос позволил выявить неготовность преподавателей ESP осуществлять многокомпонентное формирующее оценивание в цифровой среде и общую тенденцию к упрощению оценочных процедур. Сделаны выводы о необходимости разработки курса повышения квалификации для преподавателей ESP, направленного на устранение методического дефицита в области оценивания компетентностных результатов обучения иностранному языку в целом и в цифровой среде, в частности.

Ключевые слова: *преподаватели ESP, формирующее оценивание, цифровая среда, компетентностный подход, технический вуз*

ESP Teachers' Preparedness to Assess Competence-Based Learning Outcomes of Engineering Students in a Digital Environment

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The article considers the problem of ESP teachers' assessment competence in a digital learning environment of an engineering university. The underlying methodology of formative assessment is analyzed from the perspective of competence-based approach. The authors raise the questions about ESP teachers' awareness of formative assessment and their ability to use digital instruments for assessing foreign-language professional communication competence (FPCC) of engineering students. The survey of 47 ESP teachers working at Bauman Moscow State Technical University (BMSTU) was conducted to analyze teachers' perception of their assessment practices. The results of the survey revealed ESP teachers' *reluctance to implement multi-step formative assessment procedure and the tendency to simplify digital assessment process. The authors came to a conclusion about the need to design a professional development course to eliminate ESP teachers' deficit of competence-based assessment methodology and develop their digital assessment skills.*

Keywords: *ESP teachers, formative assessment, digital learning environment, competence-based approach, technical university*

Introduction

The modern requirements for educational training are conditioned by axiological strategies put forward by the government to comply with the trends and challenges of our society. The first strategy, competence-based approach to training professionals, sets educational goals that should be transferred to expected learning outcomes, which represent professional competences and soft skills. The competence-based paradigm needs changing focus of assessment — from norm-referencing (comparing students' works with a benchmark and with each other) to formative (evaluating students' works in dynamics focusing on practical skills and personal academic growth). Integration of formative assessment methods require teachers' deep insight into assessment values and readiness to implement time-consuming classroom practices.

The second strategy is a purposeful transformation of universities into a digital data-driven system, independent and secure. Digital transformation of universities imposes many requirements on the lecturers in terms of their ability to use digital learning tools, design digital learning environment and make digital assessment of students' learning outcomes.

Language education in engineering universities being realized mostly on the ground of ESP methodology is based on the same axiological strategies, emphasizing competence-based training and assessment and necessity of developing ESP teachers' digital skills. However, lesson observation has shown that ESP teachers have difficulties in solving both tasks — assessing a foreign-language professional communication competence (FPCC) of engineering students and applying digital tools for its realization in a digital environment.

When talking about enhancing ESP teachers' assessment competence, it is important to consider the requirements for their digital skills. Modern education implies various learning formats. In the context of universities' digital transformation, ESP teacher should be able to switch easily from face-to-face learning to distant or blended learning. In addition to ability to develop digital learning environment, ESP teachers have to be prepared to transfer multi-step formative assessment procedure to LMS or mobile apps used for educational purposes without losing adequacy and validity of assessment.

Despite the fact that ed-tech has become a part of our life, some teachers are still techno-wary. It takes long lime to learn how to use a new piece of equipment and sometimes all teachers' energy goes into that challenge. Early lessons with a new tool become technology-focused, rather than aim-driven. Giving priority to pedagogical goals, ESP teachers need to make sure that they do not show off new cool tech tricks, but use tech tools to a real purpose.

In this context it is important to answer the following questions:

1. Are ESP teachers well aware of formative assessment methodology? Do they practice it in their lessons with engineering students?

2. How comfortable are ESP teachers with assessing engineering students' learning outcomes in a digital environment? Do they have necessary digital skills?

The objective of this research is to evaluate the preparedness of ESP teachers to integrate formative assessment methods in a digital learning environment of an engineering university. For this purpose, a survey of 47 respondents working as ESP teachers at BMSTU was conducted. The survey included the questions about competence-based approach and formative assessment methodology, ESP teachers' digital competence and requirements for digital assessment tools.

Methodology

The notion of assessment in education is transforming as new theories and practices emerge. Until the mid-twentieth century assessment meant primarily the measurement of the results of acquired knowledge, by comparing them with a certain benchmark. Russian teachers B.G. Ananyev, V.A. Sukhomlinsky, Sh.A. Amonashvili contributed greatly to the development of the theory of assessment, understanding assessment as a process which not only affects successful learning, but also the personality of the student. In light of the development of pedagogical assessment, special attention should be paid to the research of Benjamin Bloom, an American psychologist studying methods of learning. Bloom's theory and its modified version can also be applied to the assessment process itself, including the assessment of students' ESP competence. When formulating a question, creating test tasks, it is possible to check consecutively: reproduction, understanding of information, ability to use acquired information in a specific situation, ability to structure information, ability to make inferences based on criteria and standards, ability to combine different elements of acquired knowledge to form new knowledge and ideas [1].

Russian authors K.M. Inozemtseva, E.V. Prilipko, Y.A. Tarabarina devoted their studies to competence-based approach in teaching and assessment of students' ESP competence.

Teacher's assessment activity is undergoing significant modification due to the transition from knowledge assessment to the assessment of students' competence development [2]. According to K.M. Inozemtseva, ESP training in the context of the competence-based approach should be focused on the formation of students' readiness for foreign-language professional communication [3]. In defining the foreign-language professional communication competence (EPCC) of a future specialist, K.M. Inozemtseva speaks about bringing them as close as possible to the requirements of potential employers and describes them as the capability of a university graduate to perform as a subject in the international professional community [4]. Y.A. Tarabanina points out that the assessment of EPCC includes the assessment of written and oral speech skills [5].

According to current trends, competences can be assessed through summative and formative assessment. Summative assessment is a result-based assessment. An example of summative assessment is a final exam. Formative assessment is a dynamic process of shaping and assessing students' competences.

The issue of formative assessment and its positive impact on the educational process is addressed in the works of Russian scientists I.S. Fishman, M.A. Pinskaya, M.A. Vikulin, L.V. Vilkov and Western authors Brink, Andersson, ed. H.L. Andrad, Biggs J., Rust C. In order for assessment to be formative according to L.M. Vilkova it should include a number of components [6]:

- setting learning objectives,
- teacher and students' agreeing on assessment criteria,
- self assessment,

• peer assessment,
• students' feedback.

The use of digital tools for formative assessment has been addressed by researchers J.W. Gikandi, D. Morrowa, N.E. Davisa, M.A. Bodogni, Pezzino, J.M. Faber, H. Luyten, A.J. Visscher. According to A. Bodogni, digital tools such as supporting students' activities, organising feedback, activating students' self-assessment are important [7]. M. Pezzino believes that the ability of a digital platform to provide multiple passes of a test, combined with instant feedback, makes it possible to record the student's understanding of the material covered and to ensure that this understanding is corrected [8]. In addition to the importance of using feedback in digital assessment, a number of authors suggest the effectiveness of adaptive tests, which adjust to the individual student's characteristics [9].

Based on the above-mentioned publications, the following requirements for digital assessment platforms can be identified when carrying out formative assessment of students' foreign language competences: capability to create multi-level adaptive tests, capability to track students' progress, capability to perform self- and peer assessment, capability to obtain feedback from the students.

Discussion and results

The first question of this experiment reflects the ESP teachers' understanding of the definition of an engineering students' ESP competence. Most of the respondents (83.3 %) associated this concept with the students' readiness to use a foreign language for engineering purposes. 9.5 % of the respondents associated the notion of FPCC with students' acquisition of a foreign language course at an engineering university. 7.1 % of the respondents defined FPCC as "a student's readiness to understand and translate technical texts from/into a foreign language". None of the respondents associated FPCC with mastering technical terminology in a foreign language.

The development of FPCC is indissoluble with the process of its assessment and control, therefore the question arises as to how ESP learning outcomes are assessed at a technical university. The distribution of answers is shown in Fig. 1. Over a half of the respondents (52.4 %) chose the dynamic assessment by means of a combination of oral and written communicative ESP tasks. 31 % of the surveyed teachers opted for testing as an interim assessment (at the end of a module or semester). In the minority were those teachers who chose either only oral communicative tasks or only written ones.

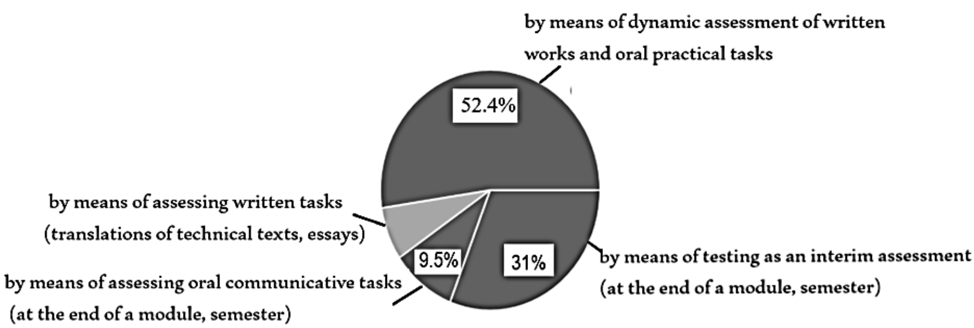

Fig. 1. Survey respondents' perception of how to assess FPCC at an engineering university

The findings indicate that the use of dynamic assessment is popular among ESP educators as they are aware of FPCC being a personal characteristic that can be assessed in dynamics. Dynamic assessment reflects the essence of formative assessment. The experiment showed that over a half of the respondents (59.5 %) specified all the components of formative assessment. However, quite a large percentage (21.4 %) of ESP teachers overlooked learning objective setting and teacher and students' collaborative development of assessment criteria, which indicates superficial knowledge of formative assessment methodology. Fig. 2 shows the distribution of the answers.

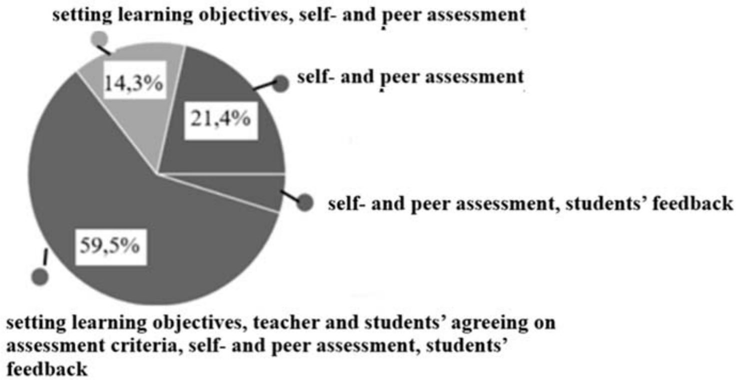

Fig. 2. Survey respondents' perception of formative assessment components

Subsequent questions of the survey were related FPCC assessment in a digital environment. The survey revealed that a number of teachers (19 %) question the very possibility of assessing the competency-based outcomes of teaching students in a digital environment. Some teachers (7 %) believe that digital assessment is possible, but only by means of assessing oral communication tasks via videoconferencing. About 19 % believe that assessment is possible through the use of test platforms, while the majority of respondents (about 55 %) believe that assessment of competence-based learning outcomes is possible through integration of oral and written assignments into the digital learning environment of the university.

The authors hypothesized that ESP teachers may have some requirements for the platforms and mobile apps used for digital assessment. Some of the requirements included in the survey are given below:

- capability to create multi-level adaptive tests,
- capability to track students' progress,
- capability to perform group tasks,
- capability to perform self- and peer assessment,
- capability to perform a set of written and oral tasks on the same platform/app,
- capability to obtain feedback from the students.

The respondents could choose more than one answer. The distribution of answers is shown in Fig. 3. It should be noted that the most popular option is "the capability to perform a set of written tasks and take an oral survey using the same platform". Surprisingly, the feedback option, on the other hand, has been the least popular with ESP teachers. The other features of the platforms have roughly the same ratings.

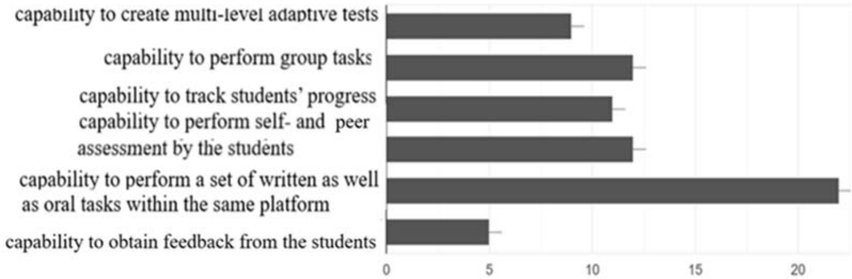

Fig. 3. ESP teachers' requirements for the platforms and apps used for digital assessment

Regarding the question of teachers' preparedness for working with modern digital assessment tools, four groups of teachers were identified:

1. ESP teachers who use ready-made digital tests placed in the university's LMS. This is the largest group, accounting for 50 % of all teachers surveyed.

2. ESP teachers who create their own digital tests on several test platforms. This group accounted for 26 %.

3. ESP teachers who carry out a comprehensive dynamic assessment of engineering students' communicative skills using several digital platforms. This group amounted to about 14 %.

4. ESP teachers who do not know how to work with digital assessment tools. This group accounted for about 10 % of all respondents.

Conclusion

The emergence of new assessment approaches and methodologies, and the continuous development of digital capabilities for the assessment of student learning outcomes lead to a multifactorial transformation of the assessment activity of university teachers.

The results of the survey in this study revealed diversity of responses among ESP teachers. It can be noted that teachers are generally aware of formative assessment, but this method of assessment is not widely used in real teaching situations. Only fragments of formative assessment are used. The importance of setting learning objectives is overlooked by about 30 % of the respondents and almost 40 % do not take into account the component related to the development of evaluation criteria. When analyzing the use of feedback in pedagogical practice, the experiment revealed a contradiction. Although about 80 % of teachers identified feedback as a component of formative assessment, only 5 out of 47 respondents chose feedback when asked to select the most important features of digital platforms for assessment. This reveals an underestimation of the practical importance of this formative assessment tool. Regarding the question of teachers' preparedness for working with modern digital assessment tools only 14 % of ESP teachers answered that they carried out comprehensive dynamic assessment of engineering students' communicative skills using several digital platforms. However, 10 % of ESP teachers answered that they did not know how to work with digital assessment tools.

The authors can conclude that it is necessary to design professional development courses to enhance the competence of ESP teachers in the EPCC assessment of engineering students and in the applying of assessment digital tools.

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Национальный корпус немецкого языка

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Любой естественный язык должен быть задокументирован. Немецкий язык существует с 750 г. н. э. и входит в первый десяток самых распространённых языков мира. Из-за богатой истории немецкого языка только языковые корпусы могут предоставить его данные во всей полноте. Рассмотрен национальный корпус немецкого языка — Deutsches Wörterbuch der Deutsche Sprache. Цель статьи — провести обзор и анализ корпуса. Представлены история и характеристики корпуса, его наиболее важные составляющие и необходимая документация. Показаны также особенности функционала корпусного менеджера.

Ключевые слова: *национальный корпус немецкого языка, база данных, корпусные словари, немецкий язык, национальный корпус*

German National Corpus

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Every natural language must be documented. German language exists from 750 AD and is part of the top ten most common languages in the world. Due to rich history of German language, only language corpora can present its data in entirety. The current article examines German National Corpus — Deutsches Wörterbuch der Deutsche Sprache. The goal is to review and analyze the language corpus. The article shows corpus history and characteristics, its most important features and necessary documentation. Corpus manager features are also mentioned.

Keywords: *German National Corpus, database, corpus dictionaries, German language, national corpus*

Introduction

Digitales Wörterbuch der Deutschen Sprache (DWDS), also known as Das Wortauskunftsystem zur Deutsche Sprache in Geschichte und Gegenwart, is a versatile, multimedia, multistylistic, monitor, tagged, free-to-use, full text complex of corpora, that describes German language in dynamic (since 1600) and in its current state. It is the most popular German corpora.

DWDS was created by The Berlin-Brandenburg Academy of Sciences (BBAW) on the basis of their own spoken and fiction corpora. Search results consist of grammar characteristics, meaning, etymology, use frequency, synonym groups etc. It benefits from handmade excerpts, because it does not omit words in context and can be adjusted to different search criteria [1].

The research goal is a review and analysis of the main characteristics and functions of German National Corpus.

Backgrounds of the DWDS corpus

At the beginning of the DWDS project in 1999, there was no acceptable German language corpus of the 20th century. On the one hand, there was a LIMAS Corpus, one of the first generation (1973). Despite its balance, it was too small to form the textual basis for a large monolingual dictionary. On the other hand, big text collections available at the institute for German language (IDS) in Mannheim focused mainly on recent newspaper texts, many samples from provincial newspapers. personal (autobiographies, letters), specialized (advisory books, advertisements), scientific texts, national newspapers, documentary and prose works. Moreover, IDS corpus contains few texts from the first half of the 20th century and was not chronologically balanced [1].

New editions of dictionaries and corpuses rely on several available newspapers. For example, Negra and TüBa-D/Z use Frankfurter Rundschau and die Tageszeitung. Analogically, the corpuses underlying the lexicograph tools are created for LexiView, joint project between a Langenscheidt publisher and Stuttgart university. It is still a current problem because resources are opportunistic and insufficient [1].

In 2004 Sharoff made a German language corpus on the basis of web sources, similar to the size of the BNC (British National Corpus). In spite of the interesting data, it does not suit the need for a reference corpus [1].

There were 3 main motivations for the DWDS project.

First, there is no German Dictionary that can suggest a satisfactory representation of the vocabulary of the entire 20th century: the Grimms' monumental opus (1854-1960) and Duden dictionary barely present the language of the first half of the century (vocabulary of the second half of the German Empire, Weimar Republic and the Third Reich). These facts indicate that there is a barrier to understanding of the German language as a means of communication by anyone who uses it as a native or second language [1].

Second, traditional dictionaries are composed in alphabetical order and structured into separate notes. It has a serious lack for sequentially description of words belonging to one and the same lexical field, as to show meaningful relatedness, a new dictionary should not order its words alphabetically but rather by lexical categories, types of syntactic constructions, and lexical fields [1].

Third, despite the huge role of dictionaries in compiling large databases, they do not form a balanced corpus of the German language. Dictionaries rely on manual selection of words and usage from texts or use mixed way of manual selection and automatic one, so electronic corpuses are formed opportunistically [1].

Electronic corpuses avoid these problems. Here the issue is to filter interesting words in a large mass of data. To achieve better consistency and completeness of examples, such a factor as frequency is important. The frequency in the corpus can reveal to what extent words or collocations are typical, we can determine their relative frequency in real German texts [1].

Contents of German National Corpus

The corpus consists of 106 million words and over 200000 articles. It is possible to choose time periods and types of texts. Several types of subcorpora are present: literary (26 %), newspaper (27 %), scientific (22 %), nonliterary (20 %) and spoken (5 %) texts.

DWDS consists of six dictionaries, thirty five different corpora, statistics and frequency data, coronavirus dictionary, videos on topic "Learning dictionary", linguistic tests.

Defining dictionary. Contemporary German dictionary (WDG) consists of six tomes and was created by the German Academy of Sciences at Berlin between 1952 and 1977 moderated by Rut Klappenbach. From February, 2002 to March, 2004 WDG was digitalized, structured and transferred for research to BBAW. The text corpus was created and broadened with the support of German Research Fond (DFG). It is accessible for reference work on its website since March, 2003 [2].

Today DWDS refers to several dictionaries [3]:

- defining dictionary DWDS;
- etymological dictionary DWDS;
- Open Thesaurus;
- Contemporary German dictionary;
- the German dictionary of Jacob and Wilhelm Grimm;
- digital historical dictionary.

WDG dictionary entries with automatically generated information of synonyms, hyponyms, hypernyms, frequently used collocations and text examples can be found in the main defining dictionary [2]. Contents of a dictionary entry: headword; word's grammatical behavior; definition with examples; etymological zone (optional); frequent collocations; context examples; quotation; frequency of use and frequency curve; links to other dictionaries; links to various corpora [3].

Text corpora. DWDS' corpora are constantly broadened. In May, 2018 they consisted of 13 million continuous words and are distinguished into two intertwined subcorpora: the main corpora and the additional corpora. The main DWDS corpora consists of 100 million words. It is evenly distributed throughout the twentieth century, text types are balanced and the corpus itself is not inferior to British National Corpus (BNC). BBAW made agreements about using texts with more than 20 publishers (K.G. Saur Verlag, SPIEGEL, Suhrkamp, Ullstein, ZEIT, Baufe Verlag, Diogenes, Eichborn, Hoffmann & Campe, Kiepenheuer & Witsch, S. Fischer Verlag) and various state and independent authors. Annotation of data and metadata is conducted in XML in line with TEI policy. Most of the texts of the main DWDS corpus are copyrighted, and the whole texts are not to be downloaded. Search of quotations is available for free on the DWDS website. Due to that reason, works of T. Mann, H. Mann, M. Walser, H. Böll, J. Habermas, V. Klemperer can be found in the Internet [2]. Since full time balance cannot be achieved for transcribed spoken texts, they are distributed as a separate corpus in special corpora.

The additional corpus includes more than 1,5 billion words and consists mostly of newspaper sources of 1980-2006. It is not balanced, since its purpose is to show the whole of the language and check its relevance [2].

DWDS Metacorpus refers to following historical corpora [3]:

- complete works of Alexander von Humboldt (1790–1859);
- Polytechnical Journal (Polytechnisches Journal, 1820–1931);
- Digital collection of German colonialisms (DSDK, 1884–1920);
- German text archives;

• German text archives' additions (Deutsches Textarchiv Erweiterungen);
• Main German text archive corpus (Deutsches Textarchiv Kernkorpus);
• Die Gartenlaube;
• GEI-Digital; Die Grenzboten;
• Text + Berg (1864–1900).

From thirty five corpora nineteen are available to unregistered users, sixteen more are available after registration and three are available upon request. Corpora are classified based on their purpose: reference corpora — 3, metacorpora — 6, newspaper corpora — 5, special corpora — 12, web corpora — 8 [3].

There are three ways of searching information in corpora [3]:

1. KWIS — Key Word In Context. Forms and aligns sentences in a certain way, so the searched word and its position could be seen clearly in comparison. Moreover, KWIS restricts the number of symbols before and after the searched word.

2. Voll — "full". The initial search format. Gives one full sentence with the searched word.

3. Maximal — "maximal". Gives a full sentence with the searched word plus one sentence before and after.

Frequency statistics. Frequency statistics is presented in DWDS in three different ways [3, 4]:

1. Frequency curve. This kind of a diagram represents frequency of use of the searched word over the years on million tokens. Several curves can be used to compare several words respectively.

2. Frequency tables. The tables are classified by parts of speech, that are frequently used in collocations with the searched word.

3. DiaCollo. Provides a chart where different parts of speech are colored to represent the frequency of them being used in collocations with the searched word. Warm colors represent higher frequency, cold colors represent lower frequency. There is a slider above the diagram, where years can be manually chosen (or played on different speed, if necessary).

Corpus managers. DWDS is based on two corpus managers: DiaCollo (Diachronic Collocations) and DDC (Dialing/DWDS Concordance). DiaCollo is a software tool for the discovery, comparison, and interactive visualization of the typical word combinations for a user-specified target term. Characteristic word combination profiles based on various underlying text corpora can be requested for a particular time period, as well as direct comparisons between different time periods. It is used in diachronic corpora such as the Deutsches Textarchiv (DTA) or the Corpus of Historical American English [4]. DDC is an open-source corpus search engine used by the DWDS, DTA, and ZDL (Zentrum für digitale Lexikographie der deutschen Sprache) projects at the BBAW [5].

Conclusion

The DWDS corpus embraces the huge spheres of language. Also it gives lots of functions, for example, lets measure and compare the frequency of the word usage. It allows to perform various linguistic and non-linguistic targets, which distinguishes the DWDS corpus from other ones.

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Когнитивный анализ дискурса

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Анализ дискурса представляет собой единство процесса языковой деятельности и ее результата (текста). Дискурс включает в себя текст как неотъемлемую часть. Термин «дискурс» определяется как один из самых популярных и широко используемых в современных гуманитарных науках. Понятие дискурса включает широкий спектр характеристик как лингвистических, так и экстралингвистических свойств, позволяющих рассматривать его как продукт речевого действия с присущей ему смысловой однородностью, актуальностью, привязанностью к определенному контексту. Когнитивный подход предполагает, что языковая деятельность является одним из видов когнитивной деятельности человека, и языковые явления могут быть адекватно осознаны только в контексте других когнитивных процессов таких как представление знаний, память, внимание, сознание.

Ключевые слова: *дискурс, анализ, когнитивный подход, когнитивная стилистика, раздел лингвистики, контекст*

Cognitive discourse analysis

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The analysis of cognitive discourse is the unity of the process of the linguistic activity and its result (a text). A discourse includes a text as an integral part. The term “discourse” is determined as one of the most popular and widely used in modern humanities. The concept of the discourse is very capacious and includes a wide range of characteristics of both linguistic and extralinguistic properties, which allow us to consider it as a product of a speech action with its inherent semantic homogeneity, relevance, attachment to a specific context. The cognitive approach assumes that a linguistic activity is one of types of a human cognitive activity, and linguistic phenomena can be adequately realized only in the context of other cognitive processes, such as knowledge representation, memory, attention, consciousness.

Keywords: *discourse, cognition, cognitive approach, analysis, branch of linguistics, cognitive structure, context*

Linguistic discourse analysis

A discourse analysis is a huge interdisciplinary field. A variety of disciplines including linguistics, anthropology, psychology, sociology, and many others contribute to the discourse analysis. We are interested in a linguistic discourse analysis as a part of linguistics belonging to the paradigm of constituent-oriented fields, such as phonetics/phonology, morphology, and syntax. The linguistic discourse analysis deals with linguistic constituents of the maximal, unlimited size i.e., whole discourses [1].

The linguistic discourse analysis has three main issues of concern. The first question, usually in the study of any natural phenomenon, is a question of classification, or *taxonomy*: what types of a discourse occur? The second question concerns the internal organization of a discourse: what is its *structure*? The third question is: how is a discourse related to more local, smaller-scale linguistic phenomena, or, more specifically, how *discourse factors influence such smaller-scale phenomena* (grammatical, phonetic, etc.). It is useful to briefly overview these three parts of the linguistic discourse analysis [2].

Taxonomy of discourses

There are several ways in which particular discourses can differ from each other. The first major taxonomy is based on the mode of a discourse, i.e. the opposition between a spoken and written discourse [3]. The second central taxonomy of a discourse is a classification of genres. Discourse genres are classes of discourses that correspond to certain standard communicative goals, typical of particular discourse communities. Discourse genres crosscut the modes, e.g. the genre of a story can appear in the spoken mode and in the written mode, still being the same genre. Genres can be defined in terms of underlying genre schemata: templates that generalize the order of meaningful components, or "moves", in a 275 token of the given genre, e.g. according to Chafe [4], stories told by conversationalists follow the following schema: (a) orientation; (b) complication; (c) climax; (d) denouement; (e) coda [4].

Other differences between kinds of a discourse relate to the so-called *functional style* and a *degree of formality*. The notion of the functional style developed in Russian linguistics is defined in terms of typical social domains, such as lay, official, commercial, political, learned, etc. A degree of formality depends on the type of social relationship between discourse participants including their relative a status, a gender, an age, etc., and is closely related to the phenomena often subsumed under the notion of politeness. Both functional styles and formality are reflected in many lexical, grammatical, and phonetic choices made by a speaker [5, 6].

Cognitive approach to discourse analysis

Cognitive linguistics is the study of how a language relates to a human mind. A definition for this trend in research is the so-called *cognitive commitment* formulated by Lakoff. This is the commitment to coordinate linguistic research with what is known about mind and a brain from the neighboring sciences also exploring cognition, in particular psychology and a neuroscience [7]. Other important (and early) formulations of similar ideas in modern linguistics belong to van Dijk and Kintsch [5]. Actual research done by Cognitive Linguistics does not always live up to the standards of the cognitive commitment. It seems that having this criterion in mind is extremely important. After all, boundaries between sciences are often accidental, arbitrary, of a historical nature, while the object of study, the mind, is one and undivided.

A language has two major functions and two corresponding modes of existence that can be called using a computer metaphor, *on-line* and *off-line*. The online mode of a language is a communicative transfer of various kinds of information between individuals. The central phenomenon of this mode is the natural discourse, as it unfolds dynamically in a real time. The off-line mode of a language is the information storage. One of the central phenomena characteristics of this mode is a relatively stable system of lexical semantics.

Grammar is also often viewed in an off-line way, as a system of mappings between forms and functions. Cognitive Linguistics, as an established trend of thought in modern science has mostly addressed off-line phenomena. This is true of Lakoff's well-known work that is considered to be foundational for Cognitive Linguistics. Most of the time, the practice of Cognitive Linguistics has ignored natural discourse data and has not been interested in discourse phenomena [7].

Analysis approaches and methods

The methodology of Cognitive Discourse Analysis is applied in several aspects. It provides an operationalized way of capturing a verbalized content using linguistic insights, particularly from two areas [8]: Systemic Functional Linguistics (SFL) [9] and Cognitive Linguistics (CL). CL highlights the relationship between a language and a thought [10]. In particular, lexicogrammatical structures in a language are systematically related to cognitive structures and processes. This structural fact correlates with principles of a language in use: the way we think is related to the way we talk.

When speakers are asked to verbalize thoughts, they draw abstractions in systematic ways from general repertory of a language to express currently relevant cognitive aspects. The choices in relation to a cognitively demanding situation reveal crucial aspects of conceptualizations and thought patterns. For instance, seemingly synonymous expressions such as *over* and *above* carry different implications and underlying concepts. While *above* clearly refers to the vertical dimension in example 1, *over* is actually polysemous; it seems reasonable to infer, in example 2, a sense of *covering* — a fundamentally different concept than verticality, and therefore a significant choice in the verbalization:

- Example 1: There is a poster above the hole in the wall.
- Example 2: There is a poster over the hole in the wall.

This kind of analysis is further enhanced and informed by insights from another well-developed line of research in linguistic theory, Systemic Functional Linguistics. SFL established the fundamental view on a language (i.e., the lexicogrammatical system) as a network of options from which speakers choose in meaningful and systematic ways. Its grammatical framework, SFG (Systemic Functional Grammar) specifies in great detail the particular functions of each lexicogrammatical option in English. This allows for assessing the functional significance of a particular linguistic choice in a native English speaker's discourse in the light of other possible options. For instance, the same real-world situation can be described by either of the following (among other possibilities):

- Example 1: Tom gave the phone to her.
- Example 2: The phone was given to her.
- Example 3: She was given the phone.

While example 3 specifies Tom as the Agent and starts with this information as the Theme (in SFL terms), the other two choices do not mention the Agent at all — he is apparently considered by the speaker as irrelevant for the communication, or possibly unknown. The Theme in example 2 is the phone, and the Beneficiary ("she") only appears later on in the clause. In contrast, example 3 starts with the Beneficiary, giving her a different status in the flow of the discourse. Similar effects of the interplay of lexical choices, grammatical packaging, and syntactic order emerge equivalently in other languages which have been specified using the SFL framework to varying degrees.

With respect to the verbalization of thought, SFL and CL together provide valuable resources for interpreting systematic patterns of choices across speakers. If speakers confronted with the same real-world situation (as in the latter example) systematically omitted mention of the Agent (Tom) in their verbalization of how they perceived the situation, this would clearly indicate a lack of conceptual saliency or relevance for considerations of relevance in the verbalization of spatial concepts. Moreover, if they, in a different condition, did tend to mention the Agent in an equivalent situation, the conceptual prominence of the Agent would clearly depend on the condition in which the situation was presented.

In addition to perceiving a visually presented scene in different ways based on the cognitive prerequisites, the inferences and decisions following from the presented information may be reflected in verbalizations. Crucially, relevant insights into the speakers' underlying concepts may be found not only in the explicit content of *what* people say [11], but also by *how* they say it. Among speakers, systematic patterns of linguistic choices can reveal crucial implicit aspects including the level of explicitation (e.g., choosing quantitative or qualitative terms, such as *in five minutes* vs. *soon* for a temporal description, or adding more elaborate information [12], degree of novelty (in SFL terms: thematic structure interacting with Given/New), perspective (speaker's own egocentric, somebody else's perspective, or allocentric / objective [13], and many other conceptual aspects that speakers do not readily verbalize explicitly but nevertheless reveal in the way they speak.

Analysis procedure

A systematic analysis of such phenomena provides a useful pathway to access cognition, drawing (where possible) on knowledge about relevant features of a language supported by grammatical theory, cognitive linguistic semantics, and other linguistic findings. Although linguistic expertise thus provides useful background, the general approach, to start with, is simple enough to be adopted by non-linguistic experts, with the most important feature being operationalization and systematization of a language analysis. The methodological steps of CODA are straightforwardly accessible to researchers in various disciplines. In a nutshell, they involve:

Step 1: Scope: Identify what extent language is relevant or meaningful for the research question at hand. In general, CODA can be applied for the analysis of mental representations (such as the interpretation of visualizations), as well as problem solving processes. Limitations concern situations in which the targeted cognitive processes are too low-level and rapid to be verbalized at all, even considering the significance of implicit linguistic choices.

Step 2: Data collection techniques: Consider the range of established methods for eliciting verbalizations so as to identify the most suitable one for current purposes, keeping in mind that different text types (e.g., interview data as opposed to verbalizations of thought of the *think-aloud* type as proposed by [11] lead to fundamentally different linguistic effects, and can also trigger different levels of cognitive focus.

Step 3: Data preparation techniques: Spoken language data need to be transcribed, using systematic conventions that are both feasible and suitable for the purposes at hand. The data should be digitalised and transferred, where applicable, into the researcher's chosen analysis software (e.g., Excel), using a suitable segmentation of linguistic strings [14].

Step 4: Content analysis: The content of the collected data is to be fully understood, and it is typically beneficial to engage in a thorough in-depth content analysis following frameworks described in [15]. Besides identifying explicit content of relevance to the research question, this also supports the researcher in developing intuitions about patterns in the verbalizations across speakers that deserve more systematic attention on a detailed linguistic level.

Step 5: Analysis of linguistic features: This is the core aspect of CODA, and may seem somewhat daunting for researchers new to the methodology, especially those from outside Linguistics. A useful procedure to get started is to extend the content-based intuitions in the previous step, with a particular emphasis on contrastive aspects, comparing participant groups or conditions. If participants appear to talk differently about the same phenomenon under different conditions, this intuition needs to be specified: what exactly do they say, what is the range of linguistic options that they use? Capturing initial intuitions as precisely and concretely as possible amounts to an in-depth qualitative analysis of relevant linguistic phenomena in the data. This also paves the way for an operationalization of the initial observation, needed for the purposes of systematic data annotation. Relevant instances of the phenomenon in question, or potential occurrences of the same, need to be identified systematically across the relevant data set. This could be the complete set of transcriptions collected in the study, or a particular subpart for which the phenomenon in question applies. Tenbrink provides a number of prominent specific analysis avenues to exemplify this important methodological step in detail. However, there are no theoretical limits to the range of phenomena that could be investigated in a linguistic data set. Ultimately, the extent to which a linguistic usage pattern is relevant or meaningful is determined by the task setting together with the research question motivating the study. Once the linguistic structures of interest have been identified in the collected language data, relevant detail information about the significance of particular linguistic choices can then be identified in the relevant literature, based on a targeted literature research, using resources accessible to the researcher in light of their background and expertise.

Step 6: Reliability: It is important to ensure that the annotation of a linguistic phenomenon is done in such a way that a different observer would reach the same conclusions on the same set of data. There are many ways to achieve this; the most widely accepted method is to calculate inter-coder reliability using one of various statistical tests, e.g., [15]. Another option that is frequently used (though less clear to report) is to employ iterative coding procedures and thorough checking and re-checking by several coders, until complete agreement and thorough insight into the data is reached.

Step 7: Identification of patterns: Once the data set is systematically annotated in a reliable way, it is time to identify patterns of interest in the data, using quantitative methods. This may or may not confirm the intuitions gained in step 4, which motivated step 5. If intuitions about contrastive patterns are not confirmed, the outcome of the quantitative analysis may still be of interest; also, it may be relevant to state simply that a phenomenon exists in (some parts of) the data at all, especially if it offers relevant insight into the cognitive processes of interest. Additionally, it may be useful to add another iteration to the coding process in order to gain deeper insights, perhaps focusing on a different phenomenon. While the coding and analysis steps are typically iterative, and researchers may find themselves inspired by the data to ask further interesting follow-up questions, it is nevertheless crucial to keep the original research motivation firmly in mind. Only a coherent report centering on a specific question will eventually catch the readers' attention. Language data, by their nature, can never be exhaustively analyzed; linguistic theory offers far too many possible analysis avenues (whole books have been written on single sentences). Depending on purposes, it may be most beneficial to restrict the analysis to a limited number of phenomena (perhaps just one or two striking effects that emerge from the scrutiny of linguistic structure), along with careful examination of the explicitly verbalized content.

Step 8: Triangulation and extensions: In many studies, a language is not the only kind of data collected. Other values that linguistic results can be triangulated with could be performance data, eye movement patterns, reaction times, memory data, behavioral strategies, and so on. Relating significant linguistic choices to other measures can be extremely revealing with respect to the underlying cognitive processes [8]. All those 8 steps a vital for cognitive discourse analysis.

Conclusion

A discourse analysis is a bench mark of linguistics, similar to phonetics, syntax, etc. Discourse analysis deals with constituents of maximum scope — whole discourses and their parts. The relevance of discourse problems depends least on theoretical dogmatism and scientific fashion because unlike the basic concepts of other branches of linguistics (phoneme, word, sentence), a whole discourse is an obvious fact that is not a theoretical construct. By now, it seems certain that a general picture of a language cannot be considered complete unless it takes discourse issues into account.

Any unprejudiced look at the panorama of contemporary linguistic discourse analysis shows that the main feature of this discipline is the following: it is an extremely mosaic, heterogeneous, unstructured array of approaches, theories, methods, and phenomena under study. This mosaic is hardly surprising. Discourse analysis is one of the youngest fields of linguistics, and its subject matter is objectively more complex than the phenomena studied in more conventional fields. On the other hand, discourse analysis has a clearly delineated object of study. This distinguishes it from a range of studies such as pragmatics, for example. Therefore, discourse analysis has a chance to overcome its mosaic and unstructured nature and become a “full-fledged” branch of linguistics.

This paper attempts to offer a coherent sketch of discursive problematics and a unified format for its description. The discursive problematics breaks down into two main issues — questions of a discourse structure and questions of the influence of discursive factors on the smaller constituents. The questions of division of discourses into modes, types and genres are also important.

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УДК 81

Особенности перевода заголовков с русского на английский язык (на материале научно-технических текстов по космонавтике)

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Рассмотрены особенности перевода заголовков с русского на английский язык на материале заголовков научно-технических текстов по космонавтике. Проанализированы способы формулирования русскоязычных заголовков. Заголовки проклассифицированы по общим моделям, выделены общие характеристики научно-технических заголовков, продемонстрированные на примерах. Изучены структурные и лексические особенности перевода заголовков научно-технических статей с русского на английский язык.

Ключевые слова: *заголовки, научно-технические тексты, перевод, классификация заголовков, модели заголовков*

Russian-English Translation of Headings (Based on the Material of Scientific-Technical Texts on Cosmonautics)

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This article reviews special features of translation of headings from Russian into English based on the collected headings of scientific-technical cosmonautics texts. Ways of phrasing Russian headings were analysed. Headings were systemized according to common models, which were demonstrated on examples. Structural and lexical features of Russian-English translation of scientific-technical articles' headings were researched.

Keywords: *headings, scientific-technical articles, translation, classification of headings, translation of headings*

Introduction

The heading is the first source of information about a certain article, that is why the title needs to convey the text's contents as fully as possible. Other than that, a bibliographer works based on the heading, determining in which part of the database the article needs to go. The title needs to be phrased in a way to interest and push the target audience towards reading the full text [1].

The title should be created after finishing the main text of the paper. It needs to be noted that the final phrasing of the heading is meant in this context. Creating the title can simplify the author's definition of the article's aim (why the paper was written, which aspect of the topic it is devoted to, etc.). The goal and the field of the scientific article often define the title, because they show all of the research's "reference points" [2].

Among other scientific article's elements, the heading holds great interest from the point of its correct design. The graphic design of the title, which includes a certain font size, colour, position on the page, can make the heading more attractive, as well as create a more successful communicative act. In other words, here works the law of mass media — the more appealing is the heading, the more chances there is that the article will be read [3].

Aim of the study is to research special features of creating scientific-technical cosmonautics artciles' headings, and methods of transmission of those features into the English language.

The title as an element of a scientific-technical text

During the creation of articles, the main attention of authors is directed to the contents of their paper. However, when their work is finished a lot of people face the problem of naming their article. The title might seem like a non-essential element, that is why plenty of authors undermine its importance. Nevertheless, the heading is what readers see first and, based on that, determine whether to read the full paper or not. It is crucial to phrase the title not only to catch readers' attention, but to accurately convey the article's contents.

Russian articles on aviation and cosmonautics, published in the "Cosmic Research" journal in years from 2015 to 2022, were the material of this study. English versions of the same articles were taken from the translated version of the journal [4]. The full volume of illustrative material was 200 Russian articles and their translated equivalents.

First of all, Russian headings were analysed. Out of 200 collected titles 100 % were in the form of a nominative group and 0 in the form of a sentence. That shows that Russian authors tend not to use verbs in their headings, for example:

О возможных причинах положительного возмущения глобального электронного содержания в период сложного гелио-геофизического события в сентябре 2017 г.;

Перспективы использования гало-орбиты в окрестности точки либрации L2 системы Солнце — Земля для наземно-космического радиоинтерферометра миллиметрон.

It needs to be noted that about 35 % of Russian headings contain a coordinating conjunction, for example:

Коррелированные возмущения верхней и нижней ионосферы по данным синхронных измерений параметров сигналов ГНСС и радиосигналов ОНЧ диапазона;

Нижняя ионосфера Арктики в июне 2015 г. при сильной магнитной буре и солнечных рентгеновских вспышках по данным затменного радиозондирования на межспутниковых трассах GPS — Formosat.

Constructions that contain little information are often used in Russian scientific articles' titles, like «К вопросу о …», «Актуальные проблемы …», «О роли …», «Использование …», «Подходы к трактовке …», for example:

К вопросу о большом взрыве с расширением вселенной;

К вопросу об автономном уточнении параметров вращения земли на борту космических аппаратов. Анализ возможностей развиваемой информационной технологии.

Another model used in Russian headings includes using genitive constructions, for example:

Исследования микрофонного эффекта для перспективных детекторов нейтронного и гамма-излучения космического применения и методы его подавления;

Исследование магнитосфер активных областей на солнце методами радиоастрономии.

Structural and lexical features of Russian-English translation of scientific-technical articles' headings

In the researched material the average amount of words in Russian headings was 12 and in English headings ~15 with the norm of 8–15 words [4].

Headings that a separated into two parts by punctuation marks are 7 % of the full volume of studied titles, out of which 71 % are separated by a colon. Headings are separated to show the main and the additional parts. Often it is parts of the research, dates and terminology. Such model is present in the translated versions as well. Nowadays, such model can be seen in most of Russian headings, but it is more popular in works of foreign authors (*"AccelerometerMountingMethods: Types, Effects, andSolutions"*).

Scientific-technical papers are often divided into several parts due to size restrictions. Parts are written out by using a colon or a comma. For example:

Ретроспектива проблемы космического мусора. Ч. 2. Мониторинг космического мусора естественного происхождения в околоземном пространстве оптическими методами метеорной астрономии (Retrospective on the Problem of Space Debris. Part 2. Monitoring of Space Debris of Natural Origin in Near-Earth Space Using Optical Methods of Meteor Astronomy);

Некоторые вопросы идентификации крупномасштабных типов солнечного ветра и их роли в физике магнитосферы. 3. Использование опубликованных некорректных данных (Some Problems of Identifying Types of Large-Scale Solar Wind and Their Role in Magnetosphere Physics: 3. Use of Published Incorrect Data).

Next feature is the usage of dates in papers' titles. Scientific-technical articles are prone to be extremely detailed. Authors write details of their research in the heading, which increases the number of words and makes it difficult for readers to understand the meaning, in this case, dates:

О возможных причинах положительного возмущения глобального электронного содержания в период сложного гелио-геофизического события в сентябре 2017 года (On Possible Causes of Positive Disturbance of Global Electronic Content during a Complex Heliogeophysical Event on September 2017).

Terminology is the last thing connected to details to be discussed. In general, it includes different equipment and names of certain scientific processes:

Перспективы использования гало-орбиты в окрестности точки либрации L2 системы Солнце — Земля для наземно-космического радиоинтерферометра миллиметрон (Prospects for Using the Halo-Orbit in the Vicinity of the L2 Libration Point of the Sun — Earth System for the Ground-Space Millimetron Radio Interferometer);

Коррелированные возмущения верхней и нижней ионосферы по данным синхронных измерений параметров сигналов ГНСС и радиосигналов ОНЧ диапазона (Correlated Disturbances of the Upper and Lower Ionosphere from Synchronous Measurements of Parameters of GNSS Signals and VLF Radio Signals).

The translation process is slowed by constructions that contain little information. The same construction can be translated differently. For example, this is how the phrase "К вопросу о..." was translated:

On the Question of the Big Bang and Accompanying Expansion of the Universe (К вопросу о большом взрыве с расширением вселенной);

Water Formation in the Lunar Regolith (К вопросу об образовании воды в лунном реголите).

Genitive constructions, used in Russian headings, are often translated by the preposition "of":

Study of the Microphonics for Prospective Space-Based Neutron and Gamma-Ray Detectors and Methods for its Suppression (Исследования микрофонного эффекта для перспективных детекторов нейтронного и гамма-излучения космического применения и методы его подавления).

There are features specific only to English headings. For instance, 99 % of gathered titles contain "simple" prepositions (in, on, for, from, to, into, etc.), and 8 % contain non-finite verb forms.

A Study of Rayed Structures in Auroras by Triangulation Methods: 1. Height Profiles of Volume Emission Rate.

It needs to be noted that compared to Russian authors, English authors often use sentences as their articles' headings ("Modern Motor Drivers Enable a Common Platform for Power Tool Designs").

There are no Russian headings in the form of a question in the material collected. However, such model is popular among English authors. Such structure makes the title look less official, thus creating a connection between the author and the reader. The reader asks the question and the article answers it, which helps bring readers closer to the research topic ("What is it About Audio Distortion? Understanding Nonlinear Distortion").

The headings in English preserve the Russian models. However, there is an interesting example of translation changes in the title:

К 50-летию государственной программы «Янтарь» комплексные исследования электрореактивных двигателей при полетах в ионосфере земли (Integrated Studies of Electric Propulsion Engines during Flights in the Earth's Ionosphere).

As it can be noticed, the English variant does not have the additional information *"К 50-летию государственной программы «Янтарь"*. The reason to that may be the orientation towards a foreign audience, who are not familiar with this project.

Another interesting example is shown below. It contains the most words out of all gathered headings. It is a great example of the scientific-technical articles' detailed nature. The terminology that is written out in 18 words may be skipped without losing any important information:

Результаты разделения вклада галактических космических лучей и внутреннего радиационного пояса земли в суточную дозу, зарегистрированную дозиметрами ДБ-8 системы радиационного контроля на борту международной космической станции за период с 2001 по 2014 годы (Results of Separation of the Galactic Cosmic Rays and Earth's Inner Radiation Belt Contributions to the Daily Dose Obtained by DB-8 Dosimeters of the Radiation Monitoring System Onboard the International Space Station in 2001–2014).

Conclusion

In the research process specific features of phrasing Russian scientific-technical cosmonautics articles' titles were studied, as well as their transmission into the English language. Analysis of said features and different types of headings was conducted.

Recommendations to phrasing of articles' headings were given, main mistakes made by authors were described. In addition, mistakes made in the translation process of titles and models of English variants of headings were studied.

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УДК 81’33

Способы определения корректного местоимения собеседника при общении в социальных сетях

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Исследован комплекс проблем, связанный с трудностями при обращении к незнакомым людям в социальных сетях. Рассмотрены актуальные способы определения корректных местоимений при обращении к собеседнику. Проанализирована выборка профилей англоязычных пользователей в социальных сетях. Сделан вывод, что лучший способ обращения состоит в использовании гендерно нейтрального местоимения singular they или же местоимения, указанного в профиле собеседника.

Ключевые слова: *английский язык, английские местоимения, род (грамматическое понятие), гендерная нейтральность, гендерно-нейтральный язык, лингвистический сексизм, социальные сети*

Ways to Determine the Proper Pronoun of the Interlocutor when Communicating in Social Networks

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The author investigated a set of problems associated with difficulties in referring to strangers in social networks. The actual methods of determining proper pronouns when referring to the interlocutor are considered. The sample of profiles of English-speaking users in social networks is analyzed. It is concluded that the best way to address is to use the gender neutral pronoun singular they or the pronoun indicated in the interlocutor's profile.

Keywords: *English, English pronouns, gender, gender neutrality, gender-fair language, linguistic sexism, social networks*

In the modern world where people often don't use their real names or photos in their profiles on social networks, it's important to refer to strangers politely, and using proper pronouns is a great way to create a good dialogue online. But usually it's hard or even impossible to tell which pronoun suits the person only by profile picture and name. The correct use of pronouns is especially important for queer teenagers. Many of them suffer because their parents and relatives refuse to use the proper pronouns for them. This can lead to a constant feeling of dysphoria, depression, and other serious problems. If their identity is not also respected in social networks, which often become an outlet in a misunderstood family, then the situation may get worse. That's why it's so important to learn how you refer to strangers, especially young people, online.

The problem of choosing the proper pronoun when referring to a stranger is still not well studied and described yet, especially when it comes to gender neutral pronouns.

Although there are studies of L.V. Savateeva [1] regarding the reference of pronouns in English and work of A. Pershay [2] devoted to language sexism in English, where he's saying that English is androcentric and the placeholder pronoun is always *he*, which is unacceptable in today's world where people shouldn't be judged by their gender. As mentioned in our previous study on gender-neutral language [3], even though it is still evolving, it is already considered good practice to use the correct pronouns for a person if it is known that they prefer certain pronouns rather than always using *he*.

In this paper, a selection of profiles on Twitter and Instagram social networks, as they are the most popular in their field, will be reviewed and analyzed. This paper will also define and describe ways to determine the proper pronoun when referring to strangers online.

So, one way to solve the problem of addressing a stranger on twitter is to look at their profile and check if they have preferred pronouns written there before you tweet. According to the culture of the most tolerant parts of the most popular social networks such as Twitter and Instagram, it is customary to write your pronouns directly in the name field through a straight line, in the profile description, in the location or place of work fields. They're usually written in the format "*he/him | they/them*" or "*he | they | xe*". Therefore, if you see written pronouns in a person's profile, feel free to use them when addressing correctly without guesswork.

Also, if your profile lists words that look like nouns next to regular pronouns, such as *star/starself*, *void/voidself*, *moss/mosself*, don't be surprised, these are neopronouns. They are not as widely used in society as *singular they,* which will be discussed next, or some other well-known gender-neutral pronouns. However, the use of neopronouns has several advantages. Everybody can choose any word that represents them as a person and make it their pronoun. Also, they can choose a word that they just like in terms of sound and spelling. If you find it difficult or uncomfortable to refer to a person using neopronouns, you can always use any other pronoun that is more familiar to you, indicated in the person's profile.

Another suitable way is to address the person with *they*. This pronoun is called *singular they* and has been used around the world as gender-neutral for several centuries, including in business correspondence, formal documents, or in everyday life when referring to strangers, so almost all people won't mind if you use this pronoun in their direction. However, don't forget that *singular they* is the same gender-neutral pronoun as everyone else, and not all people use it in relation to themselves. However, you can refer to the person as they until you're corrected or until the end of the conversation, if the person isn't bothered by such an address.

As a material for studying the problem of determining the preferred pronouns of social network users, 30 English-language Twitter user profiles and 20 English-language Instagram user profiles were selected. They were sorted by the age of the account owner, if one was specified, and country of residence, if one was specified. Next, the accounts were examined for the presence of the indicated pronouns.

According to the results of the study of this sample, it was found that pronouns are mainly indicated by active users of Twitter and Instagram under the age of 30. The sample did not identify countries where users from which did not indicate pronouns at all or from which they always indicated their pronouns, however, on average, users from the United States were more likely to indicate their preferred pronouns. Neopronouns are most often indicated by users from the United States too. This arises because the US, being an English-speaking country, is not only the very first to pick up inclusive language trends and put them into use, but often invent them. Therefore, users from the United States are more likely than users from other countries to both indicate their preferred pronouns in general and use neopronouns as their preferred pronouns in particular.

As for Russia, the majority of people using these social networks in English were between the ages of 16 and 35. Pronouns were listed in about 40 % of users, and mostly they were standard pronouns such as *he, she, singular they*. It can be explained by the fact that in Russia very few people know about the existence of neopronouns, and therefore they are not used so often.

There is also a common misconception that “non-standard” pronouns are only used by trans and queer people, but this is not true. Any person, whether female, male or non-binary, can choose any pronouns they like and use them instead of or together with other “standard” pronouns for their gender. Pronouns are as much a way of expressing yourself and your personality as are looks or hobbies. So if you see a profile that in appearance belongs to the female, don't immediately address them with *she*, it's still a good idea to ask for a preferred pronoun or use the *singular they*.

So if you don't know person's pronouns, it's certainly a good idea to address by *singular they* and then ask for their preferred pronouns, especially if you're talking in private messages rather than in an open reply thread. This will show that you respect your interlocutor and their ways of expressing themselves.

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Инженерные технологии

УДК 621.981.1

Анализ образования гофров при формовке в стесненных условиях деталей уголковой формы

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Экспериментальными исследованиями установлена возможность и условия образования гофров на стенках детали уголковой формы при формовке заготовки уголковой формы в стесненных условиях. Разработана модель, описывающая три стадии процесса образования гофров на стенке детали. Получены соотношения и графики, определяющие границы области соответствия контура детали допустимому значению. Даны зависимости для расчета утолщения детали в вершине при переформовке.

Ключевые слова: *гофр, утонение, утолщение, переформовка, контур детали*

Analysis of Corrugations during Molding under Cramped Conditions of Corner-Shaped parts

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Experimental studies have established the possibility and conditions of corrugation on the walls of the corner-shaped part when forming the corner-shaped blank in constrained conditions. A model describing three stages of the corrugation process on the wall of the part is developed. Relationships and graphs are obtained that determine the boundaries of the area where the contour of the part corresponds to the allowable value. Dependences are given for calculating the thickening of the part at the top during reshaping.

Keywords: *corrugation, thinning, thickening, reshaping, part contour*

Aircraft designs use a large number of thin-walled corner-shaped parts produced from a sheet in bending dies.

The bending process is accompanied by thinning of the wall part, which reduces the performance of space-rocket hardware components and can lead to an increase in the mass products [1. 2]. The thinning process is well known from [3, 4]. The thinning of technological parameters and mechanical properties of materials was studied in [5, 6].

A method with combating thinning was proposed in [7]. It consisted in creating an excess of metal due to a controlled mismatch between the contours of the part and the workpiece and subsequent molding workpiece under cramped conditions. Notwithstanding, compression of the part flange during molding can lead to formation corrugations.

Stability loss is complex and is of great interest from a scientific point of view. Euler laid the foundations of the entire theory of buckling under compression. A great contribution to its development was carried out in the papers of outstanding Russian scientists V.I. Feodosiev and Yu.N. Rabotnov [8, 9]. Notwithstanding, the conditions for forming corrugations in the technology of molding thin-walled parts of an angle shape in cramped conditions are much more complicated than axial compression.

In this regard, in order to substantiate the regimes for this technology, it is important to study the process of corrugation formation. This work is devoted to the solution of this problem.

In accordance with [7], the thickening top of the part is carried out in the forming process of a V-shaped workpiece under the action of force *F* with fixed ends *A* and *C* (Fig. 1). At point *B*, a gap is created between the workpiece and the bottom plate of the press die.

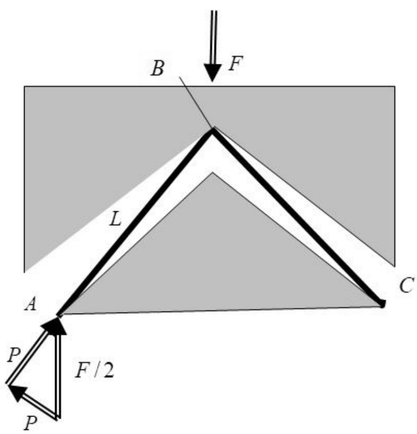

Fig. 1. Scheme for acting forces during the formation of a V-shaped workpiece under cramped conditions

To study the formation corrugations in the technology of molding thin-walled corner-shaped parts under cramped conditions, a computational experiment was used in the Deform-3D software environment. The finite-elemental model is shown in Fig. 2.

The calculation was carried out for material 12Х25Н16Г7. The length of the plate was 34mm, thickness 0.8mm. The gap between the plate and the press tool was chosen to be 4mm. To describe the diagram of the stress-strain state, it was taken dependence

$$\sigma = \begin{cases} E\varepsilon \\ \sigma_T(1 + a\varepsilon - b\varepsilon^2) \end{cases}$$

where $E\varepsilon$ is elastic region; $\sigma_T(1 + a\varepsilon - b\varepsilon^2)$ are areas of plastic deformation; σ, ε are stress and strain; σ_T is yield strength (330 MPa); a, b, E are elastic modulus ($a = 8.6513; b = 16.6885; E = 200000$ MPa).

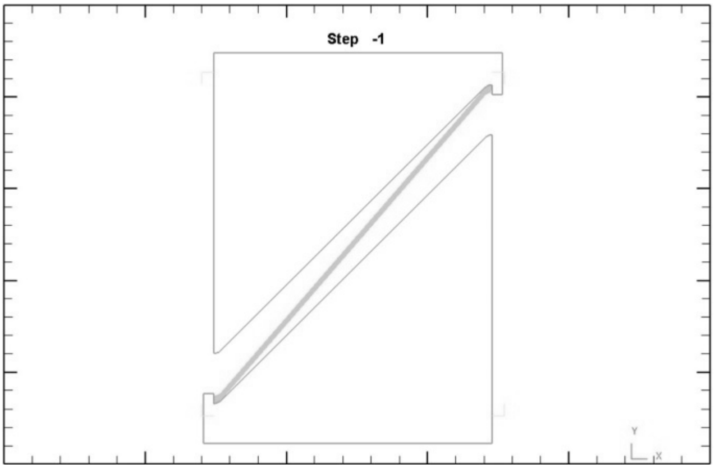

Fig. 2. Finite-element model of plate compression under cramped conditions

The calculation results were displayed step by step and included the change in the coordinates of the cell nodes, as well as the distribution of stresses and strains. The step number and residual clearance are related to each other by the ratio

$$N_{\text{step}} = 160\left(1 - \frac{H}{H_0}\right)$$

where H_0 is the initial gap between the plate and the press tool.

Calculations make it possible to establish several schemes for the process of corrugation formation. In a clearly observed pattern *A* the distances between the contour of the deformable plate and the planes of the pressing tool decrease under the action of lateral forces and forces moments (Fig. 3 for step 10).

We can assume that the length of the plate contour does not change, and the contour can be represented as a broken line, as shown in Fig. 4 (scheme of deformation *A*) [10].

From the condition of length contour constancy, we obtain a relationship between length L_{10} sections fitting the plate to the tool and distance H between the planes of the press tool:

$$L_{10} = \frac{l_0^2 - L_0^2 - \sqrt{2}L_0H - H^2}{4\left(l_0 - L_0 - \frac{H}{\sqrt{2}}\right)} = \frac{L_0}{2}\frac{\sqrt{2} + \overline{H}(1 + H^*)}{H^{*2}}\frac{1 - H^*}{\overline{H}};$$

$$\overline{H} = \frac{H_0}{L_0}, H^* = \frac{H}{H_0}.$$

Ratio analysis shows that at $H \to 0$ with length of $L_{10} \to \frac{l_0+L_0}{4} \approx \frac{L_0}{2}$, but at $L_{10} = 0$ distance $H = H_0$.

In the areas where the plate adheres to the tool L_{10} compressive stresses increase, which can lead to loss of stability of the plate contour according to the scheme shown in Fig. 5.

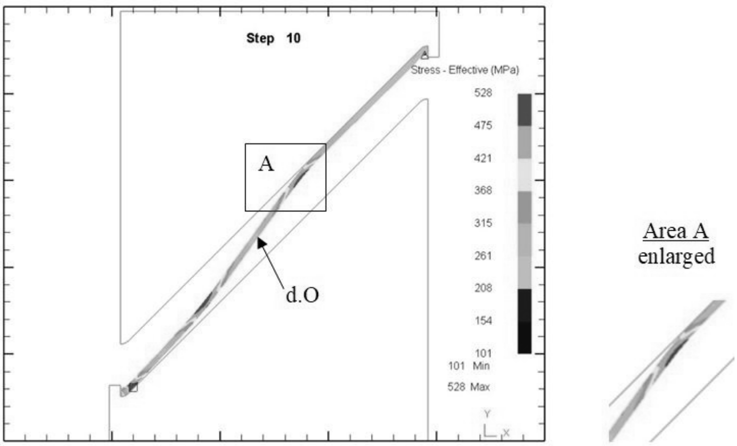

Fig. 3. Deflections and stress distribution for step 10

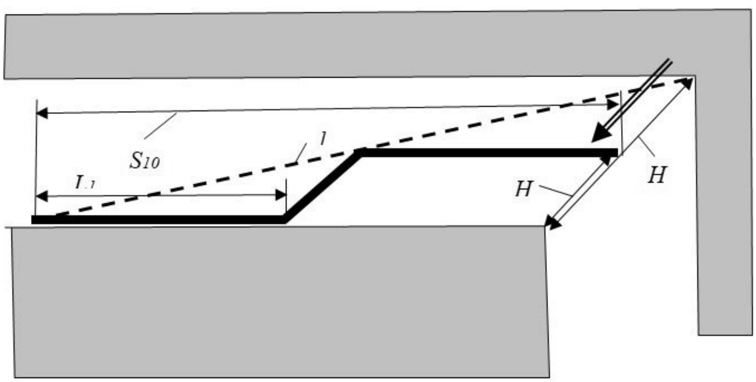

Fig. 4. On the calculation of the end of deformation according to scheme A

This is confirmed by the calculation results for moment step 40 presented in Fig. 6.

The critical buckling stress can be estimated from the formula

$$\sigma_{kp} = \frac{P_{kp}}{b\delta} = \frac{\pi^2 E}{12}\left(\frac{\delta}{\mu L_{10}}\right)^2.$$

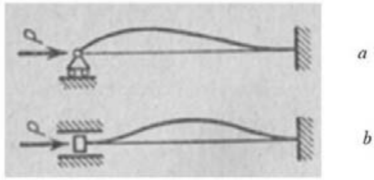

Fig. 5. Plate buckling schemes depending on the boundary conditions

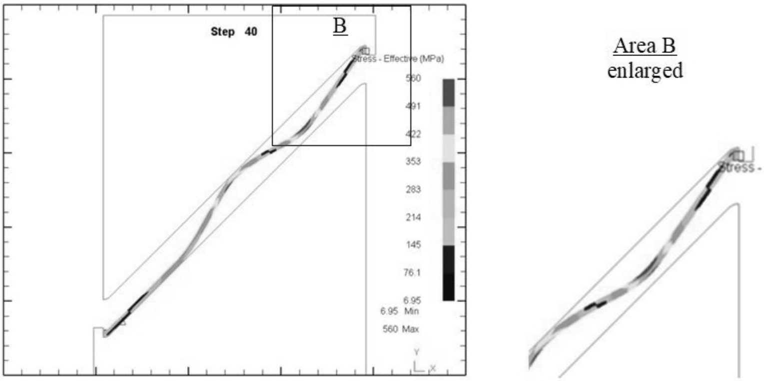

Fig. 6. Distribution of displacements and stresses during deformation according to scheme B

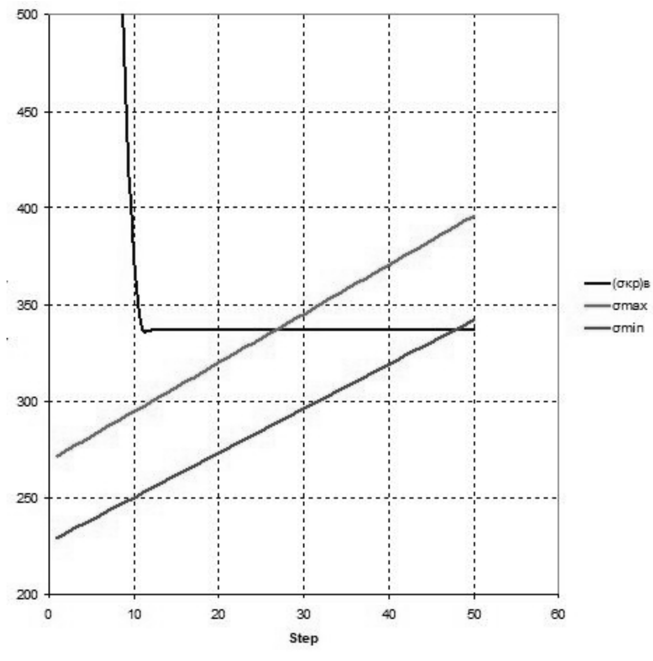

Fig. 7. Change in the critical stress value as the length of the bent part of the plate increases, as well as the change in the total stress in the plate according to the upper and lower estimates

It follows from the calculations (Fig. 7) that the critical value of the stress, as the length of the bent part of the plate increases, drops to the limit value (on the order of the yield strength).

Numerical modeling shows that the compressive stress in the plate increases and reaches a critical value according to the upper estimate at step 26, and according to the lower estimate at step 48.

With further closing plates of the press-tool, the corrugations are crushed. The length of the crushed area L_{10} increases. The formation of the next corrugation (Fig. 8) occurs according to the scheme in Fig. 5, *b*, but already in the plastic deformations region.

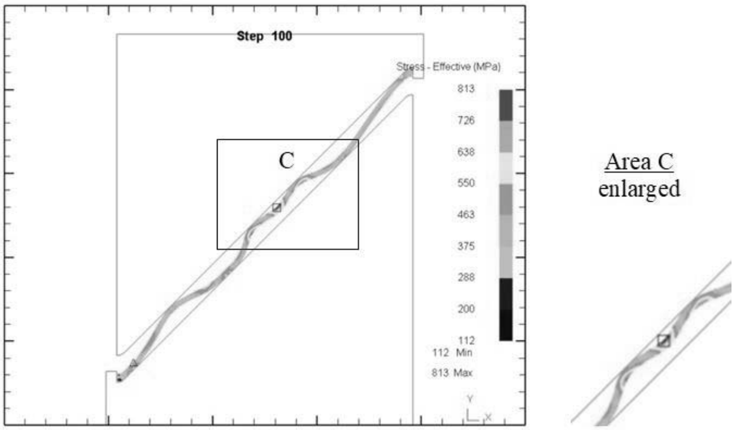

Fig. 8. Distribution of displacements and stresses during deformation according to scheme C

A physical experiment confirmed the formation of corrugations as a result of plastic deformation during the reshaping of W-shaped blanks in a tool die (Fig. 9).

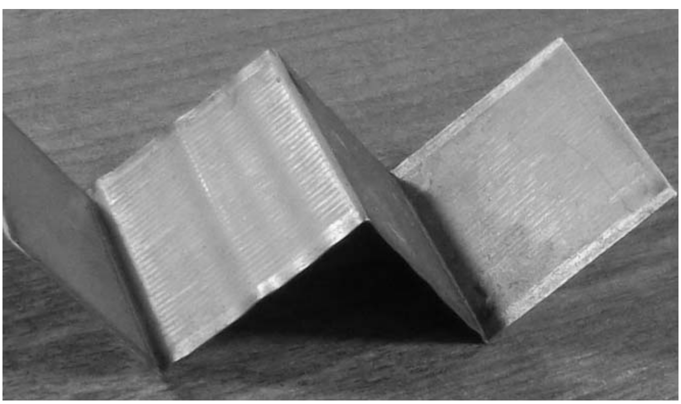

Fig. 9. Corrugations formation as a result of plastic deformation during the reshaping of W-shaped blanks in a tool die

Findings:

1. On the basis of a computational experiment, the existence of three schemes for the corrugations formation is shown.

2. The physical experiment showed that the corrugation formation occurs in the area of plastic deformations.

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УДК 623.743

Разработка транспортного дирижабля для доставки негабаритных грузов на космодром «Восточный»

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Проведен анализ мирового опыта создания летательных аппаратов легче воздуха и выявлены наиболее актуальные задачи для аппаратов данного типа в области ракетно-космической техники. Используя разработанные алгоритмы, определены характеристики и основные параметры обликообразующих систем транспортного дирижабля. Разработан облик транспортного дирижабля грузоподъемностью 100 тонн и определены его основные технические параметры.

Ключевые слова: *воздухоплавание, дирижабль, грузоперевозки, космодром «Восточный», транспортировка элементов ракетно-космической техники*

Developing of Transport Airship for Delivery Oversized Cargo to Vostochny Cosmodrome

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The analysis of the world experience in the creation of airships has been carried out and the most actual tasks for such devices in the field of rocket and space technology have been revealed. Using the above-mentioned algorithms, we have determined the characteristics and core parameters of the transport airship main systems. The appearance of a transport airship with a carrying capacity of 100 tons has been developed and its main technical parameters have been defined.

Keywords: *aeronautics, airship, cargo transportation, Vostochny Cosmodrome, transportation of elements of rocket and space technology*

Introduction

It is common in the modern world that spaceports and rocketry manufacturing plants are located at a great distance from one another. Therefore, there is a logistics problem of delivering goods (launch vehicle blocks, spacecraft parts, etc.) from one location to the other. Rocketry goods have a series of inherent distinctive features that only complicate the delivery process. Such features are: oversize and overweight as well as high sensitivity to vibrations, impacts and overloads.

Currently, most widely spread delivery methods are railroad, automobile transportation and water/avia carriage.

Each method has its own strengths and weaknesses and is suitable only for a certain type of goods to be transported. When choosing the appropriate delivery method, one must consider transportation length and time, infrastructure availability (presence of the railroads, highways, rivers, airfields, etc.), mass-inertial properties of the cargo, its responsiveness to impacts, vibrations and overloads.

Due to the development of the lunar program [1] in 2020–2040, heavy and super-heavy rocket blocks would require transportation from the construction plants to the "Vostochny" spaceport. The launch frequency is expected to be low, each cargo would be unique in its characteristics, which leads to economic inefficiency of airplane delivery. Moreover, the sheer size of the cargo, bearing in mind that the construction plants lack seaport availability, usage of water and railroad transportation is deemed to be limited at best [2–4].

Overall, there exists an upcoming problem for the space industry: how to deliver oversized cargo (super-heavy launch vehicle parts, on-ground industry objects, etc.) to the spaceport site. We offer a possible solution to this problem — a transport airship.

The aim of the research: to determine the parameters and to develop the draft construction blueprints of the transport airship suitable for the transportation of the space industry goods from the construction plants to the "Vostochny" spaceport.

The objectives of the research:

• to analyze the existing experience in the transport airship development and to summarize the key construction insights that determine the shape and form the airship (power structure type, aerodynamics, gas to be used as a fuel, engine type, etc.);

• to prepare the calculation of the main airship parameters (the volume of the shells, airship mass, engine power, flight altitude, cruise speed etc.);

• to calculate, using the above-mentioned project parameters, the core characteristics of the main systems (the power structure, steering elements, thermostat system, docking equipment, etc.);

• to develop the main systems design;

• to prepare the updated calculations based on the precise main systems characteristics;

• to determine the economic feasibility of the project as a heavy transport aircraft.

Calculation model

The main task of the transportation airship will be the delivery of space rocket parts: first launch vehicle stage (2 units) and third launch vehicle stage (1 unit), with a combined mass of over 90 tons. Secondary task will be to deliver ground infrastructure as well as to perform search and extract missions in the used stage collapse locations. Moreover, the airship would also be used as an emergency rescue vehicle for the evacuation of the returned spacecraft. Radar equipment would be mounted on the airship.

After careful analysis of the existing global experience in the development of such airships [5–12] as well as the assessment of the cargo to be delivered, we have decided upon the main design and technical parameters of the airship. Planned flight altitude is 6–

8 km, cruise speed — 100–150 km/h, cargo bay measurements — 11.5×12×55.4 m, payload — 100 tones.

It is necessary to state that we have derived the above measurements from the planned mass/volume parameters of the whole airship. At this point, the precise mass/volume parameters of the separate systems are to be calculated.

Atmospheric conditions were claimed from the analysis based on the radio probing in between 0 and 8 km alongside the route Moscow — Samara — “Vostochny” spaceport.

Using the planned velocity, required to reach the cruise speed, we have derived an equation for the airship’s engine power:

$$P_E = \frac{4 \cdot (3M_{PL})}{\eta_{ad}} \frac{V_K}{t_V}.$$

We have also derived the equations for the bearing framework (BF) and functional shell (FS) areas basing on the model shell analysis:

$$S_{BF}(V) = 1.29 \cdot V^{\frac{2}{3}};$$

$$S_{FS}(V) = 6.46 \cdot V^{\frac{2}{3}}.$$

The fuel mass, as well as the mass of the airship itself, can be calculated using the following equation:

$$M_F(V, v_K, h) = \frac{L}{v_K}\left(C_x \frac{\rho_{air} v_K^2}{2} V^{\frac{2}{3}}\right);$$

$$M(V, v_K, h) = M_{PL} + P_E\rho_E + M_F(V, v_K, h) + S_{BF}\rho_{BF} + 2S_{FS}\rho_{FS} + \rho_{air}V.$$

After that we have solved the question of the optimal flight altitude and the cruise speed. Due to the fact the maximum flight altitude increases with the increase of the hoisting force, maximum altitude should correspond with the maximum speed. The equations of the optimal altitude and the cruise speed are as following:

$$M(V, v_K, h)g = C_x \frac{\rho_{air} v_K^2}{2} V^{\frac{2}{3}} + \rho_{\mathrm{air}}\, gVv \cdot C_x \frac{\rho_{air} v_K^2}{2} V^{\frac{2}{3}} = P_E.$$

Aerodynamics scheme is a hybrid one. Thrust is achieved by exploiting the tangential shell overblow. The air leaves the shell in the direction, opposite to the airship’s movement. This system allows to reduce the drag and, hence, the fuel usage. Yawing is managed by the difference in the right- and left-side thrust openings, pitching — by the stabilization system.

Wrapping parameters were derived by using the calculations from the Software Complex (SC) SolidWorks Flow Simulation.

First, we have settled the parameters for the shell: quantity of the thrust openings *N*, width of the openings δ and impeller diameter D_{im}. Flow separation distance is equal to:

$$x_{cr} = \frac{10^6 v_{of}}{v_{of}}.$$

The amount of the thrust openings is calculated by the following formula:

$$N = \frac{1}{2}\left[\frac{D_{aao}}{x_{cr}}(\pi - \varphi_0) - 1\right].$$

The width of the opening is determined by the major of three factors: the velocity of achieving the cruise speed (thrust), doubled thickness of the alloy and the minimum technologically achievable width:

$$\delta = \left[\frac{4Mv_{airship}}{\pi t_v \rho_{air} D_{aao} v^2 \sum_{i=\lfloor \frac{\varphi_0}{\Delta\varphi} \rfloor + 1} (i\Delta\varphi)}, 50\frac{vk}{v_{of}}, \delta_{tech} \right].$$

The impeller diameter could be determined by the thrust of the entire opening cascade:

$$D_{im} = 2\left[\frac{D_{aao}}{v_{im}} \sum_{i=\lfloor \frac{\varphi_0}{\Delta\varphi} \rfloor + 1}^{N} v_i\, \delta_i \operatorname{sinsin}(i\Delta\varphi) \right]^{1/2}.$$

This is used to derive the area corresponding to the impeller. This area, in particular, could be achieved by utilization of several impellers. It is also necessary to make sure that there exists laminar airflow in between the shells, which can be explained by:

$$Re < Re_{cr}.$$

The power scheme consists of two longitudinal gas shells attached on top of the supporting truss. In the middle of the truss, there is the transversal cargo bay. The shells are quasi-rigid. The spiral air-filed pipes support the inner side of the shell. The shell is placed in check by the cords. Therefore, such scheme allows for the minimum mass with a considerable structural rigidity. Moreover, air-filed pipes also serve as an insulator. Shell deflation system, supported by the outer cords, helps to diminish the aerodynamic pressure during docking. When the air fills the pipes, normal forces start to affect the spirals, which aim to enlarge the shell. When the target volume of the shell is achieved, the inner cords, attached to the center axis of the ballonet, prevent further enlargement.

We have taken the random spiral convolution as a calculation basis for the force factors, that appear in the system when the pressure is applied to the said convolution. Thus, we have decided upon the main system parameter — the rigidity. It decreases up to a certain point of the cord movement. Achieving rigidity minimum means that any further decrease of the contact area would not influence the rigidity. In the further project development, it is necessary to bear in mind that the initial cord tension should be chosen greater than the minimum one so that the rigidity of the system would grow with the growth of strain applied to this system.

We have taken into account two situations: when the strain is applied to the center axis of the gas shell and when the strain is distributed to the outer shell surface. We have calculated a preliminary durability of the spiral pipes taking into account a possibility to use two layers of spirals.

In order to assess the insulation properties of the functional shell, we have also taken into account two possible variants of the shell layer: with one or two spiral convolutions.

We have based our airship shell development upon the idea of a “double-glazed window”. In the gas shell layer, the air-filled spiral pipe serves as the double-glaze, therefore, when calculating the heat flows inside the spiral pipe, one needs to take into account calculation methods applicable for the heat losses in the barriers with the air-filled cavities.

The calculations were carried out in the MS Excel using the step-by-step approximations. Theoretical calculations were proved worthy in the SolidWorks Simulation software.

To select the optimal size and design of the gas shell layer with the aim of maintaining long-term temperature control, we have calculated the dependence of the heat transfer coefficient from the layer thickness.

Results and Discussion

Using the above-mentioned algorithms, we have determined the characteristics and core parameters of the transport airship main systems.

The main carrying gas is the heated air; supporting one is helium. The obvious advantage of using the heated air is its availability and ease of use — the shell could be folded while docked. Helium, on the other hand, could help to increase the payload, making the airship more versatile.

Overall, the main airship parameters are stated in the Table below.

Results of the calculations

Parameter	Value
Volume, m^3	815 370
Mass, kg	394 920
Cruise speed, kmh^{-1}	108
Optimal flight altitude, km	6.28
Length×Width×Height, m	225.2×120.5×76.6

After calculating the tangential shell overblow, we have derived the following: the flow separation distance and the number of the openings are: $x_{cr} = 0.33$ m, $N = 798$, the width of the opening: $\delta = 1$ mm, the equivalent impeller diameter and the respective area are: $D_{im} = 14.283$ m, $S_{im} = 160$ m^2.

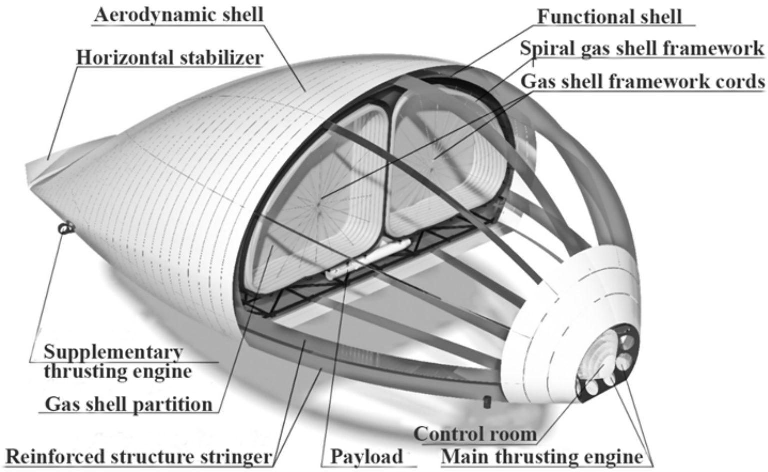
This area is a combined group of 10 impellers, each of 4.3 meters diameter, which in total form the main thrusting engine. The length of the opening k is taken as 20 mm. From one side, the length of the opening allows for a better flow direction, but from the other — increases the friction.

During the assessment of the two-layered spiral pipes durability compared to a single-layered variant, we have derived that final rigidity of the system (compared to initial single-layered calculation) has increased. The radius of the spiral convolution is equal to 0.975 m; the pipe radius is 0.65 m.

After that we have found the optimal cord system when $K_z = 1.2$. The optimal variant is as follows: 20 cords for each ballonet convolution with 71 attachment positions (the distance between the attachments is 3.17 m).

The insulating characteristics of the functional shell were derived from the SolidWorks Simulation software. To select the optimal size and design of the gas shell layer with the aim of maintaining long-term temperature control, we have calculated the dependence of the heat transfer coefficient from the layer thickness $k_l(\delta_l)$. The most suitable scheme appears when using 2 spiral pipes, when the heat transfer coefficient and the layer thickness are $k_l = 0.784\ m$ and $\delta_l = 0.97\ m$.

So, in a crude way, we have derived the main specifications of the transport airship systems. The preliminary airship design is shown in the Figure.



The airship's appearance

Conclusions

Airships have never seen use in the transportation of the space industry cargo. In our project we suggest innovative approach to the power and aerodynamic properties of an airship: quasi-rigid power structure based on the spiral pipe usage, inflated with air under pressure, as well as tangential shell overblow system.

Results of our research:

• current problems in the space industry are analyzed;

• explicit weather conditions alongside the route Moscow — Samara — Vostochny spaceport are reviewed;

• the design of the airship is created, its main aerodynamic characteristics are examined;

• the core parameters of the main systems (the power structure, steering elements, thermostat system, docking equipment, etc.) are derived;

• the structure of the above-mentioned systems is elaborated.

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УДК 629.7.085

Технологическая схема системы термостатирования стартового комплекса с применением мембранных блоков осушения воздуха

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Рассмотрена система термостатирования, спроектированная для обеспечения работы с перспективной ракетой-носителем тяжелого класса. Описаны существующие методы мембранного осушения с соответствующими конструкциями мембранных модулей и наиболее перспективными к применению на стартовых комплексах моделями. Научная новизна работы заключается в разработке принципиальных схем систем термостатирования с использованием одновременно принципов ПКХМ и половолоконных мембран. Цель настоящей статьи — провести анализ степени снижения энергопотребления воздушной системы обеспечения температурного режима стартового комплекса с помощью включения в схему двухступенчатого блока осушения из парокомпрессионной холодильной машины и мембранных осушителей.

Ключевые слова: *космодром, наземная космическая инфраструктура, стартовый комплекс, воздушная система обеспечения температурного режима, воздушная холодильная машина, осушение, мембрана*

Air Temperature Control System Technological Scheme with Membrane Dryers

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The purpose of the research is to perform energy consumption decrease degree analysis of launch rocket complex air temperature control system using two-stage drying unit including steam compression refrigerator and membrane dryers. The article discusses the temperature control system designed to operate with a prospective heavy-class launch vehicle. The membrane drying existing methods with the membrane blocks corresponding designs and the most prospective models for use at launch complexes are described. The article scientific innovation consists in the development of temperature control systems schematic diagrams including both the steam compression refrigerator and hollow fiber membranes principles.

Keywords: *spaceport, ground-based space infrastructure, launch complex, air temperature control system, air refrigerator, drying, membrane*

Introduction

One of the modern technologies improving main tasks is to increase technological efficiency and reduce energy consumption in various fields. Such trends are observed in air preparation and drying at launch complexes.

Methods and accepted assumptions

As an example, we consider the operation of an air temperature control system (ATCS) that uses the cycle of an air refrigerator for cooling and drying the air flow [1]. At a 1.0 MPa pressure and a +3 °C temperature at the entrance to the temperature control object, the air moisture content should not exceed 0.3 g per kg of dry air, what corresponds to about 100 % relative humidity at a 1.0 MPa pressure. Wet air is considered as wet and dry air two-component combination, the drying process in a membrane dryer is isothermic.

Traditional drying scheme

The traditional ATCS technological scheme is shown in Fig. 1.

The expander in this system, in addition to cooling the air flow by expanding to 1.0 MPa operating pressure, provides drying by condensation in the heat exchangers 3 and 4 to a given residual moisture content.

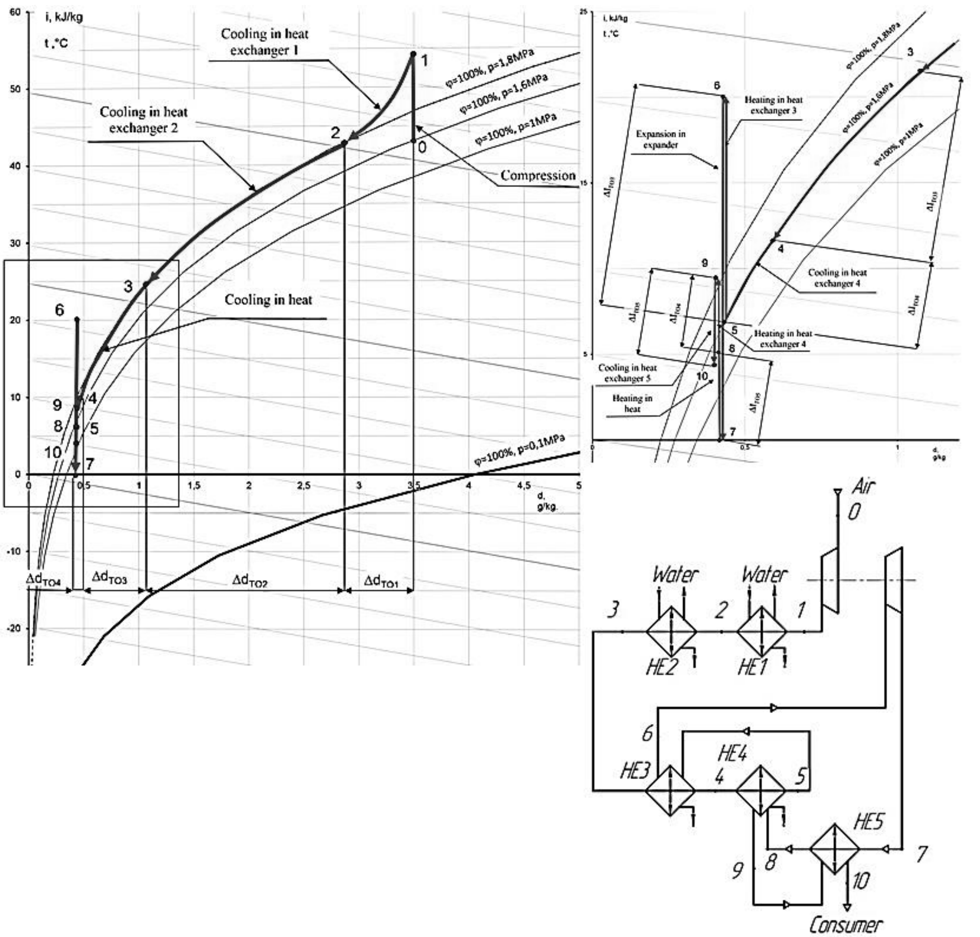

Fig. 1. Traditional ATCS technological scheme with a heat exchangers cascade and drying processes on the i-d wet air diagram for variable pressures

The air flow is compressed in the compressor to 1.8 MPa and cooled in heat exchangers cascade first with recycled water, and at a lower temperature level with a cold return air flow help after its expansion in the expander (point 7 in Fig. 1). At the outlet of the ATCS after expansion to a pressure of 1.0 MPa, the moisture content of the air corresponds to the dew point temperature of at least +3 °C (point 10 in Fig. 1). It is obvious that a further air moisture content decreases due to condensation is impossible because of the condensation mode transition to the frost formation mode at a temperature below 0 [2].

Another disadvantage of condensation drying of compressed air is the phenomenon of fogging over the cooling surface in heat exchangers, which occurs due to the transition of the state of wet air into the oversaturation zone. It reduces the efficiency of air preparation in the system and increases the real humidity parameters over the specified design parameters. The effective operation of traditional air preparation scheme shown in Fig. 1 largely depends on the operating parameters stability and minimum temperature heads maintenance in the heat exchangers-dryers [2].

Therefore, the listed above problems impose objective restrictions on the possibility of increasing the air drying degree in ATCS based on air cooling machines, which make it necessary to upgrade the air preparation technological schemes.

Drying scheme with membrane blocks and steam compression refrigerator

Technological schemes with membrane dryers may be more appealing to provide moisture content stability at the ATCS output. The application of membrane dryers in combination with steam compression refrigerator (SCR) allows to get rid of the expander stage and replace the four-stage compressor with a less energy-intensive three-stage one. The modified system technological scheme is shown in Fig. 2.

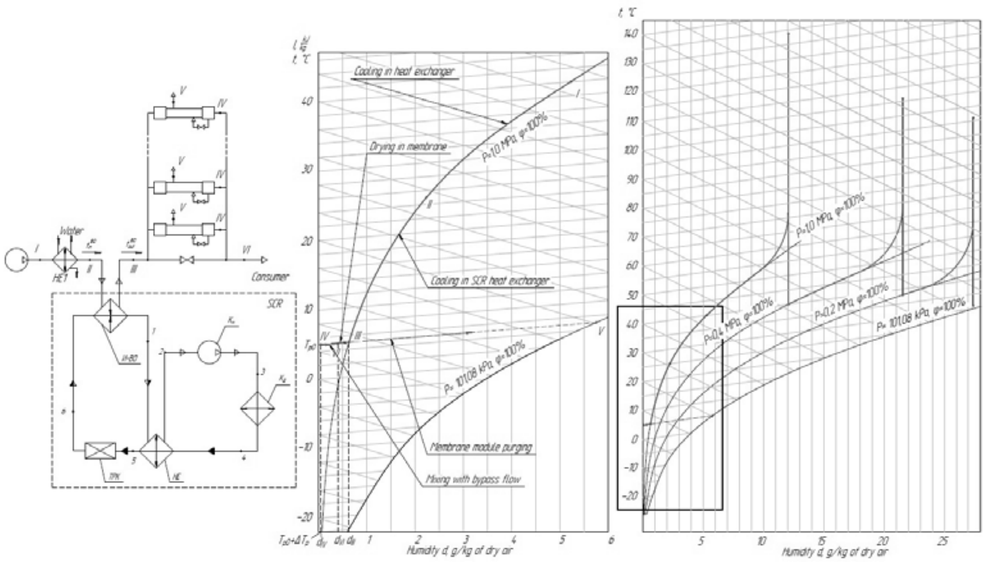

Fig. 2. Technological scheme with a SCR and membrane dryers and drying processes on the i-d wet air diagram for variable pressures

SCR is installed as the first air condensation drying stage and makes air cooled to the temperature of +5 ° C. This SCR mode allows to use a refrigerator avoiding its overcooling with its consequent defrosting necessary. The values and characteristics of the resulting SCR operating mode are shown in the Molie diagram in Fig. 3 and in Table.

Values of the SCR operating cycle nodal points parameters

Points	1	2	3	4	5	6
t, deg	5	10	42	35	31	5
i, kJ/kg	554	558	573	432	426	426
p, MPa	0.35	0.35	0.8	0.8	0.8	0.35
S, kJ/kg·K	4.557	4.575	4.575	–	–	–

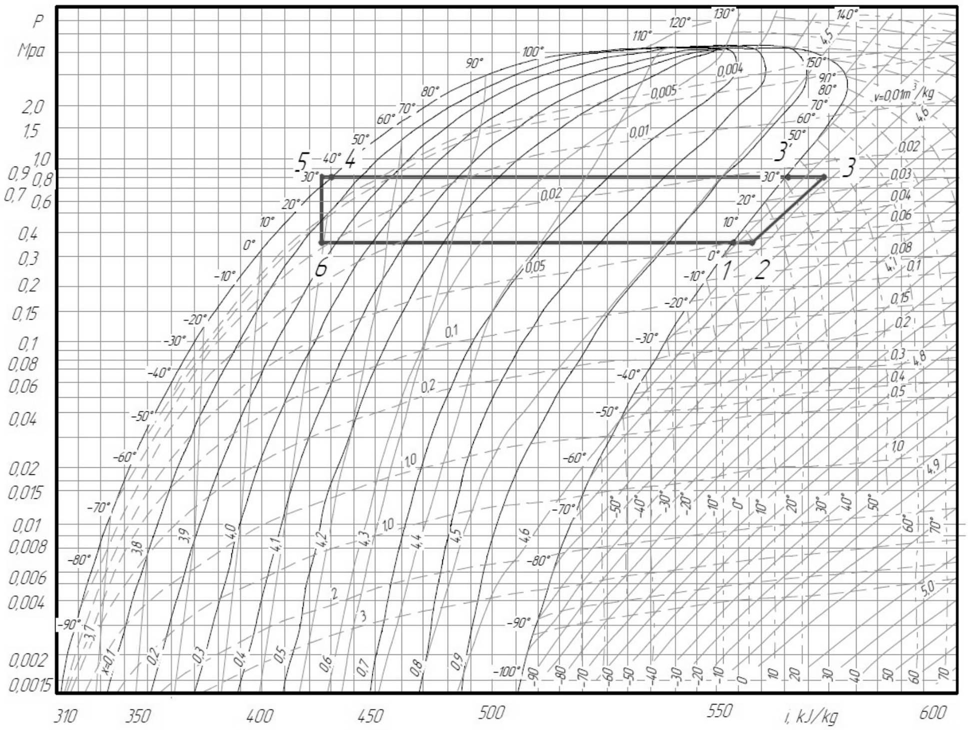

Fig. 3. SCR operating cycle processes during preliminary air drying

Based on SCR operating mode obtained data, thermophysical calculations were carried out and SCR power consumption (SCR compressor electric motor power) was determined and amounted to 16.7 kW [3].

The membrane dryers block provides the final air drying to the required dew point. Since membrane dryers have a low throughput, the membrane drying unit consists of several parallel installed dryers.

Membrane dryers have the ability to drain the flow to a dew point significantly lower than that required one. A bypass is installed in the system to regulate the flow rate, that allows to regulate the final humidity value, avoid excessive drying and optimise membrane purging losses by increasing flow operating mode accuracy. The membrane dryer block design scheme is shown in Fig. 4.

According to the design scheme and membrane dryers characteristics from open sources, while the drying ability of the membrane dryer to lower the dew point by –32 °C and 10 % purging losses of the membrane's input flow rate, the bypass flow part will be about 40 %, and the total purging loss for in the design scheme is about 6 %. With a membrane throughput of about 500 normal m^3/h, it will require 20 parallel driers installation [4].

Based on the obtained values, a three-stage compressor capable to provide 260 normal m3/min compressed air flow rate at a pressure of 1.0 MPa was selected [1]. This compressor model has 1800 kW electrical power consumption, while the original four-stage compressor's power consumption was 2500 kW.

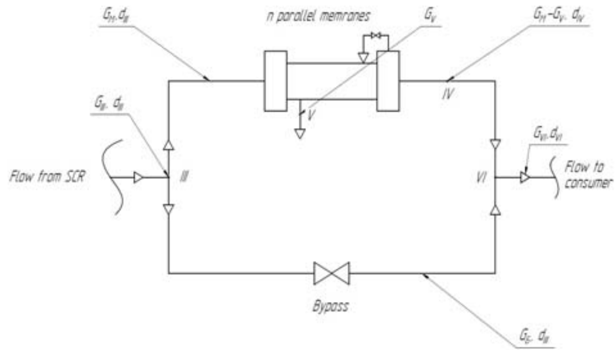

Fig. 4. The membrane dryer block design scheme

Conclusion

Therefore, despite the air consumption increase in compressor due to the membrane dryers blowing losses and SCR energy consumption, the modified system total energy consumption will be 25% lower than the traditional scheme system, which leads to a significant reduction in operating costs.

The ATCS drying unit design developed in this work provides the possibility to obtain dryed air in a wide range of flow characteristics and moisture content by dual mode control: by changing the bypass flow part and membrane unit drainage flow part. This control method also provides the possibility of fine-tuning the required mode, what increases producibility and decreases unnecessary energy losses.

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Новые удлинители цепи для самовосстанавливающихся полиуретанов

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Представлена серия соединений, предназначенных для модификации полимерной цепи различных полиуретанов для введения структурного фрагмента, способного к термически инициируемым обратимым ковалентным взаимодействиям. Бисмалеимиды (2а-д) были синтезированы из коммерчески доступных ароматических и алифатических симметричных диаминов (1а-1д) и далее введены в реакцию Дильса — Альдера с фурфуриловым спиртом в качестве диенофилов. Аддукты Дильса — Альдера (3а-3д) были получены в виде смеси эндо- и экзо-изомера. Наличие симметричных гидроксильных групп в структуре полученных соединений делает их пригодными в качестве удлинителей цепи низкомолекулярных диизоцианатных форполимеров. Наличие в структуре потенциальных удлинителей цепи термически обратимого аддукта реакции Дильса — Альдера открывает возможность создания уникальных материалов, обладающих свойствами самовосстановления. Все полученные соединения охарактеризованы методами 1Н, 13С ЯМР, масс-спектрометрии высокого разрешения с ионизацией электрораспылением и ИК-спектроскопии. Термохимические параметры обратной реакции Дильса — Альдера установлены с помощью ДСК-анализа.

Ключевые слова: *полиуретаны, полимеры, полимерные композиты, самовосстановление, реакция Дильса — Альдера, удлинители цепи*

Информация о гранте

Работа выполнена при финансовой поддержке гранта РФФИ, проект № 18-29-18037

New Chain Extenders for Self-Healing Polyurethanes

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The authors present a small series of compounds designed to modify the polymer chain of various polyurethanes in order to introduce a structural fragment with the ability of thermally-triggered reversible covalent interactions. Bismaleimides (2a-2e) were synthesized from commercially available aromatic and aliphatic symmetric diamines (1a-1e) and were further introduced into the Diels — Alder reaction with furfuryl alcohol as *dienophiles. The Diels — Alder adducts (3a-3e) were obtained as a mixture of endo- and exo-isomer. The presence of symmetrical hydroxyl groups in the structure of the obtained compounds makes them suitable as chain extenders of low molecular weight di-isocyanate prepolymers. The presence of a thermally reversible Diels — Alder reaction adduct in the structure of potential chain-extenders opens a possibility to create unique materials with self-healing properties. All compounds obtained were characterized by 1H, 13C NMR, ESI-HRMS, and IR spectroscopy. The thermochemical parameters of the reverse Diels — Alder reaction were established using DSC analysis.*

Keywords: *polyurethanes, polymers, polymer composites, self-healing, Diels – Alder reaction, chain extenders*

Introduction

Polyurethanes are a widely used class of polymers, which has been applied in many industrial areas: from light manufacturing to composite materials [1, 2]. Their share is about 8 % of all produced plastics that make them one of the most used polymers in the world [3, 4]. However, most existing polyurethanes cannot be recycled and more than 50 % of all plastic waste (including post-consumer or post-production types) is processed by landfilling [5]. In addition, there are less common methods of processing polyurethane as mechanical methods (cutting and using as filler) [6], or pyrolysis with the formation of oil, gas, and ash, which can be valuable for many industries [7, 8]. In some cases, polyurethanes can be processed using catalytic glycolysis: this reaction produces glycols that can be used in the production of polyurethanes [9]. Unfortunately, catalytic glycolysis requires more effort than mechanical methods because of economic costs, used temperature, and additional reagents [10]. Microcracks and following their failure are the most significant drawbacks of all polymer materials, including polyurethanes [11]. Engineering research has been focused recently on the design of new materials with increased robustness or the development of self-healing materials, which can heal resulting damage and recover functionality as biological systems by using autonomic mechanisms or external stimulus (heating, radiation or electricity). These studies opened a new way to create safer, longer-lasting and easily recyclable materials [12].

Self-healing ability could be introduced in polymers in various ways. The first way is creation of the capsule-based materials: healing is achieved by the introduction of a microencapsulated liquid healing agent and solid catalytic chemical materials in a polymer matrix. When a crack occurs due to damage, microcapsules release a liquid healing agent and solid catalyst, which react in the region of the damage through polymerization [13, 14]. The clearest disadvantage of the encapsulated self-healing materials is a limited number of healing attempts, i. e., when a healing agent is depleted, material stops to heal the resulting cracks [15].

Wool described the second way to create self-healing material: one-component system, where polymer matrix possess self-healing properties, i. e., healing can be accomplished without integration of the additional reagents [16]. Usually, this process can be implemented due to inherent properties of the polymer as thermoplasticity or through thermally reversible interactions (the formation of disulfide bridges, hydrogen bonds, metal complexes or covalent bonds by the mechanism of the Diels — Alder reaction). The last method is frequently used for the design of the new self-healing polyurethanes. Chen showed that polymer formation occurs by the interaction between furan and maleimide:

these groups can be lateral in the finished polymer chain or the small molecules [17]. Chen described the method of the preparation of the linear PU prepolymer containing terminal difuranic fragments: the reversible crosslinking covalent bonds between hard segments were incorporated into the PU via a DA reaction between the furan ring of the prepolymer and maleimide crosslinker [18]. However, implementation of the healing process may be accompanied by some difficulties, which are connected supposedly with a low mass transfer, the furan groups concentration in the hard polyurethane domains, and with the difficulty of the maleimides penetration into them [19].

We propose to achieve the self-healing effect by introducing low-molecular-weight chain extenders based on Diels — Alder reaction adducts of different *bis*-maleimides with furfuryl alcohol into the polymer structure (Fig. 1). These fragments based on reversible covalent interactions react with the prepolymer while forming high-molecular-weight polyurethane, which exclude occurrence of the problems described in [18, 19].

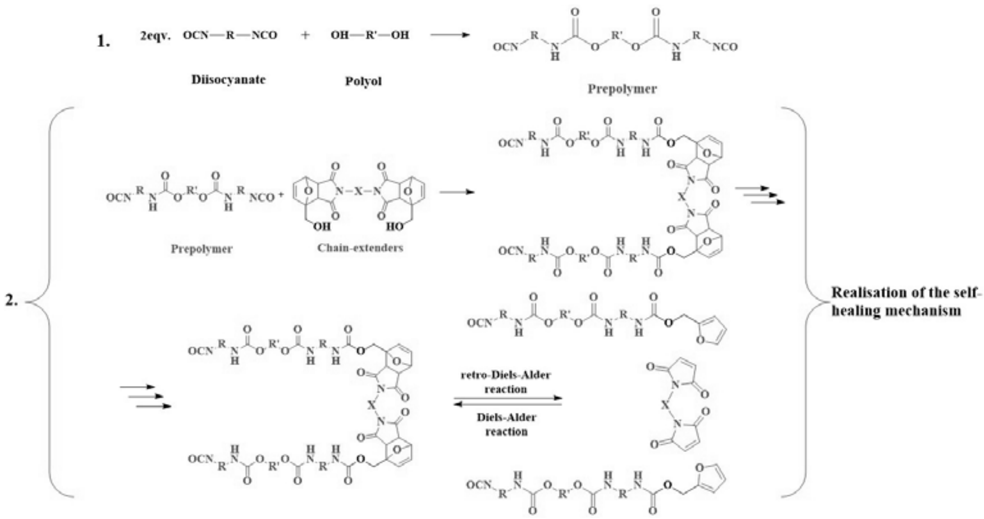


Fig. 1. Reaction between a prepolymer and DA adduct

Experimental part

Materials and methods. Furfuryl alcohol (99.5 %) was purchased from ACROS and purified by vacuum distillation. (4,4'- diaminodiphenylmethane) bismaleimide (97 %), 4,4' — diaminodiphenylsulfone (97 %), 3, 3’ — dichloro-4,4’-diaminodiphenyl methane (97 %), 4,4’ — oxidyaniline, hexane-1,6 -diamine, sodium acetate (98 %), furan-2,5-dione (98 %) and acetic anhydride (99 %) were purchased from “Sigma-Aldrich” and used as received. Acetone, diethyl ether, and methanol were purchased from “Component-reaktiv” and dried before use.

^{1}H and ^{13}C NMR spectra were recorded in DMSO-d_6 solutions on Bruker Avance 300, 400, and 600 spectrometers (300.15, 400.13, and 600.22 MHz ^{1}H frequency, respectively). The measurements were performed using the residual signals of DMSO-d_6 (^{1}H 2.50 ppm, ^{13}C 39.5 ppm) as references. *ATI-FTIR* was performed on a Nicolet iS10 spectrometer in the range of 4000...650 cm^{-1} on a germanium crystal. *The thermal behavior was examined by DSC* with a NETZH DSC 204 F1 Phoenix within a temperature range of 0 to 300 °C at

heating/cooling rates of 5/20 K/min in an argon atmosphere. A sample weight of about 3...8 mg was used for each measurement.

The high-resolution mass spectra (HRMS) were measured on a Bruker microTOF II instrument using electrospray ionization (ESI). The measurements were done in a positive ion mode (interface capillary voltage — 4500 V) or in a negative ion mode (3200 V); mass range from m/z 50 to m/z 3000 Da; external or internal calibration was made with Electrospray Calibrant Solution (Fluka). A syringe injection was used for solutions in acetonitrile (flow rate 3 μL/min). Nitrogen was applied as a dry gas; interface temperature was set at 180 °C.

The synthesis. We designed a series of low-molecular-weight chain extenders based on Diels — Alder reaction adducts of maleimides with furans. We used commercially available symmetric diamines as starting compounds, such as 4,4'-methylenedianiline (1a), 4,4'-oxydianiline (1b), 4,4'-methylene-bis(2-chloroaniline) (1c), 4-aminophenyl sulfone (1d), hexamethylenediamine (1e). Structural fragments X with different donor-acceptor properties was studied: X_{1a} — neutral non-conjugated fragment with a bridge methylene group, X_{1b} — conjugated M-donor fragment with a bridge oxo-group, X_{1c} — non-conjugated M-donor fragment with a bridge methylene group, X_{1d} — conjugated acceptor fragment, X_{1e} — non-conjugated donor aliphatic fragment.

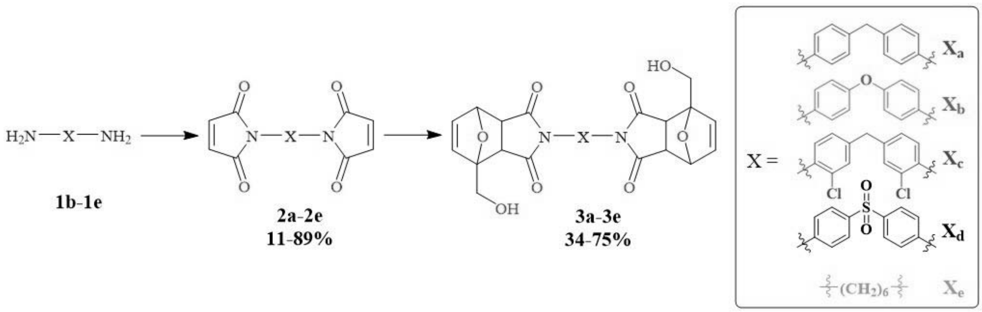


Fig. 2. Two-stage synthetic procedure to obtain the target compounds (3a-3e)

We proposed a simple two-stage synthetic procedure to obtain the target compounds (3a-3e) (Fig. 2), which includes the preparation of symmetric bismaleimides (2b-2e) and the further conversion into the adducts of the Diels — Alder reaction (3a-3e). Commercially available 1,1 '- [methylenebis(4,1-phenylene)]bis(1*H*-pyrrole-2,5-dione) (2a) was used to obtain compound 3a.

Results and discussion

We used the one-pot method presented in Fig. 3, A to obtain compounds 2b, 2c [20, 21]. Bismaleimides were obtained by heating a mixture of the initial diamine, maleic anhydride, sodium acetate, and acetic anhydride.

Compound 2d was synthesized in two steps (Fig. 3, B) [22]. Intermediate maleamic acid 2d' was isolated and purified. A low conversion was observed for (2d) when a one-pot two-step procedure was performed. There were also difficulties with isolation of the compound (2d) in that case associated with the separation of target maleimide from the acid (2d').

N,N'-hexamethylenebismaleimide (HBMI) (2e) was prepared by three-step procedure (Fig. 3, C) [14]. At first, a Diels — Alder adduct of furan with maleic anhydride (FMA, 2e') was synthesized to protect maleic anhydride double C=C bound from competing Michael reaction with an aliphatic amine. Then furan-protected bismaleimide 2e'' was obtained by reaction between the FMA (2e') and hexamethylenediamine (1e). At the last step, a protective furan group was removed by the retro Diels — Alder reaction, and the final product (2e) was isolated in 85 % yield. Despite the low total yield for the three stages (11 %), the advantage of this method is the high purity of the obtained product (2e) in comparison with one- and two-stage methods described above.

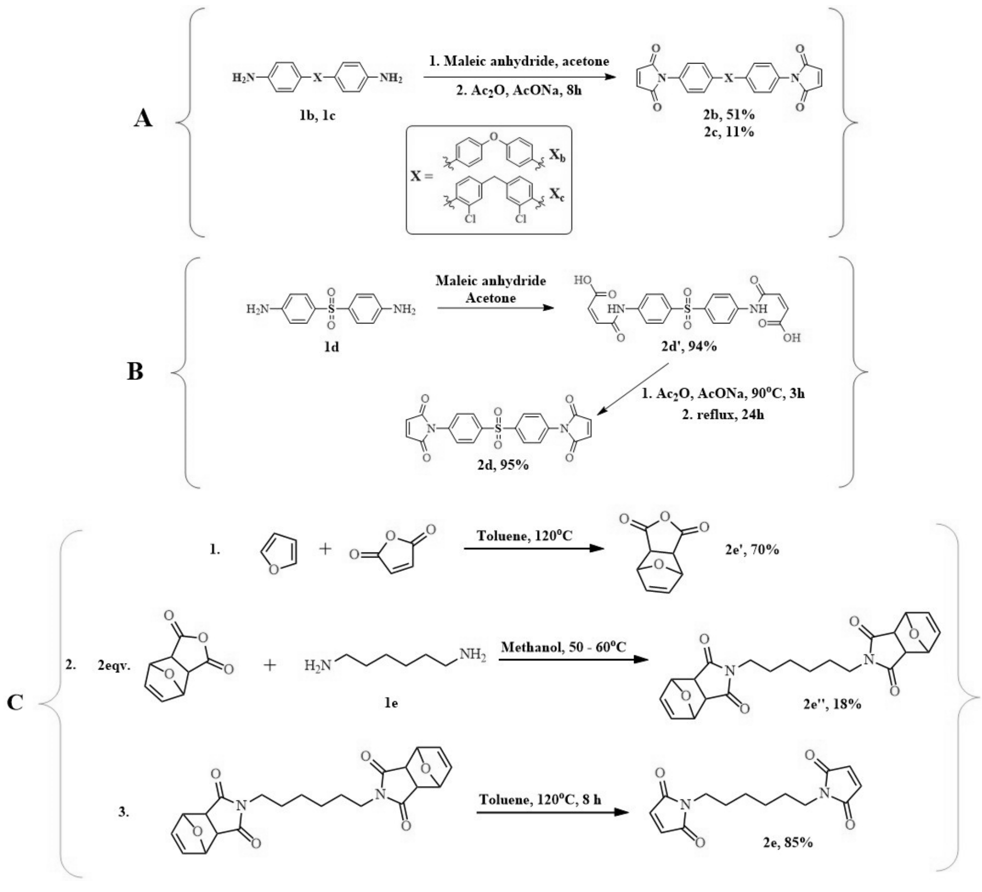
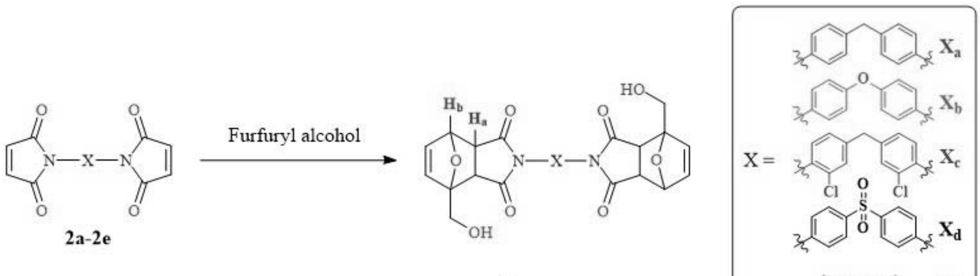


Fig. 3. The synthesis of the bis-maleimides 2c, 2d, 2e

Compounds (3a-3e) were obtained as a mixture of exo- and endo-isomers. The presence of two isomers was proven by NMR spectroscopy as described in [23, 24]. It was shown that the stereochemistry of the obtained isomer could be judged by the value of the vicinal constants of the spin-spin interaction $^{3}J_{HH}$ between H_a and H_b (Fig. 4). The $^{3}J_{HaHb}$ values of endo-isomers of the obtained compounds (3a-3e) range from 5.5 to 6.0 Hz, and exo-isomer constants range from 0.0 to 2.0 Hz. The DSC analysis showed two endothermic peaks corresponding to endo- and exo-isomers, respectively. It is commonly seen as separated peaks for two isomers, and an endo-one usually has lower values than his exo-counterpart [24].

The target compounds (3a-3e) were obtained by the Diels — Alder reaction from bismaleimides (2a-2e) and furfuryl alcohol (Fig. 4).



3a, 75%, 60°C, 72h, endo:exo (1:4)
3b, 57%, 40°C, 48h, endo:exo (1:1.5)
3c, 34%, 40°C, 48h, endo:exo (1:3)
3d, 38%, 40°C, 48h, endo:exo (1:12)
3e, 00%, 65°C, 48h, endo:exo (1:11)

Fig. 4. The synthesis of the Diels — Alder adducts

All the compounds (2a-2e, 3a-3e) were characterized by ^{1}H, ^{13}C NMR- and IR-spectroscopy, as well as by high-resolution mass spectrometry (Table).

Also, the Diels — Alder reaction adducts (3a, 3b, 3c, 3d) were characterized by DSC analysis.

Data of the ^{1}H, ^{13}C NMR-, IR-spectroscopy and high-resolution mass spectrometry analysis of compounds (2a-2e, 3a-3e)

Compounds	^{1}H-NMR (DMSO-d_6, δ/ppm., J, Hz)	^{13}C-NMR (DMSO-d_6, δ/ppm., J, Hz)	IR (ATR, neat, cm^{-1}):	HRMS (ESI)
3a	**3.02** (d, J = 6.6, 2H), **3.19** (d, J = = 6.6, 2H), **3.75-3.79** (dd, J_1 = 5.0, J_2 = 12.4, 2H), **4.03** (s, 2H), 4.07-**4.10** (dd, J_1 = 5.0, J_2 = 12.4, 2H), **5.05** (t, J = 6.0, 2H), **5.19** (m, 2H), **6.56-6.59** (m, 4H), **7.11-7.15** (d, J = 8.5, 4H), **7.36** (d, J_1 = 1.9, J_2 = 8.1, 2H), **7.59** (m, 2H)	40.61,48.50,48.59, 50.71,55.40,65.42, 81.58,92.52,127.34, 129.73,130.63,141.67, 174.66, 176.13	1780,1658, 697, 842	**Found:** $C_{31}H_{26}N_2O_8$ (M+Na) 577.1586, **Calculated:** 557.1581

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Compounds	^{1}H-NMR (DMSO-d_6, δ/ppm., J, Hz)	^{13}C-NMR (DMSO-d_6, δ/ppm., J, Hz)	IR (ATR, neat, cm^{-1}):	HRMS (ESI)
2b	**7.15** (m, 8H), **7.34** (d, J = 3.0, 4H)	123.78, 126.92, 129.33, 132.40, 153.92, 169.45	3080, 1641, 1780, 1726, 1461, 1488, 1503, 1586, 1622, 1226, 1281	**Found** $C_{20}H_{12}N_2O_5$ (M+H) 361.0811, **Calculated:** 361.0819; **Found (**M+NH_4) 378.1073, **Calculated:** 378.1084; **Found (**M+MeOH) 393.1071, **Calculated:** 393.1081
3b	**3.03** (dd, J_1 = 2.1, J_2 = 6.5, 2H), **3.20** (d, J_1 = 2.4, J_2 = = 6.5, 2H), **3.77-3.81** (m, 2H), **4.10** (m, 2H), **5.05** (br.s, 2H), **5.19** (m, 2H), **6.56-6.59** (m, 4H), **7.11-7.19** (m, 8H)	—	1781, 1658, 842, 697	**Found** $C_{31}H_{24}N_2O_8Cl_2$ (M+Na) 645.0802, **Calculated:** 645.0802; **Found** (M+NH_4) 640.1240, **Calculated:** 640.1248; **Found (M+K)** 661.0543, **Calculated:** 661.0541.
2c	**4.09** (s, 2H), **7.27** (s, 4H), **7.39-7.46** (m, 4H), **7.64** (s, 2H)	41.43, 127.37, 128.57, 129.98, 131.53, 132.20, 135.14, 143.79, 169.32.	2357, 1788, 1715, 1497, 1394, 1157, 848, 688	**Found** $C_{21}H_{12}N_2O_4Cl_2$ (M+Na) 449.0061, **Calculated:** 449.0066
3d	**3.05** (d, J = 6.4, 2H),**3.24** (d, J = 6.4, 2H), **3.76-3.79** (dd, J1 = 6.4, J2 = 12.6, 2H),**4.07-4.10** (dd, J1 = 5.9, J2 = = 12.7, 2H),**5.05** (t, J = 5.7, 2H), **5.20** (d, J = 1.8, 2H),**6.56-6.59** (m, 4H),**7.51-7.54** (d, J = 8.7, 4H),**8.11-8.14** (d, J = 8.7, 4H)	48.27, 48.43, 50.60, 80.78, 92.23, 127.92, 128.15, 128.45, 129.00, 136.61, 140.09, 173.69, 175.19	1784, 1719, 848, 707	**Found** $C_{30}H_{24}N_2O_{10}S$ (M+Na) 627.1045, **Calculated:** 627.1044.

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Compounds	^{1}H-NMR (DMSO-d_6, δ/ppm., J, Hz)	^{13}C-NMR (DMSO-d_6, δ/ppm., J, Hz)	IR (ATR, neat, cm^{-1}):	HRMS (ESI)
2e	**1.20** (m, 4H), **1.45** (m, 4H), **3.36** (t, 4H), **7.00** (s, 4H)	26.14, 28.35, 39.14, 117.10, 167.80	3088, 2908, 2857, 1759, 1454, 1372, 1129, 946, 838, 786, 695	—
3e	**1.14** (m, 4H), **1.37** (m, 4H),**2.86** (d, J = 6.4, 2H), **3.03** (d, J = 6.1, 2H), **3.30** (m, 4H),**3.66** (m, 2H), **4.00-4.03** (dd, J_1 = 6.1, J_2 = 12.6, 2H),**4.97** (m, 2H),**5.07** (s, 2H),**6.50-6.53** (m, 4H)	—	1781, 1759, 838, 695	**Found** $C_{24}H_{28}N_2O_8$ (M+H) 473.1918, **Calculated:** 473.1918; **Found** (M+NH_4) 490.2177, **Calculated:** 490.2184; **Found** (M+Na) 495.1731, **Calculated:** 495.1738

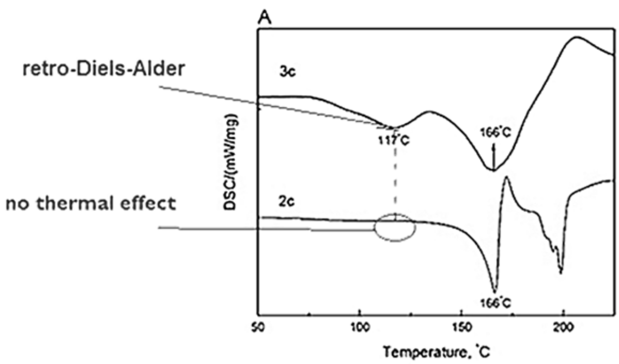

Fig. 5. DSC curves of the compounds 2c (maleimide) and 3c (Diels — Alder reaction adduct)

The DSC experiments were performed to determine the temperature of the retro-Diels — Alder reaction. We showed that the temperature of the retro-Diels — Alder reaction for compounds 3b and 3c is 117.4 °C for 3a — 132 °C, and for 3b — 123 °C. We noticed additional peaks above the temperature of the retro-Diels — Alder reaction and suggest that these side processes could be a sublimation of the bismaleimides and furfuryl alcohol through an open DSC crucible. This suggestion was confirmed by a control DSC experiment with pure bismaleimides. Thus, plot A shows the DSC curve for the adduct (3c) versus the curve for the pure maleimide (2c) (Fig. 5).

We showed that adducts formed could be reversibly cleaved back to initial maleimide and furans that opens an opportunity to create self-healing or recyclable polyurethanes.

The creation of self-healing polyurethanes could increase the product's life cycle, provide a new approach to material recycling, reduces the cost of the target material, and also makes materials more environmentally friendly [10, 11].

Conclusion

Bismaleimides (2a-2e) were synthesized from commercially available aromatic and aliphatic symmetric diamines (1a-1e) and were further introduced into the Diels — Alder reaction with furfuryl alcohol as dienophiles. The Diels — Alder adducts (3a-3e) were obtained as a mixture of endo- and exo- isomers. The presence of symmetrical hydroxyl groups in the structure of the obtained compounds makes them suitable as chain extenders of low molecular weight di-isocyanate prepolymers. The presence of a thermally reversible Diels — Alder reaction adduct in the structure of potential chain-extenders opens a possibility to create unique materials with self-healing properties. All compounds obtained were characterized by ^{1}H, ^{13}C NMR, ESI-HRMS, and IR spectroscopy. The thermochemical parameters of the reverse Diels — Alder reaction were established using DSC analysis.

We are planning to prepare a test self-healing polyurethane based on the obtained chain extenders.

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Information about the grant

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УДК 004.942

О численном моделировании акустических волн, генерируемых сжатым газом

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Рассмотрены возможности математического моделирования импульсного акустического воздействия — модель поведения среды при распространении волн сжатия. Моделирование проведено средствами вычислительного пакета Ansys AUTODYN в двумерной осесимметричной постановке и сравнено с результатами натурного эксперимента. Представленные результаты подвержены критике и построены предположения о дальнейшем усовершенствовании численной модели.

Ключевые слова: *численное моделирование, акустическое воздействие, ударные волны, лабораторные испытания, уравнение состояния*

On Acoustic Influence Simulation Generated with High-Pressure Gas

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The paper considers the possibilities of mathematical modeling of pulsed acoustic impact, namely, the behavior of the medium during the propagation of compression waves. The simulation is carried out by means of the Ansys AUTODYN computing package in a two-dimensional axisymmetric formulation and is compared with the results of a full-scale experiment. The presented results are criticized and assumptions are made about further improvement of the numerical model.

Keywords: *numerical modeling, shock waves, acoustic impact, experimental installation, equation of state*

SM4 Department laboratory in BMSTU has equipment that allows generating impulse acoustic influence of high pressure, namely a pneumatic gun with replaceable barrels of various diameters, equipped with a high-speed “ISTA” valve and a compressor. This complex allows generating an air shock wave with duration of 1...25 ms, a sound pressure level of up to 180 dB and produce up to 4 shots in 30… 40 minutes, as indicated in [1]. There is also information about the reduction in the timing and cost of the tests carried out by an order of magnitude compared to field tests.

The most important task when planning tests in the laboratory is to determine the parameters of the impact on the object under study. Since three-dimensional modeling is an integral part of the modern paradigm of designing devices and equipment, it becomes possible to pre-evaluate the impact parameters with mathematical modeling the behavior of the studied object “digital twin” under laboratory conditions.

As a preliminary step in conducting influence modeling, it is necessary to determine the materials models used. In the case of exposure to an object by a high-pressure acoustic wave, the working medium is air. As a first approximation, the equation of the ideal gas can be used as the equation of state for air, which is standard for the “AIR” model from the AUTODYN materials library, as indicated in manual [2], the constants of the model are given in reference [3]. Further, according to the parameters of the room and the source of the acoustic wave — the pneumatic gun — a numerical simulation was compiled, which scheme is shown in Fig. 1. The general view of the pneumatic gun from the muzzle can be seen in Fig. 2.

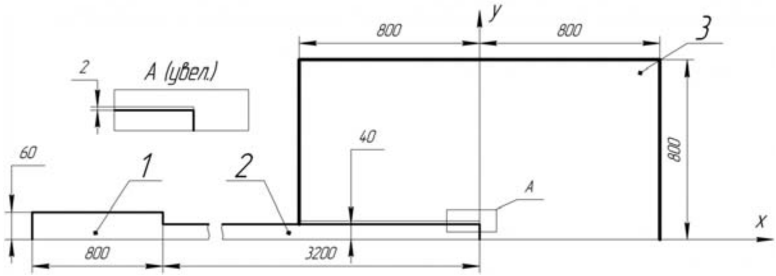


Fig. 1. Numerical simulation scheme:
1 — receiver; *2* — barrel; *3* — area of acoustic influence propagation

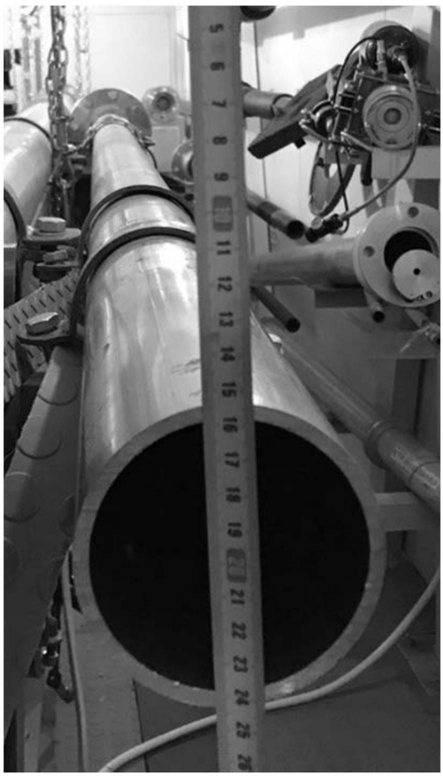


Fig. 2. General view of the pneumatic gun

The numerical problem was formulated in a two-dimensional axisymmetric formulation using the Euler approach. Domain *1*, corresponding to the receiver area, has dimensions of 800×60 mm, the cell size is 2×2 mm; domain *2*, corresponding to the barrel channel of the pneumatic gun, has dimensions of 3200×40 mm, the cell size is 2×2 mm; domain *3*, corresponding to the shock wave propagation area, has dimensions of 1600×800 mm, the cell size is 2×2 mm; the boundary conditions indicated by a thickened line are "Flow out" boundary conditions. The enlarged section shows the area of "uncountable" cells, with dimensions of 800×2 mm, simulating the gun barrel body. The location of the gauges is shown in Fig. 3. All gauges are Eulerian type gauges fixed in space.

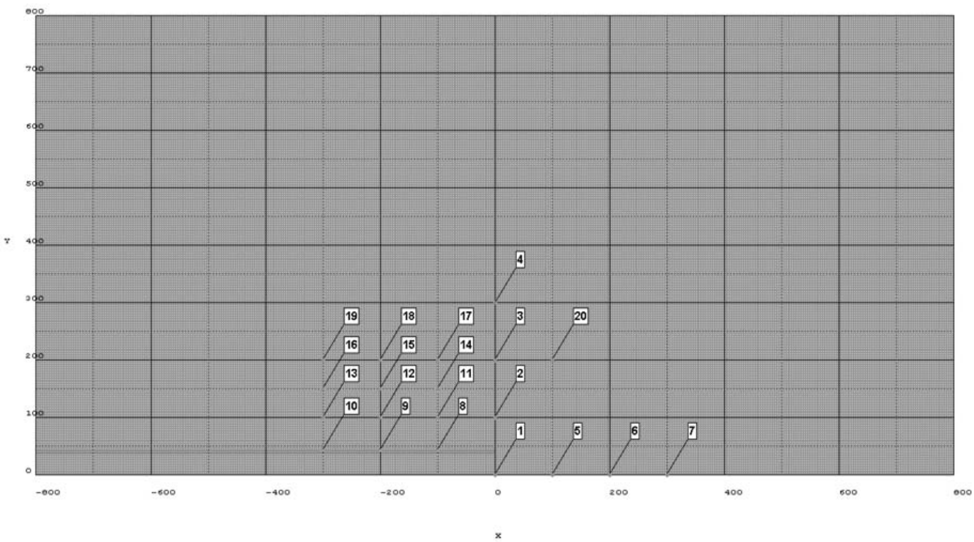


Fig. 3. Location of the gauges in the area 3

From the equation of state of ideal gas, which represents the Boyle — Mariotte law [4], an initial energy value was obtained corresponding to a pressure of 50 atm. to fill the receiver area *1* and *1* atm. for areas *2* and *3*:

$$p = (\gamma - 1)\rho e.$$

The calculated picture of shock wave propagation over the area around the barrel for several time points from the beginning of the modeling process is shown in Fig. 4.

According to the results of the mathematical modeling, the time-pressure dependences were obtained from gauges, the readings from which it is convenient to take in the laboratory to verify the numerical model, namely sensors numbered *3, 17, 18, 19* and *20*.

Experimental verification was carried out by comparing the readings of gauges in a numerical problem and pressure sensors in a laboratory experiment. The dynamic pressure sensor PS2001-5-01 manufactured by GlobalTest LLC with the characteristics specified in Table 1 was used. The signal receiver was a noise meter-vibrometer, an EECOPHISICA-110A spectrum analyzer manufactured by PKF Digital Instruments LLC, which allows to measure sound pressure levels up to 210 dB in combination with the PS2001-5-01 sensor.

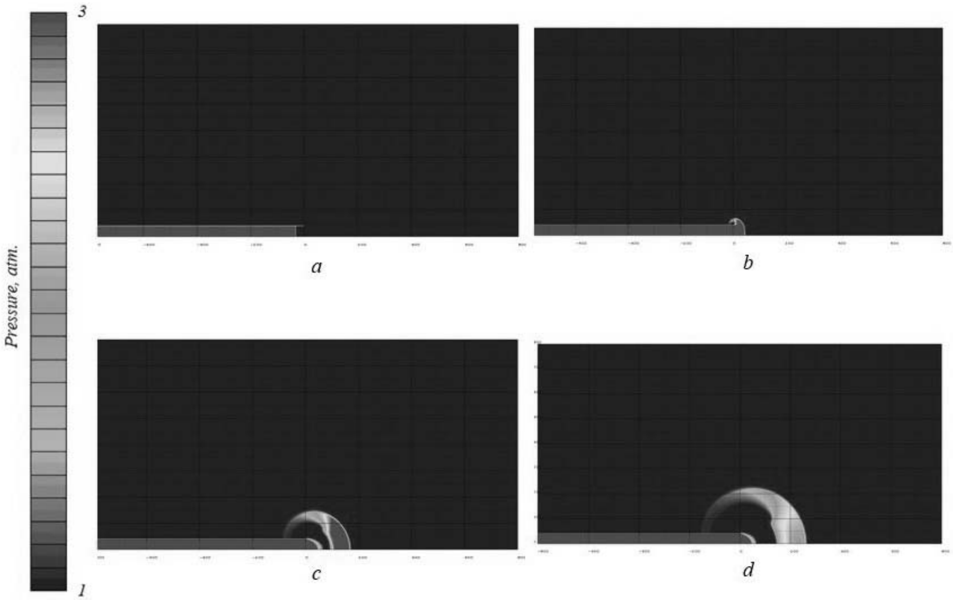


Fig. 4. The dynamics of shock wave propagation for time points:
a — 4.1 ms; *b* — 4.2 ms; *c* — 4.4 ms; *d* — 4.6 ms

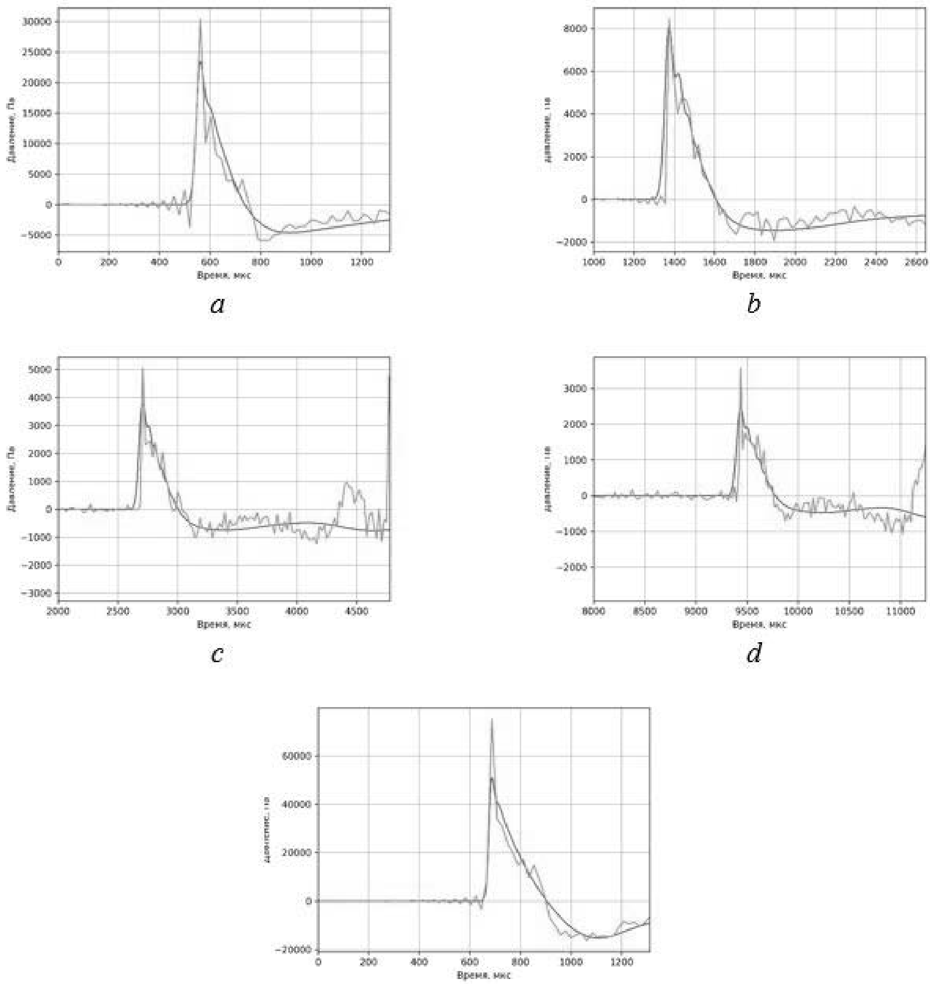
Table 1

PS2001-5-01 specification

Name	Value
Sensitivity, mV/kPa	2.12
Pressure range, MPa	0.0002–0.5
Acceleration sensitivity, MPa/g	0.0001
Sensitive element	Lithium niobate

When working with a laboratory installation, a pressure sensor mounted on a tripod at a height of 200 mm from the level of the axis of the pneumatic installation barrel was installed at the corresponding points of space in successive experiments. To prevent the parasitic effect of vibrations on the results obtained, a gasket from elastic porous material (foam rubber) was installed between the pressure sensor and the tripod. By means of Signal+3G software sensor readings were received from the signal receiver and automatically processed. Subsequently, the data were recorded in a text format and further processed for ease of comparison, the results of processing sensor readings during the experiment and during mathematical modeling are shown in Fig. 5. The point of arrival of the maximum value to the sensor is taken as a common point in time.

As can be seen in Fig. 5, b, at the location of the sensor *17*, the difference between the experimental data and the calculated data does not exceed 5 %, but at other locations the values vary greatly. Quantitative values of the maximum pressure and compression pulse length for all sensors are shown in Table 2, experimental data in the left column, model data in the right column.



e

Fig. 5. Graphs of pressure, Pa, versus time, μs, in the acoustic wave propagation region: *blue line* — simulation; *orange line* — experiment; *a* — gauge 3; *b* — gauge 17; *c* — gauge 18; *d* — gauge 19; *e* — gauge 20

Table 2

Sensor readings

Gauge #	**19**		**18**		**17**		**3**		**20**	
Pressure, Pa	3565	2478	5045	3793	8438	8085	30 402	23 432	75 165	50 938
Compression impulse duration, μs	358	471	312	388	249	317	238	222	259	261

The reasons for the difference in readings may be the following factors: imperfection of the receiver mathematical model in which the valve has a special geometry that prevents the retention of working gas masses inside the receiver; imperfection of the numerical calculation parameters settings (the number of Courant — Friedrichs — Lewy, coefficients of linear and quadratic pseudo-viscosity and smoothing), affecting the smoothing of peak values and “smearing” of the front. In further work, it is assumed by changing the parameters of numerical calculation, refining the geometric model and improving the equation of state to obtain values that do not differ from the experimental ones by more than 5 % in order to create a prototype of a complex for acoustic parameters preliminary evaluation.

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УДК 629.7.058

Полунатурное моделирование при создании системы автоматического управления летательного аппарата

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При разработке оборудования и систем для летательного аппарата проведение исключительно натурных испытаний является финансово невыгодным. В то же время использование только математического моделирования не позволяет получить достоверный прогноз поведения летательного аппарата на критических режимах полета. Для решения данных проблем тестирования проводятся с помощью полунатурного моделирования. Показаны способы применения полунатурного моделирования при создании летательного аппарата и разработана математическая модель пространственного движения летательного аппарата, которую можно использовать в стенде полунатурного моделирования.

Ключевые слова: *полунатурное моделирование, математическое моделирование, система автоматического управления, летательные аппараты, авиация*

Hardware-in-the-Loop Simulation for Creating Aircraft Automatic Control System

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Using a real plane in the process of aircraft equipment and systems testing is inefficient. At the same time only mathematical modeling usage doesn't allow to test it in critical conditions. Hardware-in-the-Loop Simulation Testing solves these problems and makes the whole testing process cheaper, faster and easier. This article describes the ways of Hardware-in-the-Loop Simulation usage in Aviation. Practical part of this paper includes creating an Aircraft Mathematical model which can be used in Hardware-in-the-Loop Simulation Testing.

Keywords: *seminatural modelling, mathematical modelling, automatic control system, aircraft, aviation*

Introduction

Creating a new car, aircraft or rocket is a complicated process. These products consist of lots of electronic control units (ECU) and subsystems which are usually created before the whole craft is ready. One of the most principal steps of this process is a step of testing.

On the one hand, using an assembled product is inefficient and not sometimes even possible due to its unreadiness. On the other hand, only mathematical modeling usage doesn't allow to test units and systems in critical conditions. Furthermore, nowadays all industrial plants do everything they can for reducing cost and time of creating process. Because of this finding the most reasonable testing way is an important point.

The solution must provide comprehensive testing without the necessity of using an assembled final product. By allowing units under test to interact with a simulated model, it's possible to test them in the early stages and uncover as many software defects as possible [1]. This is the basis of a Hardware-in-the-Loop (HIL) Simulation Testing.

Hardware-in-the-Loop (HIL): What is it? Hardware-in-the-Loop (HIL) testing is a method in which real signals from the controller are connected to a modelled system that simulates reality, forcing the controller to work as it will in the assembled product. Test and design iterations take place as though the real-world system is being used [1]. Thousands of possible scenarios can be easily run for testing units without the cost and time associated with actual physical tests.

HIL Test System consists of two main parts: Real-Time Simulator and Host Computer. Real-Time Simulator includes plant digital twin, data acquisition and signal conditioning. It also has a straight communication with the controller under test with Input/Output (I/O) modules. Host computer runs an application software that supports the setup and operations of the Real-Time Simulator. It includes plant design, testing skills and allows to setup different initial conditions [2].

The quality of the modeling software is important for the usefulness of HIL system. Besides summing up all system characteristics, it should also be paired with hardware that allows to insert errors and test real-world scenarios. Due to outstanding benefits HIL Testing is very useful in lots of industries, such as military, airspace, car industries.

Let's find out which way HIL Testing can be applicable in Aviation.

HIL Testing in Aviation. Creating an aircraft is a complicated process that is divided in lots of steps. Practically every its unit, equipment or control system is tested with Hardware-in-the-Loop Simulation.

HIL Test can be used in three main aviation fields: onboard equipment testing, control systems testing and strength tests.

Firstly, it is applied in onboard equipment testing. For this reason, the unit under test is connected with a HIL system which represents all the characteristics a real plane has, atmosphere and flying parameters and allows to set required initial conditions [3].

Secondly, HIL is used in Control Systems testing, such as Automatic Flight Control Systems. This time Control System is run by a special application on a computer which is connected with HIL System by I/O modules [3].

Thirdly, HIL is quite useful in strength tests. Different elements of aircraft body, e.g., wings, tail, chassis, are placed into the slamming devices which try to break these parts down. The element under test has lots of sensors on its surface which can detect the critical positions before the brake. This testing system can also represent various flying conditions for finding out aircraft body behavior under different circumstances [3].

Since HIL Simulation is used in Automatic Control Systems Testing the aim of the practical part is to create an aircraft mathematical model for HIL system.

Methods

This part of an article includes the description of the process of creating an Aircraft Math model. Here is a model of Automatic Control System of a vehicle in which output signals changes due to changing the meanings of ailerons, elevators, rudders and flaps angles. Initial parameters consist of linear dimensions, mass, aerodynamic coefficients, known function relations, atmosphere parameters and critical conditions for angles. Exactly these parameters can be changed depending on the vehicle [4].

Since this is a model of spatial motion, it can be described by equations of dynamics and kinematics, angular motion equations and equations for aerodynamic coefficients. The first step is to choose the most applicable software for creating this math model.

One of the best applications for this purpose is MATLAB/Simulink. It lets represent all the equations in Simulink-blocks and connect this model to extra controllers, visual or audio simulators. By the way, MATLAB/Simulink has a great written documentation for users [5]. Because of this it is a very useful application even for amateurs.

After learning the documentation, the goal is to represent all the parameters in Simulink-blocks and connect them in order they are connected in equations. That is the way of creating a math model that will represent a spatial motion of a real flying vehicle.

Results and Discussion

Fig. 1 shows a final model created in MATLAB/Simulink.

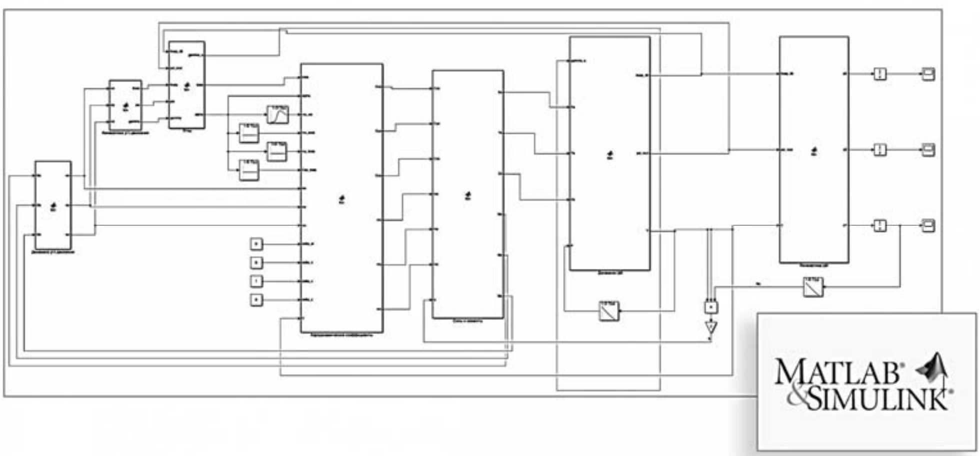

Fig. 1. Aircraft Math Model in MATLAB/Simulink

In Fig. 1 parameters *delta_el, delta_z, delta_n, delta_v* represent the meanings of ailerons, flaps, rudders, elevators angles of the vehicle. This math model allows to change the delta's and to test the Control System of the vehicle by representing the coordinates of the flight (*X, Y, Z*).

The next possible step is to connect it to the visual simulator. The most applicable one is FlightGear Flight Simulator. This simulator represent the result of simulation by showing the picture of a plane on the monitor. This way of presenting the results is the most convenient for further work. Furthermore, this application also allows to change different initial parameters in an easy way by using built-in functions. The example of the plane modeled by FlightGear and its interface are shown in Fig. 2.

Currently this math model is used for creating the system of stabilization the flight. The result of the modeling shows critical conditions and stress zones. This output information is used for choosing an appropriate coefficient of stabilization which lets improve the Control System under test.

Fig. 2. FlightGear Flight Simulator Interface

Conclusion

Hardware-in-the-Loop Simulation is applicable in lots of industries due to its outstanding benefits. It reduces cost and time of the creating process, decreases the risk of loosing an assembled plant, allows to create critical conditions and to test a subsystem before the whole craft is ready.

Aviation also uses HIL Simulation in testing onboard equipment, control systems or aircraft body strength. For control system testing it is necessary to create an aircraft mathematical model which could be connected with other simulators and controllers. MATLAB/Simulink and FlightGear Flight Simulator are the most well-known applications for achieving this aim. This paper includes the description of the process of creating a math model and discussions about the ways of its further application.

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УДК 338

Исследование изменений функций менеджмента в условиях цифровизации экономики

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Непрерывное внедрение цифровых технологий в жизнедеятельность организации формирует потребность в исследование деятельности социально-экономических систем. Актуализируется анализ изменений, происходящих в организации за счет внедрения цифровых технологий, а также появляется возможность трансформации функций менеджмента под воздействием составляющих цифровой экономики. Представлены пять базовых функций менеджмента и двенадцать составляющих цифровой экономики, которые могут быть дополнены другими функциями менеджмента и составляющими цифровой экономики.

Ключевые слова: *гибридная форма взаимодействия, индустрия 4.0, цифровизации систем менеджмента, трансформация функций менеджмента, цифровая экономика*

Research of Changes in Management Functions in the Conditions of Digitalization of the Economy

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The continuous introduction of digital technologies into the life of an organization creates the need to study the activities of socio-economic systems. The analysis of changes occurring in the organization due to the introduction of digital technologies, the possibility of transformation of management functions under the influence of the components of the digital economy is updated. For clarity, the article presents five basic functions of management and twelve components of the digital economy, which can be supplemented by other management functions and components of the digital economy.

Keywords: *hybrid form of interaction, industry 4.0, digitalization of management systems, transformation of management functions, digital economy*

Most organizations, in order to maintain their vital activity and competitiveness, adapt to the dynamically changing external and internal environment. The main trend of the modern market environment is Industry 4.0., which forms Management 4.0, which represents management in the digital age [1]. Therefore, the question arises, how will traditional management change under the influence of the modern trend? In which business environment it will exist, because one of the factors being implemented by Industry 4.0 is the availability of a virtual environment. What will happen to organizations that operate in a traditional (material) form?

The search for an answer to these and many other emerging questions is the purpose of our research.

The formation of a virtual business environment is possible, but not in all organizations, so it is necessary to create some kind of hybrid form of interaction — organizations, departments, positions — a material virtual business environment. The question of the distribution of the conditions in which an employee should work is relevant, because some activities can be carried out in a virtual business environment, and some only in a material business environment.

In order for organizations to move to a material-virtual business environment, it is necessary to transfer their material business environment to a virtual one, forming a kind of digital double, which will include a prototype of a material organization. This form is more relevant than a full transition to a virtual organization, since the activities of organizations involve the use of intangible and material resources.

Therefore, based on the use of a matrix approach to solving the problem of taking into account the components of the digital economy in the transformation of management functions, certain results of our research have been obtained. These results are presented in Figure.

CDE	CDE_1	CDE_2	CDE_3	CDE_4	CDE_5	CDE_6	CDE_7	CDE_8	CDE_9	CDE_{10}	CDE_{11}	CDE_{12}
Y	FBDL	DW	IoT	MMS	MAS	RTS	NN	AI	VR	AR	ML	DL
Y_1	+	+	+	+	–	–	+	+	+	+	–	–
Y_2	+	+	+	–	+	–	+	–	–	+	+	+
Y_3	+	–	+	+	+	+	+	–	–	+	–	–
Y_4	+	+	+	+	–	+	+	–	–	+	–	–
Y_5	–	+	+	–	–	–	+	+	+	+	–	–

The scheme of the results of the author's research on the transformation of management functions taking into account the components of the digital economy

Let us explain the designations indicated in Figure, where Y is the basic function of management: Y_1 — planning; Y_2 — organization; Y_3 — coordination; Y_4 — control; Y_5 — motivation; CDE — Components of the Digital Economy, exactly: CDE_1 — Federation Business Data Lake (FBDL); CDE_2 — Data Warehouse (DW); CDE_3 — Internet of Things (IoT); CDE_4 — Multiagent Monitoring Systems (MMS); CDE_5 — Multiagent System (MAS); CDE_6 — Robot-Technical System (RTS); CDE_7 — Neuro Net (NN); CDE_8 — Artificial Intelligence (AI); CDE_9 – Virtual Reality (VR); CDE_{10} — Augmented Reality (AR); CDE_{11} — Machine Learning (ML); CDE_{12} — Deep Learning (DL); "+" is the corresponding component of the digital economy (CDE), which, in our opinion, should be taken into account in the transformation of the basic functions of management; "–" is the corresponding component of the digital economy (CDE), which, in our opinion, can be ignored in the transformation of the basic functions of management.

So, for example, considering the component of the digital economy CDE3 (IoT), which must be taken into account in all basic management functions during their transformation, such accounting assumes that in each basic management function during its transformation in the virtual-material environment of the digital economy there will be a material (physical) component “thing”. As such, you can specify, for example, a smartphone, smart watches, tablets, laptops, computers, etc., which, with the help of the software built into them and the use of the Internet, proper communications will be carried out between the subject and the control object that possess these “things”. As a result, the subject of management with the help of KDE 3 (It) can carry out basic management functions aimed at the management object for the effective operation of the organization's management system in the conditions of digitalization of the economy under consideration.

However, not every component of CDE should be taken into account in the transformation of all basic management functions in the virtual-material environment of the organization in the digital economy. So, for example, taking into account such a component as CDE_{12} (DL) assumes, as it were, the complete absence of a management entity. Therefore, when transforming management functions in this environment, CDE_{12} (DL) can be taken into account only partially where the subject of management can transfer control and implementation of an organization's activities completely to a robot.

Similarly, the results were obtained for other components of the CDE, and such results are marked, respectively, as “+” or “–” in Figure.

Note that, in this figure, only the main components of the digital economy and only the basic functions of management are presented only for clarity. This figure can be supplemented with other management functions and other components of the digital economy to take them into account in the transformation of management functions in the digital economy and digitalization of management systems of organizations.

At the same time, the actualization of the transformation under consideration, taking into account the specifics and features of the components of the digital economy (CDE), forms a new understanding of the digitalization of the management system of industrial enterprises. The basic functions of management in the conditions of digital transformation of the organization acquire a kind of hybrid form, proposed by us in [2]. Therefore, our attempt to substantiate which of the components of the digital economy will be a factor determining the transformation of management functions under consideration seems relevant.

As our research shows, the study of scientific works in this field actualizes the formation of a system of principles and a description of the model of transformation of management functions used in traditional (with material resources) organizations, in combination of their structures with new virtual organizational and structural types [3].

So, for example, for a manager to properly implement the “planning” function in the conditions of its transformation, he needs to analyze the activities of the organization in detail by operations. Purposeful and competent knowledge of the activities of the management object in the virtual-material business process allows management to plan resources using them with minimal costs. At the same time, it is possible to optimize the processes of management decisions and their effective implementation using this mechanism.

The results of the study in such a trinity of “process, mechanism and digitalization of functions” designated by us will allow us to make a certain contribution to the formation of the theoretical foundations of a type of management under the conditional name “Management of the digital economy” [4] for their introduction into the socio-economic, organizational, managerial and technical and technological practice of modern management.

As conclusions on this article, we will answer the questions posed at the beginning of the article.

1. Under the influence of the modern trend, traditional management will change, it will become “Digital Economy Management”. At the same time, it is necessary to investigate the transformation of management functions in the digital economy, taking into account its relevant components and their specific features.

2. The formation of a virtual business environment is possible, but not in all organizations, so it is necessary to create some kind of hybrid form of interaction — organizations, departments, positions — a material virtual business environment.

3. Organizations working in the traditional form need to translate their material business environment into a virtual one, forming a kind of digital double, which will include a prototype of a material organization.

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УДК 678.5

Полисульфоны и тканевые композиционные материалы на их основе

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Рассмотрено современное состояние вопроса в области тканевых полимерных композиционных материалов с термопластичной матрицей, в частности, на основе промышленных ароматических полисульфонов. Наибольшее внимание уделено разработке технологии получения и исследованию свойств тканевых углеродных композитов. Показаны основные характеристики и особенности различных типов полисульфонов и композитов на их основе.

Ключевые слова: *термопласты, углепластики, термопластичные препреги, технология формования, полисульфон, полиэфирсульфон*

Работа выполнена в рамках программы государственной поддержки центров Национальной технологической инициативы (НТИ) на базе образовательных учреждений высшего образования и научных организаций (Центр НТИ «Цифровое материаловедение: новые материалы и вещества» на базе МГТУ им. Н.Э. Баумана)

Polysulfones and Fabric Composite Materials Based on Them

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BMSTU

This article discusses the current state of the issue in the field of fabric polymer composite materials with a thermoplastic matrix, in particular, based on industrial aromatic polysulfones. The greatest attention is paid to the development of technology for the production and study of the properties of fabric carbon composites. The main characteristics and features of various types of polysulfones and composites based on them are considered.

Keywords: *thermoplastics, carbon plastics, thermoplastic prepregs, molding technology, polysulfone, polyethersulfone*

Introduction

Aromatic polysulfones are structural thermoplastic polymers that are widely used in aerospace engineering, various branches of mechanical engineering, instrumentation, electronics, for the manufacture of a wide range of components for medical and food equipment, and membrane technology [1–5].

The family of industrial aromatic polysulfones, obtained by the reaction of nucleophilic substitution of chlorine atoms in 4,4'-dichlorodiphenylsulfone with alkaline salts of bisphenols, includes polysulfone (PSU) based on 2,2-bis(4-hydroxyphenyl)propane (bisphenol A), polyethersulfone (PES) based on 4,4'-dioxydiphenylsulfone (bisphenol C) and polyphenylenesulfone (PPSU) based on 4,4'-dioxydiphenyl.

Main characteristics of structural thermoplastic polymers. The advantages of structural thermoplastic polymers include [6–10]:

• high strength properties at low density, which makes it possible to replace metal in the structures of machines and mechanisms;

• resistance to aggressive environments (acids, alkalis, organic solvents, etc.), which ensures the possibility of long-term operation of products without the use of protective coatings;

• relatively low material consumption of products made from them, which allows to reduce the weight of the final product;

• high manufacturability, which consists in the possibility of manufacturing large-sized products of complex shape for a period of time 5–10 times less than would be required for the manufacture of similar products from metals and alloys;

• the ability to control over a wide range of thermal and electrical conductivity, radio and optical transparency, depending on the purpose of the product and the type of reinforcing fibers used;

• low capital costs for organizing the production of products from reinforced plastics;

• operability in a wide range of ambient temperatures and operating mechanical, electrical and radiation stresses.

The tightening of requirements for structural thermoplastic materials led to the use in their composition, in addition to glass fibers, first of carbon and basalt fibers, and later of organic fibers. This was required by the creation of modern space-rocket and aviation technology, the need to reduce its mass and simultaneously increase strength and endurance, as well as provide special technical properties [11–14].

Structural polymers unreinforced and reinforced with dispersed particles have long been used for the manufacture of products in all industries and are used everywhere [15–17].

At present, interest in the use of structural thermoplastics for the production of reinforced continuous fibers and fabric polymer composite materials (PCM) has grown significantly. Thermoplastics can replace thermosets as binders for fabric PCMs, which will significantly expand the scope and possibilities of such materials. Previously, thermoplastics were not used to create fabric PCMs due to technological limitations, but research in this direction is currently being actively conducted [18–21].

Industrial aromatic polysulfones

Polysulfone (PSU). Polycondensation product of 4,4'-dichlorodiphenylsulfone and bisphenol A (Fig. 1).

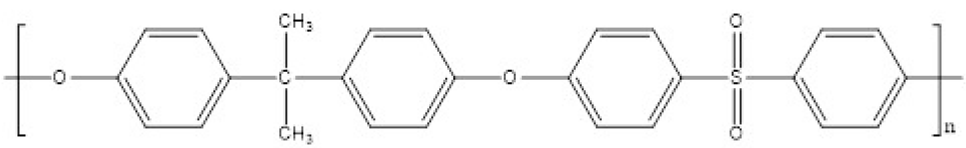

Fig. 1. Structural formula of polysulfone

Heat-resistant, strong, transparent polymer of amorphous structure. Polysulfone has high impact resistance, density — 1240 kg/m^3. Temperature of glass transition (T_{GT}) equal to 190 °C. The temperature of the start of destruction is 420 °C. The maximum operating temperature is 160 °C. Frost-resistant down to minus 100 °C. Chemically resistant, oil and petrol resistant, water resistant, resistant to acids and alkalis, withstands steam sterilization. It has good dielectric properties. Processed by injection molding, extrusion (310 to 340 °C). It is used in electrical engineering, medicine. Brands and manufacturers: PSN (NIIPM named after G.S. Petrov), Ultrason PSU (BASF), Udel, Mindel (Solvay Advanced Polymers) [10].

Polyethersulfone (PES). A domestic laboratory technology for the production of polyethersulfone (PES) (Fig. 2) by high-temperature polycondensation in solution has been developed.

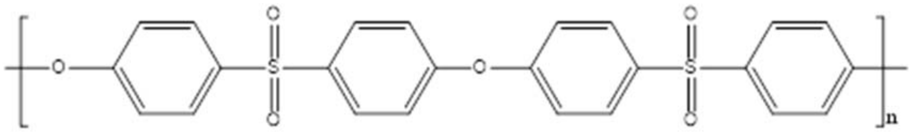

Fig. 2. Structural formula of polyethersulfone

Polyethersulfone has an amorphous structure, T_{GT} = 230 °C. Has high temperature of long operation (200 °C). Polyethersulfone has high impact resistance, density — 1370 kg/m^3. The temperature of the start of destruction is 420 °C. Frost-resistant down to minus 100 °C. Chemically resistant, oil and petrol resistant, water resistant, resistant to acids and alkalis, withstands steam sterilization. It has good dielectric properties. It is processed by injection molding, extrusion (from 310 to 340 °C) [10].

It has a wide application in electrical, electronics and instrumentation: instrumentation, oil level indicators, high-frequency insulators, junction box covers, transparent panels, flanges, insulators, switch parts, valve bodies, sensor bodies, sockets, indicator parts and much more.

For the medical industry: parts of dialysis systems, surgical instruments, sterilization trays, valve bodies, dishes for microwave ovens, filtration membranes (for highly sensitive analyzes and obtaining ultra-pure reagent water), and other parts (parts) of medical equipment that are subject to sterilization and disinfection.

Due to such features of PES as a high degree of protein adsorption, stability at pH 1–14, it is used for the manufacture of membranes (sterile filtration of small volumes of liquids: cultural liquids, pharmaceuticals, cosmetics, diagnostics, buffers, biological solutions, infusion solutions, etc.).

In the food industry, PES is used for the manufacture of membrane and depth filter cartridges (filtration of water, alcoholic beverages, etc.), for the manufacture of dishes resistant to microwave radiation.

The addition of dispersed fillers makes it possible to change the characteristics of PES: increasing fire resistance (antiperene), reducing density, reducing moisture absorption, etc.

Polyphenylenesulfone (PPSU). Amorphous polymer, has excellent hardness and stiffness, impact strength and chemical resistance. In addition to high mechanical strength and stability of characteristics over a wide temperature range, polyphenylenesulfone (Fig. 3) has an increased viscosity, therefore, it has an increased resistance to shock loads. The dispersion coefficient is low and the material does not absorb moisture well. With a small thickness and polishing, the thermoplastic becomes transparent and is easily processed mechanically.

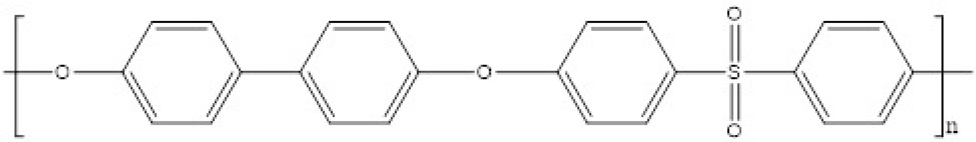

Fig. 3. Structural formula of polyphenylenesulfone

Resistant to fuels and lubricants, fats, alcohols and weak acidic and alkaline solutions. Resistance to benzene and aromatic hydrocarbons is limited. When exposed to substances with a strong dissolving effect, the formation of cracks is possible. Of particular value to PPSU polymer is its resistance to hydrolysis and hot steam.

The material has good electrical insulating properties, is resistant to high-frequency electromagnetic radiation (including X-ray), but at the same time it has good permeability for radiation in the microwave range.

Fire resistance — high, when ignited, the flame self-extinguishes.

Density — 1290 kg/m^3. T_{GT} = 218 °C. The maximum operating temperature is 190 °C.

Dispersion-reinforced thermoplastics

In the production of plastic products, dispersed reinforced thermoplastic polymers are used. Thermoplastics without additives are practically not used. Modification of thermoplastics is carried out to improve operational and technological characteristics [22]:

- fire resistance (flame retardants);
- heat resistance;
- mechanical strength;
- wear resistance;
- chemical resistance;
- reduction of moisture absorption;
- frost resistance;
- decrease in melt viscosity.

In addition, various dispersed fillers are used for coloration [22]. Examples of the use of pure and dispersion-reinforced polysulfones are shown in Fig. 4.

Products from dispersed reinforced thermoplastics are made using injection molding or pressing technologies, where the thermoplastic in the molten state is fed into the mold from the screw injection molding machine, as shown in Fig. 5.

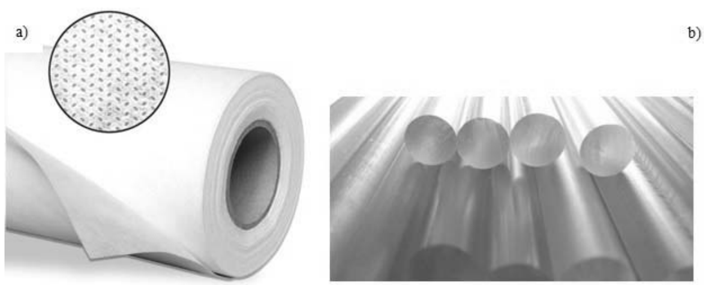

Fig. 4. Filtration membranes (a) [23] and raw materials for electrical products (b) [24] from polyethersulfone

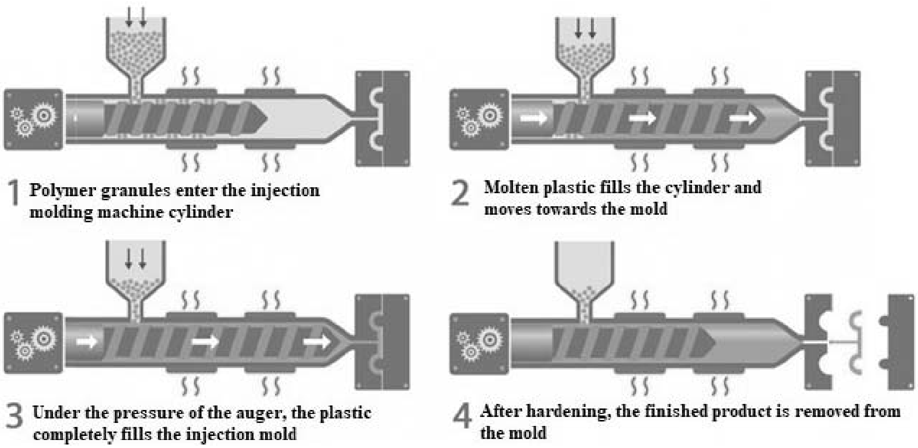

Fig. 5. Technology for the production of products from pure, dispersion-reinforced and short-fiber-reinforced thermoplastics

Thermoplastics reinforced with short fibers

Reinforcement with short fibers improves the mechanical characteristics of PES. At the same time, the technological process of manufacturing products from PES practically does not change — a screw injection molding machine is also used, only PES granules with short fibers are used. Thanks to the reinforcement with short fibers, the scope of PES significantly expands — these are parts of pumping equipment and pipeline fittings, cases of various devices (household and other appliances), car bodies, etc., shown in Fig. 6.

Fig. 6. Products from PCM on a thermoplastic binder with short fibers:
a — parts of pumping equipment and pipeline fittings; *b* — cases of various devices;
c — car bodies; *d* — PES granules with short fibers

Production of fabric PCM on a thermoplastic binder

Of greatest interest is the use of PES as a binder in the production of PCM reinforced with continuous fibers. In the manufacture of PCM based on PES, the same technologies are used as in the manufacture of PCM based on any other thermoplastic binder, only the temperature regimes differ.

Let's consider options for production technologies of PCM on thermoplastic binders.

The production of products from PCM on a thermoplastic binder reinforced with continuous fibers is not yet as widespread as the production of such PCM on thermoset binders. At the moment, the following companies have technologies for the production of thermoplastic PCMs with continuous fibers: Solvay (Cytec), Arkema (Elium, Rilsan), Arris composites, Stelia Aerospace, BÜFA Thermoplastic Composites, etc.

There are several technologies for the manufacture of thermoplastic PCM with continuous fibers:

1. Impregnation of dry filler with a concentrated solution of thermoplastic, with the addition of thermoplastic powder, and subsequent pressing,
2. Impregnation with a thermoplastic melt followed by pressing,
3. Film technology — layer-by-layer laying of filler and thermoplastic film with subsequent pressing of the package,
4. Layer-by-layer automated laying out of the prepreg using additive technologies (possible subsequent pressing), shown in Fig. 7.

The above technologies are applicable both for the manufacture of semi-finished products (prepregs) and finished products.

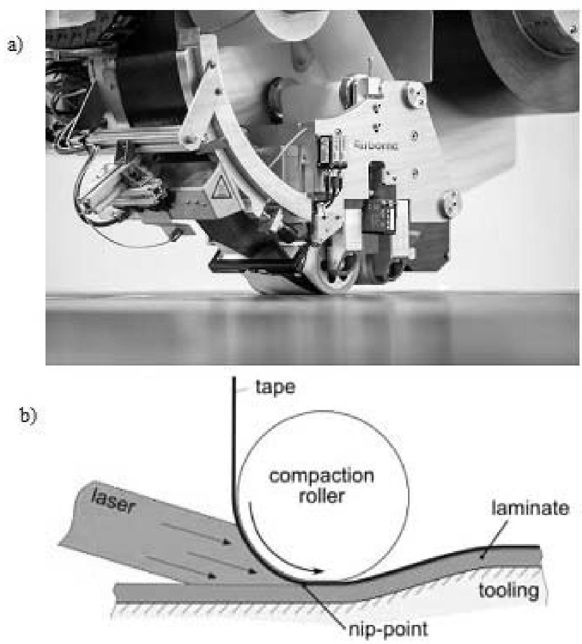

Fig. 7. Layering technology:
a — automated lay-up machine; *b* — manufacturing process scheme

Let's consider some developers and manufacturers of products and materials based on thermoplastics and continuous fibers.

Researchers at the Fraunhofer IPT Institute in Aachen Germany (industrial partner — AZL) have created a fully automated Tapelege system (Fig. 8) patented by the institute [25]. During the molding process, unidirectionally reinforced thermoplastic tapes are layered by additive manufacturing in accordance with the desired load direction. The preform is then heated and molded to the final contour. The process was initially tested on 16 mm thick PA12 and carbon fiber sheets, followed by a PEEK and carbon fiber prepreg.

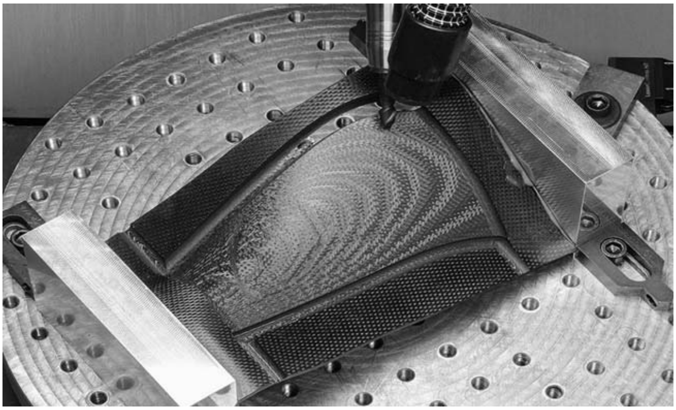

Fig. 8. Tapelege system

Arkema uses the technology of automated laying of a prepreg impregnated with a PEEK solution (Elium binder) [26], shown in Fig. 9. It also manufactures products from PCM with chopped Rilsan thermoplastic fibers (polyamide 66).

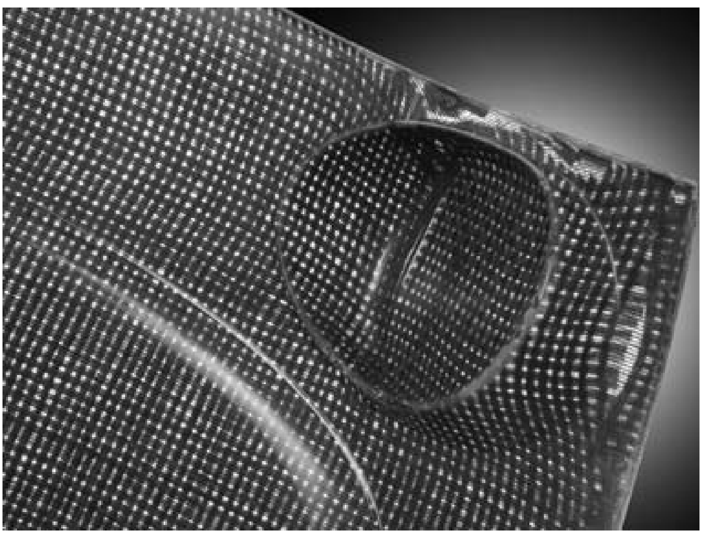

Fig. 9. Rilsan Elium carbon reinforced plastic (CFRP) by Arkema

The Solvay company, which bought the well-known PCM manufacturer Cytec, produces semi-finished products and products from AS4 fiber-reinforced polyetheretherketone (PEEK) [27], shown in Fig. 10. It uses technologies of automated layout, preform pressing and preform molding in an autoclave.

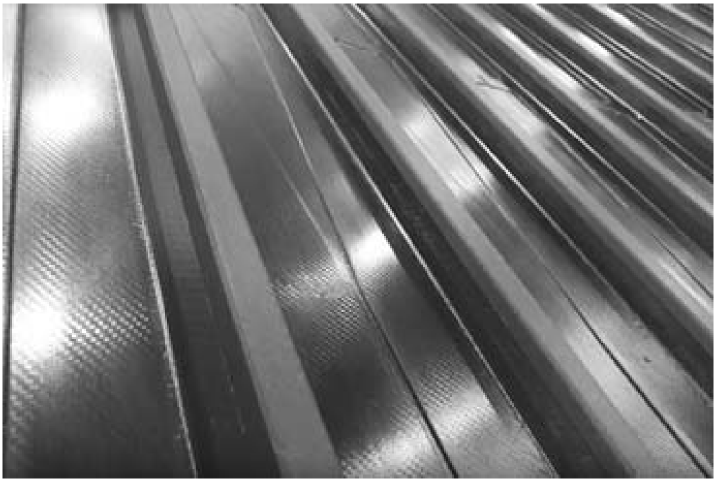

Fig. 10. Cytec PEEK PCM Products

Arris composites manufactures truss structures (Fig. 11) using additive technologies using a continuous carbon fiber coated with a PEEK layer [28].

Fig. 11. Arris composites product

Stelia Aerospace manufactures aviation stringer panels using automated laying and welding (stringers are welded), shown in Fig. 12. Polyetherketoneketone (PEKK) is used as a binder [29].

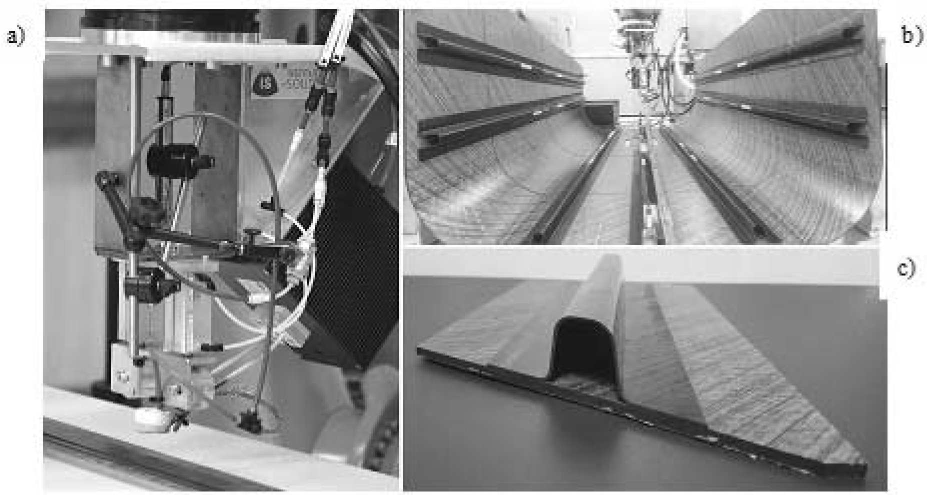

Fig. 12. Stelia Aerospace technologies: automated laying, welding:
a — welding machine; *b* — stringer panel welding process; *c* — welded stringer panel sample

Teijin produces TENAX TPUD prepreg (Fig. 13), based on carbon fiber and PEEK. When forming products from this prepreg, it is necessary to add additional volumes of the binder, either in the form of a powder or in the form of a melt [30].

Fig. 13. Thermoplastic unidirectional prepreg TENAX TPUD

BÜFA Thermoplastic Composites produces unidirectional prepregs (Fig. 14) on various thermoplastics: PEKK, Polypropylene, Polyamide 66, Polyethylene terephthalate, Polycarbonate [31].

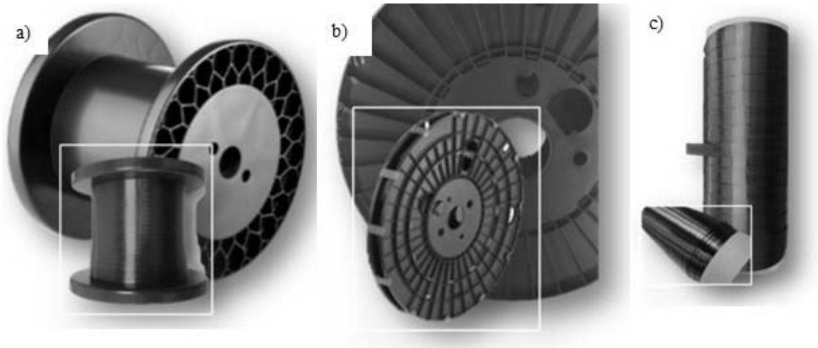

Fig. 14. BÜFA thermoplastic prepregs:
a — wide prepreg bobbin; *b* — narrow prepreg strip; *c* — standard prepreg

SGL Carbon manufactures unidirectional prepregs (SIGRAFIL) (Fig. 15) on various thermoplastics: Polyetherketonketone, Polypropylene, Polyamide 6, Polyethersulfone, Polycarbonate, Polyphenylene sulfide [32].

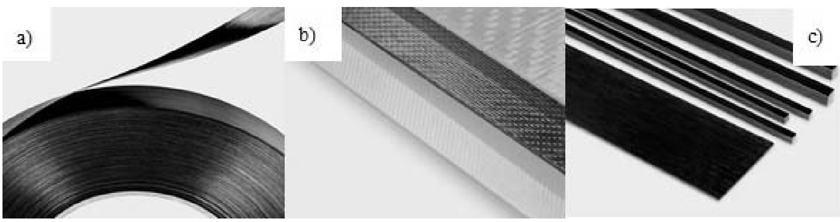

Fig. 15. SIGRAFIL thermoplastic prepregs:
a — prepreg tape; *b* — beam produced from prepreg; *c* — profiles produced from prepreg

There are still a sufficient number of companies and research organizations involved in the development and production of PCM on thermoplastic binders. All of them use the technologies and materials described earlier.

Conclusion

Analysis of sources in international and Russian databases showed that research and development on the creation of semi-finished products and products of fabric PCM based on PES are carried out in a limited volume and there are no offers of such products on the market. At the same time, research and production of fabric PCMs based on other thermoplastic binders (mainly PEEK and PA66) are becoming widespread in world practice. However, there are no such developments and, moreover, finished products in

Russia. Under these conditions, a group in BMSTU is developing a technology for the manufacture of prepregs and products from previously synthesized PES reinforced with continuous fibers and fabrics.

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УДК 629.7.058

Оптимизация траектории беспилотного летательного аппарата на основе адаптивного псевдоспектрального метода

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Для того чтобы обеспечить безопасность процесса полета беспилотного летательного аппарата, квадрокоптерный беспилотный летательный аппарат используют в качестве объекта исследования для решения проблемы обхода препятствий в процессе движения. Метод штрафных функций применяют для устранения ограничений на столкновение во время движения беспилотного летательного аппарата. К адаптивному псевдоспектральному методу прибегают для преобразования задачи оптимального управления в задачу нелинейного программирования. Результаты моделирования показывают, что метод штрафных функций необходимо задействовать для устранения ограничений, адаптивный псевдоспектральный метод может решить проблему уклонения от беспилотного летательного аппарата, что может соответствовать практическим ограничениям проекта.

Ключевые слова: *адаптивный псевдоспектральный метод, метод штрафных функций, обход препятствий, планирование траектории, задача нелинейного программирования*

Unmanned Aerial Vehicle Trajectory Optimization Based on Adaptive Pseudo-Spectral Method

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In order to ensure the safe flight process of an unmanned aerial vehicle, a quadcopter drone is taken as an object of study to solve the problem of avoiding obstacles during movement. The penalty function method is then used to remove collision constraints during the drone's movement. The adaptive pseudo-spectral method is used to convert the optimal control problem into a nonlinear programming problem for solution. Simulation results show that the penalty function method is used to eliminate the constraints, the adaptive pseudospectral method can solve the drone evasion problem, which can meet the practical constraints of the project.

Keywords: *adaptive pseudospectral method, penalty function, obstacle avoidance, trajectory planning, nonlinear programming problem*

Введение

Беспилотные летательные аппараты (БПЛА) достигли стремительного развития во всем мире. Хотя системы БПЛА обладают большим потенциалом, все еще предстоит преодолеть много трудностей, прежде чем БПЛА получат широкое признание. В частности, для того, чтобы технология БПЛА продемонстрировала свои преимущества в процессе военного применения и была полностью популяризирована в гражданской сфере, она должна обладать высокой степенью автономного управления в воздухе, что требует, чтобы беспилотники обладали способностью обнаруживать, отслеживать и избегать автономных целей. Многие ученые исследовали разработку подходов к планированию траектории и методов предотвращения столкновений на основе алгоритмов Дейкстры [1], алгоритма поиска A* [2], быстрорастущего случайного дерева (Rapidly-exploring Random Tree, RRT) [3], интеллектуального алгоритма [4, 5]. Эти методы используют геометрическое планирование траектории. Хотя эти алгоритмы могут решить проблему обхода препятствий во время движения БПЛА, существуют две проблемы. Первая проблема рассматривает БПЛА как частицу в процессе оптимизации, игнорируя характеристики модели движения БПЛА. Вторая проблема заключается в том, что не учитывают ограничения процесса полета БПЛА. Поэтому для решения этих проблем создают модели движения БПЛА и воздушных целей. Процесс оптимизации учитывает ограничение столкновения, ограничение количества состояний и ограничение количества управления во время полета.

Учитывая модель движения БПЛА и сложные ограничения БПЛА, задача предотвращения столкновений БПЛА по существу является задачей оптимального управления. Методы оптимизации для задач оптимального управления в основном делятся на косвенные методы и прямые методы. Основной принцип прямого метода заключается в непосредственном поиске функционального значения в соответствии с состоянием объекта проектирования или целевого функционала уравнения процесса и в соответствии с ограничениями. Псевдоспектральный метод [4], как новый прямой метод, получил наибольшее исследование за последние 20 лет для быстрого решения задач оптимального управления. По сравнению с традиционным прямым методом псевдоспектральный метод имеет больше преимуществ в размере области сходимости и скорости сходимости. В 2004 г. были преобразованы интегральные уравнения и ограничения в задачи нелинейного программирования с помощью псевдоспектрального метода Гаусса и доказаны, что условия первого порядка дискретных гамильтоновых двухточечных краевых задач и условия Каруша — Куна — Таккера (Karash — Kuhn — Tucker) эквивалентны [5]. Таким образом, теоретически оптимальность результатов в определенной степени гарантируется.

Псевдоспектральный метод был применен в инженерной практике. В [6] предложена схема планирования траектории БПЛА, основанная на hp-адаптивном псевдоспектральном методе Радау. В [7] использована псевдоспектроскопия Лежандра для решения проблемы формирования БПЛА для достижения минимальных стандартов контроля ошибок формирования и энергопотребления. В [8] изучена проблема тактического планирования траектории малозаметного БПЛА в радиолокационной игре.

В настоящей статье, основанной на упрощенной модели четырехроторного БПЛА с шестью степенями свободы, hp-адаптивный псевдоспектральный метод в сочетании с алгоритмом последовательного квадратичного программирования использован для решения проблемы предотвращения столкновений четырехроторного БПЛА, метод штрафных функций применяют для решения технологических ограничений. В процессе моделирования всесторонне рассмотрены ограничения граничных значений, ограничения предотвращения столкновений и переменные ограничения; моделирование завершено с наименьшим временем в качестве цели оптимизации, а результаты моделирования проанализированы.

Описание проблемы

Рассмотрим проблему обхода препятствий для БПЛА.

Кинетическая модель. Исследована проблема предотвращения столкновений квадрокоптерного БПЛА, который моделирован методом Ньютона — Эйлера. Упрощенная нелинейная динамическая модель четырехроторного БПЛА выглядит следующим образом:

$$\begin{cases} \dot{x} = v_x, \\ \dot{y} = v_y, \\ \dot{z} = v_z, \\ \dot{v}_x = [U_1(\cos\phi\sin\theta\cos\psi + \sin\phi\sin\psi)]/m, \\ \dot{v}_y = [U_1(\cos\phi\sin\theta\sin\psi - \sin\phi\cos\psi)]/m, \\ \dot{v}_z = [U_1(\cos\phi\cos\theta - mg)]/m, \\ \dot{\phi} = p, \\ \dot{\theta} = q, \\ \dot{\psi} = r, \\ \dot{p} = \left[lU_2 + qr\left(I_y - I_z\right)\right]/I_x, \\ \dot{q} = [lU_3 + pr(I_z - I_x)]/I_y, \\ \dot{r} = \left[U_4 + pq\left(I_x - I_y\right)\right]/I_z. \end{cases}$$

Здесь x, y, z — положение центра масс четырехроторного БПЛА относительно начала координат инерциальной системы координат; v_x, v_y, v_z — скорость четырехроторного БПЛА в инерциальной системе координат; I_x, I_y, I_z — момент инерции квадрокоптерного дрона, соответствующего трем осям; l — длина центра пропеллера от начала координат системы координат корпуса; m — масса квадрокоптерного дрона; U_1, U_2, U_3, U_4 — четыре управляющих входа квадрокоптерного беспилотного летательного аппарата; g — гравитационное ускорение.

Задача оптимизации. Часть задачи оптимизации заключается в преобразовании задачи оптимизации траектории формирования квадрокоптерного БПЛА в задачу математической оптимизации, которая включает в себя три части: модель, ограничения и целевую функцию. Задача обхода препятствий БПЛА может быть описана как задача оптимального управления:

$$\min J = t_f;$$

$$\begin{cases} (x-50)^2 + (y+5)^2 \geq 25, \\ |v_x| \leq 5m/s, \left|v_y\right| \leq 5m/s, |v_z| \leq 5\ m/s, \\ |\phi| \leq \pi/2, |\theta| \leq \pi/2, |\psi| \leq \pi/2, \\ |p| \leq 1.7/s, |q| \leq 1.7/s, |r| \leq 1.7/s, \\ |U_1| \leq 21.03N, |U_2| \leq 0.6703N, |U_3| \leq 0.6703, N, |U_4| \leq 0.6703N. \end{cases} \quad (1)$$

Здесь x, y, z — информация о местоположении БПЛА в инерциальной системе координат; v_x, v_y, v_z — информация о скорости БПЛА в инерциальной системе координат; ϕ, θ, ψ — информация об ориентации БПЛА в системе координат тела; p, q, r — информация об угловой скорости БПЛА в системе координат тела;U_1, U_2, U_3, U_4 — условие ограничения управляющей величины.

С точки зрения эффективности полета БПЛА в качестве показателя производительности, оптимизированного для обхода препятствий БПЛА, выбирают наименьшее время. Используя метод штрафных функций для обработки процесса обхода препятствий БПЛА, формула (1) может быть эквивалентна формуле (2):

$$\min J = t_f + 1000 \times$$
$$\times \int_{t0}^{t_f} \{sign[(x-50)^2 + (y+5)^2 - 25] - 1\}\,[(x-50)^2 + (y+5)^2 - 25]dt;$$
$$\begin{cases} |v_x| \le 5\ m/s, |v_y| \le 5\ m/s, |v_z| \le 5\ m/s, \\ |\phi| \le \pi/2, |\theta| \le \pi/2, |\psi| \le \pi/2, \\ |p| \le 1.7/s, |q| \le 1.7/s, |r| \le 1.7/s, \\ |U_1| \le 21.03N, |U_2| \le 0.6703N, |U_3| \le 0.6703, N, |U_4| \le 0.6703N. \end{cases} \tag{2}$$

Hp-адаптивный псевдоспектральный метод. Конкретные принципы и этапы алгоритма псевдоспектрального метода можно найти в [9]. Ниже в основном представлен метод обновления hp-adaptive.

Hp-адаптивный псевдоспектральный метод делит всю временную область на N временных интервалов, а затем дискретизирует каждый временной интервал с помощью псевдоспектрального метода Гаусса. Предполагая, что количество дискретных точек в каждом временном интервале равно I, путем проверки ограничений в середине каждого временного интервала определяется, надо ли корректировать временной интервал и количество узлов.

Среди них ограничение $e^{(k)}$ уравнения дискретного состояния в середине k-го временного интервала и ошибка $b^{(k)}$ ограничения пути могут быть выражены как

$$\begin{aligned} e^{(k)} &= \left|\dot{X}^{(k)} - \frac{t_k - t_{k-1}}{2} f^{(k)}\big(X^{(k)}, U^{(k)}, \tau^{(k)}, t_k, t_{k-1}\big)\right|, \\ b^{(k)} &= C^{(k)}\big(X^{(k)}, U^{(k)}, \tau^{(k)}, t_k, t_{i-1}\big). \end{aligned}$$

Если $e^{(k)}$ и $b^{(k)}$ меньше заданной погрешности ε_d, то переменные текущего состояния и управляющие величины являются приближенными решениями оптимального управления. Если $e^{(k)}$ и $b^{(k)}$ больше, чем ε_d, то количество дискретных точек внутри сетки необходимо увеличить или сетку необходимо реконструировать, и в конкретном методе перераспределения используют идеи, показанные ниже.

Рассмотрим определение метода подбора очков:

$$c^{(k)}(\tau) = \left|\ddot{X}_m^{(k)}(\tau)\right| \Big/ \left|\left[1 + \dot{X}_m^{(k)}(\tau)^2\right]^{\frac{3}{2}}\right|.$$

Пусть $c_{\max}^{(k)}$ и $\overline{c}^{(k)}$ — максимальное значение и среднее значение $c^{(k)}(\tau)$, полученные за k-й период времени соответственно, и устанавливают сумму решения $j_k = c_{\max}^{(k)}/\overline{c}^{-(k)}$. Порог кривизны устанавливается заранее. Если $j_k < j_{\max}$, надо увеличить полиномиальный порядок каждого временного сегмента; если $j_k > j_{\max}$, — разделенный временной сегмент.

Далее рассмотрим увеличение порядка полинома. Количество точек сопоставления в каждом периоде времени k до N_k^- и N_k^+ после увеличения изменияется соответственно, а количество точек сопоставления после увеличения выражается как

$$N_k^+ = N_k^- + ceil\left[\lg\left(e_{\max}^{(k)}\right) - \lg(\varepsilon_d)\right] + X.$$

Рассмотрим увеличение количества сегментов. Обозначим количество перераспределений за k-й период времени как n_k, которое может быть выражено как

$$n_k = Y \cdot ceil\left[\lg\left(e_{\max}^{(k)}\right) - \lg(\varepsilon_d)\right].$$

Здесь Y — произвольная константа, аналогичная X, увеличением количества сегментов можно управлять, установив его размер.

Таким образом, приведена стратегия выбора дискретных точек и сегментов hp-адаптивного псевдоспектрального метода. После этого задача дискретного нелинейного программирования может быть решена с помощью существующего зрелого алгоритма последовательного квадратичного программирования, и, наконец, может быть получена оптимальная траектория.

Анализ численного моделирования

Проектирование траектории задачи столкновения квадрокоптерного БПЛА с наименьшим временем полета в качестве цели оптимизации. Результаты моделирования получены более чем через 400 с, диаграммы моделирования показаны на рис. 1 и 2.

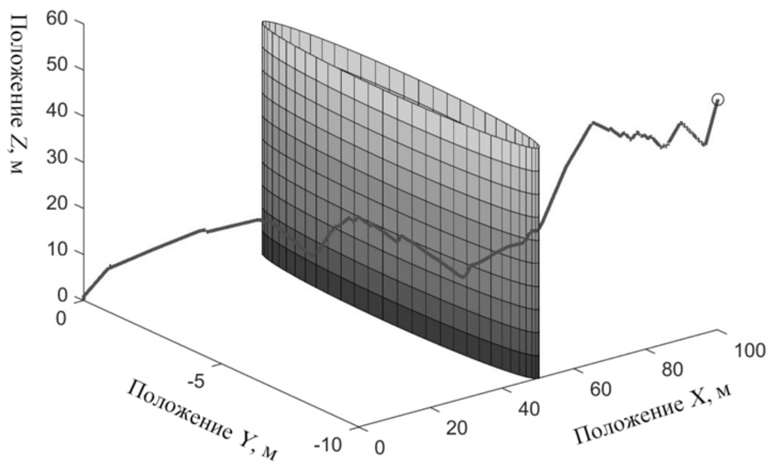

Рис. 1. Траектория движения беспилотного летательного аппарата

При решении оптимальной траектории БПЛА с наименьшим временем в качестве цели оптимизации БПЛА прибывает в желаемое положение одновременно с желаемым положением через 32 с. Видно, что изменение положения БПЛА происходит относительно плавно; скорость может соответствовать требованиям ограничений (см. рис. 1 и 2).

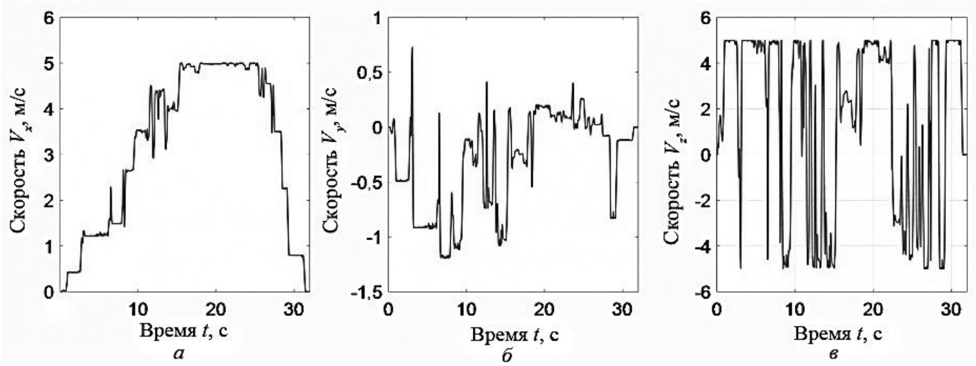

Рис. 2. Скорость беспилотного летательного аппарата:
а — скорость по оси *x*; *б* — скорость по оси *y*; *в* — скорость по оси z

Заключение

Исследована автономная задача оптимизации траектории формирования квадрокоптерного БПЛА с шестью степенями свободы и установлена модель квадрокоптерного БПЛА, подходящая для оптимизации траектории. В процессе оптимизации траектории для предотвращения столкновений квадрокоптерного БПЛА с использованием hp-адаптивного псевдоспектрального метода рассмотрены ограничения модели и состояния квадрокоптерного БПЛА, метод штрафных функций использован для устранения технологических ограничений в движении БПЛА. Оптимальная траектория проектирования может соответствовать требованиям инженерной практики. По сравнению с традиционным планированием траектории рассмотрены как аэродинамические ограничения и ограничения по предотвращению столкновений при полете БПЛА, проверка завершается с помощью моделирования. Результаты показывают, что hp-адаптивный псевдоспектральный метод оказывается эффективным для решения проблемы предотвращения столкновений беспилотных летательных аппаратов.

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Применение аддитивных технологий при изготовлении гидропневмокомпонентов и гидромашин

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Международный комитет ASTM F42 по аддитивным технологиям производства определил такое производство как процесс соединения материалов для создания объектов на основе данных 3D-модели, обычно слой за слоем, в чем заключается отличие от методов субтрактивного производства. Благодаря дополнительной технологии изготовления гидравлические элементы и гидравлические машины сложной формы изготавливают с меньшими затратами времени и веса с большей долговечностью, улучшенными характеристиками потока и структуры. Такие элементы и машины выполняют по специальному дизайну, который соответствует характеристикам материалов, используемых в аддитивной технологии изготовления необходимых деталей без усложнения конструкции. Существует возможность создавать тестовые макеты, полностью имитирующих размеры и характеристики обрабатываемых деталей для снижения временных и экономических затрат.

Ключевые слова: *аддитивное производство, 3D-печать, гидравлические компоненты, гидравлические машины, селективная лазерная плавка*

The Use of Additive Technologies in the Manufacture of Hydro-Pneumatic Components and Hydraulic Machines

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ASTM F42 International Committee on Additive Manufacturing Technologies has defined such manufacturing as the process of joining materials to create objects based on 3D model data, usually layer by layer, which is different from subtractive manufacturing methods. With additive manufacturing technology, complex shaped hydraulic elements and hydraulic machines are manufactured in less time and weight with greater durability, improved flow characteristics and structure. Such elements and machines are made to a special design that matches the characteristics of the materials used in additive *manufacturing technology to produce the required parts without complicating the design. It is possible to create test mock-ups that fully simulate the dimensions and characteristics of the parts to be machined in order to reduce the time and cost involved.*

Keywords: *additive manufacturing, 3D printing, hydraulic components, hydraulic machines, selective laser melting*

Введение

Одним из главных прорывов в области производства за последние три десятилетия стало аддитивное производство (АП). Первоначально представленные как процессы быстрого прототипирования, методы АП теперь используются и для конечных продуктов.

Общий основной принцип этой многообещающей области развития технологий заключается в изготовлении деталей послойным способом, а ее множественность (на сегодняшний день доступно более двадцати процессов АП [1, 2]) позволяет создавать практически любую форму. Эти методы становятся все более и более демократичными, и в настоящее время существуют компании, внедряющие эти технологии для широкого спектра применений (например, в крупных компаниях аэрокосмической промышленности).

Революция в производстве приводит к большей свободе и альтернативам в дизайне, но при этом требует либо адаптации существующих методов проектирования, либо новых парадигм дизайна. Это вызвало академические и промышленные интересы в так называемой новой области теории и методологии проектирования: проектирование для аддитивного производства.

Поскольку традиционные подходы к проектированию в области проектирования для *X* ограничивают пространство дизайнерских решений, необходимо приложить дополнительные усилия, чтобы охватить уникальные возможности, предлагаемые АП.

Кроме того, даже если методы АП предоставляют больше свободы, у них есть свои специфические ограничения (например, точность, геометрия поверхности, размер элементов, скорость сборки и т. д.), которые необходимо учитывать на ранних стадиях проектирования, чтобы иметь конструкцию деталей, благоприятную для аддитивного производства. Процессы АП однозначно характеризуются (в разной степени) четырьмя возможностями [2]:

• сложность формы: послойное изготовление АП позволяет создавать практически любую форму детали;

• иерархическая сложность: элементы любого масштаба длины (микро-, мезо- и макроуровня) могут быть интегрированы в геометрию детали, что сделало решетчатые конструкции беспрецедентной сложности легко изготавливаемыми [3];

• сложность материала: в зависимости от процесса материалы и свойства материалов могут варьироваться по всему объему детали. Эта возможность способствует исследованиям функционально классифицированных материалов [4, 5] или, в более общем плане, деталей из мультиматериалов [6];

• функциональная сложность: могут быть изготовлены полностью (или частично) функциональные механизмы. Такие процессы, как прямая запись и даже моделирование плавленого осаждения, могут создавать проводящие чернила, что позволяет печатать и электронные компоненты.

Обзор литературы

Подход к методу аддитивных технологий для изготовления гидравлических компонентов сложной формы и геометрии, которые трудно или невозможно изготовить обычными технологическими методами, является новым перспективным применением для производства деталей с уменьшенным весом и габаритами. Этот способ изготовления отвечает требованиям, предъявляемым к высокоточным и легким деталям для авиационной и аэрокосмической промышленности.

Требуемая деталь может быть изготовлена с проточными каналами, которые могут быть размещены именно там, где они необходимы, и в оптимальном размере и форме с использованием технологии селективной лазерной плавки. Гидравлические и пневматические агрегаты из-за их функционального поведения имеют определенные конфигурации, которые было бы трудно или невозможно достичь обычными методами производства: механической обработкой или литьем.

Внедрение аддитивных технологий имеет некоторые преимущества для гидравлических и пневматических компонентов:

• возможность изготовления небольших объемов сложных узлов (тонкие стенки, специальные каналы, увеличивающие пропускную способность на 20...30 %);

• сокращение времени выполнения заказа на производстве до нескольких дней;

• консолидация деталей, интеграция нескольких деталей в единое целое;

• производство различные варианты компонентов, и создание тестовые прототипы для оценки альтернативных вариантов проектирования;

• изготавливать детали из прочных и коррозионностойких металлических порошков.

Поскольку селективная лазерная плавка (СЛП) является новым и передовым технологическим методом, механические свойства, такие как прочность на растяжение, предел текучести и модуль упругости, должны быть обеспечены путем разработки соответствующего метода СЛП (набора технологических параметров СЛП). Главный вопрос: как можно сравнить свойства деталей СЛП с теми, которые изготавливаются традиционными процессами?

Компании используют метод конечных элементов в программном обеспечении MSC Software Simufact Additive, ANSYS Additive для прогнозирования отклонения формы детали во время процесса СЛП, вызванного высокими температурами и внутренними напряжениями. Можно изменять толщину стенок и формы каналов, указывающих зоны разрушения, оценивать напряженно-деформированное состояние и выбирать параметры СЛП, получая требуемую точность и гладкую поверхность. Сочетание параметров СЛП (мощность лазера, скорость сканирования, расстояние штриховки, лазерное пятно и т. д.) влияет на свойства готовой детали и качество продукции.

Каждый материал имеет различную температуру нагрева и охлаждения, в зависимости от скорости и потребляемой энергии при взаимодействии с металлическим порошком. Тепловое состояние вызывает образование микроструктуры, которая обеспечивает соответствующие свойства материала: прочность, жесткость и эластичность. К сожалению, многие материалы СЛП требуют термической обработки после обработки из-за напряжений и горячего растрескивания, которые могут возникнуть в процессе СЛП [7].

Многие типы гидравлических и пневматических компонентов уже производятся с помощью аддитивных технологий. Например, в компании Aidro напечатали штабелируемый гидравлический клапан с улучшением его конструкции (рис. 1) [8].

а *б*

Рис. 1. Гидравлический клапан улучшенной конструкции:
а — гидравлический клапан, изготовленный из стали; *б* — переработанный гидравлический клапан, изготовленный методом 3D-печати из нержавеющей стали

Клапан, полученный 3D-печатью, весит на 60 % меньше, но сохраняет ту же прочность, что и обработанная деталь. Для того чтобы иметь легкий гидравлический клапан, корпус клапана был переработан для 3D-принтера. Внедрение аддитивного производства может обеспечить улучшение номинального расхода, меньшую утечку, меньший объем, вес и содержит меньше деталей,что упрощает изготовление гидравлических и пневматических компонентов. Клапан на рис. 1, б реализован с помощью метода 3D-печати таким образом, что конструкция не содержит меньшей деталей и имеет меньший вес, чем клапан на рис. 1, а, в котором есть внешняя оболочка, объединяющая корпус клапана и основание, что, соответственно, увеличивает вес конструкции.

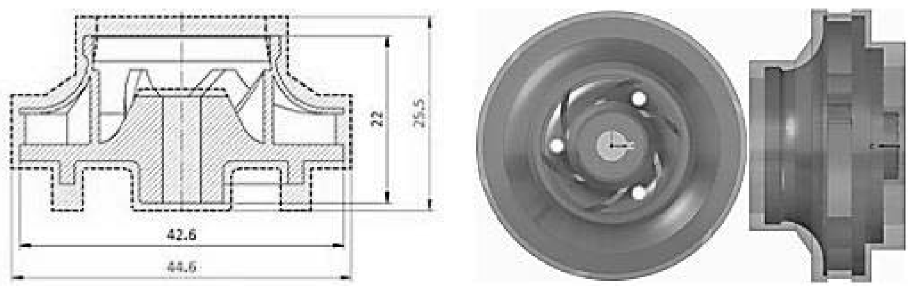
На рис. 2 показан напечатанный на 3D-принтере коллектор для сельскохозяйственной техники, деталь выполнена из металлического порошка AlSi10Mg, который сочетает в себе хорошие прочностные и термические свойства с низким весом и гибким потенциалом. Такой коллектор для сельскохозяйственной техники весит на 75 % меньше, чем изготовленная традиционным методом деталь последующей обработки.

Рис. 2. 3D-печатный коллектор для сельскохозяйственной техники

Металлический порошок AlSi10Mg часто используется для деталей с тонкими стенками и сложной геометрией. Испытания под давлением показали, что механические свойства (прочность на растяжение, относительное удлинение, ударная вязкость и твердость) не уступают коллектору, изготовленному из традиционных материалов [9].

В [10] проведены исследования, связанные с конструкцией центробежного насоса с закрытым рабочим колесом, в зависимости от модели. Аддитивные методы, представленные 3D-печатью, так как базовая модель закрытого рабочего колеса и модель АП были спроектированы с использованием Solid Edge (версия 2019, Siemens PLM Software, Кельн, Германия) в соответствии с рекомендациями и ограничениями АП [11–18].

Закрытая конструкция крыльчатки для АП не имеет отверстий (шпоночных пазов и отверстий для балансировки осевого усилия), чтобы предотвратить задержку металлического порошка и осаждение опорной конструкции. Кроме того, закрытое рабочее колесо имеет припуск на внешней поверхности для операций последующей обработки. На внутренние поверхности не было добавлено никакого дополнительного материала. Внешний диаметр базовой модели составляет 42,6 мм, а высота — 22 мм, но для закрытой крыльчатки АП внешний диаметр составляет 44,6 мм, а высота — 25,5 мм (рис. 3).



а *б*

Рис. 3. Закрытое рабочее колесо:
а — схема закрытого рабочего колеса (*черный цвет* — базовая модель; *красный цвет* — модель АП); *б* — вид сверху и сбоку базовой модели (*оранжевый цвет*) со смещенным материалом (*серый цвет*)

В [10] исследован полный процесс изготовления закрытого рабочего колеса Inconel 625 для системы жидкостного контура с механической перекачкой (Mechanical pumped liquid circuit system, MPFL) с помощью технологии выборочного лазерного плавления в порошковом слое (Laser Powder Bed Fusion, LPBF). Закрытое рабочее колесо АП было построено с ориентацией в +60°. Рентгеновское компьютерное сканирование было проведено для анализа возможных дефектов, которые могут возникнуть во время изготовления (пористость, кавитация, пустоты, включения и т. д.), которые показали очень небольшое содержание пустот, не повлиявшее на свойства материала или производительность закрытого рабочего колеса.

Операции постобработки показали хорошие результаты по шероховатости и стабильности размеров; тем не менее процесс обработки абразивным потоком может быть дополнительно улучшен за счет использования более адаптируемых абразивных сред и параметров процесса для достижения однородного процесса чистовой обработки лезвий. Исследование балансировки выполнено на закрытом рабочем колесе с классом балансировки 2,5 G с использованием одной плоскости коррекции.

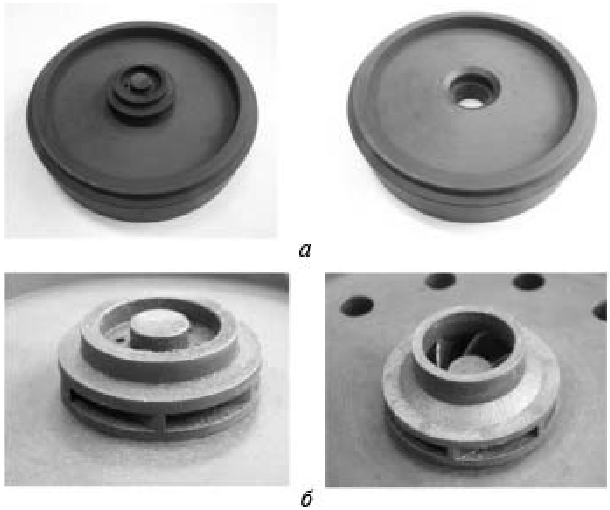


Рис. 4. Настроенная оснастка, необходимая для выполнения процесса чистовой обработки абразивным потоком (*а*), и закрытого рабочего колеса, установленного для финишной обработки (*б*)

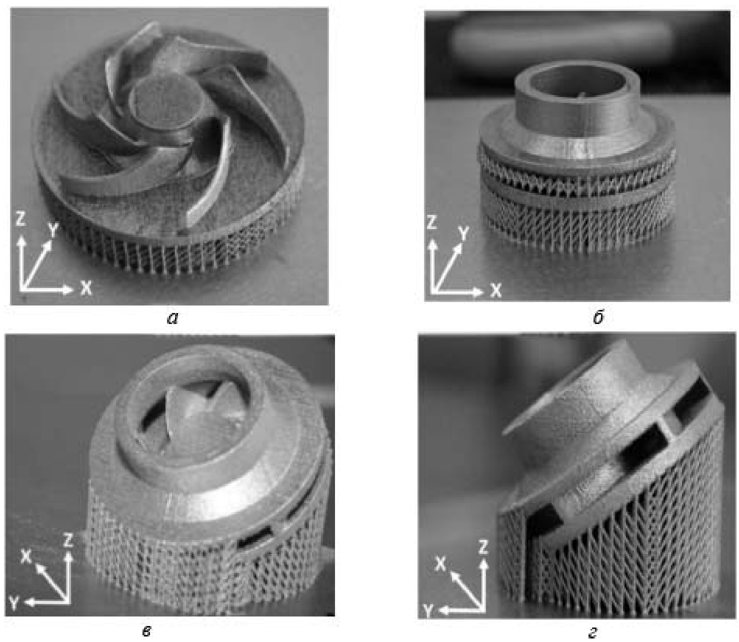
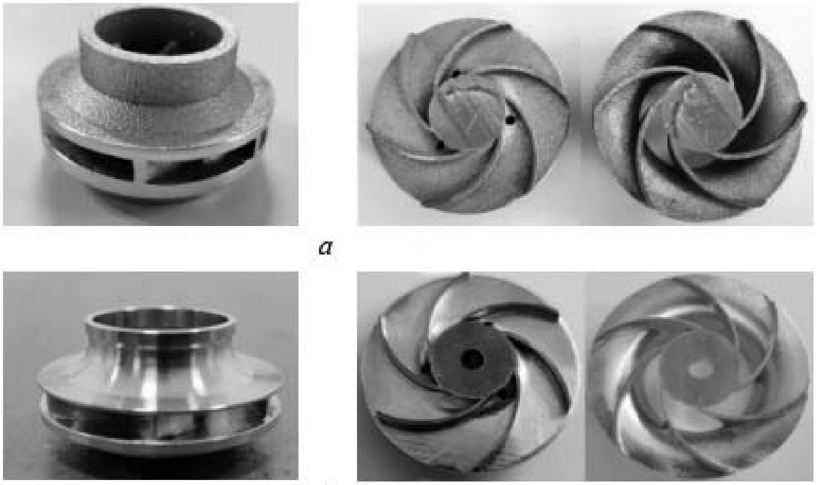


Рис. 5. Открытое рабочее колесо и закрытые рабочие колеса, построенные с разной ориентацией на строительной плите:
а — открытое рабочее колесо, построено с ориентацией оси *Z* (направление здания); *б* — закрытое рабочее колесо, построено с ориентацией оси Z (направление здания); *в* — закрытое рабочее колесо, построено с ориентацией + 32° (под углом 32°); *г* — закрытое рабочее колесо, построено с ориентацией + 45° (под углом 45°)



а

б

Рис. 6. Закрытое рабочее колесо АП:
а — до последующей обработки (без термической обработки);
б — после постобработки всех поверхностей

Для анализа возможных дефектов, которые могут возникнуть при изготовлении (пористость, кавитация, пустоты, включения и т. д.), проведены рентгеновские компьютерные томографии, показавшие очень небольшое содержание пустот, которые не оказывали влияние на свойства материала или производительность закрытого рабочего колеса.

Наиболее современной технологией изготовления макетов в настоящее время является методика 3D-прототипирования, т. е. изготовление деталей на 3D-принтере. Такая технология позволяет изготавливать макеты в очень сжатые сроки и точно передавать форму проточной части натурного насоса с отклонениями, как правило, не превышающими 0,2 мм. Пример такого макета, разработанного и изготовленного на кафедре Э-10 МГТУ им. Н.Э. Баумана, приведен на рис. 7.

Рис. 7. Макет насоса, изготовленный методом 3D-прототипирования (оболочечная модель до заливки)

Однако эта технология имеет ряд ограничений, связанных как с особенностями собственно изготовления деталей на 3D-принтере, так и с их прочностью в процессе испытаний и т. п. [19]. Поэтому очень важно определить пределы коэффициентов масштабирования при переходе от натурного насоса к модельному (макету) с учетом вышеперечисленных особенностей [20].

В области изготовления более крупных насосов и макетов насосов распространение аддитивных технологий пока несколько ограничено. Как правило, методами 3D-печати изготавливают рабочие колеса и корпуса насосов малого размера (т. е. тех габаритов, которые влезают целиком в рабочую камеру 3D-принтеров, наиболее распространенные размеры рабочих камер: от 200 до 500 мм). Также 3D-принтеры используют в высокоточном литье для печати выжигаемых моделей (чаще по восковой или фотополимерной технологии), но такие модели не несут силовой нагрузки (рис. 8).

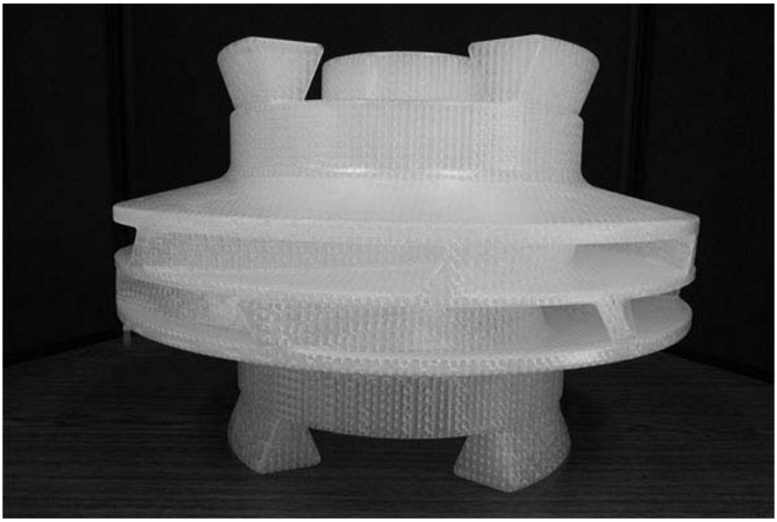


Рис. 8. Выпеченная выжигаемая модель для отливки рабочего колеса

В Московском энергетическом институте (техническом университете) проводили пробные испытания полирядного насоса разработки профессора Г.М. Моргунова с размером проточной части 100..150 мм (выпечена целиком из АБС-пластика, рис. 9) [21].

В ряде компаний, занимающихся разработкой скважинных нефтяных насосов (например, компания «Новомет»), применяли или применяют 3D-принтеры для выпекания целиком из пластика ступеней таких насосов (внешним диаметром до 150 мм, диаметры колес до 100 мм, масштабный коэффициент 1,0) с последующими их гидравлическими испытаниями во внешних металлических корпусах. Это позволяет сократить сроки разработки таких ступеней, но в данном случае задача облегчается малым размером и малой мощностью ступеней скважинных насосов.

Аналогичные работы по созданию макетов скважинных (артезианских) насосов проводили в компании ОАО «Завод Промбурвод». На рис. 10 приведены примеры таких макетов.

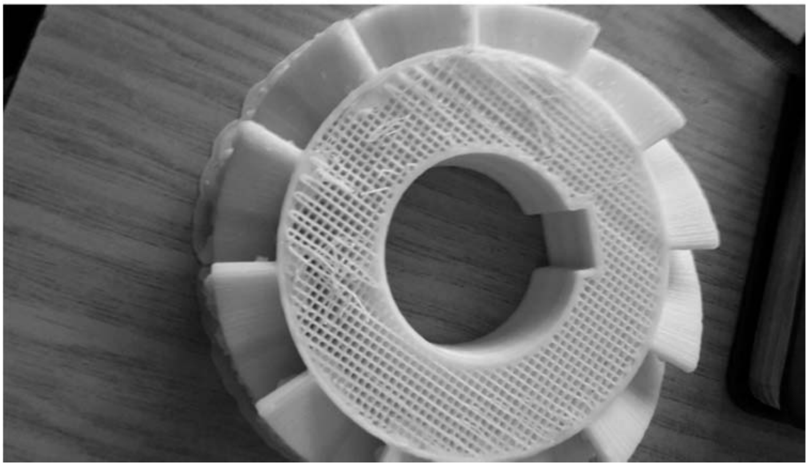


Рис. 9. Элемент модели полирядного насоса

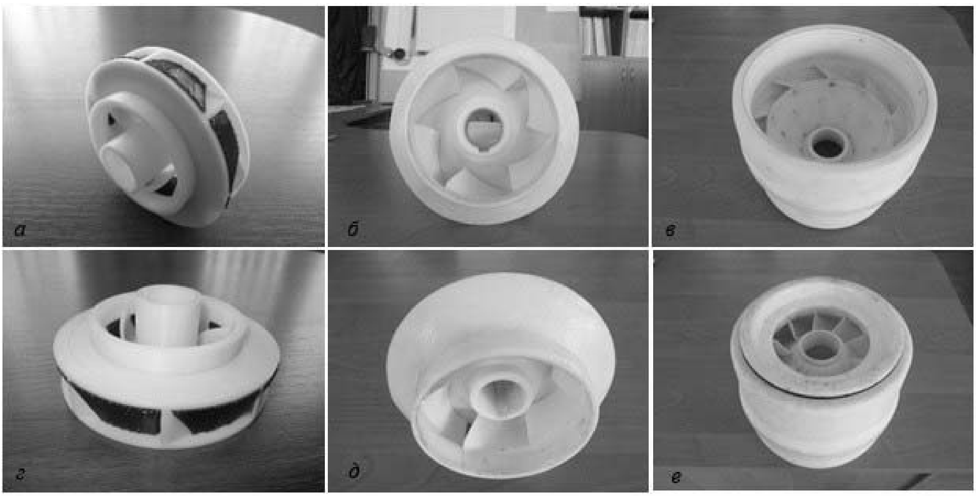


Рис. 10. Макеты ступеней артезианских насосов компании ОАО «Завод Промбурвод»:
а, *б*, *в*, *г*, *д*, *е* — различные положения 3D-модели закрытых рабочих колес

Заключение

Расширяющиеся технологии производства материалов обеспечивают быстрое изменение технологии производства, необходимое для развития многих новых отраслей промышленности и новых технологий. Применение в биологических протезах и тканевой инженерии, производстве, изготовлении искусственных протезов из тканевых 3D-каркасов обеспечивает эффективные технические средства, технология быстрого производства обеспечивает прототипирование для быстрого развития дизайна конфигурации автомобилей и самолетов, ускоряет скорость разработки продукта.

Технология изготовления элементов гидропневмоприводов и гидромашин путем прироста материалов подходит для компонентов аэрокосмической продукции при изготовлении единичных и небольших партий и обладает некоторыми преимуществами (низкая стоимость и высокаяэффективность), имеет также большой потенциал применения в лопатках турбин авиационных двигателей, производстве моделей и производстве деталей сложной прецизионной конструкции [22]. Дальнейшее направление развития — керамические детали технологии быстрого прототипирования и композитные материалы технологии быстрого прототипирования.

Таким образом, применение инновационной технологии производства материалов и объединение на этой базе предприятий является фундаментальным направлением развития технологий производства материалов. Целью повышения эффективности производства методами аддитивных технологий является повышение как точности микропроизводства до нанометрового уровня, так и эффективности производства крупных компонентов с точки зрения их прочностных характеристик, а также разработка новых материалов и методов контроля технологии производства.

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Инженерный бизнес и менеджмент

УДК 004.67

Определение компонентов автомобиля, приводящих к отзывным кампаниям

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Рассмотрен набор данных, подготовленный Управлением по расследованию дефектов (США). Проведен разведывательный анализ данных. Проанализированы наиболее популярные марки автомобилей на американском рынке. Исследована динамика изменения количества отзывных кампаний в зависимости от года выпуска транспортного средства. Рассчитано среднее количество лет между датой покупки транспортного средства и датой начала отзывной кампании. Определено девять элементов автомобиля, которые чаще всего выходят из строя.

Ключевые слова: *отзывная кампания, Управление по расследованию дефектов (США), Национальное управление безопасностью движения на трассах (США), транспортное средство, дефект, Python*

Identification of Vehicle Components Leading to Recall Campaigns

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The article discusses a data set prepared by the Office of Defects Investigation. The feature engineering is conducted. The most popular car brands on the American market are analyzed. The dynamics of changes in the number of recall campaigns depending on the year of manufacture of the vehicle is investigated. The average number of years between the date of purchase of the vehicle and the date of the recall campaign is calculated. Nine elements of the car have been identified, which most often fail.

Keywords: *recall campaign, Office of Defects Investigation, National Highway Traffic Safety Administration, vehicle, defect-free tests, Python*

Introduction

A modern car is a technically complex product. According to Toyota, their cars consist of an average of 30,000 elements, which implies extremely complex logistics and production processes [1]. One of the key characteristics of the vehicle is safety, which is determined by the high level of quality of individual components and the final product.

The National Law on Road Traffic and Vehicle Safety was adopted in the USA in 1996 to timely identify defects and improve the quality of vehicles [2]. According to this law, the Ministry of Transport has the right to require the vehicle manufacturer to conduct recall campaigns if a defect has been detected. In total, more than 390 million passenger cars, trucks, buses, recreational vehicles, motorcycles and mopeds, 46 million tires, 66 million units of automotive equipment and 42 million child seats have been recalled since 1967.

Scientists are conducting safety research on public roads using data from open source recall campaigns. Nichols and Foumier (1999) studied the impact of recall campaigns on the reputation of vehicle manufacturers [3]. Rapp and Taylor (2002) investigated recall initiation [4]. They found that the government more often tries to initiate a recall related to defects in a large number of vehicles. At the same time, vehicle manufacturers are more likely to conduct recall campaigns related to the elimination of inexpensive defects. Yong-Kairon and Hugo (2011) found that the recall of a dangerous model can reduce the number of accidents on the roads by 20 %.

The purpose of this article is to identify the most frequently failing elements of the vehicle.

Data and methods

The dataset that has been used in this study had been prepared by the National Highway Traffic Safety Administration (NHTSA) and hosted on the data science competition platform Kaggle [5]. Due to the fact that the dataset contains about 124 thousand values, it is reasonable to use the Python programming language for analysis. The full data analysis code is provided in the Github repository.

The first stage of data analysis is feature engineering. The data frame consists of 15 columns (variables) and 123,837 rows (values). The dataset includes 10 categorical and 5 numeric variables. A categorical variable is a discrete quantity that can take one value from a limited set of values. In turn, a numerical variable is a quantitative continuous quantity.

The first three variables (Record ID, NHTSA Campaign and Manufacturer Campaign) are categorical and represent the serial numbers of the record, the NHTSA campaign and the manufacturer. These variables are not of significant interest in the study, so we removed them from the dataset.

The categorical variable Recall Type contains information about the type of recall campaign: the recall may be related to a vehicle, equipment, tires or car seat. In this paper the elements of the vehicle are considered, so it is necessary to select the lines of the dataset that satisfy the condition Recall Type = VEHICLE. The 106,492 values were remained in the data frame.

The variables Vehicle Make and Vehicle Model are categorical and contain information about the vehicle manufacturer and the vehicle model. In total, the dataset includes 1,503 manufacturers and 10,294 models.

The Fig. 1 shows twenty most popular vehicle manufacturers. The absolute leader in the number of recall campaigns is Ford. It should be noted, the dataset includes not only American automakers, but Japanese (Toyota, Honda, etc.) and German (BMV, etc.).

The categorical variable Vehicle Manufacturer contains information about the full name of the company that manufactures vehicles. For instance, for the variable Vehicle Make = FORD, the variable Vehicle Manufacturer takes the values FORD MOTOR COMPANY, FEDERAL-MOGUL CORPORATION and others. This situation is due to the fact that vehicle of the same brand can be produced at different factories.

The quantitative variable Model Year contains information about the production year for particular vehicle. It should be noted that the variable can take the values 9999. This situation is most likely due to the fact that in some cases car owners may not know exact production date. The maximum obviously incorrect values are entered into the database, so that one can easy remove them.

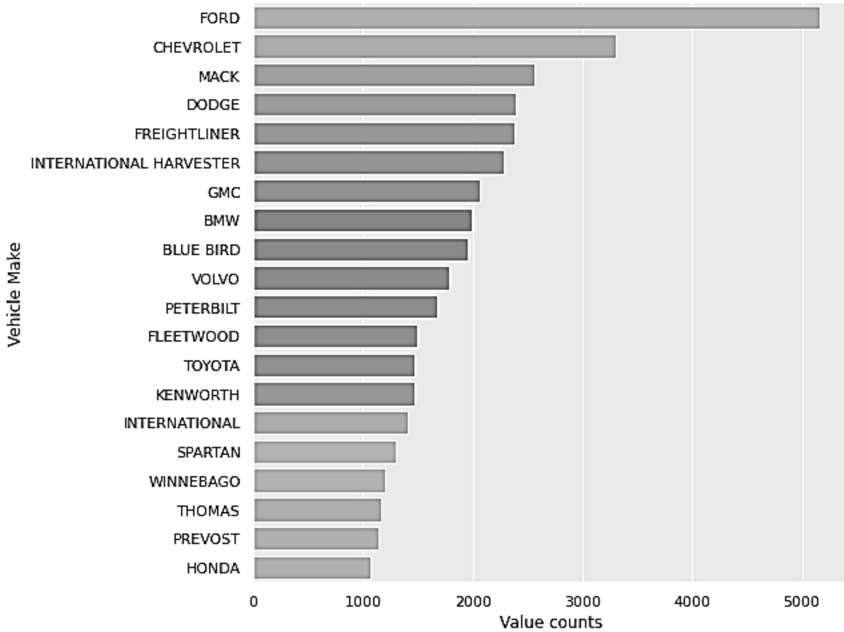

Fig. 1. Top 20 vehicle manufacturers

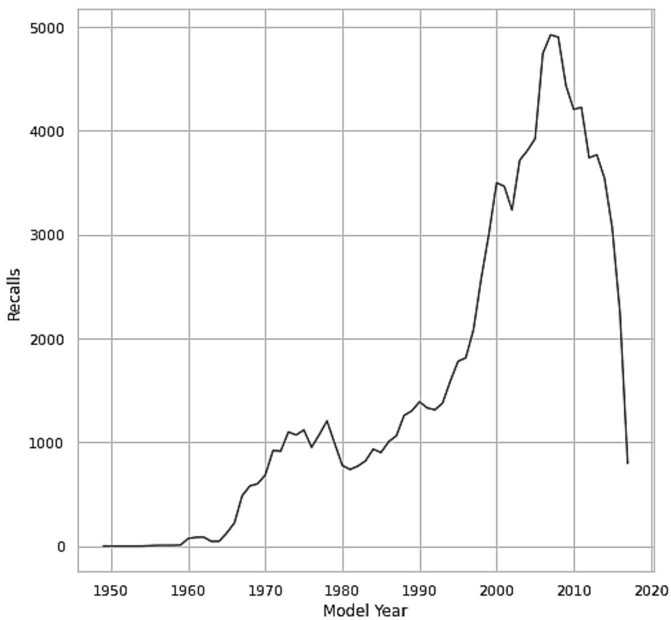

Fig. 2. The number of recall campaigns depending on the production year of the vehicle

The dataset contains vehicles produced from 1949 to 2018. It should be noted that the number of recalls directly depends on the number of vehicles sold in a particular year.

Fig. 2 shows a graph of the distribution of recalls depending on the date of production of the vehicle. The vertical axis indicates the number of recall campaings and the horizontal axis shows a production year. Between 1949 and 1980, there was a significant rise in number of recalls form 1 to 1300. However, there was a slight fall in 1980. This situation may be related to the fact that in the 80s there was a socio-economic crisis in the United States (inflation was 13.5 %). The population had less available cash, the volume of vehicles sold decreased, therefore, the number of recalled vehicles also decreased.

Over the next 30 years there was a significant rise from 900 to 5000 recalls. In 2008, there was a peak at 5000 recalls. During this period, an excessive number of loans were issued and the population had more opportunities to buy a vehicle.

After the 2008 crisis, the plot has a negative trend. This situation may be due to the fact that after 2008, most automakers began to design a series of cars on the same platform. Production involves a reduction in design costs, since one platform can be used for several car models. Therefore, there should be fewer potential problems and recalls, since one platform is being tested by more consumers.

In general, after 2010, the number of recall campaigns decreased. It can be assumed that the quality of vehicles and components has become higher.

The greatest interest in the paper is a variable of the string type Recall Component, which contains information about the reason for the recall of the vehicle. This variable includes several levels that can be used to identify the cause of the breakdown. The analysis of these levels is the main task of the research.

The numeric variable Estimated Units contains data on the number of recalled vehicles of a particular brand, model and manufacture year with the same cause of breakdown. This variable is one of the key variables in the dataset under consideration.

The categorical variables Recall Initiative and Recall Manufacturer include information about the organization from which the recall initiative came, and about the manufacturer who carried out the recall campaign. The recall initiative can come from three organizations:

- ODI — Office of Defects Investigation;
- OVSC — Office of Vehicle Safety Compliance
- MFR — Manufacturer.

Fig. 3 show bar chart that presents information about the number of recall campaigns initiated by the three organizations mentioned earlier.

According to the data, in the vast majority of cases, manufacturers are the initiator of the recall.

It should be noted that the variable Recall Manufacturer, as a rule, matches with the variable Vehicle Manufacturer. Therefore, the same factory produces vehicles and deals with the recalls and compensation for damage.

In addition to the described variables, there are variables with the “date and time” type: Manufacture Start Date (the start date of production of a particular brand and model vehicle), Manufacture End Date (the end date of a particular brand and model vehicle) and Recall Notification Date (the date when the company received notification of the recall of the vehicle). As a result of converting variables and coding additional functions, the author of the paper calculated the difference between the year of the recall company (Recall Notification Date) and the year of vehicle production (Model Year). Fig. 4 shows a boxplot of the scope of this value.

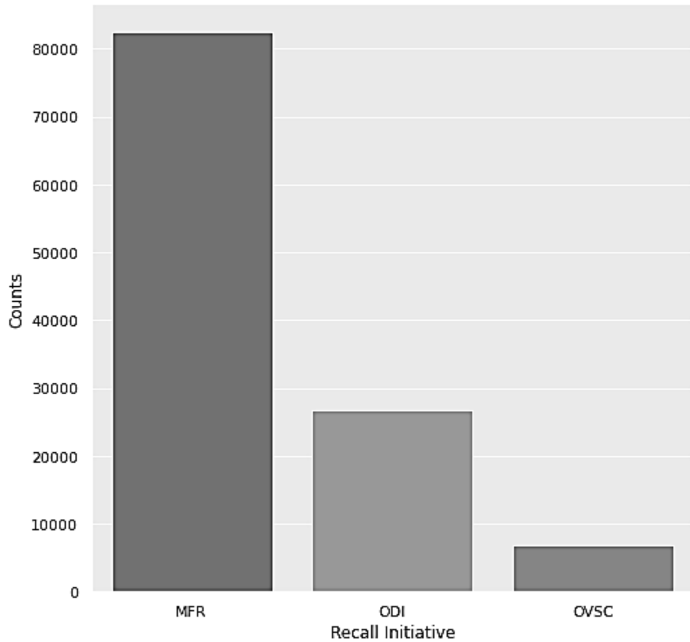

Fig. 3. The number of recall campaigns depending on the initiate organization

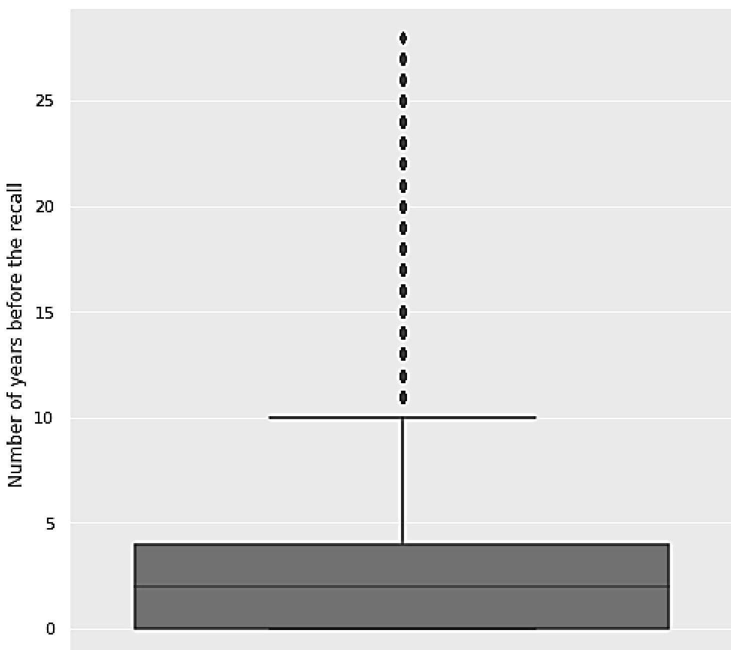

Fig. 4. Boxplot of the number of maintenance years before the first breakdown

As a result of the analysis of the information received, the following conclusions can be drawn. Firstly, 75 % of breakdowns occur in the first 4 years of maintenance. Secondly, the minimum matches with the first quartile, which means that up to 25 % of all malfunctions are detected in the first year of vehicle buying. This situation may be associated with errors at the design stage, which can be identified and eliminated during the first year of maintenance. Thirdly, the maximum value is 10 years. Likewise, there are sample values (values that are greater than the maximum), which indicate that in some cases a recall campaign could be carried out after 25 years of maintenance of the vehicle.

Therefore, feature engineering was carried out: all variables included in the dataset were analyzed. The data frame was created, which will be used to determine the elements of the vehicle that, more often breakdown.

Results

The variable Recall Component contains 5 levels of the reason for the recall campaign. The first level is significant in this paper. The author of the research has coded additional functions for identification the first level. In addition, the number of recalls (Estimated Units) was calculated for each element of the first level. Fig. 5 shows the result of these calculations.

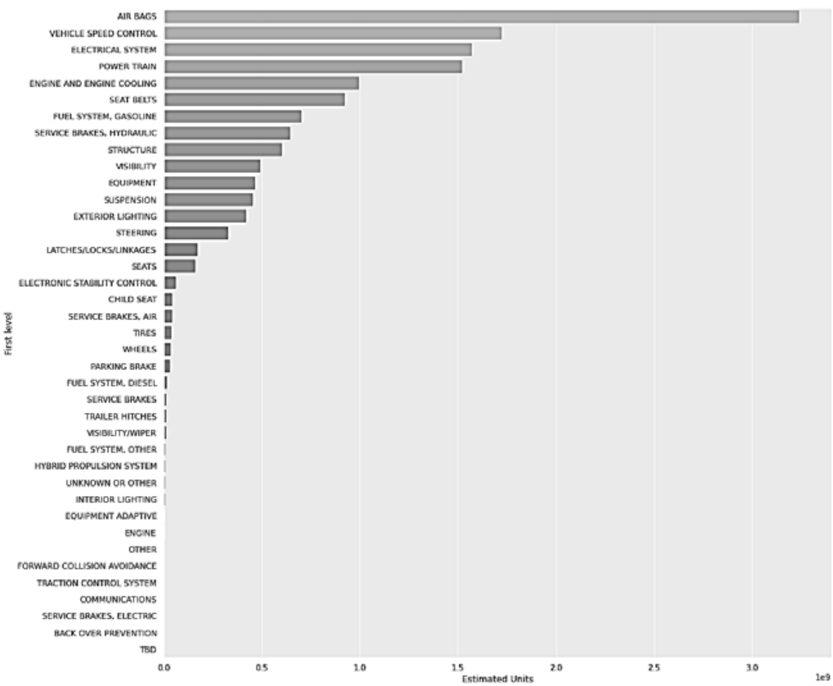

Fig. 5. Failing vehicle elements of the first level

The first level contains 39 enlarged names of vehicle elements. In order to determine the most significant names, it is necessary to calculate their frequency of occurrence in the dataset. Table shows the most frequently failing elements of the vehicle.

Table 1

The most frequently failing elements of the vehicle

First level	Estimated units	Part	Cumulative part
Air bags	3 242 302 336	0.22	0.22
Vehicle speed control	1 725 074 460	0.12	0.34
Electrical system	1 570 036 868	0.11	0.45
Power train	1 521 361 586	0.10	0.55
Engine and engine cooling	993 289 762	0.07	0.62
Seat belts	921 846 493	0.06	0.68
Fuel system, gasoline	702 700 378	0.05	0.73
Service brakes, hydraulic	642 524 179	0.04	0.77
Structure	600 557 796	0.04	0.81

In that way, there are 9 elements that break down in 80 % of recall campaign. At the same time, about a quarter of all recalls are airbags.

Discussion and conclusion

As a result of the conducted research, nine most frequently failing elements of the vehicle were identified. It is necessary to note some conclusions.

Firstly, in 31 % of cases, the recall is related to the safety system: airbags, seat belts and hydraulic braking system. Vehicle manufacturers should pay special attention to these elements of vehicles and ensure a high level of quality.

Secondly, a gasoline-based fuel system is presented in the list of elements. Then it can be wrongly argued that a gas-based fuel system is more reliable. Nevertheless, there are more cars with a gasoline system in absolute terms than cars with a gas system. Therefore, this indicator should be treated with skepticism.

Thirdly, it is impossible to imagine a modern car without electrical components. At the same time, about 23 % of all reviews (speed sensor and electrical system) are related to electronics. In this case, it is advisable to reconsider possible suppliers.

Fourth, the remaining elements (transmission, engine and design) are related to the design stage, so it is necessary to eliminate design errors.

It should be noted that in this work only the first level of classification of breakdowns was considered. In subsequent studies, it is reasonable to consider the remaining 4 levels.

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УДК 336.761.5

Корреляционно-регрессионный анализ динамики котировок акций и показателя чистой прибыли ПАО «Газпром»

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Проведено исследование динамики котировок акций и показателя чистой прибыли ПАО «Газпром» за 2014–2021 годы с использованием методов корреляционно-регрессионного анализа. На основе полученных результатов разработаны полиномиальные регрессионные модели и приведены доказательства статистической значимости этих моделей. С использованием разработанных регрессионных моделей сделан прогноз вариантов значений котировок акций и показателя чистой прибыли ПАО «Газпром» на 2022–2024 годы в целях долгосрочного инвестирования в акции ПАО «Газпром».

Ключевые слова: *корреляционно-регрессионный анализ, регрессия, корреляция, акции, инвестирование, Газпром*

Correlation and Regression Analysis of the Dynamics of Stock Quotes and the Net Profit Indicator of PJSC Gazprom

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The article provides a study of the dynamics of stock quotes and the indicator of the net profit of PJSC Gazprom for 2014-2021 using the methods of correlation and regression analysis. Based on the results, polynomial regression models are developed, which demonstrates their statistical significance. By means of the developed regression models, the given study makes a forecast of options for the values of stock prices and the net profit indicator of Gazprom PJSC (Public joint-stock company) for 2022-2024, thus serving the purpose of long-term investment in Gazprom PJSC shares.

Keywords: *correlation-regression analysis, regression, correlation, stocks, investment, Gazprom*

Introduction

Gazprom PJSC is a diversified multinational energy corporation with 50 % state participation. The company owns the world's largest gas transportation system, with a total length of 170 thousand kilometers. It is a holding company of the Gazprom Group. Gazprom PJSC directly sells only natural gas and leases its gas transmission system. The main areas of activity are geological exploration, production, transportation, storage, processing and sale of gas, gas condensate and oil, sale of gas as motor fuel, as well as production and sale of heat and electricity. Gazprom owns a significant part of the shares of Gazprom Space Systems, a subsidiary of the telecommunications services industry. The company's share in the world's gas reserves makes 16 %, while in Russia it is 71 %. Gazprom accounts for 12 % of global and 68% of Russian gas production. It ranks seventeenth in the list of the largest energy companies according to S&P Global Platts (2018).

Gazprom is the largest producer and exporter of liquefied natural gas (LNG) in Russia. The company is developing the current Sakhalin-2 project, as well as implementing new projects in this area. It is one of the four largest Russian oil producers. The total installed capacity of Gazprom's electric generating assets in Russia is about 16% of the total installed capacity of the state's power system. Gazprom ranks first in the world in the production of thermal energy.

Due to the company's development and growth, the share price of Gazprom PJSC for 2014-2021 increased more than twice, with its price ranging from 149 rubles (June 2014) to 350 rubles (October 2021). PJSC Gazprom pays dividends, which currently amount to 10 % of net profit. Further, the abbreviation Gazprom will be used instead of PJSC Gazprom .The correlation and regression analysis used statistical data from the official websites of the Moscow Stock Exchange [2] and PJSC Gazprom [3], and the method is widely described in the following sources [1, 4, 5].

Procedure

The markup of the stock price movement chart of the company is shown below (Fig. 1). It shows that the company has a fairly good uptrend. In the future, there might arise two developments in the dynamics of quotations: a further upward trend or an instant collapse of the company's shares. Since there are no fundamental prerequisites for a downward trend, Gazprom's net profit is growing, the company itself is competing for the growth of shares, which gives an assumption of the upward trend. In addition, Gazprom's consolidated revenue according to the information and analytical terminal "ETHER-Interfax" in 2021 is 10.209 trillion rubles, EBITDA — 3.586 trillion rubles, net profit — 2.388 trillion rubles.

To carry out correlation and regression analysis, various polynomial mathematical models will be considered to predict the possible value of the price for the period up to 2024. At the same time, regression models are not taken into account, since within the framework of a priori it is assumed that we get into an uptrend.

Fig. 2 presents the simplest model, which is paired linear regression. The abscissa scale is presented in relative form. The starting point is 2014. Further, the relative form of the predictor "year" will be used everywhere to simplify the type of regression models. The equation of paired linear regression obtained by the study is as follows:

$$y = 16.83x - 33782.$$

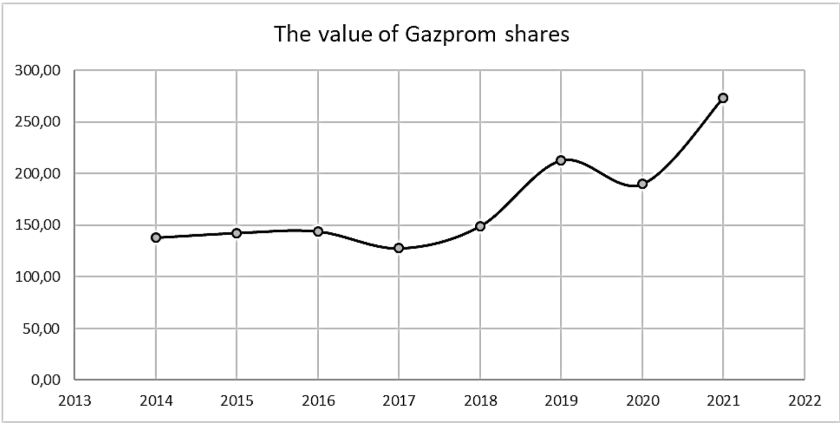

Fig. 1. Dynamics of Gazprom's share price 2014–2021

At the same time, determination R^2 = 0.67; the Fisher criterion F = 12.75; the $F_{Critical}$ = = 0.011774044 — allow to conclude about the statistical significance of the obtained regression equation. Additionally, according to the Cheddock scale, the influence of the predictor “x” on the dependent variable “y” is very high and the resulting regression equation can be used for predictive purposes. Using the obtained regression equation, we obtain a predicted change in the average value of Gazprom's share price in the range from 248 to 282 rubles for 2022–2024.

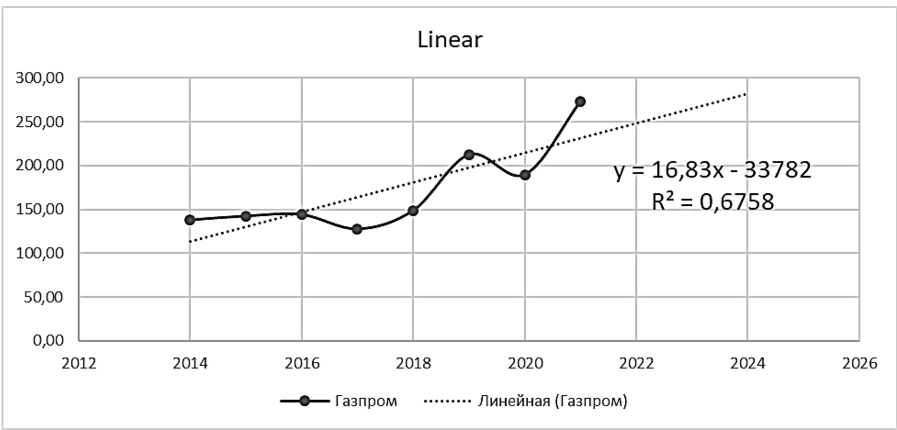

Fig. 2. Forecast of Gazprom's share price dynamics in the framework of paired linear regression for 2022–2024

The joint charts of Gazprom stock prices and the second-order polynomial regression graph are shown in Fig. 3. The results of the study made it possible to determine the second-order polynomial regression equation, which looks as follows:

$$y = 4{,}52x^2 - 18{,}224.75x + 18{,}367{,}386.39.$$

Evaluation parameters: determination coefficient R^2 = 0.87; Fisher criterion F = = 40.15384615; $F_{critical}$ = 0.000722904 — allow to conclude about the statistical significance of the obtained regression equation. Based on the Cheddock scale, it can be concluded that the influence of the predictor “x” on the dependent variable “y” is very high. As a result, the regression equation can be used for forecasting purposes. Using the obtained regression equation, we obtain estimates of the change in the average value of Gazprom's share price in the range from 316 to 448 rubles for 2022–2024.

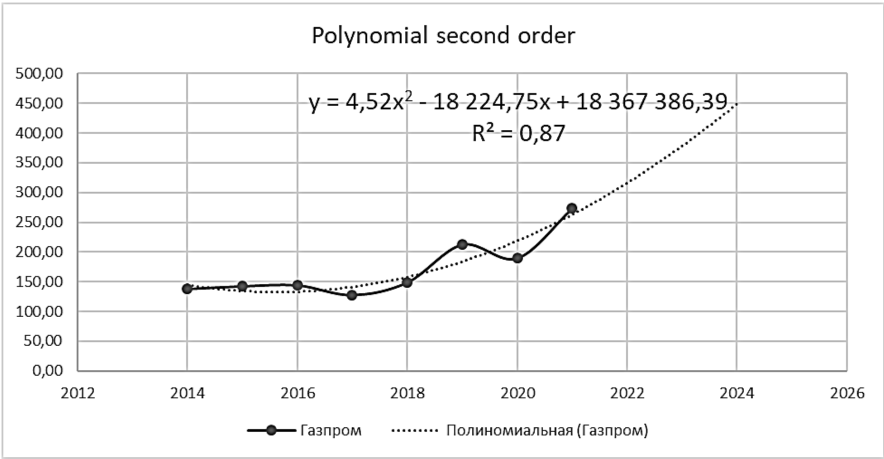

Fig. 3. Forecast of Gazprom's share price dynamics within the framework of a second-order polynomial regression for 2022–2024

The joint charts of Gazprom stock prices and the third-order polynomial regression graph are shown in Fig. 4. Below is the third-order polynomial regression equation obtained as a result of the study:

$$y = 0{,}43x^2 + 5173745.02x - 3473226991.91.$$

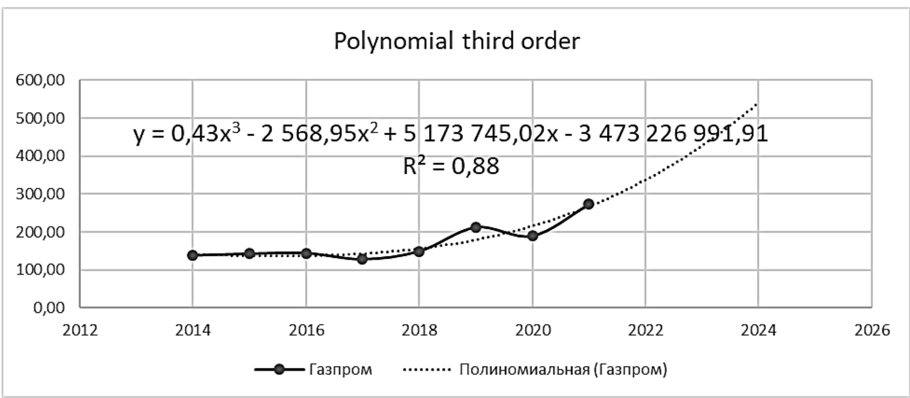

Fig. 4. Forecast of Gazprom's share price dynamics within the framework of a third-order polynomial regression for 2022–2024

The calculated coefficient of determination $R^2 = 0.88$; Fisher's criterion $F = 44$; $F_{Critical} = 0.00056621$ — present the statistical significance of the obtained regression equation. Using the Cheddock scale, it is found out that the influence of the predictor "x" on the dependent variable "y" is very high. And the above regression equation can be used for predictive purposes. Using the obtained regression equation, we obtain estimates of the forecast of the average value of Gazprom's share price in the range from 337 to 540 rubles for 2022–2024.

Since the correlation coefficient R between stock quotes and net profit at the moment makes 99 %, it is obvious that we should expect a corresponding trend in net profit during 2022–2024. To filter the regression models of the dynamics of Gazprom's shares, we can observe regression models of the net profit indicator for 2014–2021. However, in the case of 2021, Gazprom's annual profit will be presented in the annual report only in the first quarter of 2022. In this regard, we will use the estimate of the company's expected revenue for 2021. Gazprom raised its revenue forecast in 2021 from 7.8–8.0 trillion rubles to 8.1–8.2 trillion rubles. After analyzing this information, it can be assumed that the company's net profit about 1.315 billion rubles. Lower Gazprom's joint net profit graphs and a paired linear regression graph are presented (Fig. 5).

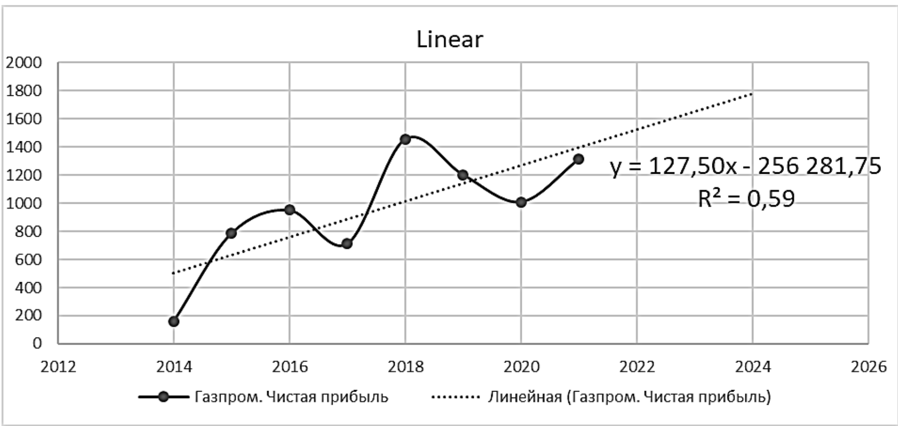

Fig. 5. Forecast of Gazprom's net profit dynamics within the framework of paired linear regression for 2022–2024

The equation of paired linear regression obtained as a result of the study is as follows:

$$y = 127{,}50x - 256281{,}75.$$

The coefficient of determination $R^2 = 0.59$; the Fisher criterion $F = 8.634146341$; $F_{Critical} = 0.026001915$ this allows us to conclude about the statistical assumption of the obtained regression equation. In addition, according to the Cheddock scale, the influence of the predictor "x" on the dependent variable "y" is the mean and the resulting regression equation can be used for predictive purposes. Using the regression equation obtained, we obtain a projected change in Gazprom's net profit in the range from 1523.25 to 1778.25 billion rubles for 2022–2024.

Fig. 6 shows joint graphs of Gazprom's net profit and a graph of paired linear regression of the third-order polynomial regression.

Fig. 6. Forecast of Gazprom's net profit dynamics within the framework of a third-order polynomial regression for 2022–2024

Similarly, as was done above, let's consider a third-order polynomial regression. As a result of the study, the following third — order polynomial regression equation was obtained:

$$y = 7{,}53x^3 - 45608{,}09x^2 + 92076773{,}10x - 61963669515{,}72.$$

Parameters of the equation estimation: coefficient of determination $R^2 = 0.75$; Fisher criterion $F = 18$; $F_{Critical} = 0.00542395$. This allows us to conclude about the statistical significance of the obtained regression equation. Based on the Cheddock scale, it can be concluded that the influence of the predictor "*x*" on the dependent variable "*y*" is average. As a result, the regression equation is valid for forecasting purposes. Using the obtained regression equations, we obtain estimates of the change in the average value of Gazprom's net profit in the range from 1431.68 to 2248.48 billion rubles for 2022– 2024.

The below graph shows the fourth-order polynomial regression (Fig. 7).

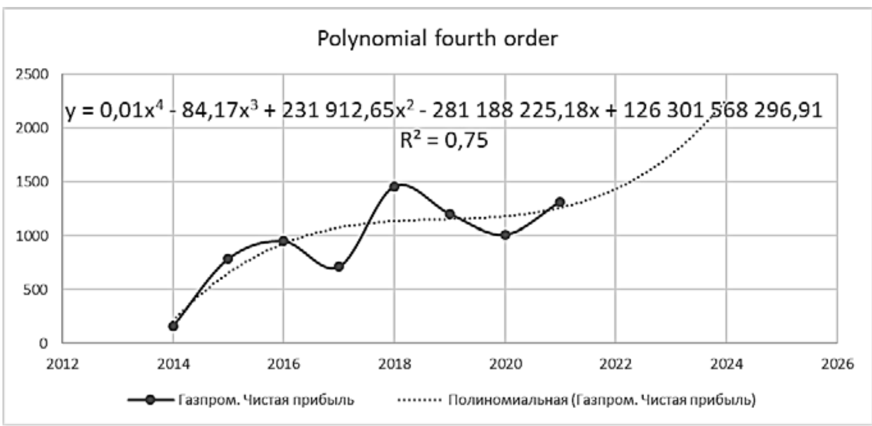

Fig. 7. Forecast of Gazprom's net profit dynamics within the framework of the fourth-order polynomial regression for 2022–2024

Below is the fourth-order polynomial regression equation obtained as a result of the study:

$$y = 0{,}01x^4 - 84{,}17x^3 + 231912{,}65x^2 - 281188225{,}18x + 126301568296{,}91.$$

The calculated coefficient of determination $R^2 = 0.75$; Fischer's criterion $F = 18$; $F_{Critical} = 0.00542395$ should determine the conclusion about the statistical significance of the obtained regression equation. Using the Cheddock scale, we observe the influence of the predictor "x" on the dependent variable "y" is very high. Hence, the above regression equation can be used for forecasting purposes. Using the regression equation, we obtain estimates of the forecast of the average value of Gazprom's net profit in the range from 1427.58 to 2248.32 billion rubles for 2022–2024.

With higher-order polynomial regression models for stocks and net profit, there is a significant divergence between the dynamics of the stock price forecast and the value of net profit. Given the strong correlation between these two indicators (R = 99 %), the regression models were not taken into account.

Results

The share price of PJSC Gazprom more than doubled in 2014–2021, from RUB 149 (June 2014) to RUB 350 (October 2021). PJSC Gazprom pays dividends, which currently amount to 10 % of net profit.

Below is a table with the expected prices of the company's shares based on the correlation-regression analysis (Table 1).

Table 1

Expected share price of the company

Type of analysis	R^2	F	$F_{Critical}$	Share price, r
Linear	0.67	0.01	0.011774044	248–282
Polynomial second order	0.87	40.15	0.000722904	316–448
Polynomial third order	0.88	44.0	0.00056621	337–540

In addition, it is worth noting the table with the expected profit of the company based on the correlation-regression analysis (Table 2).

Table 2

Expected profit of the company

Type of analysis	R^2	F	$F_{Critical}$	Net profit, b.r.
Linear	0.59	8.63	0.026001915	1523.25–1778.25
Polynomial third order	0.75	18.0	0.00542395	1431.68–2248.48
Polynomial fourth order	0.75	18.0	0.00542395	1427.58–2248.32

Conclusion

Finally, the general conclusion from the point of view of investing in PJSC Gazprom can be formulated as follows. The obtained results of the correlation and regression analysis show that currently it is advisable to make a long-term investment in PJSC Gazprom. The expected average share price of Gazprom PJSC during 2022–2024 could be in the range of

248–540 rubles per ordinary share. Also, the expected net profit during 2022–2024 is expected to be in the range of 1427.58–2248.48 billion rubles in accordance the electronic resource of Gazprom Moscow Exchange.

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УДК 65

Модели и методы внедрения информационной системы управления производственно- хозяйственной деятельностью предприятия

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Исследованы методы и модели внедрения информационных систем для роботизированной автоматизации бизнес-функций предприятия. Рассмотрены принципы построения модели с учетом входных и выходных параметров и сложности внедряемого продукта, а также рассмотрены методы внедрения от самых простых и дешёвых до сложных и дорогих. Выявлены преимущества использования моделей и систем имитирования реальных процессов, протекающих в структуре управления предприятий и случаи, когда могут возникнуть проблемы во время внедрения решений. Установлено, что данные методы и модели внедрения информационных систем для роботизированной автоматизации эффективны и применимы в разных предприятиях и под разные задачи следует использовать разные решения по поводу применяемых методов и моделей внедрения.

Ключевые слова: *коробочное внедрение, облачное внедрение, входные данные системы, каскадная модель, итерационная модель, эффективность внедрения*

Models and Methods for Implementing an Information System for Managing the Production and Economic Activities of an Enterprise

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Methods and models of implementation of information systems for robotic automation of business functions of the enterprise are investigated. The principles of model building, taking into account the input and output parameters and the complexity of the implemented product, as well as implementation methods from the simplest and cheapest to the most complex and expensive are considered. The advantages of using models and systems to simulate real processes in the management structure of enterprises, and cases where problems may arise during the implementation of solutions were identified. It is established that these methods and models of implementation of information systems for robotic automation are effective and applicable in different enterprises and for different tasks should be used different decisions on the applied methods and models of implementation.

Keywords: *box implementation, cloud implementation, system input data, cascade model, iterative model, implementation efficiency*

Introduction

The sharply increasing interest in the use of digital assistants for organizing processes in organizations is due to the fact that organizations want to leave part of the work of their employees to machines that can handle routine work in order to free up employees' time for more important tasks for the company. And this interest gives rise to such questions as "How to implement software products? What software products does our company need? What needs to be done to use these products? How much money should be spent and what will change as a result? and a number of other questions that can only be answered after studying the methods and models for implementing systems to automate business processes in a company.

The relevance of studying the issues of integration of the enterprise management system and software products for automating enterprise processes is explained by the sharp changes in the attitude of organizations to the digital transformation of processes, since a well-chosen program and integration in the existing conditions of the enterprise will significantly reduce the operating cycle of enterprise divisions, reduce the cost of products and increase the cost and efficiency of the organization [1].

Main part

There is an opinion that if the process is completed in more than 15 minutes, the level of complexity can be set by the algorithm, repeated with a frequency of more than a week and is important for the functioning of the system, department, division or company, then this process is subject to automation.

It can be concluded that these parameters are included in the information component for the decision to start informatization of any processes. According to statistics, such routine processes account for 80 to 90 % of the work of any organization.

Modeling of the selected process is a process split into parts, the study of the main characteristics and relationships between the elements of the process and the process with other processes in the system [2].

The execution stage involves the compilation of an algorithm and the development of the program itself, which will automate the process.

Monitoring includes testing the program under various conditions, identifying vulnerabilities and eliminating them, this is a critical stage in the implementation of an automated control system.

Management is the stage when a developer, based on business logic, constantly changes the process in the program so that it is relevant in various conditions of the enterprise.

At this stage of development, many different workflow management systems have been developed that target different areas of application and provide different functionality.

After analyzing the processes in the organization and deciding on the need to implement an information system, you need to clearly understand for yourself whether the labor potential of the IT department of the company is enough to independently implement the products of IT companies and implement your business ideas to automate any processes, since the cost depends on its platform or configuration implementations [3].

The platform differs from the configuration in that the configuration is a program developed on the basis of the platform, these 2 environments cannot work without each other. It is a difficult decision for a company to choose to buy only a platform and start developing a system for automating processes, and then accompany and support it, so most companies choose to implement it in an outsourcing company. These companies are otherwise called integrators of this product, which work in partnership with vendor companies that developed the platform, have certificates of conformity and a license to develop on vendor platforms [2].

The introduction of any information product in an organization usually occurs using two main methods — this is a cascade or phase method and an iterative method. Each of these methods has its own advantages and disadvantages. And when choosing an implementation method, you need input information about choosing a vendor or integrator company to implement automation processes, since, for example, when choosing an integrator company, the number of stages of implementing an automated information system is much reduced, and, therefore, you can choose a simplified method.

The essence of the cascade method is a phased consideration of the implementation process, when the output of each previous level is the final product, modified and tested, errors are not allowed at the implementation levels, since they are inputs for subsequent implementation levels.

According to the cascade method, the beginning of each stage accompanies the document or product that was the final output of the previous stage.

The key features of this method are:

• its single pass. That is, the end result of each stage of implementation when applying this method is the input resource of only one process occurring after;

• has critical importance of planning, because if at some stage the results are incorrect, it will be necessary to redo a lot of processes;

• the complexity of the product being developed. This method is usually used when the development product is complex, not typical, that is, it does not suit enterprises with relatively similar operating processes;

• at the very beginning of the project, it is necessary to accurately and completely formulate all the requirements for the product;

• this method is mainly used by outsourcing companies that do not know the processes taking place within the company. Their analysts collect all the requirements for the product and only then does the coding phase begin.

The second method for the implementation of an information system for managing the company's operations is the iterative method, this is a method in which an iteration is compiled that is quickly and easily changed, refined and adaptive [2].

When using this method, the stages of the implementation of the project for the implementation of the information system are divided into such iterations, and at each step you can return to the past and refine it. This method is convenient when the Organization itself implements the information system, that is, on the basis of the platform, it develops requirements for the information system being designed and codes the configuration and the automation program itself.

The main features of the application of this method are:

• multipath. That is, the result of one stage, if necessary, can serve as an input parameter for several subsequent stages of project implementation and, if necessary, can be changed as a result of any impacts;

• the iteration ends with testing in the real conditions of the enterprise or in its model to identify potential errors as soon as possible;

• adaptability and flexibility of iterations;

• the iterative method is used in projects to refine an already implemented solution with new functions, when the requirements for the product by business users may not be fully indicated.

Any information system in an enterprise is implemented according to three main models: a box implementation model, an electronic implementation model, and a cloud implementation model. Each of these models has its own advantages and disadvantages, and for different companies, a model should be selected that is suitable for work. Boxed implementation of an information system involves the purchase of an information product of a standard solution by an organization and the use of this solution to implement its business tasks. This model is usually implemented in small or medium-sized enterprises. The features of this model are:

• low cost. This feature is explained by the fact that the solution is typical and the vendor sells an already developed solution for the mass market;

• standard functionality. This feature suggests that the "box" is a software product. Small or medium-sized organizations can afford to buy an IT company's solution and adapt to the functionality of this product;

• these features are the main ones that need to be taken into account when choosing this model for implementing an information system to automate any business tasks of an enterprise.

The disadvantages of this model are:

• does not take into account the specifics of the business — for example, you will not buy a "box" for a new, digital business model;

• customization of system parameters is limited — employees in the organization will have to adjust to the program, and not vice versa;

• "boxes of one supplier are rarely integrated with "boxes" of other suppliers, which makes it difficult to interact within the company, this suggests that even if the first information system in the company is boxed, the second one can no longer be the same, since the setting for the functionality of the first systems must be carried out already atypical;

• the business logic is "fixed" in a closed code, which excludes the possibility of quick adaptation to changes in the business environment.

To eliminate these shortcomings, an electronic implementation model was developed. This model supports both "boxed" or standard solutions, as well as non-standard ones. When choosing this model, you can choose both typical ones, when the developer company accompanies the processes of updating and supporting only the platform itself, and non-standard ones, where you can buy support for the configuration itself and an automated solution as an additional service from the company. Maintenance of the information system consists of such components as maintenance of the development platform itself and maintenance of the implemented solution.

Partial maintenance of the platform itself is carried out by the developer company on a monthly basis, updating releases and advising all partner companies that use their development platform via the hotline. Full support of the platform is purchased separately and at a separate cost. This support includes both updating the platform and updating the release and participation in seminars to familiarize them with new solutions for updates and what is planned to be done. Maintenance of the implemented solution is carried out only when the solution is developed by the developer company itself and a separate support package has been purchased for this. This support includes:

• changing the automation algorithm when changing the logic of the business process in the company;

• control of business exceptions. That is, a constant analysis of legislation or other external factors that may exclude the flow of this business process in this way;

• control over changes in the target systems through which these business processes flow.

And the cloud solution model can contain all the advantages of the above models, but it works via the Internet and there is a danger of losing confidential data, this problem is solving by vendors but now it is not too safe to choose this model for the big organization.

Conclusion

A correctly set goal of implementing an information system is the key to the success of this implementation. The correct goals associated with the processing of information: storage, data retrieval, tasks associated with calculations, grouping, analysis. When implementing the system, all this takes less time. And the choice of methods and implementation models also come from the goals set for the process automation department. Even if we assume that information specialists know how to change business processes, they still do not have the necessary administrative resource, and the expected result does not depend primarily on software. This is clearly a confusion between cause and effect. The effect of the implementation of an information system directly depends on the implementation method, if you choose a simple method when implementing a complex program with a high code, this will either lead to high costs for improving the method or developing the program from the beginning [4]. The implementation model also plays an important role, since it determines where the refinement process will take place in the future, improving the code when changing the business logic. Therefore, the effectiveness of their further functioning depends on the methods and models implemented by software products.

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УДК 004

Анализ перспективных технологий цифровизации в наукоемком секторе экономики

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Проведен анализ перспективных технологий цифровизации, в частности группы технологий Big Data и AI. Одной из особенностей проведенного анализа является рассмотрение данных технологии в рамках программы цифровой экономики в Российской Федерации. Для анализа современного состояния технологий и перспективных направлений использования в наукоемком секторе экономики использованы инструменты анализа публикационной активности и анализ открытых данных о реализованных проектах, в сфере рассматриваемых технологи в Российской Федерации.

Ключевые слова: *цифровизация, цифровые технологии, большие данные, искусственный интеллект, цифровая экономика*

Analysis of Promising Digitalization Technologies in the Science-Intensive Sector of the Economy

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This article analyzes promising digitalization technologies, in particular the group of Big Data and AI technologies. One of the features of the analysis carried out is the consideration of these technologies within the framework of the digital economy program of the Russian Federation. To analyze the current state of technologies and promising areas of use in the science-intensive sector of the economy, tools for analyzing publication activity and analyzing open data on implemented projects in the field of the technologies under consideration in the Russian Federation were used.

Keywords: *digitalization, digital technologies, big data, artificial intelligence, digital economy*

Introduction

In recent decades, industrialized countries have actively increased and are increasing the number of digitalization processes in economic activity, these processes are global in nature and affect all sectors of the economy. The tasks and processes of digitalization have changed over time, starting with the tasks of accounting and control, which led to the introduction of databases and basic business systems, first in high-tech sectors of the economy, and then spreading to the rest. The issues of digital transformation are especially relevant in science-intensive industries, where the use of digital information and knowledge takes a leading place in the process of manufacturing a product.

However, in the modern world, digitalization has become an integral part of any successful business, the success of which is influenced by many factors both inside and outside the company. Therefore, many companies are concerned about finding new technologies that will not only help optimize business operations and increase profits, but also combine with the digital systems already installed in the company so that companies prosper. For efficient operation, companies in science-intensive sectors of the economy need to control and manage the production of products at each stage of the value chain, which is practically impossible to do without the use of auxiliary tools [1]. This paper proposes an analysis of one of the main digitalization technologies Big Data and AI in the Russian Federation in the context of the state program “Digital Economy of the Russian Federation” [2].

Methods

In the course of the study, it was necessary to systematize promising digitalization technologies and determine their boundaries. Since technologies have many intersecting subtechnologies, it became necessary to determine those related directly to Big Data and AI technologies. For this, hypotheses were put forward on the basis of expert assessments and analytical work of the authors in the technological areas of interest.

For an objective quantitative assessment of the scale of research and innovation activities, estimates were made of the volume of scientific publications, the pace of technology development, and finding intersections between the areas of knowledge under consideration. The analysis of publication and patent activity was performed on the basis of the Lens service database [3], which includes more than 193 million papers from the Microsoft Academic scientific publications database, 124 million papers from the CrossRef database, and 32 million papers from the PubMed database. In general, this database contains more than 13 million works from the field of Computer Science, which allows you to create a fairly complete picture of the technologies in question. The search for relevant publications was carried out using a system for filtering knowledge areas identified using ML models of the Microsoft Academic Services (MAS) system [4].

The second objective of the study was to assess the practical significance and economic effect of the use of AI and Big Data technologies. Based on previous works [5, 6], the main available ways to conduct such an assessment are a survey of experts from companies using the technologies of interest and an analysis of open information about the implementation of projects on the websites or blogs of companies. However, such methods do not provide an opportunity to obtain specific quantitative estimates and are limited to obtaining information about the generalized impact of the technologies under consideration on the business, and in most cases, they are biased towards the positive experience of project implementation.

Results

The analysis of indicators of publication activity in the field of Big Data and AI technologies was carried out using the resources of The Lens Scholarly Work platform [4], to create a relevant sample of publications, a filtering system was used for the fields of the field of knowledge (Field of Study), marked up using ML-models of the Microsoft system Academic Services (MAS) [4]. To obtain a relevant sample of scientific publications, the parameters presented in Table 1 were used.

Big Data technologies include a significant part of AI technologies: ML methods and intellectual analysis using ML tools, as, for example, it is presented in [2, 7]. This paper presents an attempt to distinguish between them, so based on the analysis of previous works and statistical analysis of publications in the field of Computer Science, the following areas of knowledge were selected: work directly with the mention of the term Big Data, cloud computing, IoT, Data Mining, approaches to data analytics and scaling issues, which is extremely typical in matters of processing and storing Big Data objects. In the field of AI, already established areas of knowledge are selected: ML, neural networks, deep learning, NLP, computer vision and pattern recognition tasks. The graphs in Fig. 1 show the dynamics of the number of publications in the world in the studied areas, broken down by types of publications. The sample included papers published in scientific journals and conference reports, as well as books and dissertations.

Table 1

A set of filters to create a relevant selection of publications using the lens platform [3]

Technology	Filter	Values
Artificial Intelligence	Date range	2010–2021 years
	Publication Type	journal article, conference proceedings article, conference proceedings, book chapter, book, dissertation
	MAS Field of Study	Artificial intelligence, Machine learning, Natural language processing, Deep learning, Computer vision, Pattern recognition, Artificial neural network
Big Data	Date range	2010–2021 years
	Publication Type	journal article, conference proceedings article, conference proceedings, book chapter, book, dissertation
	MAS Field of Study	Big Data, Cloud computing, Data analysis, Data mining, Internet of Things, Scalability, Distributed systems

Publication activity in the field of AI from 2010 to 2017 slightly increased, however, accounting for about a quarter of works in the field of Computer Science, however, since 2018. publication activity in the field of AI began to increase significantly, mainly due to an increase in the number of publications in scientific journals. This could be influenced by many factors, an increase in the number of online training courses, improvements in the quality of open-source software for developing machine learning models, for example, at the end of 2015, the TensorFlow library from Google appeared, the most popular platform for developing ML models.

Publication activity in the field of Big Data has increased significantly from 2010 to 2015. mainly due to the growing popularity of the Data Mining topic, which is mostly a marketing name for a combination of ML methods and advanced analytics, as well as methods for obtaining data, but in parallel with this topic, the number of publications in the field of cloud computing has actively increased, which really opened up great potential opportunities for business and development of the Big Data area. This confirms the fact that publications in the field of Big Data themselves began to gain popularity along with an increase in the number of publications in the field of cloud computing (Fig. 2).

Fig. 3 compares the areas of knowledge found in two samples. Since the total number of works in the samples is not uniform, about 30 % of the articles are articles from the field of Big Data, the most even distribution of works is reflected in the field of Computer Science. As can be seen from the Fig. 3, despite the obvious separation of AI methods from Big Data, they have a significant intersection in such areas of knowledge as ML, neural networks, deep learning. It is also interesting that the work in the field of cluster analysis in terms of relative quantity prevails in the work of the Big Data industry, since this task was given more attention in the early stages of the development of ML, and its implementation has already found application in many business systems.

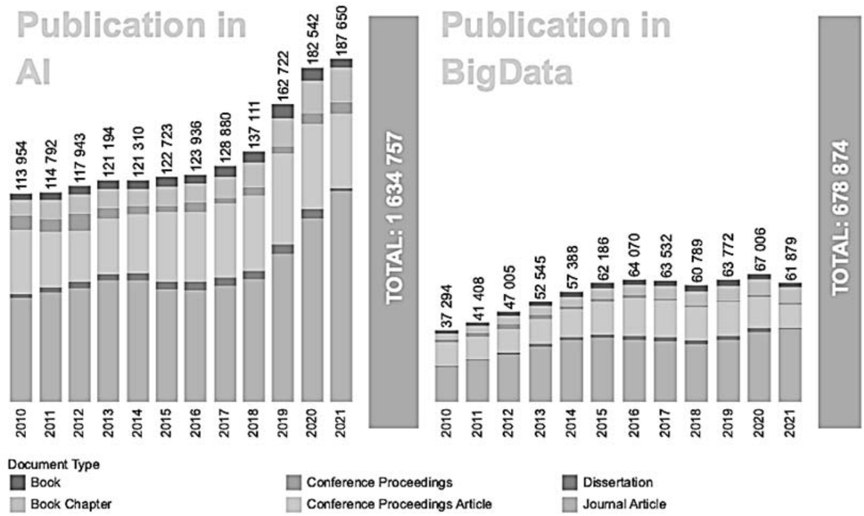

Fig. 1. Dynamics of publication activity in the areas of AI and Big Data for 2010-2021

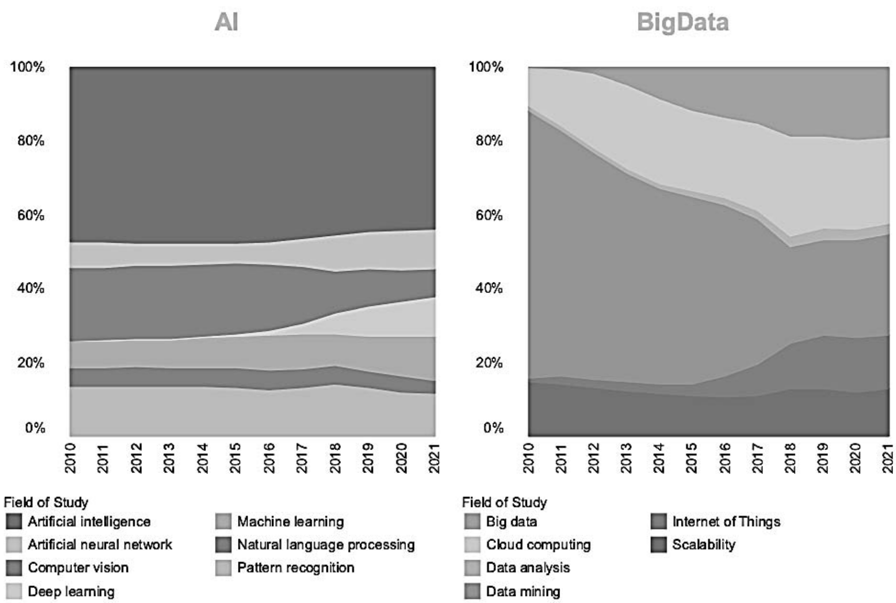

Fig. 2. The ratio of publications in the considered fields of knowledge

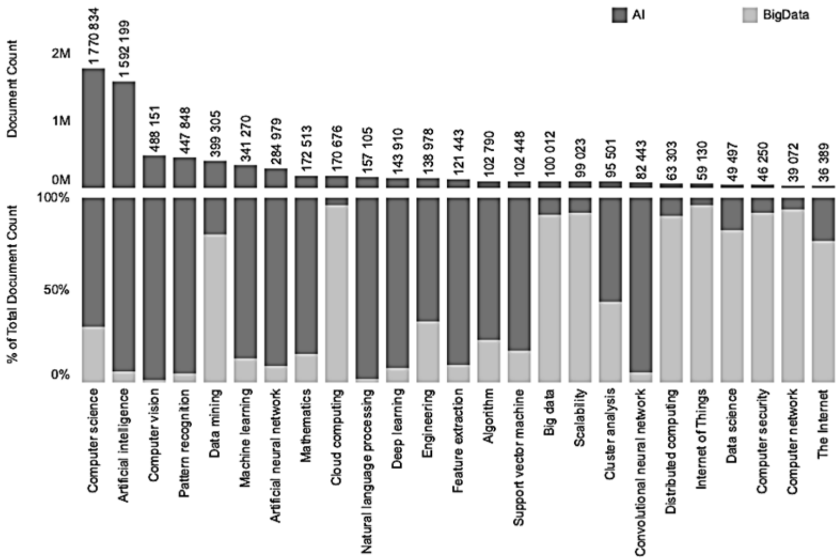

Fig. 3. The main intersections of AI and Big Data knowledge areas

The technologies in question have been actively developing for more than 10 years, but quite large markets have already been created around them, according to Gartner reports, the AI-based software market in 2021 amounted to $51.5 billion, and the Big Data market in 2020 was $206.9 billion. In [7], a comprehensive analysis of the implementation of government contracts for R&D on "end-to-end" technologies of the digital economy was carried out (Fig. 4). As you can see, since 2018, funding for projects in the field of ML and Data Mining has increased, from applications for 2019-2020. these areas accounted for more than 80 % of the total number of projects. This is partly due to the allocation of state support for the program [2].

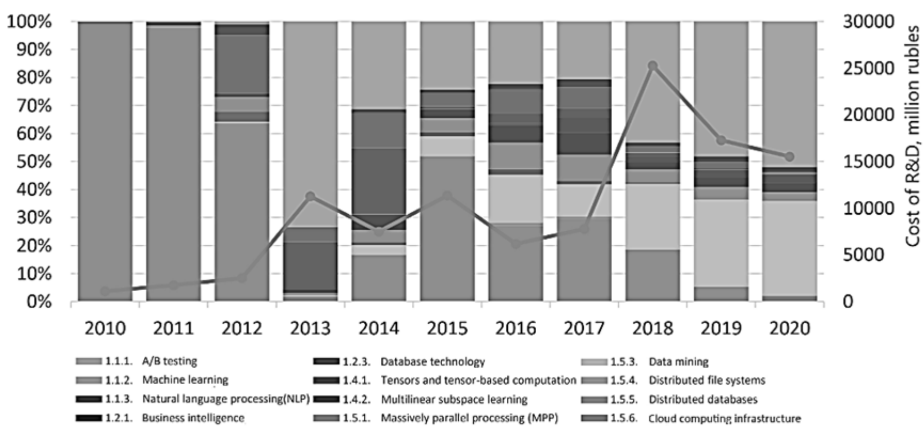

Fig. 4. Distribution of the cost of R&D in the Russian Federation by technologies of the Big Data industry [7]

To consider more successful implementations of AI and Big Data technologies in the Russian Federation. It is worth considering examples of completed projects. Basically, projects based on the technologies under consideration are carried out by companies that have developed digital systems at the heart of their business. In the Russian Federation, such companies mainly operate in the following sectors of the economy: information technology and telecommunications, the financial sector and retail. To a lesser extent in the Russian Federation, these technologies are developed in the oil and gas industry, healthcare and public administration. Consider a number of projects related to Big Data technologies (Table 2).

Table 2

Projects of big commercial companies of the Russian Federation related to Big Data technologies

Company	Technology	Project
VK	ML	VK Cloud Solutions
	Cloud technologies	VK Cloud Solutions
MTC	A/B testing	MTS Marketer
	Cloud technologies	CloudMTS
	ML	AL Laboratory in collaboration with Skoltech
Sber	Cloud technologies	SberCloud
	ML	SberDataScience
		ML Space
	Data Mining	SberData
		Sber Data Platform
Yandex	Cloud technologies	Yandex.Cloud
	ML	Yandex.Cloud
	Data Mining	DataLens
	Database	ClickHouse

As you can see, the largest digital companies in the Russian Federation are forming a business in the field of Big Data around digital platforms and the provision of services in the PaaS (Platform as a Service) format, which allows companies to create value from the cloud platform software itself, and not just from renting infrastructure. The demand for such solutions is growing rapidly, so the revenue of Yandex Cloud in the first half of 2021 increased by 240 % compared to 2020 [8].

In the field of AI, most companies provide application solutions that are directly related to business tasks. Popular tasks to be solved are:

• forecasting demand and sales•
• forecasting customer lifetime value;
• increasing the conversion of promotions;
• predictive production maintenance;
• forecasting employee satisfaction.

Only a few companies in the Russian Federation are engaged in fundamental research and the development of AI libraries. The largest contribution among such companies is made by Yandex, in particular, it has created several popular open-source software libraries, such as CatBoost, a high-performance tool for training decision trees using gradient boosting, TomitaParser, a set of NLP tools for the Russian language, hivemind, a tool for decentralized model computation Deep Learning, with the help of volunteers.

Conclusion

As a result of the analysis of modern digitalization technologies in the science-intensive sector of the economy, two overlapping groups of Big Data and AI technologies seemed to be the most promising for implementation in the science-intensive sector of the economy. To assess the current state and development directions of subtechnologies of the selected groups, an analysis of publication activity was performed, which showed a significant increase in the number of works in the field of AI, and an increase in the role of Deep Learning technologies in it, as well as an increase in the number of applied publications, indicating the high readiness of available tools for implementing technologies. AI at the enterprises of the science-intensive sector of the economy.

An analysis of the projects of commercial companies in the Russian Federation showed that it is mainly only large companies whose business is based on digital technologies that can effectively implement and use modern digitalization technologies. However, now these companies are creating an infrastructure for applying Big Data and AI technologies not only within their digital systems, but also businesses with a lower level of digitalization, implementing it in the form of cloud platforms, with access to most Big Data technologies and tools.

The introduction of such technologies can bring significant economic benefits to enterprises in the science-intensive sector of the economy; however, they will require a significant level of development of their own digital infrastructure or the use of cloud platforms, which can reduce the cost and time of implementation of such projects for most of them.

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Безграничные возможности в космосе

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Ожидается, что вся тяжелая промышленность будет перенесена в космос через 30–50 лет. Емкость космического рынка растет в среднем на 15…20 % каждый год. Многие важные ингредиенты, кристаллические структуры и новые лекарства от рака могут быть произведены в космосе. Первая полностью частная миссия на Международную космическую станцию стартовала с Космического центра Кеннеди (John F. Kennedy Space Center). Следующим экономическим пространством станет Луна. Генеральный директор НАСА Брайденстайн планирует новую лунную экспедицию в 2024 г., которая позволит добывать ценные металлы и редкие элементы, необходимые для различных областей экономики. Для транспортировки этих материалов создаются космические логистические цепи.

Ключевые слова: *экономика космоса, Луна, лунная миссия, космические логистические цепочки, развитие космоса, полеты в космос*

Unbegrenzte MALSglichkeiten im Weltraum

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Es wird erwartet, dass die gesamte Schwerindustrie in 30–50 Jahren in den Weltraum verlagert werden wird. Die Kapazität des Raumfahrtmarktes wächst jedes Jahr um durchschnittlich 15...20 %. Viele wichtige Inhaltsstoffe, Kristallstrukturen und neue Krebsmedikamente können im Weltraum hergestellt werden. Die erste rein private Mission zur Internationalen Raumstation wurde vom John F. Kennedy Space Center aus gestartet. Der nächste Wirtschaftsraum wird der Mond sein. NASA-Generaldirektor Bridenstein plant für 2024 eine neue Mondmission, bei der Edelmetalle und seltene Elemente abgebaut werden können, die für verschiedene Wirtschaftszweige benötigt werden. Für den Transport dieser Materialien werden weltraumgestützte Logistikketten eingerichtet.

Keywords: *Raumfahrtindustrie, Mond, Mondmission, Raumfahrtversorgungsketten, Raumfahrtentwicklung, Raumfahrt*

Die führende Rolle in der modernen Welt spielen neue Technologien. Sie lassen den Gesellschaften die neuen Markte zu öffnen und zu erschließen.

Eins der führenden Entwicklungsgebiete wird die Weltraumindustrie. Viele wissenschaftliche Entdeckungen werden im Rahmen der Entwicklung der Kosmologie und der Astrophysik gemacht. Heute haben wir die riesige Anzahl der Galaxien, Sterne und Exoplaneten entdeckt. Wir konnten das schwarze Loch fotografieren und bereiten uns auf den Start einer Weltraumexpedition zum Mars vor.

Das Interesse am Weltraum wächst rasant und exponentiell, und heute sehen nicht nur Kosmologen, Astrophysiker und Astronauten, sondern auch Unternehmer und Regierungen der führenden Länder Möglichkeiten im Weltraum .

Und das ist tatsächlich: der Weltraum hat ein enormes Potenzial für die Entwicklung und viele Gelegenheiten für die Gesellschaftsführung. Ich werde im Rahmen dieses Artikels einige von ihnen betrachten.

Der Amazon-Gründer Jeff Bezos hat kürzlich einen radikalen Vorschlag gemacht. Er meint, dass die gesamte Schwerindustrie — das, was schmutzig ist oder Kohlenstoff verbrennt, in 30–50 Jahren ins All verdrängt werden soll [1]. Und das ist wahrhaftig möglich. Erinnern wir uns an das Apollo-11 Programm, das vor 50 Jahren durchgeführt wurde. Heute ist der Weltraum zum alltäglichen Ereignis für uns geworden.

Die Kapazität des Weltraumsmarktes wächst jedes Jahr im Durchschnitt um 15...20 % [2].

Im Jahre 2018 hat die Kapazität des Weltraumsmarkts von 360 Milliarden Dollar oder 305 Milliarden Euro insgesamt bewertet, davon 125,5 Milliarden Dollar für die bodenbasierte Ausrüstung, 102,4 Milliarden Dollar für das TV/Radio/Breitband, 85,5 Milliarden Dollar für die Leitung und Personentransport. Wirklich beobachten wir, dass die Weltraumindustrie, die traditionell unter der Zuständigkeit des Staates war, privatwirtschaftlich wird. Das bekannteste Unternehmen, das die Raumfahrzeuge und die Ausrüstung herstellt, ist SpaceX. So ist es wirklich sehr wahrscheinlich, dass die Weltraumforschung, insbesondere des erdnahen Raums, schon in unserer Zeit allgegenwärtigen Charakter annehmen wird.

Mehak Sarang, die an der Harvard University in Boston Weltraumökonomie erforscht, sagt: wir Menschen würden zu einer interplanetaren Gesellschaft und die Ökonomie würde eine Weltraumökonomie.

Das Potenzial des Weltraums ist enorm. Es gibt viele Möglichkeiten für die High-Tech-Herstellung unter Schwerelosigkeit. So kann man im Weltraum viele wichtige Ingredienten, Kristallstrukturen und neue Krebsmedikamenten herstellen. Die Zellkulturen, mit denen die Wissenschaftler ein neues Krebsmedikament prüfen, kann man wegen der Schwerkraft nicht auf der Erde züchten [1].

Wenn wir zum Thema Weltraumtransport zurückkehren, betrachten wir Satelliten. Jetzt gibt es etwa 14 Satelliten und Raumfahrzeuge Anbieter auf dem Weltraummarkt, die miteinander konkurrieren. Der NASA- Chef Jim Bridenstin setzt ein Ziel — die Aktivität im erdnahen Raum zu kommerzialisieren und die Programme für Mond- und Marsflüge voranzutreiben. Also sind etwa 5700 aktiven Satelliten im Weltraum und etwa 10000 haben schon ausgedient und sind Weltraumschrott [1].

Satellitenindustrie kann auch das Sprungbrett für die Weltraumtourismus werden. Der Weltraumtourismus kann überaus zum anziehenden Sektor der Weltraumwirtschaft werden. Im Frühjahr 2022 wurde erste kommerzielle touristische Mission in den Weltraum geplant. Die touristische Gruppe war zur ISS am 10. April 2022 geschickt. Als Raumfahrzeug war das Crew-Dragon-Raumschiff ausgewählt. Ticketpreise waren 55 Millionen Dollar pro Person [1]. Die erste völlig private Mission zur ISS ist vom US-Weltraumbahnhof Kennedy Center um 11:17 Uhr nordamerikanischer eastern time (19:17 Uhr in Moskau) gestartet. An Bord sind vier Weltraumtouristen, darunter ehemaliger NASA-Astronaut Michael Lopez-Alegria: diese Besatzung war beim Axion Space Inc. gewählt. Der Weg zur ISS dauerte 20 Stunden. Sie blieben acht Tage auf der ISS, währenddessen mehr als 25 wirtschaftliche Forschungen und Technologiedemonstrationen durchführt wurden [3].

Völlig zivile Mission Axiom Space Ax-1 ist der erste von mehreren privaten Missionen zur ISS, die Axiom Space in dem kommenden Jahre geplant hat. Insgesamt hat das Unternehmen noch drei kommerzielle Crew-Dragon-Missionen von SpaceX zwischen 2022 und 2023 besetzt (Ax-2, deren Flugkapitän NASA-Astronautin Peggy Whitson wird, Ax-3, Ax-4).

Der Gesamtmanager des Houston Start-Up Axiom Space Inc. Michael Suffredini bereitet ein Sieben-Betten-Hotel für Gäste Touristen, Wissenschaftler, Bauarbeiter vor.

Auch jetzt können wir die Voraussetzungen dafür beobachten, dass sich vieles von dem, das auf der Erde gebaut und gesammelt wird, in der Zukunft im Weltraum montiert wird. Wir werden nur notwendige Stoffe und Zubehörteile verschicken [1].

Zum nächsten Wirtschaftsraum wird der Mond werden. Im Dezember 2020 hat die chinesische Mondmission “Chang’e 5” etwa 2 kg des Mondbodens zur Erde geliefert [4]. Es wird berichtet, dass etwa 90 % der Stoffe, die “Chang’e 5” gesammelt hat, Regolith und Basalt ist. Allerdings haben 10 % der Stoffe vollkommen andere exotische chemische Zusammensetzung. Darin gibt es unter anderem scharfe Trümmer, die sich durch den Fall von Meteoriten gebildet wurden, und verglaste Fragmente vulkanischen Ursprungs sowie Mineralien und Gesteine [4].

Der Gesamtmanager NASA Bridenstine plant im Jahre 2024 eine neue Mondexpedition, um sich dort zu befestigen. Amerikaner haben im Jahre 2009 100 Millionen Tonnen Wasser, aus dem man in der Zukunft Wasserstoff herstellen kann, transportiert [1].

Und das ist noch nicht alles, was möglich ist, um auf dem Mond wertvolle Metalle und seltene Elemente zu gewinnen, die für die unterschiedlichen Wirtschaftsgebiete notwendig sind. Für den Transport dieser Stoffe werden kosmische Logistikketten eingeführt. Der Gesamtmanager Astrobotics- Unternehmen Jim Thornton erklärt: sein Unternehmen bekomme schon die Bestellungen für den Transport wertvoller Stoffen vom Mond zur Erde. Das ist die Aufgabe des Unternehmens diese Lieferungen durchzuführen.

Auf solche Weise haben wir mehrere möglichen Optionen für die Entwicklung der Weltraumswirtschaft beobachtet. Sie können es bemerken, dass viele Unternehmen gegründet sind, um die Mission zur wirtschaftlichen Erschließung des Weltraums zu verwirklichen. Daher ist es sehr wahrscheinlich, dass wir in naher Zukunft sehen werden, wie jede der Möglichkeiten in der Realität realisiert wird und wie die Menschen zu einer interplanetaren Gesellschaft werden.

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Технологии подбора персонала в научных организациях

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Рассмотрены технологии подбора кадров в научных организациях. Проанализированы статистические данные, свидетельствующие о том, каков удельный вес затрат на науку, на каком месте по уровню валового внутреннего продукта находится Россия. Проанализированы существующие определения понятия «подбор персонала». Изучена процедура подбора персонала. Даны практические рекомендации по выбору технологии подбора персонала в научных организациях.

Ключевые слова: *научная организация, научные кадры, подбор персонала, технология, методы*

Recruitment Technologies in Scientific Organizations

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The article discusses the technology of personnel selection in scientific organizations. Statistical data are considered that indicate the proportion of expenditures on science, where Russia is in terms of gross domestic product. The existing definitions of the concept of "recruitment" are analyzed. The procedure for recruiting personnel was considered. Practical recommendations are given on the choice of technology for recruiting personnel in scientific organizations.

Keywords: *scientific organization, scientific personnel, personnel selection, technology, methods*

Highly qualified, competent personnel of a science-intensive enterprise are an important link in the process, it is on them that the efficiency of the enterprise as a whole depends. Labor resources occupy a special place in the totality of all resources of the enterprise. The task of the personnel department is to qualitatively select personnel based on certain requirements and policies of the organization.

Based on statistical data, the share of spending on science is 1.1 % of gross domestic product (GDP), a significant lag behind the leading countries of the world. So, in comparison with Israel, where 4.25 % is allocated for science, Russia is only in 34th place in the rating [1].

In an interview with N. Belyakova, she said that scientists have to pay for participation in events at the international level on their own [2]. Participation in any international congress costs about 300 euros, and this does not take into account the payment for flights and accommodation and for foreign researchers, participation in such events is included in the budget of the research project.

Currently, there are reasons why less and less people want to engage in scientific activities, including [3]:

• lack of a favorable environment for scientific activity;
• low funding;
• deterioration of scientific equipment;
• insufficiently developed strategy for the development of science;
• lack of business customers.

All the demonstrated reasons must be addressed in a complex, including the creation of attractive conditions in the labor market, making the scientific field more competitive, and being ready to attract the most talented and efficient scientists to your organization.

To date, many reliable and effective recruitment methods have been developed. Recruitment should take into account the specific characteristics of the organization and be consistent with the development strategy in order to find highly qualified specialists who are suitable in all respects. Analysis of the specifics of recruitment should begin with the definition of recruitment.

1. O. Reznikova believes that recruitment is a method of selecting the most suitable candidate for an existing vacancy in the organization, taking into account all the requirements for the position [4].

2. M. Armstrong believes that the selection of personnel is a complex procedure, during which, at minimal cost, there is a need to hire the necessary number of suitable personnel in order to meet the needs of the company.

3. Yu. Odegov defines the recruitment process as the formation of a database of candidates in order to make a definite choice in favor of the most suitable candidate in all respects [5].

Thus, recruitment is the use of effective technologies and methods to achieve results, that is, to hire a candidate suitable for certain requirements.

The recruitment process can be divided into 3 stages.

1/ Determination of recruitment needs — to identify the required number of personnel, qualification requirements for the candidate.

2/ Search for candidates — posting job ads on websites, internal search among company employees, contacting recruitment agencies.

3/ Selection of candidates in accordance with the requirements — testing, interviews with managers, preparation of an employment contract.

Recruitment technologies are different and differ in a variety of means and methods in order to find a worthy candidate for an existing vacancy. A clear and elaborated operation is not typical for the selection of personnel, in each case it is necessary to use different selection technologies. In scientific organizations, as a specific field of activity, it is possible to use such technologies as:

• executive search;
• headhunting;
• screening.

*Executive Search***.** The definition of technology can be translated as "search for professionals". In the middle of the 20th century, this technology arose in the United States as a way to fight for leadership among large corporations, the emphasis is on finding candidates among people who are not looking for work. This technology is the most effective, since the search for employees for managerial positions, for example, heads of departments, directors of enterprises, causes serious difficulty. And you should also pay attention to this technique for finding specialists in rare professions, in the scientific field there are most of such vacancies.

Headhunting. Headhunting technology is a kind of "poaching" of a specific already established specialist from one organization to another. The negotiation process in this case is quite difficult and requires high-quality training of a recruiter or with the use of third-party organizations to search for employees. The customer sets the conditions that the company is ready to accept in order to lure a professional into its organization.

Screening. Screening is a quick and low-budget way to select candidates for a position. The use of this technology does not assess personal qualities and psychological characteristics, and the assessment takes place only on formal grounds, for example, education, work experience, ability to work with a large amount of information, knowledge of some computer programs. With the help of this technology, junior specialists are selected, such as: office managers, secretaries, drivers. Employees of this category do not require specific skills and abilities.

Thus, the technologies for selecting specialists for scientific positions may be different, but the stages of selection are generally similar to each other. The main thing in the recruitment process is not to make a mistake with the choice of equipment, it is necessary to clearly understand who exactly is needed in the organization and what skills cannot be dispensed with in a particular vacancy.

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О применении бережливого производства в проектах аэрокосмической отрасли

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Рассмотрена структура проекта по разработке и созданию инновационных систем на предприятии ракетно-космической области. Выявлены узкие места в процессе планирования приятия проекта, описаны причины их возникновения и актуальные способны развязки, а также выделены области для дальнейшего исследования. Проанализированы методик бережливого производства и результаты применения методик на практике в рамках машиностроительного предприятия, отмечены недостатки и особенности.

Ключевые слова: *организация производства, проектное управление, бережливое производство, узкие места, Канбан*

On the Application of lean Manufacturing in Projects in Aerospace Industry

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The structure of the project for the development and creation of innovative systems at the enterprise of the rocket and space field is considered. The bottlenecks in the planning process of project acceptance have been revealed, the reasons for their emergence and actual decoupling possibilities have been described, and the areas for further research have been highlighted. The methods of lean production and the results of the application of the methods in practice within the machine-building enterprise are analyzed, the shortcomings and peculiarities are noted.

Keywords: *production organization, project management, lean production, bottlenecks, Kanban*

Introduction

The paper considers a high-tech enterprise of the rocket-cosmic industry. The enterprise is engaged in the production of technically complex, innovative rocket and space technology on orders from customers. The organization's management structure is project-based.

During the process of planning a new project and making a decision to accept an order, there are a number of problems, the so-called bottlenecks, errors in which lead to the loss of resources, including financial and time.

The system for ensuring the implementation of the project within the framework of the enterprise under study is considered (Figure).

The structure consists of the following elements:

• the customer (owner) of the system — the person who is the source of the requirements for the system being developed, together with the project manager and the system engineer, forms a list of requirements for the system, determines the budget and deadlines for the entire project. Interacts primarily with the project manager;

• project manager — solves issues of timing, budget, financing, interaction within the organization. Interacts with the customer, system engineer and other departments of the organization that provide the project with resources, equipment and technologies, also participates in the process of selecting employees and project partners;

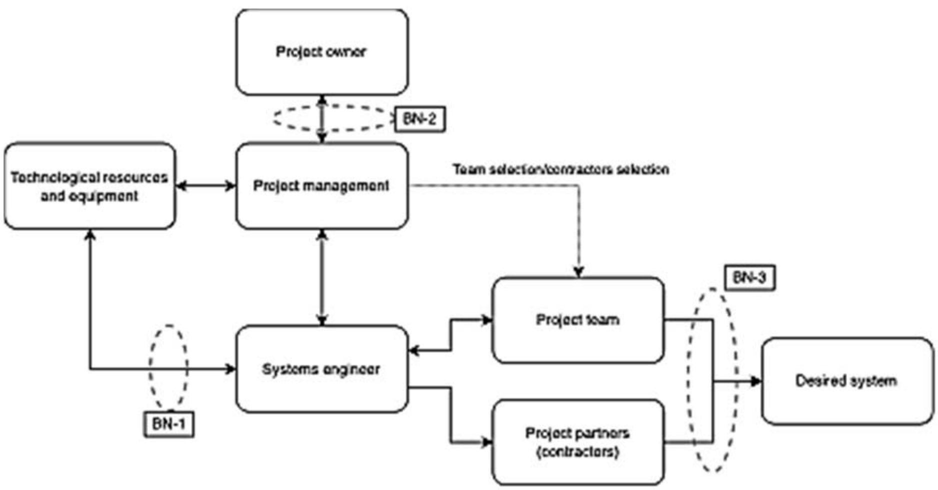
• systems engineer — has sufficient technical and organizational competencies that allow you to "link" project work, requirements, project team and partners to achieve the desired result. Interacts with the manager and logistics departments to optimize the distribution of work on the project;

• logistics — any centralized departments within the organization that perform projects that provide project work with technologies, equipment and material resources in accordance with the project budget and production employment;

• executors (team) of the project — employees directly involved in the creation of system elements are recruited from internal and external sources of human resources;

• partners (organizations) of the project — organizations that provide the project team with technical, technological, organizational, material and other resources that the project team is unable to obtain or recreate within the framework of the project organization;

• the system being developed is the result of work that fully meets the requirements of the client and performs all the designed functions. It is the result of the activity of the entire project as a whole.



Project structure

Figure shows "bottlenecks" (BN) in the structure — problem areas, planning errors in which lead to a loss of resources or do not allow the project to be completed before a certain deadline.

BN-1 — the design organization cannot provide technological and technical resources, design work is idle due to long queues from orders from other project teams, existing production facilities are used inefficiently.

BN-2 — the process of forming requirements for the project is inefficient, the requirements are rewritten many times, do not carry a significant semantic load, many requirements are not critical, but are considered as such, the technological feasibility of the requirements is not in doubt.

BN-3 — the work performed by the project team and partners does not actually correspond to the planned ones, the designed system components do not perform the necessary functions, the designed functions do not cover the client's requirements for the system being developed.

Theoretical and practical studies of the organization of project activities have made it possible to neutralize the influence of bottlenecks in many cases, to "unleash the bottlenecks". An example of such interchanges is the use of solving optimization problems of the schedule for decoupling UM-1, as well as the use of methods for improving the efficiency of production processes such as Kanban, 6 sigma, 5S and others.

In the case of BN-2, requirements methodologies are applied to establish and agree on a set of parameters that meet the requirements of realism, feasibility, technical validity, clarity and measurability.

Considering BN-3, we come to the understanding that despite the clarity of the reasons for the existence of the identified bottleneck — the lack of competencies of the project staff and partners — there is very little literature devoted to the study of ways to decouple BM in foreign and domestic sources.

The problem that arises in BM-3 is the loss of time and financial resources of the project, as well as the possible failure of the project as a whole due to the lack of a formalized system of organizational and managerial indicators that affect the choice of employees and innovative partners that are most suitable for the needs of the project in terms of competencies.

The classification of bottlenecks, causes of occurrence and unblocking methods is presented in Table 1 below.

Table 1

Bottlenecks, causes and known unblocking methods

No.	Bottleneck	Cause	Unblocking methods
1	Project work is idle despite the technical equipment of the enterprise being sufficient for the tasks	Existing production capacity is used inefficiently due to long queues from orders from other project teams	Solving schedule optimization problems, applying methods to improve the efficiency of production processes: Kanban, 6 sigma, 5S and others
2	The requirements accepted for work do not fully correspond to the requirements of the client	The process of forming requirements for the project is inefficient, the requirements are rewritten many times, do not carry a significant semantic load, many requirements are not critical, but are considered as such, the technological feasibility of the requirements is not in doubt	Application of requirements methodologies that establish and agree on a set of parameters that meet the requirements of realism, feasibility, technical validity, clarity, and measurability

End of Tabs

No.	Bottleneck	Cause	Unblocking methods
3	Loss of time and financial resources of the project at the stage of work on the creation of the system, as well as the possible failure of the project as a whole	Due to the lack of a formalized system of organizational and managerial indicators that affect the choice of the most suitable employees and innovative partners for the needs of the project, the work performed by the project team and partners does not actually correspond to the planned ones, the designed system components do not perform the necessary functions, the designed functions do not cover the requirements client to the system being developed	Creation of a formalized system of organizational and managerial indicators, which allows choosing the most suitable employees and innovative partners

To unblock BN-3, it is proposed to create a formalized system of organizational and managerial indicators, which will allow you to select the most suitable employees and innovative partners based on many parameters, including competencies, technical equipment and available budget.

Consider the factors influencing the choice of employees or partners

• money (available budget)
• workload (availability of working hours)
• reputation of candidates (in socially significant projects)
• competencies (both individuals and companies) etc.

The most important factor in terms of projects to create unique systems is competencies, since they answer the question of whether an employee / partner will be able to perform the intended work.

The assessment of resource, time and reputational factors is covered in some detail in the literature, however, the issue of determining the competencies of employees / partners, as well as determining the project's need for competencies, is covered much more poorly.

Lean manufacturing methods analysis

Let's consider ways of decoupling BN-1 according to the above classification, namely, methods for solving scheduling problems and methods for improving the efficiency of production processes. Considering the tools of lean manufacturing, we can distinguish the most popular from the literature [1, 2]:

• value stream mapping;
• pull in-line production;
• kanban;
• kaizen;
• 5S system;
• SMED system;
• TPM system;
• JIT system;
• visualization;
• U-shaped cells.

In value stream mapping, timing is used to diagnose the process of creating a product [3]. The result of the mapping is a visual graphical diagram that reflects each process, sensor, and action that a particular product goes through. Value stream mapping is a diagnostic tool. By itself, it does not allow you to stop the speed of processes, limit or reduce the number of operations. With its quality, an existing process is used. On the presence at the site of mapping, the manager can analyze the process and develop an action plan aimed at changing it.

The standardization process is also not complete without timing. In practice, timing is used not for the entire production process, but only for operations and actions performed at one workplace. Based on the results of timing, normalization and development of a recipe are noted, in which step-by-step actions that need to be developed are recorded in order to evaluate the performance of a particular job.

SMED is a system that reduces the time of setup and changeover operations, but it does not do without timekeeping, which is aimed at reflecting the actions and their time that the operator performs during the setup process. Only after the existing changeover procedure has been reflected in the timing, it is possible to analyze and identify the loss of time, which may not be present.

A review of practical implementation cases reveals the possibility of conducting a study on the relative effectiveness of identifying the above BP tools in practice in Table 2.

Table 2

Analysis of practical implementation of Value stream mapping, standardized work, SMED system

Expectations from the use of lean tools	Facts from practical implementation experience
Reducing the duration of processes	Analysis of the wrong processes → specific problems are not solved
Elimination and reduction of the number of operations	Description of the process "as it is" without further action
Developing standards for efficient work	Useless processes are optimized, which simply should not be

Pull in-line production, Kanban and Just-in-time are considered as 3 different and independent tools while they are interrelated. Pull in-line manufacturing is a Lean manufacturing approach, and Kanban and Just-in-time are tools for in-line pull manufacturing. Only after the production scheme has been changed from push to pull does it make sense to use the material pull tool in production — kanban and the Just-In-Time inventory management system.

Businesses that have been operating on a push system for many years will not be able to move quickly to a pull system. The transition to a pull scheme for the organization of production involves a major restructuring of the entire production system. Such a process requires a high intellectual potential of the enterprise and a large amount of staff time.

The transition to pull production requires not just the use of individual tools, but a systemic reorganization. It also affects work with suppliers, who will be subject to new requirements regarding the supply of materials and their quality; work related to inventory, which will have to be reduced, while maintaining the efficiency of the enterprise; work related to the restructuring of the planning system; work related to the restructuring of production (for example, the creation of U-shaped cells), etc.

An analysis of the application of methods in practice is presented in Table 3 below.

Table 3

Analysis of tools "Pull in-line production, kanban, Just-in-time system"

Expectations from the use oflean tools	Facts from practical implementation experience
Reorganization of the production system	lack of qualified specialists capable of completely rebuilding the production system; significant financial costs; the impossibility of carrying out the restructuring of production
Decrease in the level of WIP	increase in costs for the production of products that are more profitable to store in the form of WIP; stop production due to lack of stocks
Synchronous release of products	desynchronization of the work of shops, due to problems in the systems of operational and shop planning
Transition to a pull-out system of in-line production	a lengthy and unsuccessful process due to the fact that its implementation is entrusted to operational personnel; lack of a systematic approach, which is why the implementation comes to naught and is reduced to "putting things in order"

Many articles devoted to lean production [4–6] call this approach one of the modern management tools, one of the most effective business management methods and offer a set of "universal" tools, the use of which will mean that lean production is being introduced at the enterprise. Similar examples can be found in [7]. This interpretation of lean production is of interest to managers who expect to find effective methods and specific tools for managing an organization, but it is important to understand that, first of all, lean production is not a management technique, but a philosophy and ideology based on the principle of continuous improvement — kaizen.

Kaizen itself is not a technology to reduce costs or improve processes. This is a way of thinking and a principle that describes the philosophy of lean manufacturing, in which everyone, doing work, should think about what he could improve.

A review of works covering the application of these principles in practice shows that, in fact, lean production is perceived incorrectly as it is not a management technique, but a philosophy and ideology, and without a transformation in the thinking of management and employees of an enterprise, the long-term effect of implementation is not observed. The implementation of the principles in general is hampered by the unwillingness of management to change and the low level of staff confidence in lean production and a lack of understanding of the goals of its implementation.

Conclusion

In their current state projects in aerospace industry companies tend to have bottlenecks that lower the project work efficiency and lead to budget overdrafts. Although there are unblocking methods already researched and described further research can be done in an area of partners selection based on competencies.

Despite the large number of materials on lean manufacturing and the widespread use of these methods in domestic enterprises, as practice shows, this technique does not always give the expected results. Based on the literature research conducted in the article and the practical experience of implementing lean production, conclusions can be drawn that allow avoiding many shortcomings in the application of lean production methods.

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Информатика и информационные технологии

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Навигация агентов на основе искусственного интеллекта

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Рассмотрена навигация агентов и важность сервисных роботов. Представлен модульный и иерархический подход к обучению стратегиям для исследования трехмерной среды. Этот подход использует сильные стороны как классических, так и основанных на обучении методов. Использование обучения в рамках каждого модуля сохраняет свои преимущества, в то же время иерархическая декомпозиция и модульное обучение позволяют обойти высокую сложность выборки, связанную с обучением сквозных политик.

Ключевые слова: *навигация агентов, сервисные роботы, SLAM, обучение с подкреплением, глубокое обучение*

Agent Navigation Based on Artificial Intelligence

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This paper discusses agent navigation and the importance of service robots. This paper presents a modular and hierarchical approach to learning strategies for exploring three-dimensional environments. This approach takes advantage of the strengths of both classical and learning-based methods. The use of per-module learning retains its advantages, while at the same time hierarchical decomposition and modular training allow us to sidestep the high sampling complexity associated with end-to-end policy learning.

Keywords: *agent navigation, service robots, SLAM, reinforcement learning, deep learning*

Введение

В Британской энциклопедии навигация определяется как наука об управлении судном путем определения его положения, курса и пройденного расстояния [1]. Навигация занимается поиском пути к желаемому пункту назначения, предотвращением столкновений, экономией топлива и расписанием встреч. Таким образом, навигация мобильного агента — это способность мобильного робота упорядоченно перемещаться из одного места в другое.

Сервисный робот — это робот, который работает полу- или полностью автономно для выполнения услуг, полезных для благополучия людей и оборудования, они исключают производственные операции, способные принимать решения и действовать автономно в реальной и непредсказуемой среде для выполнения определенных задач.

Экономическое значение

В связи с важностью сервисных роботов Международная федерация робототехники (IFR) ожидает, что их рыночная стоимость будет продолжать расти в следующие несколько лет [2].

Стоимость продаж профессиональных сервисных роботов во всем мире выросла на 32 % до 11,2 млрд долларов США (2018–2019). Пандемия COVID-19 будет способствовать дальнейшему росту рынка. Высокий спрос на роботизированные решения для дезинфекции, роботизированные логистические решения на фабриках и складах или роботов для доставки на дом — примеры этой тенденции.

Хотя функции сервисных роботов могут быть разными, все они имеют одну общую черту — автономную навигацию.

Связанная работа

Навигация является критически важной задачей при создании интеллектуальных агентов. Задачи навигации могут быть выражены в различных формах, например, задачи с точечными целями включают в себя навигацию к определенным координатам, а семантическая навигация включает в себя поиск пути к определенной сцене или объекту. Независимо от задачи, основной проблемой навигации в неизвестной среде является ее исследование, т. е. задача эффективного посещения большей части среды. Это необходимо для максимизации охвата поиска для обеспечения лучших результатов найти цель в неизвестной среде. Это необходимо также и для эффективного предварительного картирования среды при ограниченном времени.

Когда речь идет о навигации, в настоящее время существуют две парадигмы: подходы, основанные на геометрической реконструкции и планировании пути [3], и подходы, основанные на обучении [4].

Подходы, не основанные на обучении, имеют ряд проблем. Так, например, эти подходы неустойчивы и не работают, когда есть шум в эго-оценке или локализации, делают сильные предположения (т. е. те, которые невозможно исправить) о свободном пространстве или столкновениях и не могут быть обобщены, когда навигация требует взаимодействий (открытие дверей и т. д.). Кроме того они не учитывают семантические отношения, которые могут значительно сократить пространство поиска и сильно зависят от специализированных датчиков, таких как сканеры дальности [4].

Для решения проблемы навигации используется сквозное обучение. При этом обоснованием для его использования являются следующие соображения: обучение обеспечивает гибкость в выборе модальностей ввода (классические системы определяют геометрию пространства с помощью специализированных датчиков, в то время как обучаемые системы — на основе анализа RGB изображений); использование обучения может повысить устойчивость к ошибкам в явной оценке состояния; обучение может эффективно использовать структурные закономерности реального мира, что приводит к более эффективному поведению в ранее невидимых средах [5].

Однако сквозное обучение в навигации имеет и недостатки. Обучение картографии, оценке состояния и планирование пути исключительно на основе данных в сквозном режиме может быть непомерно затратным с вычислительной точки зрения [5].

Методы

Иерархические и модульные политики в обучении с подкреплением являются активной областью исследований, направленных на автоматическое обнаружение иерархий для ускорения обучения. Однако это непростая задача, вследствие чего в большинстве работ прибегают к ручному определению иерархий.

Хорошая политика разведки требует:

• хорошего исследования новой среды, чтобы агент осмысленно перемещался, обнаруживая и избегая препятствий;

• требует, чтобы агент определял семантические подсказки, такие, как двери, которые могут облегчить исследование;

• требует, чтобы агент отслеживал, какие части среды были или не были исследованы, и оценивал, как добраться до частей среды, которые, возможно, не были исследованы.

В исследовании используется постановка задачи разведки, предложенная в [4]. В ней целью является максимизация покрытия исследуемой территории за фиксированный промежуток времени. Охват определяется как общая площадь карты, которую можно пройти. Наша цель — обучить политики, которая принимает наблюдение s на каждом временном шаге t и выдает навигационное действие a, чтобы максимизировать охват.

Предлагаемый подход состоит из трех компонентов:

• нейронного модуля SLAM;

• глобальной политики;

• локальной политики.

Нейронный модуль SLAM содержит картограф и оценщик позиции, которые предсказывают карту окружающей среды и позицию агента на основе текущих наблюдений и предыдущих предсказаний. Глобальная политика (способ, согласно которому действует и принимает решения агент) использует предсказанную карту и позицию агента для создания долгосрочной цели. Долгосрочная цель преобразуется в краткосрочную цель с помощью планирования пути. Локальная политика предпринимает навигационные действия на основе текущих наблюдений для достижения краткосрочной цели.

Поскольку наш подход предназначен для использования реальными роботами, то очень важно смоделировать шумы срабатывания и датчиков, без ошибок которых ни один робот не может работать оптимально. Как базовые показания датчиков одометрии, так и движения агента, основанные на действиях, являются шумовыми. Они реализуются с помощью моделей шума датчиков и срабатывания, основанных на реальных данных. Пространство действий состоит из трех действий: движение_вперед, поворот_влево, поворот_вправо.

Для экспериментов мы используем симулятор Habitat [6] с наборами данных Gibson [7] и Matterport (MP3D) [8]. И Gibson, и MP3D состоят из сцен, которые являются 3D-реконструкциями реальной среды, однако Gibson собран с использованием другого набора камер, состоит в основном из офисных помещений, а MP3D состоит в основном из домов с большей средней площадью сцены.

Картограф обучен предсказывать эгоцентрические проекции (вид карты сверху, где показано расположение объектов относительно оси тела человека), а оценщик позиции обучен предсказывать позицию агента с помощью контролируемого обучения. Глобальная политика обучается с помощью обучения с подкреплением через проксимальную оптимизацию политики с вознаграждением, пропорционально увеличению покрытия в качестве награды. Локальная политика обучается с помощью имитационного обучения (клонирования поведения) на траекториях исследования, построенных человеком. То есть локальная политика обучается имитировать действия, которые предпринимали люди, в то время как эти траектории в основном демонстрируют поведение исследования.

Заключение

В настоящей статье изучен модульный и иерархический подход к обучению политик для исследования трехмерной среды. Этот подход использует сильные стороны как классических, так и основанных на обучении методов, используя аналитические планировщики пути с обучаемым модулем SLAM, а также глобальные и локальные политики. Использование обучения обеспечивает гибкость в отношении входных модальностей (в модуле SLAM), использует структурные закономерности мира (в глобальных политиках) и обеспечивает устойчивость к ошибкам в оценке состояния (в локальных политиках). Предложенная модель превосходит предыдущие методы в задачах исследования и достижения точечной цели и демонстрирует сильную обобщенность по доменам, целям и задачам.

Такое использование обучения в рамках каждого модуля сохраняет свои преимущества, в то же время иерархическая декомпозиция и модульное обучение позволяют нам избежать высокой сложности выборки, связанной с обучением сквозных политик.

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УДК 004.932

Предварительная обработка входного изображения для достижения максимальной точности распознавания лиц при использовании каскадов Хаара

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За последние годы в мире искусственного интеллекта одной из самых популярных и наиболее часто используемых технологий стала технология обнаружения лиц. Эта популярность обусловлена большим разнообразием приложений и потребностей: медицинская визуализация, промышленность, транспорт, наблюдение, безопасность. Сегодня все эти сферы используют анализ фото- и видеопотоков в своей деятельности. Рассмотрены способы обработки изображения, позволяющие при неизменной использующейся технике детектирования лица с использованием каскадов Хаара, улучшить качество распознавания лиц. Эти методы представляют некоторый симбиоз имеющихся способов изменения тона и цвета фотографий: осветления, контрастности, насыщенности.

Ключевые слова: *обнаружение лиц, предварительная обработка изображений, гамма-коррекция, каскады Хаара, помеховая фильтрация изображений*

Pre-Processing of the Input Image to Achieve Maximum Accuracy of Face Recognition when Using HAAR cascades

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In recent years, in the world of artificial intelligence, one of the most popular and most used technologies has become face detection technology. This popularity is due to a wide variety of applications and needs: medical imaging, industry, transportation, surveillance, security. Today, all these areas use the analysis of photo and video streams in their activities. This article discusses image processing methods that allow, with the same used face detection technique using Haar cascades, to improve the quality of face recognition. The considered methods represent some symbiosis of the existing ways of changing the tone and color of photographs: lightening, contrast, saturation.

Keywords: *face detection, image preprocessing, gamma correction, Haar cascades, noise filter*

Introduction

Currently, an increasing number of projects have begun to apply face detection technology to solve their problems. These include software products in which the face detection function is implemented both as a secondary component that allows further calculations (recognition of faces, facial expressions or emotions), and as a main component used, for example, for automatically counting event visitors or estimates of the congestion of metro lines. Successful implementation of the first and second types of projects is impossible without correct face detection.

To increase the accuracy of object detection, it is customary to use pre-processing of images, and only then — the use of various techniques for working with data. Such multi-stage work improves the quality of recognition.

Fundamentals of the application of Haar cascades in the problem of face detection

The value of the Haar sign reflects changes in the gray level in the image. A small number of features can be combined to create an efficient classifier. For example, some facial features can simply be described with rectangular features, such as: the eyes are darker than the cheeks, the sides of the nose are darker than the bridge of the nose, and the mouth is darker than the environment.

To get the characteristics for each of these five rectangular areas, we simply subtract the sum of the pixels under the white area from the sum of the pixels under the black area. Interestingly, these features make a real difference in the context of face recognition:

1. The eye areas tend to be darker than the cheek areas.
2. The nose area is brighter than the eye area.

Therefore, given these five rectangular areas and their corresponding sum difference, we can form features that can classify the parts of the face. Let's consider the work of the program for face detection, based on the work of the cascade classifier implemented in the OpenCV library, which uses the Haar signs. The raw image was originally loaded as the original image. When working, the program superimposes various rectangles with light and dark areas on the image. For each of them, the value of the Haar sign is calculated: the brightness of the pixels in each part of the rectangle is summed up and multiplied by the weight coefficient of the area. Then the difference between the light and dark parts is calculated. The result of calculating the value of the Haar sign for different parts of the image is stored and at the end of the work the classifier determines whether there is a face in the image or not. The result of the work can be seen in Fig. 1.

The program recognized 12 out of 13 faces. Now we need to process the image. Since a cascade classifier was used to determine faces, in order to obtain a different result, it is necessary to achieve a change in the value of the Haar sign for rectangular areas overlapping the image.

There are many ways to process images. Sometimes, to achieve the best effect, some of them are used sequentially one after the other. Let's consider two basic methods: noise filtering and image gamma correction.

Image processing

The images received for processing may contain digital noise, the presence of which increases the inaccuracy in the calculation of the Haar features. Algorithms used in noise filtering are used for "smoothing", which negatively affects the results of the application [1]. Noise filtering uses image processing algorithms to suppress digital noise to some extent. As a result, the value of Haar features for areas on the image will be closest to the value of features for a "clean" image, which will increase the accuracy of face detection.

The most popular among filters is the median filter. The principle of its operation is simple: the value of a pixel in the image is replaced by the value of the median brightness in its vicinity. It should be noted that for the best performance of the classifier, filtering is also used in order to reduce the clarity of the image.

After applying filtering (if it was necessary), it is necessary to correct the contrast and brightness of the image. Brightness is a numerical characteristic that shows how much the color of an image pixel is different from black. Contrast defines the spread between brightness values. Changing these characteristics can make it possible to see previously fuzzy details in the image.

Fig. 1. The result of face detection on the raw image

Among the means of correction, gamma correction of the image is most often used. This method allows you to change the brightness settings and increase the overall contrast.

The degree of signal coding is a scalar value and is denoted by the Greek letter "gamma" (y), and the process of changing the relationship between the input and output signals is called "gamma correction" or "gamma correction". To calculate γ, it is necessary to use the formula [1]:

$$y = \log_{AV_{in}} AV_{out},$$

where y is gamma value; AV_{in} и AV_{out} are input and output video signal values, respectively; A is arbitrary coefficient.

When digitizing images and then working with them without gamma correction, “direct” encoding of halftones takes place, which does not take into account the device of human vision, so the color perception of such an image in reality and on the monitor screen will differ. To reduce this difference, cameras and monitors use color correction using a gamma curve. The coding process is described by the formula

$$V_{out} = (AV_{in})^{y}.$$

The value $y < 1$ is called the coding gamut. For the greatest standardization of the encoded values of the input signal, there are GOSTs in Russia, and in most other countries there are standards and recommendations. This allows you to change the gamma values for the output signals, thereby simplifying the way to select the numerically necessary parameter to achieve a certain color rendition.

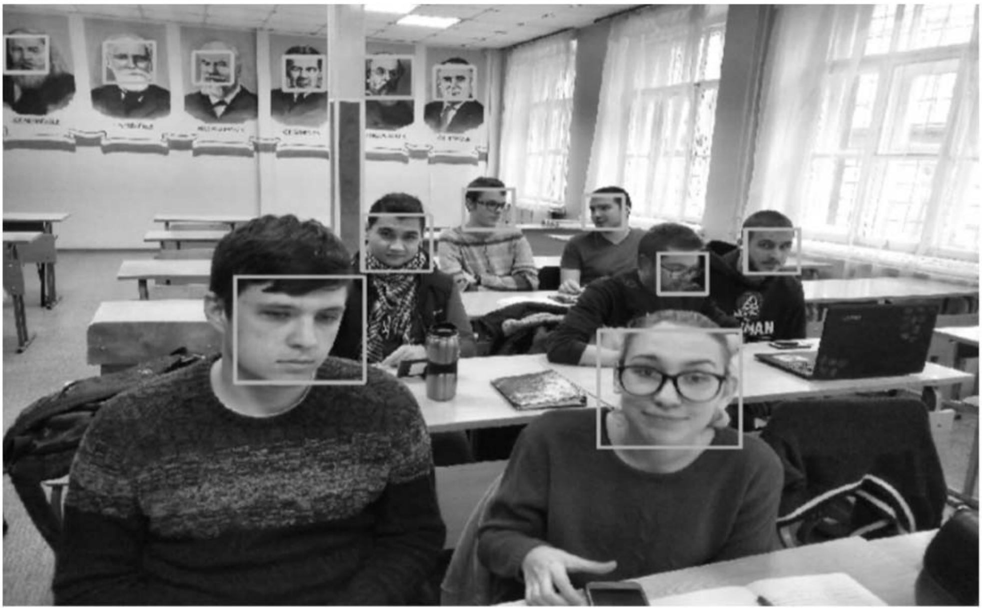

Fig. 2. The result of face detection in the processed image

In the Russian Federation, there is a standard developed for high-definition digital television, which states that when correcting basic color signals, the coefficient should be equal to 0.45. This means that the average gamma value for converting input to output must be around 2.2. As a result of applying such a gamma, the resulting colors belong to the sRGB space.

Analyzing the formula used for the encoding process, we can conclude that for values $y < 1$, the color tone of the photo decreases non-linearly, the image loses its contrast: it decreases the difference between the darkest and lightest tones, the picture becomes less bright and clear. When using $y = 1$, we get $V_{out} = V_{in}$, the image will not change, since the dependence will turn out to be linear, and when $y > 1$, the tonality increases non-linearly, the contrast increases, the picture becomes clearer and less bright.

A feature of the method of gamma correction of images is its non-linearity [3]. It represents some symbiosis of the available ways to change the tone and color of photographs: lightening, contrast, saturation. By brightening the image using gamma correction, details that were previously invisible due to their tonality may appear.

Thus, gamma correction allows, firstly, to transform the color of the image in such a way as to provide the greatest viewing comfort. Secondly, it is widely used in photo processing due to its non-linearity property.

However, often the use of conventional histogram equalization incurs loss of data located in the bright part of the image due to excessive brightness. Therefore, to prevent data loss, adaptive histogram equalization [4] is used, which uses contrast limiting. It allows you to limit the increase in brightness for the bright areas of the image.

As a pre-processing, it was decided to apply the gamma equalization of the original image. The result of the program can be seen in Fig. 2. All 13 out of 13 faces were recognized. The overall brightness and contrast of the image has been increased.

Conclusion

Thus, the use of Haar cascades without pre-processing of images can lead to inaccuracies that appear due to the specifics of the tone and the presence of noise in the original image. In order to minimize inaccuracies, it is necessary to apply image preprocessing.

The use of various types of image preprocessing without modifying the cascade classifier makes it possible to increase the accuracy of face detection, which is important for subsequent work with data. For pre-processing, methods such as applying filtering and gamma correction have proven themselves well.

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Распознавание образов с использованием синергетической модели Хакена на примере классификации цифр

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Рассмотрен пример задачи распознавания зашумленных образов с использованием синергетических вычислений по методу Хакена. Приведен процесс распознавания образов при помощи синергетической модели, а также проанализирован пример задачи распознавания одной из трех цифр. Показаны результаты распознавания образа, решения дифференциального уравнения и построения графика потенциальной функции в MATLAB. Сделан вывод о том, что формирование эталонных векторов для решения реальных проблем является непростой задачей.

Ключевые слова: *синергетика, синергетическая модель, параметр порядка, MATLAB, моделирование*

Pattern Recognition Using Haken’s Synergetic Model Applied to Digits Classification

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An example of the problem of recognition of noisy images using synergetic calculations according to Haken's method is considered. The process of pattern recognition using the synergetic model is presented, and an example of a problem of recognition of one of the three digits is analyzed. The results of image recognition, the solution of the differential equation and the construction of the graph of the potential function in MATLAB are shown. It is concluded that the formation of reference vectors for solving real-world problems is not an easy task.

Keywords: *synergetic, synergetic model, order parameter, MATLAB, simulation*

The recognition of noisy patterns occurs in many tasks in various fields, primarily in natural sciences, economics and social sciences. Usually, such a task arises in the recognition of some situation on the basis of a feature vector available. Therefore, for its solution, intelligent systems that have the property of associativity are often used [1]. Many intelligent systems do not have the property of associativity or have a number of other disadvantages. Their disadvantages are overcome by using Haken's synergetic approach. As with most intelligent systems, Haken's synergetic model includes learning and recognition processes [2].

The process of recognition of a situation by a feature vector X is described by the differential equation $\dot{X} = -\frac{\partial E}{\partial X}$ and is reduced to its solution under given initial conditions $X(0) = X_0$. These initial conditions represent the initial pattern of the recognized situation, and the solution represents the pattern of the reference situation V [3].

According to Haken, a dynamic system for recognising and classifying a situation based on a fixed feature vector X is:

$$X = \sum_{k=1}^{M} \lambda_k (V_k^+ X) V_k - B \sum_{k' \neq k}^{M} \sum_{k' \neq k}^{M} (V_k^+ X)^2 (V_k^+ X) V_k - C(X^+ X) X, \qquad (1)$$

where B and C are constants; λ_k is the attention parameter of the k-th reference pattern; M is the number of references. An pattern can be recognized if its attention parameter is positive, and the convergence rate of pattern recognition is controlled by λ_k, B and C.

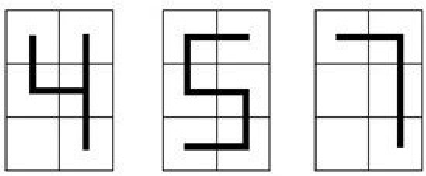
Thus, the initial pattern recognition process is as follows: for a given test pattern X_0 the dynamics of system (1) translates the initial unknown state $X(0) = X_0$ through intermediate states $X(t)$ into one of the reference pattern-states V_k, i.e. $X_0 \to X(t) \to V_k, 1 \leq k \leq M$ [2].

Using the replacement of the variable $p_k = V_k^+ X$ in (1), Haken proceeded to equation:

$$\frac{dp_k(t)}{dt} = \lambda_k p_k - B p_k \sum_{i \neq k}^{M} p_i^2 - C p_k \sum_{i=1}^{M} p_i^2. \qquad (2)$$

Equation (2) is used to classify patterns. For the current vector under test X_0 its parameter of order $p_k(0) = V_k^+ X_0$ is calculated. Here V_k^+ is a conjugate vector. The value of $p_k(0)$ is an initial condition for the solution of equation (2). The initial pattern is closer to k-th reference V_k, if the resulting solution p_k has the maximum value [4].

Let us consider the application of the synergistic model for text character recognition. A group of three characters is chosen as references (Fig. 1).



a

$V_4 = [01, 01, 11, 11, 00, 01]$

$V_5 = [11, 10, 11, 11, 10, 11]$

$V_7 = [10, 11, 00, 01, 00, 01]$

b

Fig. 1. Reference vectors:
a — text characters; *b* — vector representation

The image of a reference symbol is converted into a vector representation. Since vectors are a combination of two digits (presence (absence) of horizontal and vertical fragments of a symbol in a certain cell), it is decided to assume that vector values are formed in the binary system [5, 6]. To work with vectors in MATLAB, reference vectors are converted element by element from binary to decimal system as follows:

$$V_4 = [1,1,3,3,0,1]$$

$$V_5 = [3,2,3,3,2,3]$$

$$V_7 = [2,3,0,1,0,1]$$

The reference vectors are then centred and normalised in order to obtain vectors whose parameter sum is zero. After performing these operations, the new vector V_k with index k satisfies the conditions:

$\sum_{j=1}^{N} v_{kj} = 0$ (the sum of all components of vector k is zero)

and
$\sum_i^N \mid v_{ki} \mid = 1$ (the vector length is 1).

The next step is to calculate the conjugate vectors $V_k^+ = (v_{k1}^+, v_{k2}^+, \dots, v_{kN}^+)$. This is a very time-consuming and complex operation, especially in the case of large N. In order to convert the algorithm to the general case, a loop must be added.

Let us find the inverse matrix $A = W^{-1}$, using one or another algorithm to find the inverse matrix. The operator inv(W) performs LU-decomposition of the input matrix (or LDL-decomposition if the input matrix is hermitian). It then uses the results to form a linear system whose solution is the inverse of the inv(W) matrix. For sparse inputs, inv(W) generates a sparse identity matrix and uses the backslash.

Using matrix A, we find the conjugate vectors:

$$v_i^+ = Av_j^T, i = 1, \dots, M.$$

The set of attached vectors must satisfy the orthonormalization relations. Here v_j is a column vector, where the Kronecker symbol is of the form:

$$\delta = \begin{cases} 0, & \text{if } i = j, \\ 1, & \text{if } i \neq j. \end{cases}$$

The image "6" is taken as an arbitrary vector X, as being most similar to the number "5" (Fig. 2).

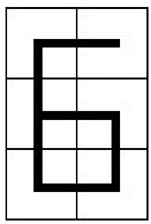


Fig. 2. Digit to test

The last step in the first calculation stage is to calculate the initial values $p_k(0)$:

$$p_k(0) = V_k^+ X_0. \tag{3}$$

The calculations result in the following order parameter values for the reference vectors:

$$p_4 = -0.3379;$$

$$p_5 = 0.9573;$$

$$p_7 = -0.5574.$$

The second stage of synergetic calculations consists in solving the system of differential equations (2) under initial conditions (3). Let us perform calculations of the first step with the presentation of intermediate results. The result is the following system of three differential equations:

$$\frac{dp_1(t)}{dt} = \lambda_1 p_1 - p_1^3 - Cp_1(p_2^2 + p_3^2);$$

$$\frac{dp_2(t)}{dt} = \lambda_2 p_2 - p_2^3 - Cp_2(p_1^2 + p_3^2);$$

$$\frac{dp_3(t)}{dt} = \lambda_3 p_3 - p_3^3 - Cp_3(p_1^2 + p_2^2).$$

We then solve the system of differential equations in time steps and at each time step calculate the value of the potential function $E\big(p_1(t), p_2(t), p_3(t)\big)$:

$$\begin{aligned} E\big(p_1(t), p_2(t), p_3(t)\big) & \\ &= -\frac{1}{2}(\lambda_1 p_1^2 - \lambda_2 p_2^2 - \lambda_3 p_3^2) \\ &+ \frac{B}{4}\big(p_1^2(p_2^2 + p_3^2) + p_2^2(p_1^2 + p_3^2) + p_3^2(p_1^2 + p_2^2)\big) \\ &+ \frac{1}{4}(p_1^2 + p_2^2 + p_3^2)^2. \end{aligned}$$

The solution of the differential equation and the potential function is shown in the graph. Fig. 3 shows that digit “6” is most similar to pattern “5”, as parameter p_2 tends to 1. Thus, image recognition and classification is performed.

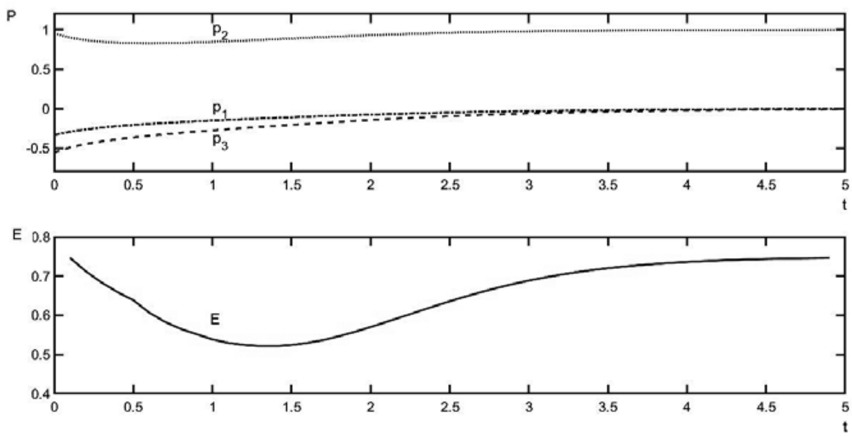


Fig. 3. Solving the differential equation and potential function for the digits recognition example

Note that this example is given only to demonstrate a possible principle of encoding source information in the form of a vector and to illustrate the application of the synergistic model for the recognition of distorted digits. The formation of reference vectors for real concrete problems is not an easy task. For more complex cases, where the digits have diagonal or semi-circular lines (e.g. digits “7” or “1”) more components have to be introduced than just horizontal and vertical lines.

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Исследование адаптивных методов управления робототехническими устройствами

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Представлено описание основных проблем и методов машинного обучения с имитацией демонстрации, а также сравнение преимуществ и ограничений различных методов. На основе этих методов приведено обсуждение ключевых проблем имитационного обучения. Рассмотрен прогноз о будущих тенденциях развития и улучшения имитационного обучения. Имитационное обучение тесно связано с другими алгоритмами в практических роботизированных системах.

Ключевые слова: *обучение роботов на демонстрации, интеллектуальное управление, динамическая система, нейронная сеть, машинное обучение*

Study of Adaptive Control Methods for Robot Devices

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A description of the main problems and methods of machine learning with simulated demonstrations is presented, and the advantages and limitations of the different methods are compared. Based on these methods, a discussion of the key problems of simulation learning is given. A prediction about future trends in the development and improvement of simulation learning is considered. Simulation learning is closely related to other algorithms in practical robotic systems.

Keywords: *training of robots on demonstration, intelligent control, dynamic system, neural network, machine learning*

Введение

Имитационное обучение (IL) двигательным навыкам роботов, известное как обучение на основе демонстрации (LfD) или программирование путем демонстрации (PbD), относится к процессу, с помощью которого роботы приобретают двигательные навыки путем изучения обучающих образцов. Как правило, для извлечения характеристик движения из одной или небольшого числа обученных траекторий, а затем обобщения характеристик для новых ситуаций, необходимо, чтобы робот имел лучшую адаптируемость.

Для интеллектуальных многоцелевых роботов недостаточно выполнять набор заранее запрограммированных действий или моделей поведения: при возникновении возмущений (например, отклонений положения) оперативные задачи робота могут не выполняться. Технология обучения роботов на демонстрациях (LfD) [1] является альтернативой технологии предварительного программирования роботов и обучения программированию. Обучение роботов заключается в том, чтобы дать роботу возможность научиться выполнять учебные задачи из обучения (обучение перетаскиванию, дистанционному управлению и наблюдение (видео, извлечение обучающей информации с изображением) и т. д.), которое отличается от традиционных методов. Самая большая разница между LfD и традиционными методами заключается в том, что робот может понять определенный навык работы и при этом иметь определенную способность к обобщению в новых ситуациях, а не простое повторение.

Объект имитации

Демонстрационное обучение имеет широкий спектр применений, таких как стратегии управления обучением, стратегии манипулирования человеческими объектами и траектории, обучаемые человеком или уменьшенные по размерам. В настоящей статье в качестве объекта обучения для анализа использовали только траекторию человеческого обучения. В настоящее время распространенным симуляционным обучением является обучение робота через человека (кинестетическое обучение), чтобы реализовать передачу человеческих навыков роботу, в частности, в режиме компенсации гравитации (Gravity compensation). В этом режиме человек может непосредственно перетаскивать робота, чтобы научить его определенной задаче, и в то же время записывать угол соединения, конечное положение и позу, силу и момент робота с помощью собственных датчиков робота, прямой кинематики и системы зрения. Состояние окружающей среды (например, положение объектов или препятствий, состояние других совместных роботов или пользователей и т. д.), и далее использовать алгоритм имитационного обучения для изучения траектории, полученной в результате обучения, для достижения цели моделирования навыков обучения.

При обучении роботов остается достаточно места для временного мелкосерийного производства, что может сэкономить время, которое следует использовать для ручного программирования и отладки. Это требует от робота более высокого интеллекта, поскольку его недостаточно для выполнения набора заранее запрограммированных действий или поведения. Как только возникает помеха (например, отклонение положения), оперативная задача робота может завершиться неудачей.

На рис. 1 приведены типичные сценарии по отслеживанию движения робота по траектории.

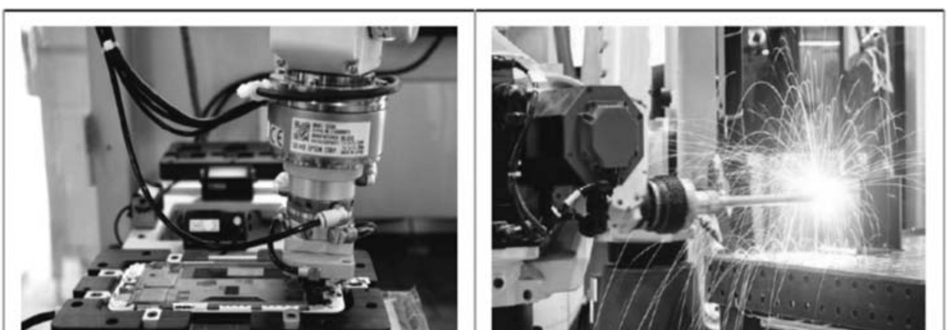

Рис. 1. Сценарии применения отслеживания движения робота по траектории: слева — дозирование, справа— сварка

Основные методы имитационного обучения

Примитив динамического движения (DMP). Примитив динамического движения (dynamic movement primitives, DMP) предлагает компактную реализацию модели движения с использованием Data Science. В этой модели вводят концепцию моторных примитивов, согласно которой человеческое поведение состоит из последовательности выполнямых основных действий, что позволяет роботу воспроизводить движения, похожие на человеческие. Кроме того, эту модель можно использовать для изучения траекторий в условиях неопределенности в сочетании с обучением с подкреплением. Тем не менее метод DMP можно использовать только для обработки одной демонстрации. Однако необходимы множественные демонстрации, потому что оптимальное движение трудно достичь с помощью только одноразового обучения, даже для эксперта.

Динамическая оценка устойчивости системы (SEDS). SEDS — это один из наиболее популярных методов, изучаемых сегодня различными исследовательскими институтами, с использованием модели смеси Гаусса (GMM) для моделирования динамической системы движения. Первоначально провели сравнение по способности каждой вероятностной модели экспериментально извлекать признаки и обнаружили, что лучше всего работает смешанная регрессия Гаусса (GMR).

На рис. 2 приведена регрессия, выполненная с использованием модели смеси Гаусса.

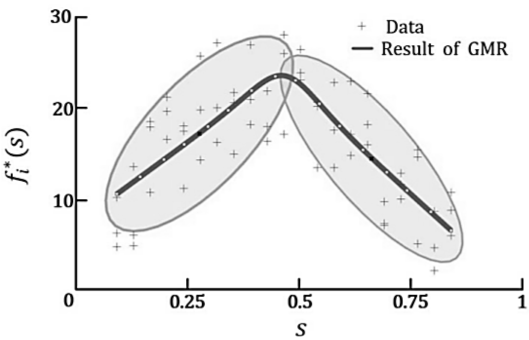

Рис. 2. GMM и регрессия (название рисунка непонятное)

Однако сторонники SEDS указали, что условия устойчивости, основанные на SEDS [2], являются достаточными условиями для обеспечения глобальной асимптотической устойчивости нелинейных движений при смеси гауссовых функций. В этих условиях можно моделировать большое число вариантов движений робота, но эти глобальные условия стабильности могут быть слишком жесткими, чтобы гарантировать точность моделирования некоторых сложных движений.

Нейронно-отпечатанные устойчивые векторные поля (NIVF). В [3] предложен метод стабильных векторных полей с нейронным отпечатком (NIVF). Локальные ограничения устойчивости выводят из параметризованных квадратичных функций Ляпунова и вводят в процесс обучения для повышения устойчивости обучаемой системы. В [4] дополнительно расширен метод NIVF с помощью подходящих функций-кандидатов Ляпунова, полученных из данных, а затем была решена задача оптимизации, полученная из функций-кандидатов Ляпунова.

Хотя этот метод может точно воспроизводить изученные действия, стабильность может быть гарантирована только в ограниченной области, по-прежнему отсутствуют строгие доказательства глобальной асимптотической устойчивости, а время обучения таких методов моделирования велико.

Контрольная функция Ляпунова на основе динамики движений (CLF-DM). Всесторонне учитывая точность, стабильность и скорость обучения, в [5] предложен метод управления динамическими движениями на основе функции Ляпунова (CLF-DM), который основан на контроле функции Ляпунова для повышения точности моделирования и скорости обучения. В этом подходе сначала создается допустимая функция-кандидат Ляпунова, согласующаяся с набором данных, а затем изучается с использованием стандартных методов регрессии, где используется стабильный член, чтобы гарантировать глобальную асимптотическую устойчивость. По сравнению с методами SEDS и CLF-DM [6] можно использовать CLF-DM для обучения на большом количестве наборов данных. Однако для обеспечения устойчивости необходимо решать оптимизационную задачу на каждом шаге вычисления, что усложняет вычисление. Кроме того, при вычислении чувствительность параметров может привести к ухудшению производительности по сравнению с SEDS.

τ-SEDS. В [7] предложен метод τ-SEDS, в котором используют диффеоморфное преобразование между функциями-кандидатами Ляпунова, а затем применяют SEDS в качестве обучающего к преобразованному пространству. Экспериментальные результаты показывают, что этот метод имеет такую же стабильность, что и SEDS, однако точность моделирования и время обучения выше и больше, чем у SEDS.

В таблице приведены сравнительные характеристики эффективности двухточечных методов обучения движению.

Сравнение различных подходов к обучению движениям

Метод	Точность обучения	Глобальная стабильность	Время обучения
SEDS	Общая	Рассмотрено	Среднее
NIVF	Высокая	Не было рассмотрено	Короткое
CLF-DM	Общая	Рассмотрено	Среднее
τSEDS	Высокая		Длинное

Заключение

Основываясь на анализе, приведенном в настоящей статье, алгоритмы с хорошими характеристиками с точки зрения точности, стабильной скорости обучения все еще нуждаются в дальнейших исследованиях.

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УДК 517

Исследование математических моделей для решения многопараметрических задач в области логистики

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Логистические услуги занимают важное место в современном мире. Однако существует проблема неточности в формировании загрузочного пространства. Исследовано применение многопараметрической оптимизации для решения этой проблемы. Рассмотрены некоторые методы многопараметрической оптимизации и указаны концепции их работы. Приведены ограничения, налагаемые на реализацию алгоритма. Кроме того, предложен алгоритм действий по оптимизации загрузочного пространства.

Ключевые слова: *оптимизация, многокритериальный анализ, алгоритм, логистика, метод решения*

Research of Mathematical Models for Solving Multiparametric Problems in the Field of Logistics

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Logistics services occupy an important place in the modern world. However, there is a problem of inaccuracy in the formation of the boot space. This article discusses the application of multiparametric optimization to solve this problem. Within the framework of the article, some methods of multiparametric optimization are considered and the concepts of their work are indicated. The limitations imposed for the implementation of the algorithm are also given. In addition, an algorithm of actions for optimizing the boot space is proposed.

Keywords: *optimization, multi-criteria, analysis, algorithm, logistics, solution method*

The solution to the problem of determining the effectiveness of information for its further processing can be found using multiparametric studies. In order to increase productivity in relation to a typical task and field of activity, rational use of multiparametric optimization, dividing it into several multiparametric tasks. This approach to solving the problem allows us to consider a mathematical model of a situational problem, determine significant input data and, based on them, analyze, evaluate possible improvements, and also apply these data in practice in providing a processed process optimization request.

To determine the most optimal way to solve the optimization problem, it is necessary to consider the query within the framework of multiparametric tasks in order to maximize the coverage of information flows and determine their significance. Based on the identified parameters, a subjective approach to the processing of an incoming request and the corresponding most effective solution is determined.

Multi-criteria optimization is the process of simultaneous optimization of two or more conflicting objective functions in a given domain of definition.

Multi-criteria optimization problems are found in many fields of science, technology and economics.

Let's determine what criteria are necessary to solve an abstract problem with a set of variables:

1. Deterministic information flows (variables).
2. Prioritization of specific privileged threads.
3. Identification of a specific optimization goal.
4. Analysis of the most suitable solution method.

Among the optimality criteria, the Pareto Criterion, Lexicographic order and scalarization are distinguished. These criteria allow us to evaluate the effectiveness of the changes proposed for improvement.

The Pareto criterion. Pareto optimality is a state of the system in which no indicator of the system can be improved without deterioration of any other indicator. The pareto-optimal state of the market is a situation where it is impossible to improve the situation of any participant in the economic process without simultaneously reducing the welfare of at least one of the others.

Lexicographic order. Lexicographic order is the relation of linear order on a set of words over some ordered alphabet. The lexicographic order got its name by analogy with alphabetical sorting in the dictionary. Lexicographic (dictionary) order is a way of ordering and sorting words, which is commonly used in dictionaries, encyclopedias and alphabetical indexes. It is based on rules that make it easier and faster to find the right information.

Scalarization. Scalar ranking is an approach to solving multi-criteria decision-making problems, when a set of quality indicators (optimality criteria) are reduced to one using the scalarization function — the objective function of the decision-making problem. In some cases, instead of one generalized criterion and solving one corresponding scalar optimization problem, it is proposed to consider a sequence of generalized criteria and a sequence of scalar optimization problems. Unfortunately, many of the similar procedures described in the literature do not always lead to effective solutions.

The method of successive concessions. The method of successive concessions for solving multicriteria optimization problems is used in the case when particular criteria can be ordered in descending order of their importance

The method of unconditional optimization. Despite the fact that unconditional optimization of a function of one variable is the simplest type of optimization problems, it occupies a central place in optimization theory from both theoretical and practical points of view.

Nonlinear programming. What is common to nonlinear programming methods is that they are used to solve problems with nonlinear optimality criteria. All methods of nonlinear programming are numerical methods of the search type. Their essence is to determine the set of independent variables that give the largest increment of the optimized function.

According to the Association of E-Commerce Companies, the e-commerce market has grown by 44 % since the beginning of 2021 [1]. This suggests that modern people prefer purchases with home delivery or to the point of delivery of orders. Based on the increase in the number of orders, we can conclude that the load on logistics services and companies is increasing.

Currently, one of the most popular types of transportation is land transport 40 %.

However, there is a problem of inaccuracy in the formation of a logistics unit for sending cargo, that is, placing cargo inside the vehicle. Most often, the difficulty lies in the correct formation of a “package” of units for transportation, since the cargo may have different endpoints. As a result, part of the way the vehicle passes partially filled or almost empty.

This article proposes a method for solving the problem of cargo space optimization using multi-criteria optimization methods.

Prerequisites imposed for solving this problem [2]:

• forming a database of goods with destination points and assigning them a certain range status, including the storage and transportation periods of units of products;

• determination of the maximum permissible loading space and weight, taking into account the restrictions imposed depending on the type of vehicle and local laws on the limitation of load capacity in different territories;

• other features of transportation, including: climatic conditions along the route, passage of border points, mandatory rest time of the driver (for long-distance transportation).

After receiving the necessary information, it is proposed to use the algorithm [3] for choosing the best load, the main positions of which are:

1. Determining the routing of a unit of goods and the formation of clusters of names by destination points, primarily identical;
2. Determination of special conditions for transportation, including: urgency of delivery, compliance with the required temperature, fragility of the unit of production, additional fasteners and further categorization, primarily identical;
3. Calculation of aggregate data on the entire volume of cargo within clusters and categories submitted for transportation, namely: dimensions, weight, type of container and additional fasteners;
4. Formation of a "loading map" based on the most similar clusters and categories of special transportation conditions, based on mathematical modeling of the loading space of a transport unit, taking into account the limitations identified at the stage of preliminary analysis;
5. Making changes to the boot space, if necessary, by adding adjacent/partially adjacent categories to the calculation, after prioritized "clusters".

Thus, when using a mathematical apparatus [4] for analyzing products for transportation, as well as dividing into clusters based on the similarity of parameters, optimal loading of a transport unit and its classification by a set of parameters is achieved. Multi-criteria optimization in this case acts as an analytical regulatory link to reduce the cost of transportation by using the maximum available loading space in a transport unit and increasing the configuration of units of goods for transport. When solving the problem of optimizing transport operations, cluster analysis, multi-criteria optimization and mathematical modeling are used.

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Некоторые вопросы лицензирования программного обеспечения

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Рассмотрены типы лицензирования программного обеспечения. Различные организации часто используют нелицензионное программное обеспечение. Дано объяснение, какую ответственность несет пользователь за использование пиратских версий программного обеспечения, а также преимущества использования лицензионного программного обеспечения. Цель настоящей статьи — научить лицензировать и проверять программное обеспечение на наличие лицензии, а также помочь разобраться в типах лицензий на программное обеспечение, определить их различия и назначение.

Ключевые слова: *лицензирование, программное обеспечение (ПО), пиратская версия, виды лицензий, преимущества, ответственность*

Some Questions about Software Licensing

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This publication is intended for those who want to understand software licensing. Various organizations often use unlicensed software. This article explains what responsibility a user has for using pirated versions of software and the advantages of using licensed software. The purpose of writing this article is to teach you how to license and check software for a license, as well as help you understand the types of software licenses, determine their differences and purpose.

Keywords: *software licensing, software, licensing, pirate version, types of licenses, advantages, responsibilities*

Introduction

For the developer, the license agreement primarily protects ownership and income generated by the distribution of the software. For the user, the license agreement can serve as the basis for the legitimacy of the use of the software.

The main document which defines the rights and obligations of a software user is the license agreement which comes with the product purchased on paper or electronically. This agreement defines the terms of use of this copy of the product. In fact, the software producer establishes a specific security structure for the use of his software.

A software license is a legal instrument governing the use and distribution of copyrighted software. Usually, a software license allows the recipient to use one or more copies of the software, and without a license. Such use would be considered infringement of the publisher's copyright under the law. A license acts as a guarantee that the software publisher, which owns the exclusive rights to the software, will not sue the one who uses it [1].

Types of software licenses and licensing

Basically, software is divided into two big groups — free software (free and open-source licenses) and proprietary software (commercial licenses). In between these groups are proprietary software which can be divided in half, such software can be downloaded and used, but until the user pays for its use, the user may have some performance problems or functional limitations.

Types of licenses. Free Use:

• open;

• free.

Non-free use:

• conditional Free;

• commercial.

Free software is defined only as open-source products which anyone can freely use, copy, study, and modify in any way they wish. People were supposed to volunteer to improve its design, but in fact free software only gained prominence in the industry when corporations became interested and invested in its development. For example, among the notable contributors to the GNU/Linux kernel, you will find not only RedHat, but also IBM, Google, and even Microsoft [2].

Open licenses include: Open-Source programs with open-source code that can be modified.

Free license types include: Freeware, GPL, Adware, Postcardware, Donationware, Nagware/Begware. Conditional free license types include: ShareWare, TrialWare, Demoware.

Commercial license types include: Commercial. The main purpose of such programs is to make profit; the code of such programs is closed.

The developer's copyright protection is the different software licensing schemes. For each type of software product, different types of licenses are used.

The following criteria are also often used in determining licensing characteristics:

• linking the licensed code to code under another license, such as when the code is provided as a library;

• the right to distribute the code to third parties;

• the right to modify the code;

• the ability to grant a patent;

• private use — whether the modification can be used privately, e.g., for internal use by a corporation;

• sublicensing — whether the modified code can be distributed under another license, such as copyright;

• the use of trademarks associated with the code.

These characteristics are often spelled out in the license agreement of both free and proprietary software, in order to avoid disagreements between the rightsholder and the user [3].

Types of licensing

Demo. A version of software with limited functionality. It is usually distributed for free and has no time limit. If the user wants access to all the features, he buys a serial number (key).

Trial. Providing full access to the software for a limited period of time (e.g., 30 days) or with a limited number of runs (e.g., 20 runs). Typically provided so that the user can evaluate the product and purchase a key for future use.

Original equipment manufacturer (OEM). Pre-installed software is one of the cheapest options. The point is that the user buys the software along with the computer or server itself and can only use it on the purchased PC.

Full Package Product. A «boxed» product is used mainly for retail sales and is convenient for individuals or small businesses. You buy one «box» and it doesn't matter how many people use this PC, you get permission to use the software product on one PC. It is also possible to change the PC, but a certain number of times.

Volume Licensing. A Volume Licensing is convenient for companies which have many employees, computers and therefore need to buy many licenses. At the same time, the company receives a registered software license, which contains information about the client (name, address, etc.), a list of software and keys for its installation. With this licensing scheme, companies applying for a special license, software developers or distributors offer significant discounts, technical support, solutions for non-standard situations, etc. This is by far the best way for companies to buy new software or upgrade it.

Subscription. Subscription for a software license provides for monthly or yearly payments. This scheme is suitable for companies that purchase more than 10 licenses (Table). It allows users to get almost all the main benefits of using this product with minimal initial costs [4].

Licensing types

License type	Payment	Product action time	Where to use	Functionality
Demo	Not required	Forever	On any hardware that supports this software	Incomplete
Trial	Not required	Limited to the number of days or runs of the program	Only on the equipment on which the software was installed	Full
Original equipment manufacturer (OEM)	One time	Forever	Only on the equipment on which the software was installed	Full
Full Package Product (FPP)	One Time. When purchased out-of-the-box	Forever	Limited number of installations	Full
Volume Licensing (VL)	One Time. When purchased by a company	Forever	On all company equipment that supports this software	Full
Subscription (SUB)	Produced several times in a certain period (month, year)	Before the subscription (payment) expires	On any hardware that supports this software after authorization	Full

Advantages of software with a license

Installing licensed software on computers gives businesses many advantages.

1. The ability to take advantage of technical support at any time. The result is prompt resolution of issues with the utility.

2. Protection against risks arising from the use of pirated software — such actions violate copyright law. In case this circumstance is detected, the company will have to pay a large fine as well as compensate the damage caused to the owner. At the same time, the equipment (computers, laptops) can be confiscated.

3. Regular updates — timely installation of all updates reliably protects the computer from virus attacks and also opens up access to the possibilities provided by new versions. In addition, many developers provide their customers with free or discounted access to updates.

4. Stable operation and a high level of performance. It excludes any failures, freezes, obtrusive ads, incompatibility with other utilities, etc.

5. Forming a positive image of the company — a company that has licenses for all the programs installed in its office has the image of an honest partner, who can be trusted.

6. Professional advice when purchasing — it is very important to have clear instructions on how to use this or that product. Therefore, organizations here get one more advantage in the form of qualified assistance from the developer.

A real chance to improve the functionality of the software — many manufacturers ask their customers for feedback on the product. Therefore, you can provide your suggestions on functionality and get the desired improvements in the new version [5].

Responsibilities for using pirated versions

Using pirated software can result in administrative or criminal liability.

Such offenses are covered by article 7.12 of the Administrative Code. The amount of fine for organizations may be 30–40 thousand roubles. In this case, intangible assets used without a license, as well as the equipment on which they were launched, can be confiscated.

Criminal liability for such an offense is provided for in Art. 146 of the Criminal Code. The condition of emergence — the cost of pirated programs exceeds 100 000 rubles (large size) or one million rubles (especially large size).

Conclusion

In conclusion, it should be noted that today there are significant problems with the use of licensed software on both home computers and equipment in educational, government, commercial and other structures. This article listed the types of licenses and options for obtaining them [6].

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УДК 004.94

Имитация двумерных сигналов в базисе Фурье как инструмент построения графов

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Исследован подход к построению графов по заданным параметрам посредством гармонического метода имитации сигналов в базисе Фурье. Приведены теоретические аспекты представления графов в виде двумерных сигналов при помощи матриц смежности. Статья содержит краткое описание метода имитации в базисе Фурье и результаты эксперимента по построению графа при помощи этого метода. В рамках анализа экспериментальных результатов обсуждаются характерные черты построенного графа. Рассмотрены перспективные задачи применения предложенного подхода. Определен путь дальнейшего исследования.

Ключевые слова: *двумерные сигналы, построение графов, системное моделирование, гармонические методы, имитация сигналов*

Работа выполнена в рамках государственного задания Министерства науки и высшего образования Российской Федерации (тема № 0705-2020-0041 «Математические основы метода имитации сигналов в базисе Фурье»). Исследование выполнено за счет гранта Российского научного фонда (проект № 22-11-00049 «Теоретическое углубление результатов и разработка конкретных практических применений в рамках систем управления»).

Generating Graphs with Two-Dimensional Signal Simulation in Fourier Basis

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This paper is devoted to the approach of generating graphs on preset parameters with the harmonic method of signal simulation in Fourier basis. Theoretical aspects for representing graphs as two-dimensional signals via adjacency matrixes are introduced. The paper contains a brief description of the simulation method in Fourier basis and results of an experiment directed at generating a graph with such a method. As part of analyzing the experimental results specific traits of the generated graph are discussed. The perspective problems for applying the suggested method are considered. The route for future research is determined.

Keywords: *two-dimensional signals, generating graphs, systems modeling, harmonic methods, signal simulation*

Introduction

Problems studied within the theory of signal processing are now being considered for new kinds of signals, e. g. multidimensional or, in particular, two-dimensional ones [1]. One of such problems is a problem of signal simulation dealing with producing signals from preset parameters such as spectral density functions. From the variety of methods available for solving such a problem in this paper the harmonic method of 2D signal simulation in Fourier basis has been chosen. Graphs are mathematical objects especially useful for describing binary relations that constitute the structure within some arbitrary system. Representing graphs as adjacency matrixes and then representing those matrixes as 2D signals renders the instruments developed within the theory of signal processing accessible for graph processing and opens up a route towards generating graphs with the methods of 2D signal simulation such as the one in Fourier basis. Theoretical basics of an original approach towards generating graphs consisting of representing graphs as 2D signals and simulating such signals in Fourier basis are given in the "Methodology" section. Experimental results and brief analysis are provided in the "Results" section. Conclusion delivers generalized overview of the work and speculates on the future research route.

Methodology

Graph is a set of vertices representing certain objects and edges representing the links or relationships between those objects [2]. Mathematically this may be written as $G = \langle V, E \rangle$, where G is a graph; V is a set of vertices v_i, $i \in [1, N]$, N is a number of vertices; E is a set of edges e_j, $j \in [1, M]$, M is a number of edges. Edges may also be denoted as *(u, v)*, where u and v are the vertices that are connected by a particular edge. For example, on Fig. 1a graph G has four vertices: *a*, *b*, *c* и *d*. It also has 3 edges: *(a, b)*, *(b, d)* и *(d, c)*.

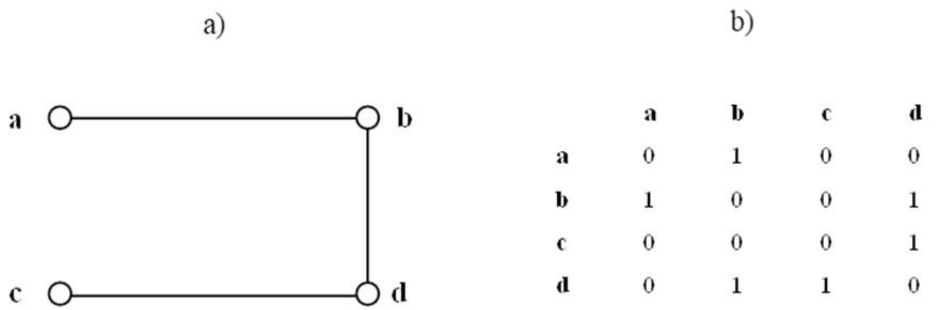


Fig. 1. Graph G (a) and its matrix (b)

When it comes to computer memory, graph may be represented in different ways. The way that is easiest to translate into digital 2D signals is an adjacency matrix with dimensions $N \times N$, where N is a number of vertices, and the element $a_{i,j}$ characterizes the edge *(i, j)* [3]. Such a matrix for the graph 1a is shown on figure 1b: the characterization of an edge is limited to signifying that such an edge *(i, j)* exists, in which case $a_{i,j} = 1$, otherwise $a_{i,j} = 0$.

The method of 2D signal simulation in Fourier basis inputs the energy spectral density function [4]. The arbitrarily selected energy spectral density function S_E used for obtaining experimental results in this paper is shown on the Fig. 2.

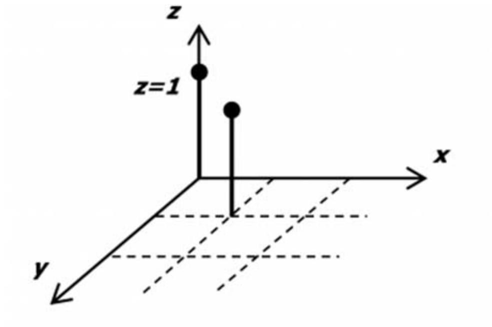


Fig. 2. Energy spectral density function chosen for simulation

Different spectral density configurations are to be discussed separately outside of this work. The special point should be made in the future about difference of energy, power and probability spectral density functions and their applicability to the task of generating graphs [5].

Fourier coefficients X_F are then calculated to link the frequency domain of the energy spectral density function and the spatial domain where signals exist:

$$X_F(0,0) = \sqrt{\frac{S_E(0,0)}{N_1^2 N_2^2}}, \quad X_F(n,0) = \sqrt{\frac{S_E\left(\frac{2\pi}{N_1}n, 0\right)}{N_1^2(1+\lambda_n^2)}}, \ X_F(0,m) = \sqrt{\frac{S_E\left(0, \frac{2\pi}{N_2}m\right)}{N_2^2(1+\lambda_m^2)}},$$

$$X_F(n,m) = \sqrt{\frac{S_E\left(\frac{2\pi}{N_1}n, \frac{2\pi}{N_2}m\right)}{N_1^2 N_2^2\left(1+\lambda_{n,m}^2\right)}}, \quad n \in [0, N_1 - 1), \quad m \in [0, N_2 - 1).$$

The coefficients obtained are multiplied by random coefficientsμ and γ that take values of “+1” and +-1” randomly. This way the random Fourier coefficients Y_F are calculated:

$$Y_F(n,m) = [\mu(n,m) - j\gamma(n,m)]X_F(n,m), \quad Y_F^*(n,m) = [\mu(n,m) + j\gamma(n,m)]X_F(n,m),$$
$$n \in [0, N_1 - 1), \quad m \in [0, N_2 - 1).$$

The random Fourier coefficients are then used to form the resulting signal *y(i, j)*:

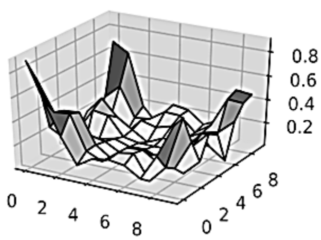
$$y(i,j) = Y_F(0,0) + \sum_{n=1}^{N_1-1} \left[Y_F(n,0)\exp\left(j\frac{2\pi}{N_1-1}ni\right) + Y_F^*(n,0)\exp\left(-j\frac{2\pi}{N_1-1}ni\right)\right] +$$
$$+ \sum_{m=1}^{N_2-1} \left[Y_F(0,m)\exp\left(j\frac{2\pi}{N_2-1}nj\right) + Y_F^*(0,m)\exp\left(-j\frac{2\pi}{N_2-1}nj\right)\right] +$$
$$+ \sum_{k_1=1}^{N_1-1} \sum_{k_2=1}^{N_2-1} \left\{Y_F(k_1,k_2)\exp\left[j2\pi\left(\frac{k_1 i}{N_1-1} + \frac{k_2 j}{N_2-1}\right)\right] +\right.$$
$$\left. Y_F^*(k_1,k_2)\exp\left[-j2\pi\left(\frac{k_1 i}{N_1-1} + \frac{k_2 j}{N_2-1}\right)\right]\right\}, i_1 \in [0, N_1 - 1),$$
$$i_2 \in [0, N_2 - 1).$$

In the case of digital signals the i and j are considered to be integers addressing the values in a matrix sized $N_1 \times N_2$. The Fourier coefficients are stored in a matrix too, n and m taken to be integers. Those matrixes then may be interpreted as adjacency matrixes from which graphs can be restored and visualized.

Results

The spectral density function from figure 2 has been processed. The simulation borders have been set as $N_1 = 10$ and $N_2 = 10$. The coefficientsμ and γ have been set as “+1” for determined non-random simulation. Visual representation of the signal simulated is shown on Fig. 3a, its matrix is shown on 3b. The borders impact the number of vertices in the resulting graph and, obviously, the variety of the graphs generated.

a)



b)

	0	1	2	3	4	5	6	7	8	9
0	0.888	0.594	0.32	0.104	0.188	0.208	0.188	0.104	0.32	0.594
1	0.693	0.455	0.469	0.178	0.118	0.218	0.242	0.034	0.177	0.616
2	0.255	0.424	0.433	0.185	0.092	0.214	0.222	0.135	0.119	0.37
3	0.143	0.312	0.194	0.165	0.091	0.167	0.13	0.167	0.028	0.157
4	0.214	0.021	0.115	0.144	0.1	0.107	0.046	0.129	0.215	0.352
5	0.097	0.293	0.273	0.113	0.086	0.083	0.086	0.113	0.273	0.293
6	0.214	0.352	0.215	0.129	0.046	0.107	0.1	0.144	0.115	0.021
7	0.143	0.157	0.028	0.167	0.13	0.167	0.091	0.165	0.194	0.312
8	0.255	0.37	0.119	0.135	0.222	0.214	0.092	0.185	0.433	0.424
9	0.693	0.616	0.177	0.034	0.242	0.218	0.118	0.178	0.469	0.455

Fig. 3. Signal simulated (a) and its matrix (b)

The matrix can already be used to construct the weighted graph as the values in the matrix are not limited to being “1” or “0” as to represent existent and non-existent edges. The values in the matrix are real numbers and provide the weights for the edges that can be interpreted as lengths of the edges or the time it takes to travel across them [6]. However, for the sake of easier visualization, it has been decided to transform the matrix into the unweighted matrix as the one on 1b. Thus, the values greater than “0.2” have been substituted with “1” and the ones lesser with “0”. The “0.2” value is therefore referred to as the threshold. The choice of threshold affects the number of edges and the number of vertices. The resulting graph is shown on Fig. 4.

The resulting graph is a directed graph as the edge *(i, j)* does not automatically imply the edge *(j, i)*. The vertices that have an edge *(i, i)* into themselves are colored black. One important quality of the graph generated, that is clearly visible on its signal representation 3a, is that the periodical nature of harmonic constituents of the signal leads to the signal being visually “almost symmetrical”. Indeed, as seen on 3b, the symmetry can be found in the matrix if the first row and the first column were to be dropped thus deleting the first vertex of the graph. Such a flawed symmetry may be useful when modeling real life systems represented by graphs [7]. As seen on 1b the structures depicted by undirected graphs produce symmetrical matrixes.

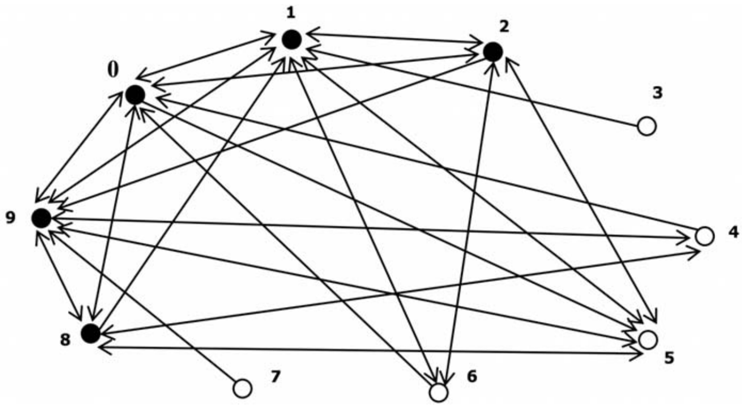


Fig. 4. Resulting generated graph with the threshold set at “0.2”

However, when structures evolve some nods deteriorate, new connections form, all adding the noise-like fluctuations on top of the simple symmetrical form. One example would be websites starting with having mutual links and then some of those links being deleted as website change their purpose or, indeed, fall prey to hackers [8]. Yet another example would be a perfectly symmetrical social communication network of friends getting rarified as certain people loose contact with each other or worsen their relationship [9]. The one vertex that hurts the overall symmetry of the graph may represent a nod exercising control over a symmetrically interconnected subsystem therefore providing a way of modeling control systems. Random signal simulation that has been described theoretically via random coefficients, but has not been executed in this paper, paves the way towards modeling dynamically changing systems [10].

Conclusion

During the experiments a graph has been generated via the harmonic method of 2D signal simulation in Foruier basis with an arbitrary energy spectral density function serving as an input. Principles for such an approach towards graph generating have been provided. Graphs generated are notable for possessing a characteristic that can be described empirically as flawed symmetry — the characteristic that has prospects in the area of real life system modeling. Problem of graph-to-signal interpretation have been defined and one route towards solving it via the chosen threshold value has been utilized. The specifics discovered, however, are to be studied and corroborated theoretically in due course. Further experimental scrutiny is to be directed at discovering particular applications of the approach described to modeling systems of various natures. Cross disciplinary analysis of the models and research into different spectral density functions should also be included into future research.

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УДК 004.93

Отслеживание объектов дорожной сцены в реальном времени на основе алгоритма SORT

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Рассмотрены алгоритм SORT (простое онлайн-отслеживание и отслеживание в реальном времени) и проблема его улучшения. Представлена основная теория алгоритма SORT, дана информация о фильтре Калмана и венгерском алгоритмое, используемых в алгоритме SORT. Новая структура улучшенного алгоритма получается путем каскадного сопоставления. Приведены экспериментальные результаты с использованием видео дорожных сцен. Особое внимание уделяется проблеме применения улучшенного алгоритма SORT в будущем.

Ключевые слова: *алгоритм отслеживания объектов SORT, фильтрация Калмана, Венгерский алгоритм, каскадное сопоставление, дорожная сцена*

Tracking Objects of the Road Scene in Real Time Based on the SORT Algorithm

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The article is devoted to the consideration of the SORT (Simple Online Tracking and Real Time Tracking) algorithm and the problem of improving it. The basic theory of the SORT algorithm is presented, information is given about the Kalman filter and the Hungarian algorithm used in the SORT algorithm. The new structure of the improved algorithm is obtained by cascade matching. Experimental results with the use of video road scenes are presented. Particular attention is paid to the problem of applying the improved SORT algorithm in the future.

Keywords: *SORT object tracking algorithm, Kalman filtering, Hungarian algorithm, cascade matching, road scene*

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Введение

Технология отслеживания объектов в области компьютерного зрения является важным предметом изучения, которое имеет большие перспективы применения в таких областях, как военное наведение, взаимодействие человека и компьютера, беспилотный автомобиль и т. д. Алгоритмы визуального отслеживания объектов делятся на две категории:

1. Алгоритм отслеживания на основе корреляционной фильтрации: MOSSE (фильтр минимальной выходной суммы квадратов ошибок), и KCF (фильтрация корреляции ядра).

2. Алгоритм отслеживания на основе глубокого обучения: SORT (простое онлайн-отслеживание и отслеживание в реальном времени).

В 2016 г. Алекс Бьюли, Зонгюань Гэ (Alex Bewley, Zongyuan Ge) и другие разработали SORT (простое онлайн-отслеживание и отслеживание в реальном времени) для отслеживания объектов. Алгоритм SORT намного превосходит другие алгоритмы отслеживания того же периода [1, с. 3464–3468].

Представлен алгоритм отслеживания объектов SORT и приведены улучшения алгоритма SORT, а также описан эксперимент с использованием видео дорожных сцен. Эксперименты показали как высокую производительность подхода, позволяющего работать в режиме реального времени, так и высокую точность, позволяющую использовать подход в реальных практических задачах.

Работа была реализована в среде Python 3.8.

Описание предложенного алгоритма отслеживания объектов

Начальная точка SORT отличается от классического алгоритма тем, что он не использует никаких признаков внешнего вида сопровождаемой цели при отслеживании объектов, а использует только положение и размер рамок обнаружения для оценки движения цели и ассоциации данных. Алгоритм не выполняет повторной идентификации, только ориентирует на сопоставление кадров, а не на надежность обнаружения ошибок. Ядром SORT является комбинированная версия фильтра Калмана и венгерского алгоритма, которая позволяет добиться лучшего эффекта отслеживания. В то же время скорость отслеживания достигала 260 Гц, что было в 20 раз быстрее, чем другие методы [2, с. 2953– 2960].

Модель прогнозирования здесь предназначена для распространения информации, такой как идентификация цели, на следующий кадр. То есть для аппроксимации смещения каждого кадра объекта используется единая модель, которая не зависит от других объектов и движения камеры, снимающей объект. Состояние каждой цели моделируется как

$$X = [x, y, s, r, \dot{x}, \dot{y}, \dot{s}]^T,$$

где x, y — координаты центра цели; s, r — размер (площадь) и соотношение сторон рамок обнаружения соответственно; $\dot{x}, \dot{y}, \dot{s}$ — представляют собой координаты центра предсказания следующего кадра и области кадра обнаружения.

Соотношение сторон здесь фиксированное, поэтому соотношения сторон переднего и заднего кадров одинаковы. Рамки обнаружения используются для обновления целевого состояния, а составляющая скорости в нем решается с помощью фильтра Калмана. Если нет полей обнаружения, связанных с целью, модель линейного прогнозирования используется без коррекции.

Ассоциация данных. Используется венгерский алгоритм присваивания для ассоциации данных, а используемая матрица стоимости представляет собой IOU между предсказанным положением исходной цели в текущем кадре и кадром обнаружения цели в текущем кадре. Конечно, результаты присвоения меньше указанного порога IOU и являются недействительными. Установлено, что использование IOU позволяет решить проблему кратковременной окклюзии цели. Это связано с тем, что при обнаружении цели наложенный объект обнаруживается, но исходная цель не обнаруживается. Предполагается, что наложенный объект связан с исходной целью. Затем после того, как окклюзия закончилась, поскольку IOU между объектов аналогичного размера часто бывает больше, правильная ассоциация может быть быстро восстановлена. Это основано на том факте, что площадь козырька больше целевой [3, с. 3047–3055].

Создание и удаление идентификаторов отслеживания. Создайте маркер для объекта в видео при его первом появлении. Когда объект покинет экран, удалите маркер. В это время необходимо учитывать все перекрывающиеся обнаружения, меньшие порога IOU, что указывает на то, что все еще есть объекты, которые не были отслежены [4]. Трекер инициализируется как рамка обнаружения со скоростью, равной 0. Поскольку в данный момент скорости нет, ковариация компонента скорости инициализируется большим значением, чтобы отразить эту неопределенность. Кроме того, новый трекер проходит период прогрева, в течение которого он накапливает достаточно информации, необходимой для связи с обнаружением цели для предотвращения ложного отслеживания. Если трекер не обнаружен в течение определенного периода времени T (в эксперименте используется 1 кадр в качестве продолжительности), отслеживание остановится, что предотвратит бесконечное увеличение количества трекеров. Есть две причины, по которым T установлено равным 1. Первая заключается в том, что объекты при фактическом обнаружении обычно не движутся с одинаковой скоростью, а вторая заключается в том, что основное внимание в статье уделяется краткосрочному отслеживанию цели. Кроме того, удаление потерянных целей как можно быстрее может повысить эффективность отслеживания.

Фильтрация Калмана. Фильтрация Калмана может найти «оптимальное» оценочное значение, используя значение, предсказанное математической моделью, и измеренное значение наблюдения, чтобы найти «оптимальное» оценочное значение (оптимальное здесь относится к наименьшей среднеквадратической ошибке) [5, с. 868–884].

Венгерский алгоритм — это алгоритм ассоциации данных, по сути, алгоритм отслеживания, который должен решать проблему ассоциации данных. Предположим, что есть два набора S и T, в наборе S есть m элементов, а в наборе T есть n элементов. Что нужно сделать венгерскому алгоритму, так это сопоставить элементы в S с элементами в T попарно (может быть, не совпадают). В сочетании со сценарием отслеживания S и T — кадр t и кадр $t - 1$. Задача венгерского алгоритма состоит в том, чтобы сопоставить рамки обнаружения кадра t с рамками обнаружения кадра $t - 1$, чтобы отслеживание завершено [6, с. 1201–1208].

Структуры алгоритм SORT и улучшенного алгоритма

Структура алгоритма показана на рис. 1. Рабочий процесс всего алгоритма выглядит следующим образом: обнаружения — это ящики, обнаруженные целью; трекеры — это информации о трекерах.

1. Создайте соответствующие трекеры из результатов, обнаруженных в первом кадре. Инициализируйте переменные движения фильтра Калмана и предскажите его соответствующий кадр через фильтр Калмана.

2. Выполните сопоставление IOU между кадром обнаружения цели кадра и кадром, предсказанным трекером в предыдущем кадре, а затем вычислите его матрицу стоимости (1-IOU) по результату сопоставления IOU.

3. Используйте все матрицы стоимости, полученные в п. 2, в качестве входных данных венгерского алгоритма для получения результата линейного сопоставления. На данный момент получено три вида результатов. Первый — несогласующие трекеры, эти трекеры необходимо удалить; второе — несогласующие обнаружения, такие обнаружения инициализируют как новые трекеры; третье — согласующие трекеры, это означает, что предыдущий кадр и следующий кадр отследили успешно и обновили соответствующую переменную трекеров с помощью фильтрации Калмана.

4. Повторяйте пп. 2, 3, пока видеокадр не закончится.

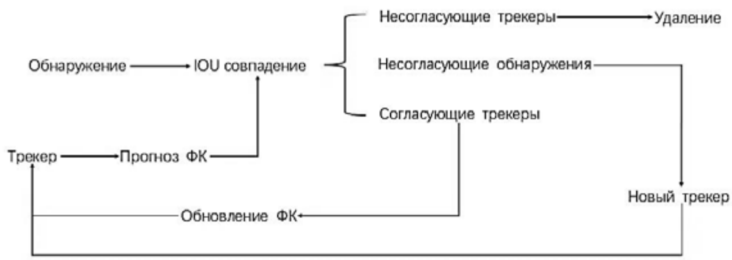

Рис. 1. Структура алгоритма SORT

Поскольку алгоритм SORT по-прежнему является относительно грубым алгоритмом отслеживания, когда объект закрыт, особенно легко потерять собственный идентификатор. Улучшенный алгоритм добавляет к алгоритму SORT каскадное сопоставление (классификационный алгоритм) и подтверждение нового трекера. Трекеры делят на подтвержденное и неподтвержденное состояние. Недавно сгенерированные трекеры находятся в неподтвержденном состоянии; трекеры в неподтвержденном состоянии должны соответствовать обнаружениям определенное количество раз (по умолчанию — 3), прежде чем их можно будет преобразовать в подтвержденное состояние. Подтвержденные трекеры должны постоянно не совпадать с обнаружениями определенное количество раз (по умолчанию 30 раз), прежде чем они будут удалены.

Рабочий процесс улучшенного алгоритма показан на рис. 2.

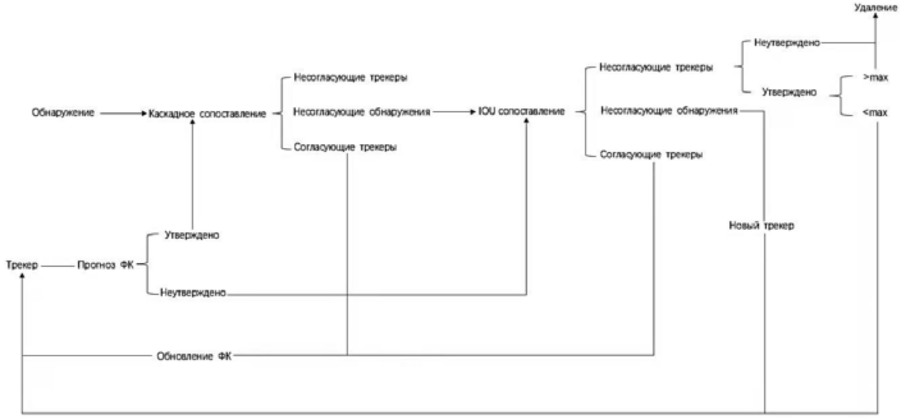

Рис. 2. Структура улучшенного алгоритма SORT

Результаты экспериментов методом алгоритма и улучшенного алгоритма

Рис. 3. Результат методом алгоритма SORT

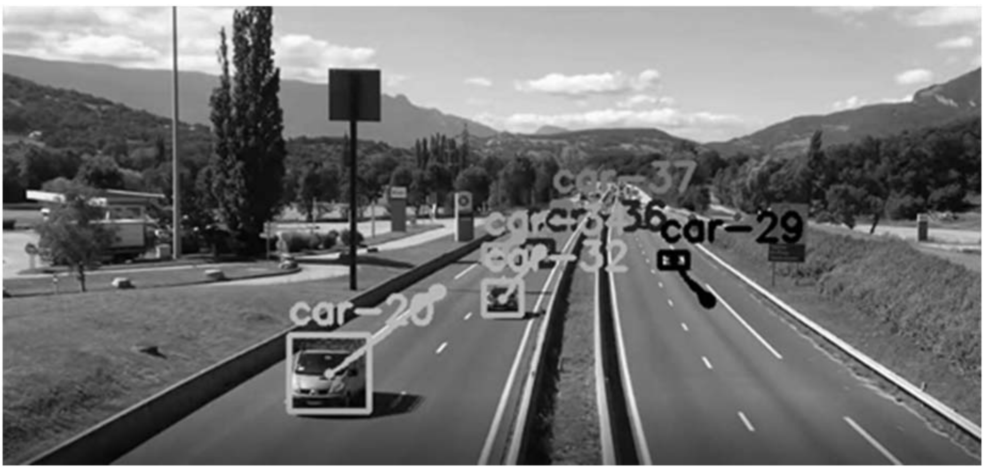

Рис. 4. Результат методом улучшенного алгоритма SORT

На рис. 3. только три автомобиля отслежено. На рис. 4. хорошо видно, что в дорожной сцене почти каждый автомобиль идентифицирован, пронумерован и отслежен, а траектория движения отмечена в центральной точке.

Заключение

Из экспериментальных результатов сравнения видно, что улучшенный алгоритм с каскадным сопоставлением позволяет лучше идентифицировать и отслеживать объекты в дорожной сцене, с высокой скоростью и высокой точностью, и практически ни один объект не пропускается. Эксперименты показали как высокую производительность подхода, позволяющего работать в режиме реального времени, так и высокую точность, позволяющую использовать подход в реальных практических задачах. Алгоритм будет иметь хорошие перспективы использования в сфере беспилотных автомобилей.

Работа выполнена при финансовой поддержке государственного комитета КНР по управлению фондом обучения за границей.

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УДК 004.2

Принципы моделирования ввода систем конвергентной обработки графов в задачах искусственного интеллекта

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Рассмотрены основные принципы и схемы моделирования ввода систем конвергентной обработки графов для решения задач искусственного интеллекта. Конвергентная обработка дается как объединение различных типов вычислителей в общей вычислительной задаче. Графы рассмотрены в более прикладном значении для целей оперирования знаниями. Предложен подход построения графа знаний при помощи управления потоками вычислений в рамках конвергентной вычислительной системы. Приведено обсуждение моделирование входа такой системы путем сопоставления графов с определенными свойствами и выработки алгоритма.

Ключевые слова: *моделирование, моделирование ввода, моделирование случайных графов, конвергентная обработка графов, потоковая обработка графов, графы в задачах искусственного интеллекта*

The Input Modeling for Convergent Graph Processing in Artificial Intelligence

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This paper discusses basic principles and schemes of convergent graph processing systems input modeling for artificial intelligence. Convergent processing is given as a combination of different types of calculators in a common computational problem. Graphs are considered in applied sense for knowledge management purposes. An approach to knowledge graph construction using computing flows control within a convergent computing system is proposed. Modeling the input of such a system by comparing graphs with certain properties and developing an algorithm is discussed

Keywords: *modeling, input modeling, random graph modeling, convergent graph processing, stream graph processing, graphs in artificial intelligence*

Introduction

Convergent data processing implies the convergence of different types of calculators in a shared computational task. Convergent computer system management is observed in paper [1].

The main advantage of using convergent computing systems for graph processing is the possibility of redundant storage of various graph representations. Each representation of the graph has its advantages for solving a particular problem, which is largely devoted to the paper [2].

Graph usage in artificial intelligence tasks has no general direction of development. Typically, knowledge base is used, and knowledge graph is represented as an ontology.

Problems of creating, reproducing, and processing ontologies as knowledge graphs are developed in paper [3]. Global open ontological knowledge graphs such as Wikidata and Google Knowledge Graph are also being developed [4].

In this paper graphs are used in a more applied sense. That sense is similar to the L_1 and L_2 levels of the DFRE approach [5]. DFRE has high importance for the convergent processing task of knowledge graphs because it contains a description of sequential graph processing from level to level for calculating the analysis result using artificial intelligence.

At the same time, the DFRE approach allocates "simple" machine learning tasks to the L_0 level, which includes:

• identifying scene objects;

• defining characteristics and external attributes of scene objects;

• definition of simple (initial) connections between objects of the scene, for example, the general vector of motion, relative location, etc.

The DFRE approach is distinguished by the continuous process of constructing a target L^* graph. This graph is based on the results of data processing by machine learning. L^* consists of continuously performed conclusions. In aggregate, a system of sequential processing of input data is presented. The direction of graph streaming processing is currently widely developed, for example, in [6].

Principles and architecture

Convergent graph processing in artificial intelligence problems can be clarified by the following principles:

• source data processing is performed outside the convergent computing system;

• consolidation of the source data processed in different ways into a single graph (according to the DFRE classification of the L_1 level) is performed dynamically in a single component;

• graph processing takes place in a streaming convergent manner: the system nodes contain local copies of parts of the graph, and graph storage is redundant from the point of view of its representations;

• the graph processing algorithm depends on the specific task of artificial intelligence: it is necessary to provide a methodology for controlling the sequence of calculations based on graphs.

The main limitation of convergent graph processing is the model of the graph stored in it.

Figure shows the organizational architecture of the convergent graph processing system. The example shown in the figure assumes the search for subgraphs isomorphic to these query graphs as a convergent processing task. The example corresponds to the DFRE tasks description.

The system input can be either a newly composed graph or a part of it defined one at the same vertices. The question of separating a new graph and a graph defined on the same vertices is beyond the scope of this paper.

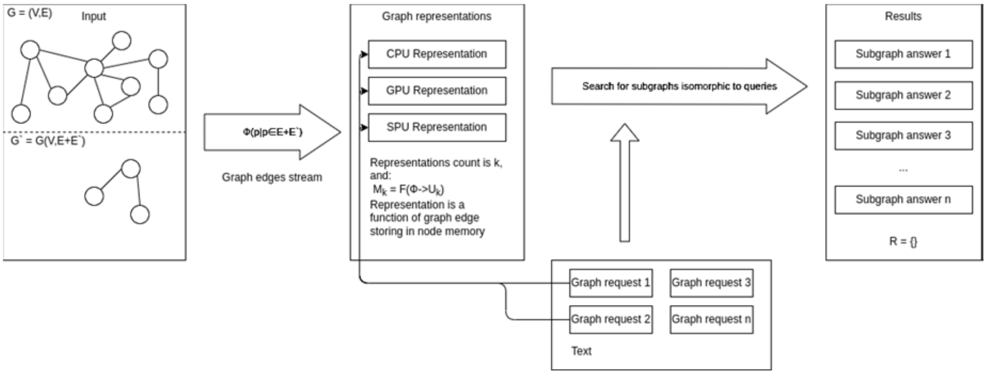
Different graph representations allow storing and accumulating private graph structures in parallel. The figure contains an enumeration of hardware graph storage types but methods of graph representation are not specified.

A general mathematical basis for storing graphs on various calculators and representing the original graphs in the streaming form of the transmission of graph edges consists of several formulas.

The graph is $G = (V, E)$ where $E \subset V \times V$.

For graph complement $G' = G(V, E + E')$. Only edges are added, and all vertices are known at the initial moment.

Edges are transmitted by the stream $\Phi(p|p \in E)$. Representations in another hand can be described as objects $M_k = F(\Phi \to U_k)$.



Organizational architecture of the convergent graph processing system

Result of the convergent graph processing system is a set of conclusions. At the current level of the task description, it is impossible to clarify the characteristics of conclusions. Moreover, they depend on the characteristics of the problem statement itself, i. e. they are determined by the developer solving the artificial intelligence problem using a convergent graph processing system.

The most important property of knowledge graphs is that they represent real networks on a par with social networks and web graph networks. This property makes it possible to use the developed mathematical apparatus for modeling real graphs for graph modeling.

Graphs in artificial intelligence tasks unambiguously correspond to the idea of preferred attachment [7]. This idea is that the new knowledge in the knowledge graph “tends” to connect with the already existing knowledge with a superior number of connections. However, this is a random process from the point of view of modeling the graph construction process.

Real knowledge graphs also have clusters of strong connectivity in the nodes of the most general knowledge. Such knowledge represents both possible connecting objects between knowledge of different nature and objects about which the greatest amount of information is known in the system.

The question of weighing and attributing edges of the knowledge graph is a matter of separate consideration. In the case of neural networks or other machine learning algorithms for knowledge graphs generation, there always will be attributes in association with edges. However, it is impossible to identify patterns in general, outside of a specific task.

Additional properties of knowledge graphs.

1. Knowledge graphs can be considered only in sequence or as part of a set.
2. Knowledge graphs have a giant component.
3. Knowledge graphs with growth contain a small number of central vertices of connectivity clusters. The larger the size of the knowledge graph, the less vulnerable the knowledge graph is to the removal of knowledge vertices.

4. The knowledge graph has a low diameter. There are no long chains of facts in one particular knowledge. However, it makes sense to look for such chains in the sequences of knowledge graphs at the meta-level.

Graph modeling scheme

The main idea of knowledge graph processing is to identify patterns, or subgraphs, isomorphic to these graphs. It is necessary to find specific answers to basic logical schemes of data connections.

The main task is to build a “compiler” of the most successful way of storing and processing a graph to solve artificial intelligence problems.

There is a problem with ensuring the convergence of various devices and methods of storing and processing graphs. The problem exists because the processing is meant to be streaming — the knowledge graph is so large that it makes no sense to store it entirely on one node in the system.

Generalized scheme is the following.

1. The knowledge graph gradually appears at the input of the system.
2. The system is physically a collection of computing units with many types: CPU, GPU, and FPGA
3. The graph is as large as it cannot be completely stored in the memory of any computing unit.
4. The task is to provide management of such a system, with static or dynamically generated queries, to build a graph processing order on these resources — the problem of planning with known graph properties.
5. The result of processing is a set of subgraphs of the original knowledge graph, each of which is isomorphic to one of the query graphs.
6. Properties of the set of knowledge graphs and differences from the host graph.
7. The presence of gigantic components — a cast of knowledge obtained to solve a single problem or class of problems is assumed to be mainly related, meeting the strict definition of a giant component for a sequence of graphs.
8. The knowledge graph sparsity is determined by the generator settings. We assume that we discard some unnecessary details in the input.
9. A separate issue is discarding.
10. We do not study knowledge graphs from the point of view of security as host/web graphs. We are not interested in the presence of stability and vulnerability.
11. The question of whether or not the presence of a vulnerability property in the knowledge graph hinders requires additional research.
12. The result of this study will influence the validity of the use of random host graph generation models for modeling knowledge graphs.
13. The graph is oriented, but the inverse edges with the opposite facts are assumed automatically.
14. A priori assume that the degrees of the vertices correspond to the theorem on the vertices of real networks.
15. The properties of the Pagerank will not interest us.

Graph generation technique

The generation is based on the Balobash-Borgs-Riordan-Chayes model [7].

The model has five parameters α, β, γ, δ_{in}, δ_{out}. These numbers are non-negative, and the sum of the first three is one. Number δ_{in} is the initial attraction of each vertex, and number δ_{out} is its initial setting links urge.

At the start, there is a graph $G_0 = G(t_0)$ with t_0 edges. For the sake of certainty, we assume that this is one vertex with t_0 loop edges. Next, exactly one edge is added at each step, so that at a time t there would be graph $G(t)$ with t edges.

However, sometimes a new edge is drawn between already existing vertices. As a result, the number of vertices at a time t is equal to some $n(t)$, which turns out to be a random variable.

The graph vertex ν is chosen according to the $indeq + \delta_{in}$ if $P(\nu = \nu_i) = \frac{indeq(\nu_i)+\delta_{in}}{t+\delta_{in}n(t)}$.

Similarly, we can say that the graph vertex is chosen according to the $outdeq + \delta_{in}$.

With $t \geq t_0$ graph $G(t+1)$ is obtained from graph G_t according to the following rules:

• with probability α, a new vertex ν and an edge coming out of the vertex ν added to any of the existing vertex ω, which is selected according to $indeq + \delta_{in}$;

• with probability β, an edge is added from an existing vertex ν to an existing vertex ω, where ν and ω are selected independently: ν according to $outdeq + \delta_{in}$, and ω — according to $indeq + \delta_{in}$;

• with probability γ, a new vertex ω and an edge coming out of the existing vertex ν is added, where ν is selected according to $outdeq + \delta_{in}$.

At the end of the process, a knowledge graph will be obtained that meets the above conditions. The model is quite accurate and at the same time easy to implement.

Conclusions

Convergent data processing implies the convergence of different types of calculators in a shared computational task. Graph usage in artificial intelligence tasks has no general direction of development. Graphs are considered in this paper in a more applied sense for knowledge management purposes.

This approach allows us to present the process of building a knowledge graph as the management of flows processed within a convergent computing system.

Input modeling of such a system makes it possible to test in practice the principles of convergent graph processing.

Modeling, in turn, requires matching graphs to certain properties and developing a special algorithm presented in this paper.

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УДК 004.8

Метод оптимизации на основе алгоритма роя частиц

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Рассмотрен нейросетевой роевой алгоритм оптимизации — метод роя частиц. Приведена краткая история возникновения и разработки алгоритма. Выделены основные требования к агентам, участвующим в алгоритме. Приведена формула, описывающая работу алгоритма, на основе которой корректируются модуль и направление скорости агентов. На примере задачи определения площади сравнены результаты обучения генетического алгоритма и метода роя частиц на разных промежутках времени, и сделаны соответствующие выводы.

Ключевые слова: *метод роя частиц, роевые алгоритмы, нейронные сети, искусственный интеллект, методы оптимизации*

Optimization Method Based on the Particle Swarm Algorithm

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This research paper considers a neural network swarm optimization algorithm - the particle swarm method. A brief history of the emergence and development of the algorithm is given. The basic requirements to the agents involved in the algorithm are highlighted. The formula describing the work of the algorithm, on the basis of which the modulus and direction of agents' velocity are corrected, is given. By the example of the problem of determining the area the results of training the genetic algorithm and the method of particle swarm are compared at different time intervals, and the corresponding conclusions are made.

Keywords: *particle swarm algorithm, swarm algorithms, neural networks, artificial intelligence, optimization methods*

The particle swarm algorithm is a numerical optimization technique that maintains a total number of possible solutions, which are called particles or agents, and moving them in space to the best solution found in that space, all the while being modified due to the agents finding more favorable solutions.

The very first computer model of the PSA was invented back in 1986 by Craig Reynolds. He, while creating a graphical model, came up with fairly simple rules of behavior for swarm particles, which made the swarm look extremely similar to a real bird's swarm counterpart.

However, the classical model of the PSA was created only in 1995 by Russell Eberhart and James Kennedy [1]. Their model differs in that the particle-agents of the swarm, in addition to obeying some rules, exchange information with each other, and the current state of each particle is characterized by the particle's location in decision space and the speed of movement.

If we make an analogy with a flock, we can say that all the agents of the algorithm (particles) in a flock can be birds or fish, setting for themselves three rather simple tasks:

1. All agents must avoid overlap with the agents around them.
2. Each particle must adjust its speed according to the speeds of the surrounding particles.
3. Each agent should try to keep a sufficiently small distance between itself and the surrounding agents.

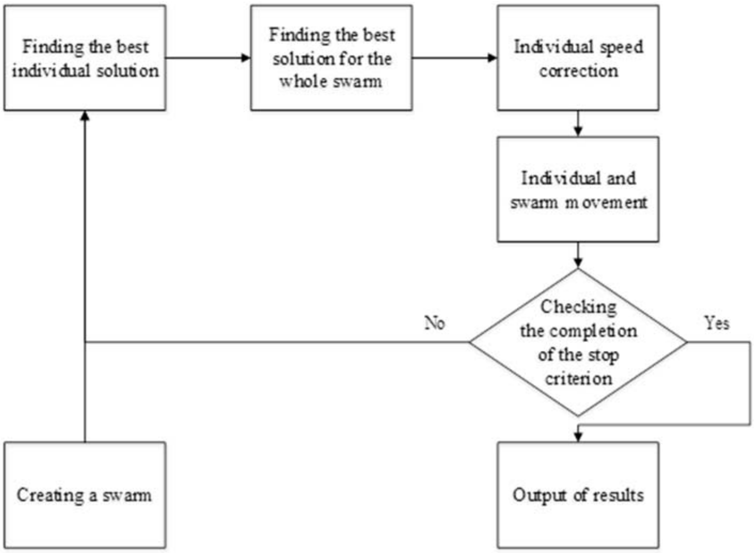


Fig. 1. PSA operation method

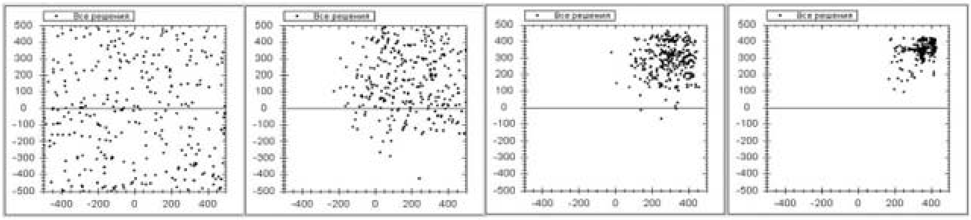
As can be seen in Fig. 1, the particle swarm algorithm is an iterative process that is constantly in flux. In order to understand how the PSA algorithm functions, we can consider the search region as a multidimensional space with agents of our algorithm. Initially, all agents are at random locations in the space and with a random velocity vector. At each of the points that a particle visits, it calculates a given function and fixes the best value of the desired function. Also all particles know the location of the best search result in the whole swarm, and with each iteration the agents adjust their velocity vectors and their directions, trying to get closer to the best point of the swarm and at the same time to be closer to their individual maximum. In doing so, the desired function is constantly being calculated and the best value is searched for. Fig. 2 shows an example of the PSA operation.

The concept of this algorithm is described by the formula according to which the modulus and direction of the agents' velocity is corrected (1) [2].

$$\omega + rnd(\square) \cdot (P_{best} \cdot \chi) \cdot c_1 rnd(\square) \cdot (g_{best} \cdot \chi) \cdot c_2 \quad (1)$$

where ω is the integration coefficient, which determines the balance between how far the agent will “go” in the study and how much the agent will want to stay close to the previously found optimal solutions; P_{best} is coordinates of the best point found by the agent;

g_{best} is coordinates of the best swarming point; x is current coordinates of the point; *rnd*() is random coefficient, taking value between 0 and 1; c_1 and c_2 are acceleration constants.



a *b* *c* *d*

Fig. 2. Example of swarm operation using the PSA method:
a — the initial position of the particles; b — the movement of particles to the extreme;
c — grouping of particles at the extremum; *d* — the final position of the particles

Initially this algorithm was applied to the research of the social psychologist, Kennedy, but the greatest spread of this algorithm could get in solving optimization problems of various nonlinear-multivariate equations. This algorithm in the modern world is used in machine learning, for solving optimization problems and in various exact and experimental sciences, such as bioengineering, etc.

Let us consider the performance and efficiency of this algorithm on the example of the problem of determining the area, comparing the particle swarm algorithm and the genetic algorithm.

Determining the forest fire area consists of analyzing the following factors for each area: area coordinates, day of the week, probability of fire (FFMC), humidity (DMC) and relative humidity (RH), dryness (DC), initial spread (ISI), temperature, wind, rainfall. Thus, it is necessary to predict the area of the fire area using the considered algorithms by training them on real test data sets (Fig. 3).

```
X Y 1th day FFMC DMC DC ISI temp RH wind rain !area
7 5 3 5 86.2 26.2 94.3 5.1 8.2 51 6.7 0 0
7 4 10 2 90.6 35.4 669.1 6.7 18 33 0.9 0 0
7 4 10 6 90.6 43.7 686.9 6.7 14.6 33 1.3 0 0
8 6 3 5 91.7 33.3 77.5 9 8.3 97 4 0.2 0
8 6 3 7 89.3 51.3 102.2 9.6 11.4 99 1.8 0 0
```

Fig. 3. Example of a test data set

The genetic algorithm for solving this problem was implemented in Microsoft Visual Studio development environment in C# with the following parameters: number of individuals in a generation — 30; elitism — 3 individuals; selection method — roulette; crossing method — one-point; mutation — 15 %; stopping criterion — number of generations (3000).

This algorithm was not the most efficient, because even with a large number of generations a satisfactory level of error was not achieved (Fig. 4). However, the value of the initial error is quite small (–10000).

The particle swarm method was also implemented in the Microsoft Visual Studio development environment in C# with the following parameters:

• number of particles in a swarm — 30;
• stopping criterion — number of iterations (500);
• particle inertia ratio — 0.729 (universal);
• local convergence ratio — 1.4944 (universal), 0.5, 2;
• global convergence ratio — 1.4944 (universal), 0.6, 2.

The particle swarm method has fairly fast convergence with large initial error. In Fig. 5 shows that the algorithm converged from 9 513 970 to 24155.88. Also in Fig. 5 shows a comparison of algorithm performance with different parameter variants, where the best ones for this problem are: local convergence coefficient — 0.5, global convergence coefficient — 0.6. Thus, to solve this problem, none of the proposed methods was sufficiently effective in its basic implementation, since the value of the resulting error in both cases was quite large. Therefore, to solve the problem more effectively, it is necessary to move away from the linear implementation of these algorithms and use them as algorithms for training a neural network. A unidirectional neural network of multilayer perceptron type with one hidden layer was implemented in Microsoft Visual Studio development environment in C#. Each perceptron has an array of weights, corresponding to the size of the input vector, bias, error and output. The initial values of weights are set by random numbers in the range [–0.3; 0.3]. To calculate the perceptron output the following sigmoidal function is used [3] (2):

$$S = \frac{1}{1+e^{-\Sigma w_i \chi_i + blas}}. \tag{2}$$

The results of the implemented program after 1 and 10 seconds of start-up are shown in Fig. 6 and 7, respectively. The graphs show that the particle swarm method works and converges much faster than the genetic algorithm, although it starts with a larger error.

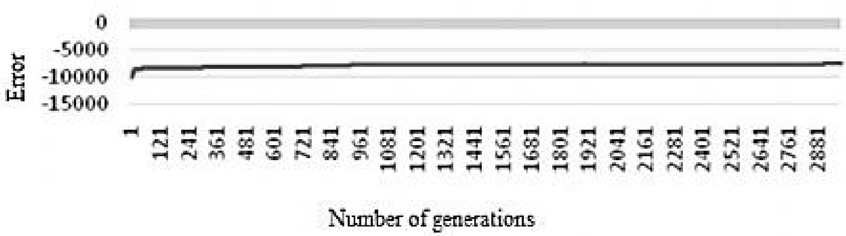


Fig. 4. The graph of genetic algorithm error dependence on the number of generations

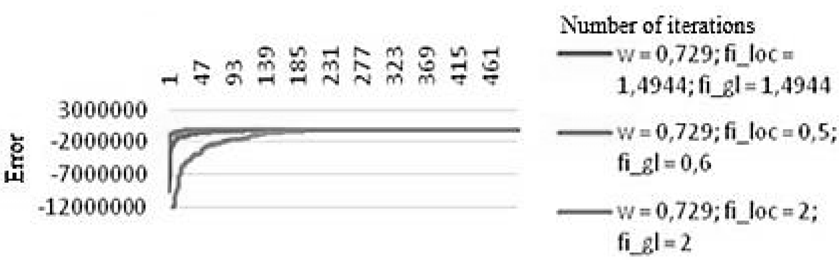


Fig. 5. Experimental results of the particle swarm method with different parameters

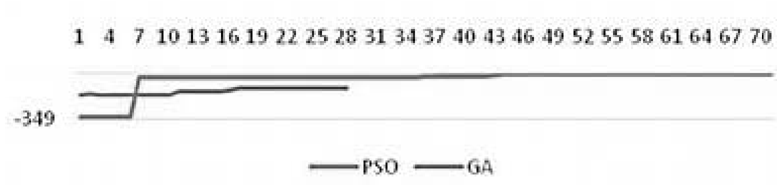


Fig. 6. Comparative graph of the algorithms at startup for 1 second

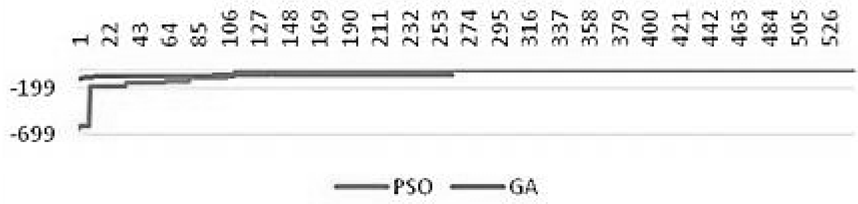


Fig. 7. Comparative graph of the algorithms at startup for 10 seconds

Thus, according to the research results it can be concluded that for the solution of the task, the implementation of basic linear algorithms did not give satisfactory results, because the minimum error value was quite large (24155.88 — PSO and 7415.93 — GA). But, despite this, when applying these algorithms to train the neural network, good results were achieved, namely, the magnitude of the initial and resulting errors decreased. The particle swarm method proved to be more effective for solving this problem.

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Генерация признаков в задаче предсказания характеристик стали после продувки

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Рассмотрена генерация признаков в задаче предсказания характеристик стали после окончания продувки. Приведен перечень доступных для анализа и генерации новых признаков исходных данных. На их основе предложены признаки, которые должны повысить предсказательную точность модели. С помощью фреймворка SHAP сгенерированные признаки оценены и отранжированы по вкладу в предсказательные модели на основе градиентного бустинга для температуры и доли углерода в стали после продувки. Сделаны выводы о том, что при наличии достаточных вычислительных мощностей генерация значимых фичей для задачи предсказания характеристик стали по окончании продувки может основываться на трех основных направлениях: генерация простых агрегатных фичей, генерация фичей основанных на особенностях техпроцесса и генерация сложных фичей, использующих подходы из других сфер применения машинного обучения.

Ключевые слова: *генерация признаков, машинное обучение, анализ временных рядов, скользящее среднее, кроссовер, продувка стали*

Feature Generation in the Problem of Predicting Steel Characteristics after Oxygen-Blowing

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This study is devoted to the generation of features in the task of predicting the characteristics of steel after purging. The list of input data available for analysis and creation of new functions is given. Based on this, functions are proposed that should increase the accuracy of the model prediction. Using the SHAP structure, the generated characteristics are evaluated and ranked according to their contribution to predictive models based on an increase in the temperature gradient and the proportion of carbon in the steel after purging. It is concluded that with sufficient computing power, the generation of significant features for the task of predicting the characteristics of steel after purging can be based on three main areas: the generation of simple aggregated functions, the generation of functions based on the specifics of the process and the generation of complex functions using approaches from other areas of machine learning applications.

Keywords: *feature generation, machine learning, time series analysis, rolling average, crossover, oxygen-blown steelmaking*

Introduction

When steel is made, iron is purged with oxygen to remove impurities. This process takes an average of 15...25 minutes at a temperature of about 1600 degrees Celsius. The process is controlled by the operator of the distribution machine, who, based on his experience and knowledge, determines the moment when the blowing process should be stopped. During the blowing process, the metal is saturated with oxygen and its temperature rises. If the purge process lasts longer than necessary, more metal is burned and less steel is produced, resulting in a loss of profit; if, on the contrary, the steel is insufficiently purged, the steel grade will not meet the specified criteria, and the purging process must be repeated, which reduces the overall productivity of the steelmaking shop.

It is not possible to perform a continuous chemical analysis of the melt during the blowing process, so reaching of desired steel composition can only be judged by indirect signs. Human attention can be dulled, so there is a challenge of automated prediction of steel characteristics at the end of the blowing process. From this problem in turn follows the problem of optimizing controlled parameters of blowing [1].

In this study, we focus on the problem of predicting state of steel at the end of the blowing process. To formalize the problem, it is assumed that the state of the steel can be considered by two main characteristics: temperature and carbon fraction. This problem is a regression problem belonging to field of classical machine learning [2]. And, as shown by Kiran Karkera [3], it can be solved as multi-target regression with a single algorithm or as two separate problems.

Regardless of the chosen solution method, a widely used step in classical machine learning is the generation of new features on the basis of existing ones [4]. Although this approach is widely accepted, the design of a specific list of features in each case is a difficult task, and the accuracy of the final predictive model depends on the quality of its solution [5].

The purpose of this study is to describe possible features in problem of predicting steel characteristics after blowing, the generation of which will significantly improve accuracy of predictive models.

Methodology

New feature generation is only one of the steps in solving the prediction problem. In addition to it, it also requires selection of a quality metric, data preprocessing, selection of the loss function and model fitting, and, as a final step, conducting prediction. However, in this study, the main focus in methodology section will be on the generation of new features, while the way to assess their importance will be given for reference in the results section.

To generate new features, it is necessary to understand structure of the raw data available for analysis. In the considered problem, it is assumed that following data are available:

• table containing the basic parameters of blowing — instantaneous oxygen flow rate and lance position (inclination);

• table containing the weight and type of scrap used in each heat;

• table containing basic information about the meltdown — characteristics of the meltdown and equipment (steel grade, casting direction);

• table containing the names, moments and volumes of bulk additives used in the technological process;

• table containing data on the start and end times of various operations during the meltdown;

• table containing the chemical composition and characteristics of cast iron;
• table containing information about the analysis of exhaust gases;
• table containing target values — steel temperature and carbon content at the end of melting.

Most of the data are of the continuous type, there are also categorical, and date time data. Thus, although the problem itself is not a time series prediction problem in classical form, elements of time series analysis can be applied in its solution.

At the first stage of the generation of features, simple aggregate indicators for continuous numerical attributes, such as maximum, minimum, mean and variance, can be generated. Also, for some initial parameters, calculation of sum may be appropriate, if in essence they reflect not the state of the system, but some quantitative changes in it. For example, summation is appropriate for the mass of scrap poured into the converter furnace during melting.

For categorical features, the basic approach is one-hot encoding, which is the creation of a separate binary variable for belonging to each of the categories observed in the dataset. One of the new variables is traditionally discarded in order to avoid multicollinearity in data [6].

Since most of the data are time series, new features can be generated based on their analysis. The simplest features that can be generated for use in a predictive model are duration of a process step, value of a quantitative indicator at the start or end of an operation, and difference in value of the indicator at start and end moments of some technological operation.

More complex attributes that can be generated on the basis of time series are associated with their approximation. If monotonous or close to it dynamics are observed for any attribute, or only one significant change in its value level, the slope coefficient of the linear regression for this attribute can become a feature.

Fig. 1 shows an example of fitted regression for the fraction of oxygen in exhaust gases.

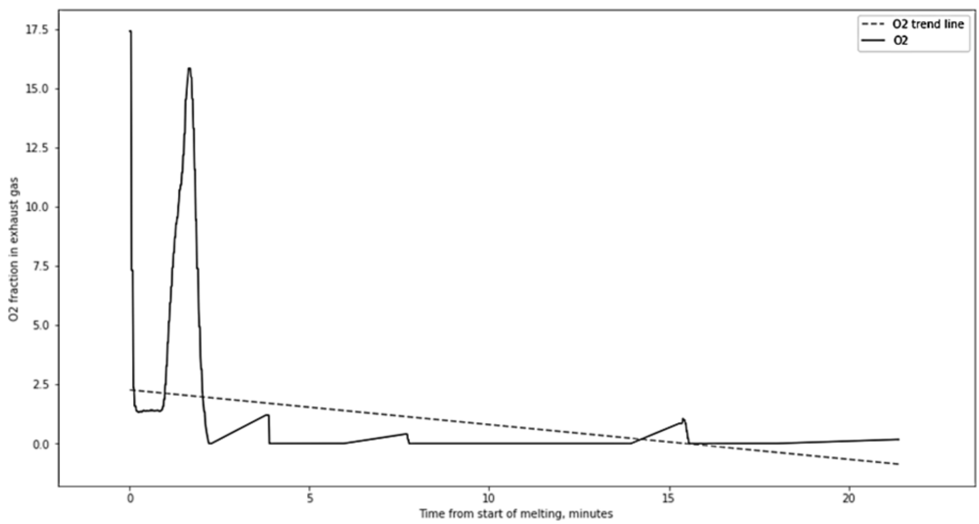

Fig. 1. Example of the trend of the oxygen fraction in exhaust gases

If trend of some indicator changes in course of melting, then a more relevant way of its approximation is smoothed time series. In this case, as the practice of algorithmic trading shows, it is reasonable to construct them with different windows for the same time series and after that to find the moments of trend change, in the points where the series smoothed by different windows intersect [7]. In the problem of generation of new features, it is possible to go further, and generate such features as time from crossover of series to the end of blowing, ratio or difference of smoothed time series at the end of blowing.

When smoothing time series, the question of choosing appropriate smoothing interval inevitably arises. In this study, the input data were presented in a per-second breakdown, while the duration of blowing, for most observations, were from 15 to 25 minutes, and changes in the trends observed visually on the plots occurred about once every 5...10 minutes. Therefore, windows of 30 and 300 seconds were chosen as basic solution.

Fig. 2 shows an example of a plot of changes in the exhaust gas temperature during blowing process, and highlights the first point of intersection of the smoothed time series, when the exhaust gas temperature began to decrease.

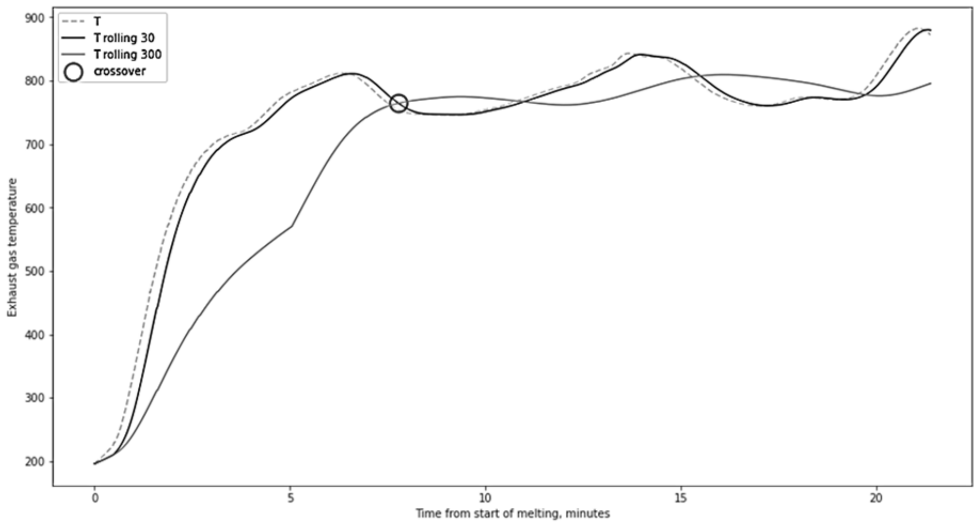

Fig. 2. Example of exhaust gas temperature rise

Finally, it makes sense to generate features and attributes based on an understanding of the technological process. For instance, additives can be divided into fuels and fluxes and aggregate their consumption by these groups. And in the exhaust gases it is possible to calculate the balance of gases $CO + CO_2 - O_2$, shown in Fig. 3 below.

This feature is based on the idea that during blowing, oxygen fed through the lance combines with the carbon in the cast iron and volatilizes as CO and CO_2 [8]. When the carbon content in the steel decreases, the value of this feature will go down and this can be tracked. As shown further, aggregated into the feature by the difference of the moving averages taken with a window of 30 and 300 seconds at the end of the blowdown, the balance of CO + CO2 — O2 in the exhaust gases proved to be most significant in the model predicting the carbon fraction in steel after the blowing.

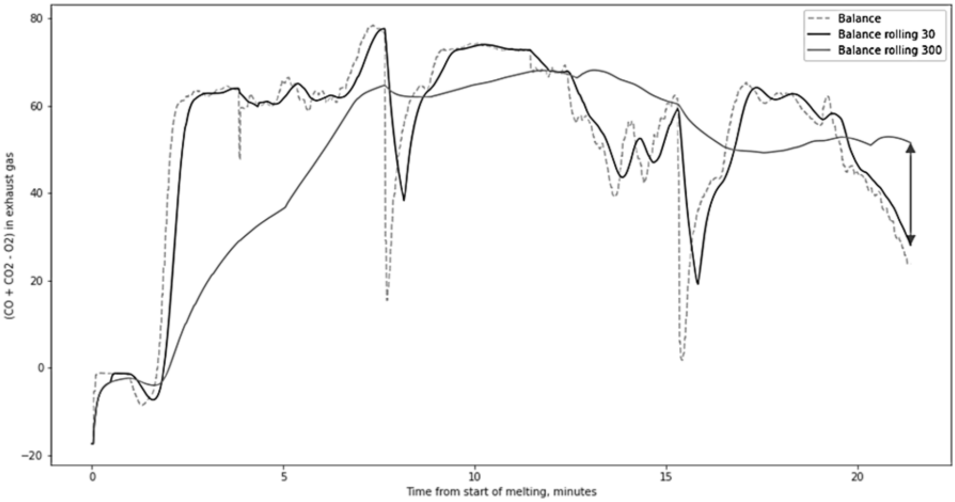

Fig. 3. Example of changing the balance of exhaust gases

Results

As part of this work, the prediction of carbon content and steel temperature was carried out using two separate sequential models. The predicted steel temperature were used as a predictor in the steel carbon fraction prediction model. Gradient boosting models from the LightGBM library were used to predict both target variables. Mean absolute error was used as the loss function. The importance of the features was evaluated using the SHAP – SOTA algorithm for interpreting complex machine learning algorithms proposed in 2017 by Lundberg and Lee [9].

Fig. 4 shows 15 most important features for predicting the temperature of the steel at the end of the meltdown.

In the chart above, the features are presented in descending order of their contribution to the predictive accuracy of the model. They make the following technological sense:

• RAS_sum — total oxygen consumption during the entire blowing process time;

• Plavka_NAPR_ZAD_МНЛЗ — binary variable shows that steel is poured through a continuous casting machine after melting;

• Plavka_NAPR_ZAD_МНЛС — binary variable shows that steel is poured through a continuous slab casting machine after melting;

• AR_max – maximum fraction of argon in the exhaust gases;

• Plavka_NMZ_SC2/ЭТ — binary variable shows that the melting was directed to smelt steel of SC2/ЭТ grade;

• H2_mean — average hydrogen fraction in exhaust gases;

• from_cross_till_end — time elapsed from the first crossover temperature of exhaust gases to the end of the melting;

• CO2_mean — average fraction of carbon dioxide in exhaust gases;

• T — temperature of exhaust gases at the end of melting;

• total_lom_weight — total weight of scrap piled up during melting;

• final_balance — difference of rolling averages taken with a window of 30 and 300 seconds on the balance of exhaust gases ($CO + CO_2 – O_2$) at the end of blowing;

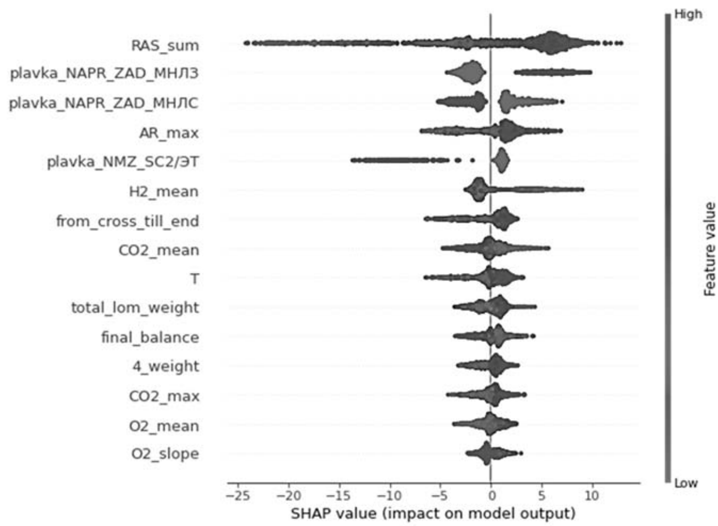

Fig. 4. SHAP feature importance in the model for steel temperature prediction

• 4_weight — total weight of scrap with code 4, piled during melting;

• CO2_max — maximum fraction of carbon dioxide in exhaust gases;

• O2_mean — average fraction of oxygen in exhaust gases;

• O2_slope — slope of linear trend of dependence of the oxygen fraction in exhaust gases on the time since start of blowing.

Fig. 5 shows similar top 15 features for predicting the carbon fraction in the steel at the end of the blowing process.

The features shown in the diagram above have the following meaning:

• final_balance — difference of rolling averages taken with a window of 30 and 300 seconds on the balance of exhaust gases ($CO + CO_2 – O_2$) at the end of blowing;

• final_T — ratio of sliding average temperatures of exhaust gases, taken with windows of 30 and 300 seconds at the end of blowing;

• AR_max — maximum fraction of argon in the exhaust gases;

• Plavka_NMZ_Ш2.1 — binary variable shows that the melting was directed to smelt steel of Ш2.1 grade;

• RAS_sum — total oxygen consumption over the entire blowing process;

• VES — weight of cast iron in the melting scoop;

• O2_mean — average fraction of oxygen in exhaust gases;

• T_pred — predicted temperature of the steel at the end of the meltdown;

• 408_weight — total weight of scrap with code 408, piled during melting;

• final_AR — ratio of sliding average argon fractions in exhaust gases, taken with windows of 30 and 300 seconds at the end of blowing;

• total_sip_weight — total weight of bulk additives piled up during melting;

• total_lom_weight — total weight of scrap piled up during melting;

• flux_weight_agg — total weight of fluxes piled up during melting;

• plavka_DUR — melting time;

• from_cross_till_end — time elapsed from the first crossover temperature of exhaust gases to the end of the melting.

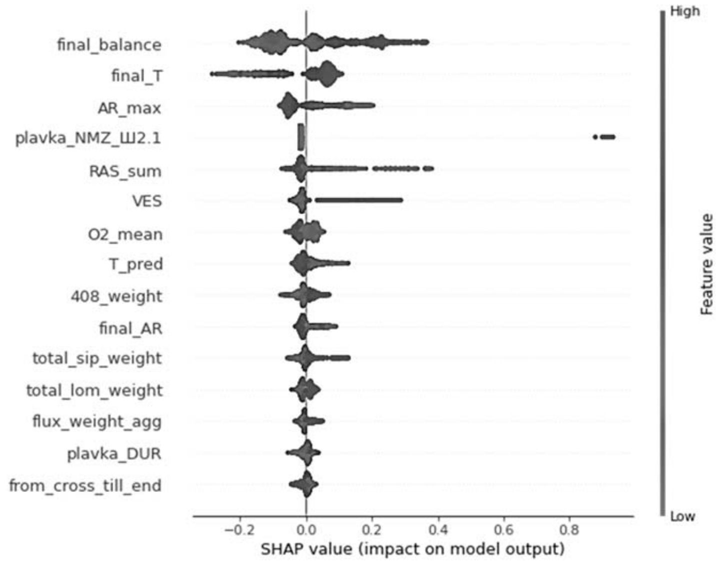

Fig. 5. SHAP feature importance in the model for carbon fraction in steel prediction

Discussion

As can be seen, the vast majority of the features with high significance are generated, rather than the original ones that were present in the original dataset. Thus, it can be concluded that the proposed features increase the accuracy of the predictive model.

However, it is worth noting that in both models, the top 15 features include some that can be considered data leaks in a sense. By this is meant features that encode direction of steel casting and target grade of the steel being melted. Obviously, the target steel grade influences decisions made by the distributor operator, and, consequently, carbon content and steel temperature at the end of blowing. But, since these parameters are known before the melting starts, it was decided to leave them in models.

It should also be emphasized that both relatively simple and complex features have ranked high in terms of predictive strength. Therefore, a general recommendation can be made that, if computing power allows it, generation of complex time-series-based features will be useful in solving problem of predicting and optimizing results of steel-blowing process. Similarly, using sequential models in this problem also increases accuracy of the second one, but slows down the calculation time.

Conclusions

The study has shown that new generated features play the main role in predictive models. At the same time, complex features based on analytical transformations of time series: linearization and moving average smoothing occupy high positions in the ranking of importance. But in addition to these, features based on simple aggregate functions, such as average, maximum, and sum taken for certain especially important attributes perform well.

Also, an important role in the predictive models is taken by the features based on the understanding of the technological essence of the blowing process: balance of exhaust gases $CO + CO_2 - O_2$ and aggregates by groups of similar bulk additives. Thus, it can be concluded that generation of meaningful features for the problem of predicting steel characteristics at the end of blowing can be based on three main fields: generation of simple aggregate features, the generation of features based on process specifics and generation of complex features using approaches from other areas of machine learning applications, such as algorithmic trading.

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УДК 004

Методы и способы исследования в кибербезопасности

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По мере того, как интернет-технологии становятся все более распространенными в обществе, угрозы кибератак возрастают, и, как следствие, повышается необходимость в кибербезопасности. Сегодня каждый имеет повсеместный доступ к Интернету, используя такие устройства, как смартфоны, планшеты и персональные компьютеры, с помощью которых можно получить выход в Сеть практически отовсюду. Однако у интернет-технологий, используемых в киберпространстве, как и практически у всех новых технологий, наряду с позитивными существуют и негативные стороны.

Ключевые слова: *интернет-технологии, кибербезопасность, вредоносное программное обеспечение, социальная инженерия, человеческий фактор, экономический фактор*

Methods and Ways of Research in Cybersecurity

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As Internet technologies become more widespread in society, the threats of cyberattacks are increasing and, as a result, the need for cybersecurity is increasing too. Today, everyone has ubiquitous access to the Internet, using devices such as smartphones, tablets, and personal computers that allow you to get online from almost anywhere. However, Internet technologies used in cyberspace, like almost all new technologies, have negative aspects along with positive ones.

Keywords: *internet technologies, cybersecurity, malware, social engineering, human factor, economic factor*

Introduction

The speed of development and change in cyberspace in recent years is amazing not only for users, but also for specialists in the field of information technology and information security. There is an exponential development in the amount of data processed, the number of devices or applications/services connected to the Internet, as well as the concepts and technologies themselves. Comprehensive digitalization and the transition of most businesses to the online format have only accelerated this trend [1].

Cybersecurity is the practice of protecting critical systems and sensitive information from digital attacks [2]. Also known as information technology (IT) security, cybersecurity measures are designed to combat threats against networked systems and applications, whether those threats originate from inside or outside of an organization.

Analyzing the approaches to the interpretation of the concept of cybersecurity, it should be noted that the reason for the need to introduce this concept was the spread and increasing commission of crimes using in-formation and communication technologies — cyber-crime.

Cybercrime should be understood as a set of crimes committed in cyberspace through computer systems or through the use of computer networks and other means of access to cyberspace, within computer networks, as well as against computer systems, computers, computer networks and computer data.

Information and cyber security is not a new research topic, but it has been a major national issue for over 20 years and has led to the rapid growth of the research literature over the past 10 years.

Cyberattacks, the attempt to hack into or otherwise disrupt or destroy computer networks or other Internet devices, is one of the prominent negative consequences of the development of Internet technologies. A cyberattack can range from something as small as an individual downloading a computer virus to something as large as hacking into entire multinational corporations to gain insider knowledge or stealing financial information from customers.

The first major function of cybersecurity is the identification of cyberattacks. This includes understanding the risk associated with cyberattacks and how to manage those risks. There is a relatively small amount of scientific literature on cyberattacks. It mainly focuses on three topics: types of cyberattacks, technologies used, and consequences [3].

The types of cyberattacks currently well studied are phishing, malware, hacking, and fraud. However, there are other types of cyberattacks that are not as well studied in the literature. These include, for example, social engineering.

Technologies involved in these attacks may include smartphones, tablets, laptops, personal computers, etc. There is also an initial understanding of cyber threats for medical technology.

Knowledge is accumulating about the immediate consequences of cyberattacks. This includes identity theft, money theft, intellectual property theft, data loss, and loss of web traffic.

The main areas of research in the field of information security, in addition to technical, are human and economic factors.

Human factor

Today, there is a rapidly growing number of studies related to human factors that influence cybersecurity behavior [4].

The current literature in this area focuses on four main factors related to human behavior in the field of cybersecurity:

- knowledge and experience in the field of cybersecurity [5];
- unrealistic trust or optimism in cyberspace [6];
- demographic factors and individual differences affecting cybersecurity;
- cybersecurity beliefs and perceptions.

In the current literature, there are also many research models created to explain the relationship between users and cybersecurity technologies. The accumulated knowledge in the field of information security takes into account many factors such as knowledge, experience, trust, attitude, age and gender that influence human behavior in cyberspace [7].

Attackers tend to look for the weakest link to break through the system, and usually the weakest link is a person, as they are directly involved in unsafe behavior.

Economic factor

Another new area of research in the field of information security is the factors that influence the practice and behavior of companies in the field of cybersecurity. The two main components in the literature are how companies should treat employees regarding cybersecurity and the costs of implementing and improving their information security strategies, and also assess information security risk management.

Companies must take care not only to protect their network from cyberattacks, but also to ensure that their employees do not put the company at risk. Research has focused on factors that can cause an employee to engage in risky behavior while on the job that could negatively impact the business.

These factors explored in current literature include employee motivation, stress, ethics, personality, and knowledge of the company's information security policy [8].

Conclusion

In the behavioral sciences, cybersecurity is still a new area of research. In the field of information and computer security, research has highlighted many critical topics such as legal issues, monitoring and morality, vulnerabilities and risks, awareness and motivation.

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Искусственный интеллект для встроенной среды

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Рассмотрено влияние процессов искусственного интеллекта (ИИ) на искусственную среду. Представлено несколько примеров исследований ИИ из работы кафедры вычислительного моделирования и моделирования Мюнхенского технического университета, которые будут включены в основанный в ноябре 2020 года Институт Георга Немечека. Сделаны выводы, что методы искусственного интеллекта демонстрируют значительный потенциал для дальнейшей автоматизации и повышения эффективности во многих областях. Это включает, в частности, застроенную среду и связанные с ней экономические компоненты. Очень часто здесь генерируются большие объемы неструктурированных данных, которые можно переработать в более качественную информацию с помощью процессов ИИ. Возможные области применения варьируются от учета существующих зданий и генерации цифровых двойников до частичной автоматизации и помощи в проектировании и планировании зданий до обработки данных мониторинга, возникающих на строительных площадках или в процессе эксплуатации.

Ключевые слова: *искусственный интеллект, деревья принятия решений, метод опорных векторов, сети Байеса, эволюционные алгоритмы, цифровые двойники*

Künstliche Intelligenz für die gebaute Umwelt

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Die Auswirkungen von Verfahren der künstlichen Intelligenz auf die gebaute Umwelt werden untersucht. Mehrere Beispiele der KI-Forschung aus der Arbeit des Lehrstuhls für Computergestützte Modellierung und Simulation an der Technischen Universität München, der in das im November 2020 gegründete Georg-Nemechek-Institut eingegliedert wird, werden als Beiträge angeführt. Methoden der künstlichen Intelligenz bieten in vielen Bereichen ein erhebliches Potenzial für weitere Automatisierung und Effizienzsteigerung. Dies gilt insbesondere für die bebaute Umwelt und die damit verbundenen wirtschaftlichen Komponenten. Hier fallen oft große Mengen an unstrukturierten Daten an, die mit Hilfe von KI-Verfahren zu besseren Informationen verarbeitet werden können. Die Anwendungsmöglichkeiten reichen von der Erfassung des Gebäudebestandes und der Erstellung digitaler Zwillinge über die Teilautomatisierung und Unterstützung bei der Gebäudeplanung bis hin zur Verarbeitung von Überwachungsdaten aus Baustellen oder dem Betrieb.

Keywords: *Künstliche Intelligenz, Entscheidungsbäume, Support Vector Machines, Bayes-Netzwerke, digitale Zwillinge*

Einleitung

Künstliche Intelligenz ist ein Teilgebiet der Informatik, das zum Ziel hat, ein technisches Äquivalent zur menschlichen Intelligenz zu schaffen. An diesem Leitziel arbeiten Informatiker gemeinsam mit Experten aus vielen weiteren Wissensgebieten.

In der KI-Forschung versucht man, mit den Mitteln der Informatik, Neurologie, Psychologie und Linguistik das Gehirn und seine Funktionen technisch nachzubilden. Die Ansätze der KI-Forschung verraten dabei auch stets etwas über unsere Vorstellung von uns als Mensch und über unser Verständnis von "Intelligenz".

Eine künstliche Intelligenz, die über einen eigenen Willen verfügt und autonom handelt, ist noch immer Fiktion. Doch in vielen Lebensbereichen spielt die visionäre Technik bereits eine zentrale Rolle, ohne dass sie immer bemerkbar wäre. Was künstliche Intelligenz genau ist und wie sie eingesetzt wird, wissen viele gar nicht. Ärzte nutzen sie für Diagnosen und Behandlungspläne, Marktprognosen sind dank KI aussagekräftiger und die Suchalgorithmen von Google werden mit ihrer Hilfe immer dynamischer. Hinter jedem digitalen Assistenten wie Cortana oder Siri steckt KI-Technologie, Autos lernen durch sie eigenständiges Fahren und Computer helfen bei der Auswahl neuer Mitarbeiter. In den USA werden bereits juristische Schriftsätze mithilfe von artificial intelligence erstellt. So hat die Forschung in den letzten Jahrzehnten für zahlreiche Teilgebiete Großes geleistet.

Künstliche Intelligenz wird auch die Art und Weise, wie wir in Architektur und Bauwesen künftig arbeiten, tiefgreifend verändern [1].

Grundlagen der KI-Verfahren

Viele Analysten sehen Künstliche Intelligenz (KI) als eine der wichtigsten Technologien, die in den nächsten Jahren zahlreiche Industriebranchen erheblich beeinflussen wird. Während einige spezifische Verfahren bereits Anwendungsreife erreicht haben, braucht es bei anderen noch Forschung und Entwicklung.

Die Künstliche Intelligenz ist bereits seit den 1960er-Jahren ein aktives Forschungsfeld, das viele Teilgebiete umfasst. In den frühen Jahren war insbesondere die symbolische KI Gegenstand des wissenschaftlichen Interesses. In diesem Zuge wurden insbesondere Verfahren für das logische Schließen (engl. Reasoning) entwickelt, die in Programmiersprachen wie PROLOG und umfangreiche Expertensysteme für verschiedene Domänen eingeflossen sind. Mit dieser Technologie lässt sich aus vorgegebenem Faktenwissen durch Anwendung von logischen Regeln neues Wissen generieren.

Seit den 1980er-Jahren stehen vor allem Verfahren des Machine Learning im Mittelpunkt der Untersuchungen. Algorithmen des maschinellen Lernens bauen ein Modell basierend auf "Trainingsdaten" auf, um Vorhersagen oder Entscheidungen zu treffen, ohne explizit darauf programmiert zu sein. In diesem Zusammenhang entstanden verschiedene Ansätze wie Entscheidungsbäume, Support Vector Machines, Bayes-Netzwerke oder evolutionäre Algorithmen. Eine Support Vector Machine dient beispielsweise dazu, Daten selbstlernend zu klassifizieren, indem sie für eine Menge von Datenpunkten automatisiert Klassengrenzen findet. Evolutionäre Algorithmen wiederum bilden ein Problem auf eine künstliche Gensequenz ab und machen sich Prinzipien der biologischen Evolution wie Mutation, Rekombination und Selektion zunutze, um für ein gegebenes Kriterium eine möglichst optimale Parameterkonfiguration zu finden.

Zum Machine Learning gehört auch das Prinzip der künstlichen neuronalen Netze (KNN), das sich mittlerweile zu einer der vielversprechendsten Techniken der Künstlichen

Intelligenz entwickelt hat. Wesentliche Idee ist dabei die Imitation des menschlichen Gehirns durch den Aufbau eines Netzwerks von miteinander verbundenen künstlichen Neuronen. Im Rechner entsteht ein Graph, dessen Knoten die Neuronen repräsentieren und dessen Kanten der biologischen Axon-Synapse-Dendrit-Verbindung entsprechen. Jede Verbindung wird mit einem Gewicht versehen, das den Einfluss des jeweiligen Eingangssignals auf das Neuron beschreibt. Diese Gewichte werden während des Trainingsvorgangs kontinuierlich angepasst, um am Ende für die präsentierten Eingangsdaten ein korrektes Ausgangssignal zu erzeugen.

Dieses Grundprinzip, das seit den 1980er-Jahren bekannt ist, wurde in den vergangenen Jahren kontinuierlich weiterentwickelt und verfeinert. Ergebnis sind unter anderem die Convolutional Neural Networks (CNN), die für das Deep Learning unter anderem bei der Bildverarbeitung eingesetzt werden. Der Begriff Deep Learning stammt daher, dass eine große Zahl verborgener Schichten (Hidden Layers) zum Einsatz kommt, die eine klar definierte Struktur und Funktion aufweisen. Zusammen bilden die Schichten die Architektur des Netzwerks. Sie selbst sind nicht mehr eindimensional wie noch bei den einfachen KNN, sondern sehr häufig zwei oder sogar dreidimensional angeordnet.

Zudem wird bei den Verbindungen zwischen den Schichten auf die Erhaltung der Lokalität geachtet. Demnach werden nicht mehr alle Knoten einer Schicht mit allen Knoten der folgenden Schicht verbunden, sondern nur die, die in räumlicher Nähe zueinanderstehen. Bei der Berechnung des Einflusses der vorgelagerten Neuronen kommt die mathematische Operation der Convolution zum Zuge: Die gleitende Multiplikation einer Input-Matrix (die z. B. die Pixel eines Bildes repräsentiert) mit einem Kernel (Filtermatrix) führt Informationen aus benachbarten Neuronen zusammen. Dadurch lassen sich unter anderem Filteroperationen auf Bildern umsetzen, die dann zum Beispiel zur Kantendetektion dienen.

Eine typische Anwendung der CNN liegt in der Verarbeitung von Bildern (meist Fotografien). Dabei lassen sich je nach Ziel der Anwendung die Klassifikation, die Detektion und die Segmentierung unterscheiden. Bei der Klassifikation wird ein Bild einer vorgegebenen Kategorie zugeordnet, wie Hund/Katze oder Pkw/Lkw/Fahrrad. Mit der Detektion hingegen lässt sich ein vorgegebener Objekttyp (z. B. ein Kran) auf einem Bild entdecken und der umhüllende rechteckige Bildausschnitt (seine Bounding Box) zurückgeben. Die Segmentierung wiederum geht noch einen Schritt weiter un identifiziert alle Pixel eines Bildes, die zu einem vorgegebenen Objekttyp gehören.

Neben den CNNs für die Bildverarbeitung gibt es immer ausgeklügeltere Varianten von Deep Neural Networks, die auf bestimmte Fragen und die spezifische Struktur von Eingangsdatensätzen zugeschnitten sind. Dazu gehören beispielsweise KNN für die Verarbeitung von Punktwolken und von Graphen [2].

Forschungs- und Anwendungsbereiche fü r die gebaute Umwelt

Künstliche Intelligenz hat grenzenloses Potenzial und Vorteile, die alle Branchen durchdringen, ihre Zweckmäßigkeit und ihr Nutzen sind in unserem Alltag überall spürbar. Die Einführung fahrerloser Autos durch die Automobilindustrie bedeutet reibungsloseren Verkehr und einen signifikanten Rückgang von Unfällen und Emissionen. In der Baubranche setzen frühzeitige Anwender die Technologie ein, um beim Bauen die Effizienz, die Sicherheit und die Qualität zu steigern.

Das Themen- und Arbeitsfeld der gebauten Umwelt — als Überbegriff für Disziplinen wie Architektur, Bauingenieurwesen, Geodäsie sowie raumbezogene Wissenschaften — ist mit einer Unmenge an Daten verbunden. Diese fallen zum Beispiel bei der Planung, Ausführung und insbesondere beim Betrieb von Bauwerken an. Sie liegen häufig in einer unstrukturierten, rohen Form vor. Hier kommen die Verfahren der Künstlichen Intelligenz beziehungsweise des Machine Learning zum Einsatz: Sie ermöglichen es, Muster und Strukturen in Daten zu erkennen und daraus höherwertige Informationen zu generieren.

Wichtige Anwendungsfelder sind das Erfassen der gebauten Umwelt und das Schaffen von hochwertigen digitalen Zwillingen für Bestandsbauwerke. Hintergrund ist, dass ein überwiegender Teil der baulichen Infrastruktur in Europa und weiten Teilen der entwickelten Welt bereits seit vielen Jahren existiert und digitale Informationen beziehungsweise Modelle im Regelfall nicht vorliegen. KI-Verfahren können hier sehr gut dazu beitragen, hochwertige digitale Zwillinge weitgehend automatisiert zu erzeugen.

Nachfolgend einige Beispiele der KI-Forschung aus der Arbeit des Lehrstuhls für Computergestützte Modellierung und Simulation (CMS) der Technischen Universität München, die in das im November 2020 gegründete Georg Nemechek Institut eingegliedert wird.

Ein Beispiel für den Einsatz von KI-Verfahren zur Digitalisierung des Bestands ist das Projekt TwinGen. Das Projektteam arbeitet hier unter anderem daran, aus Punktwolken von Brücken hochwertige digitale Zwillinge zu generieren. Der Lehrstuhl CMS hat dazu ein Verfahren entwickelt, bei dem sich hochparametrisierte vorkonfigurierte Modelle von Standardbrücken automatisiert in die aufgenommene Punktwolke einpassen. Dafür kommen unter anderem KI-Verfahren aus dem Bereich der evolutionären Optimierung zum Einsatz. Der Vorteil dieses Top-down-Ansatzes gegenüber den sonst üblichen Bottom-up-Verfahren liegt in der hohen geometrischen, topologischen und semantischen Qualität des entstehenden Bauwerksmodells. Neben der Technischen Universität München (TUM) beteiligen sich an diesem Projekt auch die RWTH Aachen und die Ruhr-Universität Bochum. Das Bundesministerium für Verkehr und digitale Infrastruktur (BMVI) fördert das Vorhaben.

Eine weitere sehr wichtige Quelle für das Erstellen digitaler Zwillinge von Bestandsbauwerken ist die Verarbeitung von vielfach vorliegenden Bauzeichnungen. Im vor kurzem ab geschlossenen Projekt RailTwin entwickelten der Lehrstuhl CMS und das Unternehmen Signon erste vielversprechende Ansätze in dieser Richtung. Die Bayerische Forschungsstiftung förderte das Projekt. Dabei konzentrierten sich die Arbeiten zunächst auf das Detektieren von Symbolen des Eisenbahnbaus in den Zeichnungen, da diese dank ihrer Standardisierung eine sehr hohe Aussagekraft besitzen. Ein entsprechend trainiertes CNN lieferte sehr gute Ergebnisse.

Ein besonderer Mehrwert entsteht durch die Kombination von Informationen aus Planunterlagen mit Informationen aus Bildern oder Videos. Dieses unter dem Begriff Sensor Fusion bekannte Verfahren kam ebenfalls im RailTwin-Projekt zum Einsatz: Dabei detektiert das entwickelte System Ausrüstungsgegenstände des Schienenbaus in Videos aus Schienenbefahrungen. Im Anschluss gleicht es ihre Existenz und Position mit den Planunterlagen ab. Auf diese Weise lässt sich ein digitaler Zwilling entwickeln, der sich aus Informationen unterschiedlicher Quellen speist.

Neben der Erfassung der existierenden Bebauung können KI-Verfahren auch den Planungsvorgang unterstützen. Im derzeit laufenden Projekt BEYOND untersucht das Projektteam beispielsweise, wie CNNs rechenaufwändige Personenstromsimulationen ersetzen können. So ließen sich in frühen Phasen des Entwurfs von Bahnhöfen und U-Bahnhöfen schnell unterschiedliche Varianten in Hinblick auf Passagierströme untersuchen. Dafür entwickelt das Projektteam eine KNN-Architektur, die als Input das Bild des

Entwurfsgrundrisses verwendet und als Output ein Bild mit vorhergesagten Personenströmen generiert. Dieses Verfahren führte zu ersten vielversprechenden Ergebnissen, die eine hohe Übereinstimmung von Simulation und CNN-Ergebnis aufweisen. Das Projekt führt der Lehrstuhl CMS zusammen mit der Deutschen Bahn und dem TUM-Startup Accu:rate durch. Das BMVI fördert es über sein Programm mFund.

Auch in Bauvorhaben, die auf der modernen modellgestützten Arbeitsweise des Building Information Modeling (BIM) beruhen, müssen aus rechtlichen Gründen neben den Modellen bis auf Weiteres auch Pläne an den Bauherrn, die Genehmigungsbehörden oder die ausführenden Unternehmen übergeben werden. Dabei müssen die Projektteams sicherstellen, dass es keine Inkonsistenzen zwischen den beiden Repräsentationen gibt, um Unstimmigkeiten und daraus resultierende Fehler zu vermeiden. Im Projekt DeepLink untersucht der Lehrstuhl CMS im Auftrag der Allplan GmbH, auf welche Weise sich BIM-Modelle und 2-D-Pläne kombinieren

lassen. Dazu setzen sie KI-Verfahren ein, um entsprechende Objekte in den Plänen zu detektieren und diese Passpunkte mit den Modellen abzugleichen.

In der Bauausführung lassen sich KI-Verfahren ebenfalls gewinnbringend einsetzen. Der Lehrstuhl CMS hat dazu Verfahren entwickelt, die die Detektion von Bauteilen und Baubehelfen in Aufnahmen von Krankameras oder Drohnen ermöglichen. So lässt sich der Baufortschritt automatisiert bestimmen und überwachen oder die Sicherheit auf der Baustelle erhöhen. In Kombination mit einem 4-D-Bauwerksmodell, das die 3-D-Geometrie der Bauteile mit ihren geplanten Bauzeiten verknüpft, hat die TUM zudem Verfahren des automatisierten Trainings entwickelt [2].

Im Übergang von Bauausführung zum Betrieb besteht häufig die Herausforderung, dass die verantwortlichen Akteure die BIM-Modelle der Planung nicht an die tatsächlich ausgeführte Realität anpassen. Entsprechend liegen keine “Wie-gebaut-Modelle” vor. Eine Masterarbeit, die zusammen mit der ETH Zürich und der Siemens AG betreut wurde, untersuchte daher, wie sich Punktwolken mithilfe von KI-Verfahren semantisch segmentieren und damit Abweichungen zwischen Modell und Realität erkennen lassen. Dabei kam ein Graph Neural Network für die Segmentierung zum Einsatz. Im Einzelnen wird zunächst die Punktwolke zu einem Dreiecksnetz vermascht und dieses Netz anschließend in einen Graphen überführt, der als Eingangsgröße für das Graph Neuronal Network dient. Resultat ist die korrekte Segmentierung der Punktwolke, das heißt das Zuordnen der einzelnen Punkte zu vorgegebenen Klassen wie Wand, Decke, Treppe und Rohrleitung.

Die aufgeführten Beispiele stellen nur einen kleinen Teil der Anwendungsmöglichkeiten von KI-Verfahren im Bauwesen dar. Der Lehrstuhl CMS und andere Institute und Einrichtungen betreuen derzeit viele weitere Forschungs- und Entwicklungsarbeiten zu diesem Thema. Ein Beispiel sind die Aktivitäten im Bereich der Physics-informed Neural Networks, mit denen sich physikalische Phänomene beschreiben lassen. In den entsprechenden KNN-Architekturen kommen dabei häufig physikalisch-mathematisch motivierte Operationen zum Einsatz — beispielsweise zur Bildung der Ableitung von physikalischen Größen in verschiedene Raumrichtungen.

Herausforderungen und Einschrä nkungen

Es gibt es eine ganze Reihe von Vorteilen und Chancen der künstlichen Intelligenz. Die wichtigsten Vorteile der Technologie betreffen die Arbeitswelt, ihre hohe Leistungsstärke und die wirtschaftlichen Perspektiven, die sie eröffnet.

Befürworter der neuen Technologie, weisen vor allem auf die Chancen hin, die künstliche Intelligenz bietet [3]:

1. Arbeitsplätze und Arbeitserleichterung: Die neue Technologie könnte für wertvolle neue Arbeitsplätze sorgen und insgesamt einen wirtschaftlichen Aufschwung bedeuten. Darüber, dass die Technologie einschneidende Auswirkungen auf den Arbeitsmarkt haben wird, sind sich alle Experten einig. Ein Gremium der Stanford University untersuchte artificial intelligence auf ihre Zukunftsperspektiven und kam zu dem Schluss, dass sich gegenwärtig noch nicht abschätzen lässt, ob die Auswirkungen auf den Arbeitsmarkt eher positiv oder eher negativ ausfallen würden. Sicher sei jedoch, dass viele Menschen ihren Lebensunterhalt nicht mehr allein durch Arbeit bestreiten könnten. Daher sehen gerade Befürworter des bedingungslosen Grundeinkommens die Technik künstlicher Intelligenz als große Chance: Das Modell der traditionellen Lohnarbeit könnte schon bald überholt sein. Auch für Tesla-Chef Elon Musk ist dies einer der Vorteile künstlicher Intelligenz: Mehr Freizeit für den Menschen.

2. Komfort: KI-Befürworter sehen die Chancen von künstlicher Intelligenz außerdem in dem erheblichen Komfort, den jede technische Neuerung für den Lebensalltag bedeutet. Das bezieht sich auf das selbstfahrende Auto genauso wie auf die intelligente Übersetzungs-Software — solche Entwicklungen stellen eine große Entlastung für Verbraucher dar.

3. Außerordentliche Leistungsstärke: Doch auch bei Aufgaben von öffentlichem Nutzen hat artificial intelligence erhebliche, wenn nicht die größten Vorteile — schließlich haben Maschinen eine geringere Fehlerquote als Menschen, und ihre Leistungsfähigkeit ist enorm. Insbesondere im Gesundheitswesen und in der Justiz bewertet man die große Vielseitigkeit intelligenter Maschinen als vielversprechend. Obwohl Experten nicht erwarten, dass Richterinnen und Richter in Zukunft durch künstliche Technik ersetzt werden, kann artificial intelligence dennoch dabei helfen, Muster eines Verfahrens schneller zu erkennen und zu objektiven Urteilen zu kommen.

4. Wirtschaftliche Vorteile: Natürlich verspricht die Technologie auch einen großen kommerziellen Gewinn für die beteiligten Wirtschaftszweige. Die International Federation of Robotics (IFR) prognostiziert, dass bis 2019 weltweit 42 Millionen Service-Roboter verkauft werden — mit einem Umsatz von rund 22 Milliarden Dollar. Eine Studie der Bank of America Merrill Lynch wiederum schätzt, dass der Umsatz der KI-Industrie bis 2020 auf über 150 Milliarden Dollar steigt. Artificial intelligence könnte für die IT-Branche und benachbarte Wirtschaftszweige also einen erheblichen wirtschaftlichen Aufschwung bedeuten — und damit auch den allgemeinen Wohlstand mehren.

5. Futuristische Projekte: Nicht zuletzt beflügelt artificial intelligence den natürlichen Entdeckerdrang des Menschen — sie wird bereits für die Exploration von Ölquellen oder zur Steuerung von Marsrobotern weiterentwickelt. Es ist zu vermuten, dass mit dem Fortschritt der Technik sich auch die Einsatzbereiche künstlicher Intelligenz weiter ausdehnen.

Die Erwartungen an die Verfahren der Künstlichen Intelligenz sind sehr hoch. Um ihre Möglichkeiten und Einschränkungen realistisch einschätzen zu können, braucht es jedoch ein grundlegendes Wissen über ihre Funktionsweise. Bei einem neuronalen Netz spielt beispielsweise die Phase des Trainings eine sehr wichtige Rolle, während der dem Netz Daten (z. B. Bilder) und die jeweils dazugehörige korrekte Antwort (z. B. eine Klassifikation) präsentiert werden. Für eine hohe Qualität des resultierenden Netzes sind die folgenden Punkte zu erfüllen:

- sehr viele Datensätze für das Training;

• die Datensätze decken den Bereich der möglichen Eingangsdaten weitgehend vollständig ab;

• die Datensätze sind möglichst ausgewogen.

Für (a) ist im Regelfall eine menschliche Bewertung erforderlich, beispielsweise in Form des Labelings — also der manuellen Markierung eines Ausschnitts auf den betreffenden Bildern. Hier liegt eine der Herausforderungen für die Anwendung von KI im Bauwesen, da eine umfangreiche manuelle Aufbereitung sehr aufwendig und auch entsprechend teuer sein kann. Anders als in anderen Bereichen steht bei den spezifischen Anwendungen des Bauwesens nur in seltenen Fällen eine große internationale Community zur Verfügung, die kostenfrei an Trainingsdatensätzen mitwirkt. Einige Forscherinnen und Forscher setzen daher auf die Generierung und Nutzung von synthetischen Daten für das Training. Damit ist jedoch die nicht unerhebliche Gefahr verbunden, dass diese Daten zu ideal sind, also beispielsweise keine Verschattungen aufweisen. Das trainierte Netzwerk versagt dann bei der Anwendung auf Realdaten. Ebenso kritisch ist das Auftreten eines unbewussten Bias in den Trainingsdaten. Dies betrifft unmittelbar die Forderungen (b) und (c), die auch bei “natürlichen” Daten eine sorgfältige Auswahl und Überwachung erfordern.

Für einen erfolgreichen Einsatz von KI-Verfahren im Bauwesen braucht es künftig daher öffentlich zugängliche Datenpools, die sich aus aufbereiteten Daten von verschiedenen öffentlichen Institutionen und privaten Unternehmen speisen. Nur so lassen sich die Anforderungen an eine breite Datenbasis zu erfüllen. Das Prinzip der “geteilten Daten” ist insbesondere vor dem Hintergrund der stark fragmentierten Baubranche eine unumgängliche Notwendigkeit für einen breiten Einsatz von KI-Methoden.

Unabhängig davon sind KI-Verfahren im Wesentlichen statistische Verfahren, die entsprechend wahrscheinlichkeitsbehaftete Aussagen tätigen können. Je nach Anwendungsdomäne ist die Zuverlässigkeit der Vorhersage sorgfältig zu prüfen, bevor derartige Verfahren in die praktische Anwendung gelangen. Dies betrifft vor allem Bereiche, bei denen Leib und Leben von Personen potenziell gefährdet sind – also unter anderem auch Anwendungen im Bereich der baustatischen Berechnungen oder der Bestimmung von Materialeigenschaften.

Damit in Zusammenhang steht, dass KI-Methoden häufig als Black-Box-Verfahren eingesetzt werden, ein genaues Verständnis der Funktionsweise des Netzwerks also nicht besteht. Für manche Anwendungen ist dies auch nicht nötig, solange das Netzwerk im Rahmen einer festgelegten Zuverlässigkeit funktioniert. Für die genannten kritischen Bereiche ist jedoch ein vertieftes Verständnis erforderlich. Das ist auch wichtig, um abschätzen zu können, wie das Netzwerk auf “Outlier” reagiert — also Eingangsdatensätze, die weit außerhalb des Wertbereichs der Trainingsdatensätze liegen. In diesem Sinne verweisen Forscherinnen und Forscher häufig darauf, dass sich KNN zwar gut für Interpolationsaufgaben einsetzen lassen (also zur Vorhersage von Werten zwischen bekannten Werten), aber nur eingeschränkt für Extrapolationsaufgaben (also zur Vorhersage von Werten außerhalb des bekannten Wertebereichs) [4].

Fazit

Die Verfahren der Künstlichen Intelligenz zeigen in vielen Bereichen ein erhebliches Potenzial für die weitere Automatisierung und Effizienzsteigerung. Dazu gehören insbesondere auch die gebaute Umwelt und die damit verbundenen Wirtschaftsteile. Hier fallen sehr häufig große Mengen unstrukturierter Daten an, die sich mithilfe von KI-Verfahren zu höherwertigen Informationen verarbeiten lassen. Mögliche Einsatzgebiete erstrecken sich von der Erfassung bestehender Bauwerke und der Erzeugung digitaler Zwillinge über die Teilautomatisierung und Assistenz beim Entwurf und der Planung von Bauwerken bis zur Verarbeitung von Monitoringdaten, die bei Baustellen oder im Betrieb anfallen. Für einen sachgerechten Einsatz braucht es jedoch immer ein vertieftes Wissen über die Verfahren und insbesondere ihrer Grenzen. Um das große Potenzial zu erschließen, ist noch viel Forschung und Entwicklung nötig.

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Интеллектуальная парковочная система как часть интеллектуальной транспортной системы

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Индустриализация мира, рост населения, медленные темпы развития городов и неправильное управление доступными парковочными местами привели к проблемам, связанным с парковкой. Существует острая потребность в безопасной, интеллектуальной, эффективной и надежной системе, которую можно было бы использовать для поиска незанятых парковочных мест, направления к стоянке, согласования платы за стоянку, а также для надлежащего управления стоянкой. Служба интеллектуальной парковки является частью интеллектуальных транспортных систем. Рассмотрены различные интеллектуальные службы парковки, используемые для управления парковками. Описанные системы смогут уменьшить проблемы, возникающие из-за отсутствия надежной, эффективной и современной парковочной системы.

Ключевые слова: *интеллектуальная транспортная система, интеллектуальная парковочная система, экспертные системы, Интернет вещей, компьютерное зрение, машинное обучение, глубокое обучение, сверточные нейронные сети, спутниковая система навигации*

Intelligent Parking System as Part of an Intelligent Transportation System

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The industrialization of the world, population growth, slow pace of urban development and improper management of available parking spaces have led to parking-related problems. There is an urgent need for a safe, intelligent, efficient and reliable system that could be used to find unoccupied parking spaces, directions to the parking lot, coordination of parking fees, as well as for proper parking management. The Intelligent Parking service is part of Intelligent Transport Systems. This article discusses the various intelligent parking

services used for parking management. The described systems will be able to reduce the problems arising from the lack of a reliable, efficient and modern parking system.

Keywords: *intelligent transportation system, intelligent parking system, expert systems, Internet of things, computer vision, machine learning, deep learning, convolutional neural network, Global Positioning System*

Introduction

Thanks to the concept of "smart city", which transforms cities into digital societies, facilitating the life of their citizens in all aspects, the Intelligent Transport System becomes an indispensable component for everyone. The Intelligent Transportation System (ITS) aims to achieve traffic efficiency by minimizing traffic problems. It provides users with advance traffic information, real-time information about local amenities, availability, and more. which reduces travel time for passengers, as well as increases their safety and comfort.

The Intelligent Transportation System (ITS) is an advanced application that aims to provide innovative services related to various modes of transport and traffic management, and allows users to be more informed and ensure safer, more coordinated and "smarter" use of transport networks [1].

All applications of ITS are based on data collection, analysis and use of the results of the analysis in the concepts of operations, control and research for traffic management, where location plays an important role. All data is collected and analyzed for further operations and traffic management in real time.

Data collection

Strategic planning requires accurate, extensive and rapid data collection with real-time monitoring. Thus, the data here is collected using various hardware devices, which lay the foundation for further ITS functions. These devices are automatic vehicle identifiers, GPS-based automatic vehicle locators, sensors, cameras, etc. The hardware mainly records data such as the amount of traffic, surveillance, speed and travel time, location, vehicle weight, delays, etc. These hardware devices are connected to servers, usually located in a data collection center, where large amounts of data are stored for further analysis.

Data transfer

The rapid transfer of information in real time is the key to mastering the implementation of ITS, so this aspect of ITS is to transfer collected data from the field and then send back this analyzed information to end users. Traffic-related announcements are brought to the attention of users via the Internet, SMS or on-board devices of the vehicle.

Data analysis

The data collected and received in the ITS are further processed at various stages. These steps are error correction, data cleansing, data synthesis, and adaptive logic analysis. Inconsistencies in the data are identified using specialized software and eliminated. The data is then further modified and combined for analysis. This corrected collective data is further analyzed to predict the traffic scenario that is available to provide relevant information to users.

There are various methods to implement an intelligent parking system.

Expert systems

Expert systems or agent-based technologies can solve the problems associated with a distributed and complex traffic environment. They are also considered the main weapon, laying the foundation for the automation mechanism for the parking and guidance coordination system. The agent has useful traits such as autonomy, reactivity, adaptability, activity, and social abilities that can be used to solve problems that have very dynamic and interactive behavior.

GPS based systems

Information about the location and availability of a parking space near a destination is provided to drivers using a state-of-the-art GPS-based navigation system. The information provided informs about the current state of the parking lot. This is why these systems cannot guarantee parking when the driver approaches the facility. There is a scientific solution based on the use of past and current parking conditions. It uses a Poisson process to model parking availability and an intelligent algorithm that helps the driver select the slot with the highest probability of being free.

Computer vision based systems

There is an image processing based system to provide parking information and directions. This system has the ability to count the number of parked cars and identify vacant lots. The system uses images to detect vehicles. A camera is installed at the entrance to take a reference image. After capturing the reference image, a sequence of images is also captured, which is then compared with the reference image for image matching using edge detection performed using the Prewitt Edge Detection operator [2]. Based on the percentage, the driver is provided with guidance and information.

Systems based on computer vision and image processing technologies usually have a high data transfer rate from the camera network to the processing units, since these systems depend on real-time video data from parking lots for feature extraction. These types of parking systems are usually suitable for outdoor parking because a single camera can cover a large area of the parking lot. However, these systems are prone to occlusion, shadow effects, distortion, and lighting changes [3].

IoT-based systems

The Internet of Things is a popular technology of the modern era, when all devices are connected to each other via the Internet. Every device connected to the Internet has a unique identifier (UID). These devices can be computing, mechanical and digital. They can transfer data without human-to-human or human-to-computer interaction. IoT technology is one of the main key technologies that developers use for smart parking systems. In IoT-based parking systems, all sensors and computing devices are connected via the Internet and can transmit data without any human intervention. The Internet connection between sensors, computing devices and storage units can be either through a wired connection or through a wireless connection.

Intelligent parking systems based on machine learning and deep learning

Machine learning is a subset of artificial intelligence that provides a system with the ability to learn and improve a specific task based on datasets or experience without explicitly programming the system. Smart parking systems based on machine learning analyze parking data to extract parking status. Moreover, these machine learning and artificial intelligence based systems can predict the occupancy status of parking lots in the coming days, weeks or even months and provide a dynamic pricing scheme, they can also track traffic congestion on certain roads and offer a smart solution for smart parking spaces.

Deep learning is a subset of machine learning and an artificial intelligence function that mimics the human brain in terms of data processing and feature extraction for decision making. DL algorithms detect unoccupied and special parking lots in ITS instead of conventional sensors, which reduces the number of them required for the system. Deep learning is also being used to predict parking occupancy.

Intelligent parking systems based on neural network

Neural networks are a combination of algorithms that extract features and underlying relationships from data sets through a process that mimics the function of the human brain. Intelligent parking systems based on neural networks are used to recognize license plates using real-time video data. Convolutional Neural Networks (CNN) and machine vision are implemented to determine the occupancy status of a parking lot. CNNs can also provide traffic information on various routes [4].

Conclusion

Due to the rapid growth of the urban population and unplanned urbanization, there has been a decrease in the number of urban parking spaces and an increase in traffic congestion. As a result, smart parking is becoming a subject of interest for both researchers and urban planners.

In this presentation I wanted to talk about the different approaches used by researchers to develop their smart parking system and their suitability for different parking lots.

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Анализ современных систем автоматизированного машинного обучения

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Рассмотрены современные системы автоматизированного машинного обучения, которые применяют для автоматизации процесса разработки моделей машинного обучения с учителем. Выделены основные этапы процесса построения модели машинного обучения с учителем для автоматической обработки с помощью большинства современных систем AutoML. Выделены перспективные направления развития в области систем AutoML. Проанализированы достоинства и недостатки автоматизации процесса моделирования.

Ключевые слова: *автоматизированное машинное обучение, анализ данных, набор данных, модель обучения, системы AutoML*

Analysis of Modern Automated Machine Learning Systems

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The article discusses modern automated machine learning systems that are used to automate the process of developing supervised machine learning models. The main stages of the process of building a supervised machine learning model for automated adaptation through most modern AutoML systems are highlighted. Promising directions of development in the field of AutoML systems are presented. The advantages and disadvantages of automation of the modeling process are also analyzed.

Keywords: *automated machine learning, data analysis, data set, learning model, AutoML systems*

Introduction

Specialists in the field of machine learning face the problem of choosing a suitable algorithm with optimal hyperparameters to describe the data. To do this, they usually perform and evaluate many configurations by trial and error. However, for novice data analysts, this is a time-consuming task. Recent advances in AutoML solve this problem by automatically finding the right algorithm with suitable hyperparameters. However, these systems are only applicable for supervised machine learning tasks.

Auto ML is a modern trend in the field of machine learning. The article considers a number of automated machine learning systems, describes their key features, solved tasks.

Methodology

Automated machine learning or AutoML is a term proposed by the community of machine learning specialists to denote methods aimed at automating the design, development of machine learning systems and applications. This direction in the field of machine learning is rapidly developing, as evidenced by a large number of publications and developments of foreign and domestic researchers.

AutoML provides different methods and processes to make machine learning accessible to non-machine learning professionals, increase the effectiveness of machine learning and accelerate research in the field of machine learning. These systems can be used without having expert knowledge in the field of machine learning. Since modern applications often work with a large amount of data, there is a need for systems that can process this data quickly. AutoML systems have been created for this purpose.

In general, the process of developing a machine learning model consists of a number of stages:

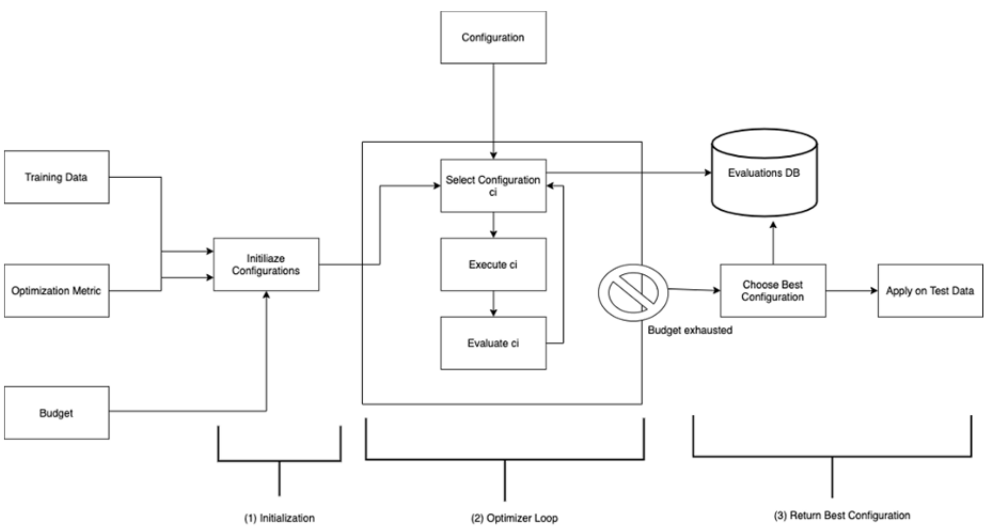
• data pre-processing;
• selection of the necessary features;
• statistical model selection;
• optimization of hyperparameters of the model;
• model training with tuned hyperparameters;
• analysis of the obtained results.

AutoML systems help automate a number of steps without losing the predictive accuracy of the target machine learning model.

Using AutoML systems, you can perform the following operations:

• Automatic data cleaning (AutoClean);
• Automatic Feature Selection (Auto FE);
• Hyperparameter Optimization (HPO);
• Meta-learning;
• Definition of neural Architecture (NAS).

Let's describe AutoML as a search problem for f that better generalizes any possible T with less human intervention. Where f can be a composition of multiple functions that can transform the input space, subsample the data, combine multiple predictors, etc.



General architecture of the AutoML system

Functions of the form $f(x) = v_{\theta_v}\left(\Phi_{\theta_\Phi}(x)\right)$ are called complete models [1] or pipelines [2] because they include all the processes that must be applied to data in order to get a supervised learning model. AutoML can be thought of as searching for functions v and Φ with corresponding hyperparameters Θ_v and Θ_Φ using D.

Figure [3] shows an example of the general architecture of the AutoML system, which is based on the Auto-Sklearn system. The purpose of these systems is to select a suitable configuration (machine learning model, ci) for a training dataset based on allocated resources (Budget).

During initialization stage, the configuration for optimizers is optimized. The optimization cycle starts iterations of the optimizer until the budget is exhausted [4]. The best configuration return stage returns the most appropriate model configuration. Let's consider a number of AutoML systems that are used in modern machine learning projects.

Auto-Sklearn

The system is written in Python and uses algorithms and methods from Scikit-Learn (15 classification algorithms, 14 feature processing methods, 4 data preprocessing methods). Auto-Sklearn implements the SMAC algorithm for configuring hyperparameters. The system is able to generate objects, select a model and configure hyperparameters. Auto-Sklearn introduces two innovations: the use of meta-learning to quickly launch a Bayesian optimization procedure, and an ensemble construction stage that uses more than one configuration found in the optimization procedure. Auto-Sklearn runs a Bayesian optimization procedure, providing initial instances from configurations that give the best results for similar datasets. In particular, meta-training shows significant improvements in all configuration estimates in the Bayesian optimization procedure, and ensemble construction turns out to be advantageous using meta-training, since more efficient models are chosen for ensemble construction [5].

Tree-based Pipeline Optimization Tool

TPOT (Tree-based Pipeline Optimization Tool) is an opensource Python project that is an alternative to Bayesian optimization methods. This system automates machine learning pipelines using genetic programming (GP), a well-known method of automatic program construction. That is, in this system, the machine learning pipeline is fully automated, and a genetic algorithm is used to determine the optimal model. The main focus of this project is supervised learning, namely a classification problem with support for 150 ScikitLearn algorithms [3], including preprocessing algorithms. This system, like Auto-Sklearn, is an add-on to the Sklearn library, but uses its own regression and classification algorithms.

A random set of 100 tree pipelines creates an initial generation as specified in genetic programming and is further optimized according to the Python DEAP package. Twenty of the best pipelines have been selected by developers in terms of maximizing cross-validation accuracy and minimizing the number of processes that are modified to create next-generation pipelines. Each pipeline produces five more using cross methods or random inserts and shrinks. The algorithm runs for 100 generations for each of the updated solutions [6, 7]. TPOT cannot work with natural language and categorical features.

Light Auto ML

Light Auto ML (LAMA) is an opensource solution developed by Sber AILab. This system allows users to automate the process of building and displaying models for the following tasks:

- binary classification;
- multiclass classification;
- regression.

The developed pipeline allows researchers to perform the following operations:

- data processing and automatic adjustment of hyperparameters;
- creation of reports describing the model development process;
- create your own pipelines from modules provided by the system;
- perform model inference.

The proposed LAMA system works with only two types of models — gradient boosted decision trees (GBMs) and linear models, which significantly reduces time without sacrificing performance for the types of problems being solved.

Results

AutoML is a modern direction in the field of machine learning. This area is actively being researched by the scientific community, which confirms the existence and development of various software systems for automated machine learning.

As a result, modern automated machine learning systems have been considered.

Modern AutoML systems help automate almost the entire process of building a model. At the moment, the following stages of modeling are automated:

- data preparation;
- overview of signs;
- building a machine learning model and optimizing hyperparameters;
- checking the constructed model;
- building reports;
- implementation of the developed model.

The advantage of AutoML systems is that they can quickly build very accurate machine learning models. Users do not need to have almost any knowledge in the field of machine learning.

The main disadvantage of AutoML systems is that the entire process of building a machine learning model is hidden. Users can make adjustments to the source code of systems, but this requires programming knowledge.

During the review, the following promising areas of development in the field of AutoML systems have been identified:

- use of complex nonlinear data processing pipelines;
- implementation of unsupervised machine learning algorithms for data preprocessing;
- selection of an algorithm for optimizing hyperparameters of the selected optimal model.

Thus, the automation of machine learning processes is a promising direction for further research.

Conclusions

The article discusses the main trends in the field of machine learning like AutoML systems. Automated machine learning replaces the traditional approach to building machine learning systems, which requires knowing almost all existing machine learning algorithms, being able to apply and configure them correctly.

Thus, the direction of machine learning automation is being actively developed. This is an extensive field of research, as evidenced by a large number of developments and research in this area of machine learning.

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Использование распределения вероятностей для регулярной генерации случайных точек в трехмерном пространстве

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Приведено понятие о распределении вероятностей и дана информация о его видах, а также показаны основные математические представления о дискретном и непрерывном распределении вероятностей. Особое внимание уделено равномерному распределению, подробно рассмотрены метод генерации случайных 3D-точек и построения полигональной сетки. Сделан вывод о важности математики и теории вероятностей для создания прикладных технологий.

Ключевые слова: *рспределение вероятностей, регулярная генерация случайных чисел, регулярная генерация случайных 3D-точек, построение полигональной сетки, метод генерации*

Using the Uniform Probability Distribution to Generate Random Points in 3D-Space

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The article gives the concept of probability distribution and information about its types, it also gives the basic mathematical concepts of discrete and continuous probability distribution. Particular attention is paid to uniform distribution, and the method of generating random 3D points and constructing a polygonal grid are also considered in detail. The conclusion, is written about the importance of mathematics and probability theory for the creation of applied technologies.

Keywords: *probability distribution, regular random number generation, regular generation of random 3D points, building a polygonal mesh, generation method*

Введение

Распределение вероятностей — это статистическая функция, которая описывает все возможные значения и вероятности, которые случайная величина может принимать в заданном диапазоне. Этот диапазон будет ограничен между минимально и максимально возможными значениями.

В теории вероятностей распределение вероятностей — это математическая функция, которая дает различные возможные вероятности в качестве результатов вероятностного эксперимента [1, 2]. Это также математическое описание случайности явления в терминах выборочного пространства и вероятности [3]. Например, если x используется для обозначения результата подбрасывания монеты («эксперимент»), распределение вероятности для X примет значение 0,5 для x = орел и 0,5 для x = решка (при условии, что монета честная). Примеры случайных явлений включают погоду на будущую дату, рост случайно выбранного человека, процент учащихся мужского пола в школе и т. д. [4].

Дискретное и непрерывное распределение вероятностей

Дискретное распределение вероятностей — это распределение вероятностей, которое может принимать несколько значений [5]. В случае, когда диапазон значений несколько бесконечен, эти значения должны упасть до нуля достаточно быстро, чтобы вероятности объединились до 1. Известные дискретные распределения вероятностей, используемые в статистическом моделировании, включают распределение Пуассона, распределение Бернулли, биномиальное распределение, геометрическое распределение и отрицательное биномиальное распределение [3]. Кроме того, дискретное равномерное распределение обычно используется в компьютерных программах, которые делают случайный выбор с равной вероятностью между несколькими вариантами выбора. Непрерывное распределение вероятностей — это распределение вероятностей, поддержкой которого является неисчислимое множество, такое, как ограничитель в действительной прямой [6]. Он однозначно характеризуется кумулятивной функцией распределения, которая может быть использована для вычисления вероятности для каждого подмножества поддержки. Существует много примеров непрерывных распределений вероятностей, например: нормальное, регулярное, хи-квадрат и другие.

Виды распределений

Как правило, процесс генерации данных о каком-либо явлении будет диктовать его распределение вероятностей. Этот процесс называется функцией плотности вероятности.

Существует много различных классификаций распределений вероятностей. Некоторые из них включают нормальное распределение, равномерное распределение, распределение хи-квадрат, биномиальное распределение и распределение Пуассона. Различные распределения вероятностей служат разным целям и представляют разные процессы генерации данных.

Существует несколько распределений, которые обычно используются, но наиболее часто используемым распределением является нормальное распределение [7], или «колоколообразная кривая», которая часто используется в финансах, инвестициях, науке и технике. Нормальное распределение полностью характеризуется его средним значением и стандартным отклонением, что означает, что распределение не искажено и действительно демонстрирует эксцесс. Это делает распределение симметричным, и на графике оно изображается в виде колоколообразной кривой.

Равномерное распределение

Равномерное распределение относится к типу распределения вероятностей, при котором все исходы одинаково вероятны. Равномерное распределение можно визуализировать в виде прямой горизонтальной линии. Существует два типа равномерных распределений: дискретные и непрерывные. Общая формула для функции плотности вероятности равномерного распределения имеет вид

$$f(x) = \frac{1}{B - A} \text{ for } A \leq x \leq B,$$

в случае, когда $A = 0$ и $B = 1$ называется стандартным равномерным распределением, а затем уравнение для стандартного равномерного распределения имеет вид

$$f(x) = 1 \text{ for } 0 \leq x \leq 1.$$

Равномерное распределение определяет равную вероятность в заданном диапазоне для непрерывного распределения. По этой причине оно важно в качестве эталонного дистрибутива.

Одним из наиболее важных применений равномерного распределения является генерация случайных чисел. То есть почти все генераторы случайных чисел генерируют случайные числа на интервале [0, 1]. Для других распределений к однородным случайным числам применяется некоторое преобразование.

Генерация случайных чисел

Большинство алгоритмов генерации случайных чисел полагаются на генератор псевдослучайных чисел, который выдает x чисел, равномерно распределенных в полуоткрытом интервале [0, 1]. Эти x случайных величин затем преобразуются с помощью некоторого алгоритма для создания новой случайной величины с желаемым распределением вероятностей. С помощью этого источника псевдооднородной случайности может быть сгенерировано восприятие любой случайной величины [8].

Генерация случайных чисел, равномерно распределенных в диапазоне [0, 1], является основой для генерации неравномерного распределения. Поскольку одна и та же программа с одним и тем же вводом всегда выдает один и тот же результат, невозможно написать программу, которая выдает действительно случайные числа. Однако для большинства целей последовательность псевдослучайных чисел будет работать почти так же хорошо.

Построение сетки со случайными 3D-точками

3D-сетка используется во многих приложениях в различных областях, таких, как медицина, механика, жидкости, изучение свойств материалов, а также в области промышленности. Все алгоритмы построения сетки зависят от генерации случайных 3D-точек для построения сетки (рис. 1).

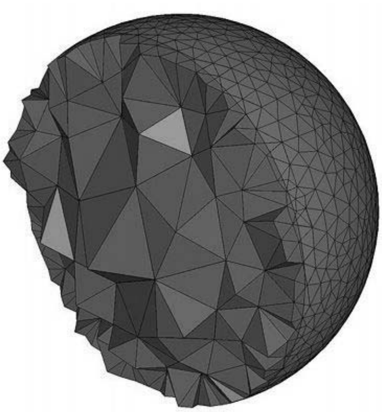

Рис. 1. Пример изображения 3D-сетки

3D-точка состоит из трех чисел, поэтому распределение вероятностей генерации точек связано со случайностью при генерации чисел *x*, *y*, *z*. Программа генератора случайных чисел была закодирована и использована для генерации случайных точек, которые служат основной цели исследования при построении сетки твердого тела и подготовке целых узлов к изучению тела.

Закономерность случайности при генерации точек

Исследование закономерности случайности при генерации точек в библиотеке (.Net). Язык программирования (C#) содержит класс (Random) для генерации случайных вещественных чисел в поле [0, 1] в соответствии с регулярным распределением точек.

Для того чтобы показать регулярность случайных точек, миллион случайных точек был сгенерирован в кубе (длина = ширина = высота = 1), и этот куб был разделен на тысячу кубов одинакового размера, а затем была нарисована следующая диаграмма, которая представляет количество точек в каждом маленьком кубе (рис. 2).

Рис. 2. Регулярность случайных генерируемых точек

Значение относительной неопределенности в случайности сгенерированных точек равно (0.21).

Заключение

Статистическая математика и теория вероятностей оказывают большое влияние на создание прикладных технологий и приложений. В конце этой работы стало ясно, что для получения оптимальных результатов необходимо хорошо разбираться в прикладной математике, и это то, что получили при разработке программы для генерации случайных 3D-точек на основе равномерного распределения при генерации трех соединений (*x*, *y*, *z*) за каждой точки.

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Автоматизированное тестирование API

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Тестирование программных продуктов является неотъемлемым этапом их создания и разработки. Наиболее простым способом тестирования является мануальное (ручное), однако оно способно быть неэффективным, поскольку напрямую зависит от классификации, внимания, профессионализма, логики и опыта тестировщика. Кроме того, ручное тестирование даже простых функций приложения занимает достаточно большое количество времени, поскольку тестировщик проверяет и анализирует каждый тестов кейс, разрабатывает их, строит схемы зависимостей. Для снижения человеческого фактора при тестировании приложений и ускорения этого процесса была реализована возможность автоматизированного тестирования. Рассмотрены особенности автоматизированного тестирования программных продуктов и приведены примеры реализации такого тестирования с помощью программы Postman.

Ключевые слова: *тестирование, автоматизация, API, протокол HTTP, Postman*

Automated API Testing

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Testing is an integral stage of the creation of software and its development. The simplest way of testing is manual testing, but it can be ineffective since it directly depends on the classification, attention, professionalism, logic, and experience of the tester. In addition, manual testing of even simple application functions takes a lot of time, since the tester checks and analyzes each test case, develops them, and builds dependency diagrams. To reduce the human factor when testing applications and to speed up this process, the possibility of automated testing was implemented. This article discusses the features of automated testing of software products and provides examples of the implementation of such testing using Postman.

Keywords: *testing, automation, API, HTTP protocol, Postman*

Automated testing is a software testing method in which a special program checks the expected result with the real one.

Automated testing is a cost-effective method of regression testing, even though automation requires more resources initially. But when test scripts are ready, they can be executed with great speed and with the same accuracy, so, its cost will gradually pay off. Also, the advantages of automated testing are the absence of a human factor in testing, due to which the quality of its code will increase; the automatic saving reports of test results; as well as the ability to reuse tests when changing the product code [1, p. 158].

The automation process consists of the following steps:

1. Preparation — the choice of functionality that will be subject to automated testing; definition of requirements, terms, tools; risk assessment.

2. Conducting — launching autotests and conducting regression testing.

3. Report — drawing up documentation with detected bugs and suggestions for improving the functionality.

Test automation is used in several cases: the data require complex mathematical calculations; inaccessibility of places in the system; functionality with a high level of risk for bugs; the need to perform many similar operations, for example, checking the validation of fields and situations when the software product has already been debugged and major improvements are not planned [2, p. 33].

There are several main approaches to automation:

• GUI-automation (automation of the graphical user interface (GUI) testing);

• Code testing;

• Automated tests interacting with the API.

This article will cover API testing.

API is a link between the developer and the environment where it should interact, it is developed either for the client or for internal use. Basically, the API is a part of the server that receives requests and sends only data as responses to them [3, p. 43].

There are a number of issues related to API testing

1. No GUI.

2. Mandatory check of exception handling

3. The need for knowledge in programming for a tester.

The API has a clear data transfer format, which simplifies the process of information exchange. HTTP requests are used for this purpose.

HTTP is an application layer protocol of the OSI model used for data transfer. Initially, it was possible to transfer only hypertext documents in HTML format with its help, but over time, this condition was improved to transfer arbitrary data. The HTTP protocol is the backbone of the Internet, providing client-server interaction between applications.

The interaction between the client and server parts of the application is carried out by sending requests and processing the responses received.

An HTTP request consists of an HTTP method, resource path, HTTP protocol version, header, and request body (optional). The HTTP response also contains the protocol version, status (error) code, status message, header, and response body.

HTTP method is a word that defines the operation performed by the client. Usually a verb (GET, POST, etc.), but can also be a noun (OPTIONS, HEAD)

The most used HTTP methods are [4]:

- GET — receiving and reading data;
- PUT — loading information to the URI specified in the request;
- POST — data transfer from user to resource;
- DELETE — deletes a resource;
- OPTIONS — determines the capabilities of the web server.

Let's look at running queries with a Postman application. Postman is an application designed to test various APIs, as well as send various requests to the server [5]. An important property of the program is the ability to create collections of API requests, which significantly speeds up development and optimizes time and resources often spent searching for a request in memory or manually filling in parameters. Postman is easy enough to work with, which is why many testers choose it as their automation tool. The main application window is shown in Fig. 1.

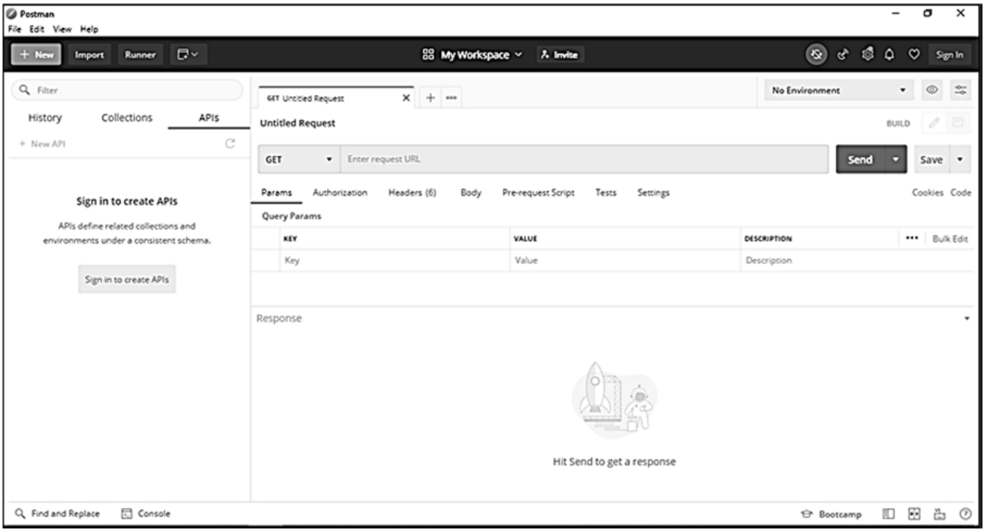

Fig. 1. Postman application window

In order to understand the structure of query execution in Postman both for standard execution and for testing, let's look at the key concepts used in it. These include Collections, Folders, and Requests. A collection is a project file that includes all requests, it has both its own scripts and its own variables. The page Collections also keep a history of past requests. The folder combines requests into one group within the collection, it can have its own scripts, but not variables. Requests are created in the constructor, but they also have their own scripts. The scheme of interaction of these elements with each other is shown in Fig. 2.

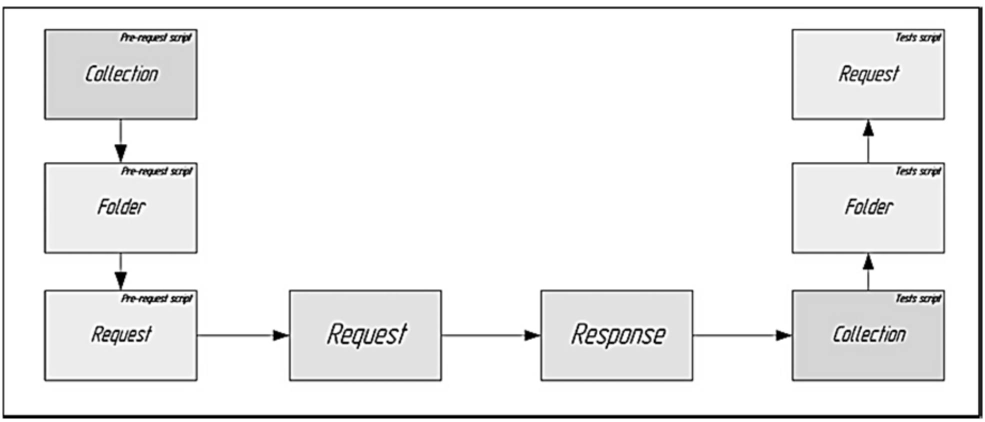

Fig. 2. Dependency diagram in Postman

Consider executing queries in Postman. To do this, we use the getNameByBookId method, which is used to get the title of a book by its identifier. The user key (userKey) and the work identifier (bookId) are passed as query parameters. The response is expected to be a string containing the title of the work. An example of executing a GET request is shown in Fig. 3.

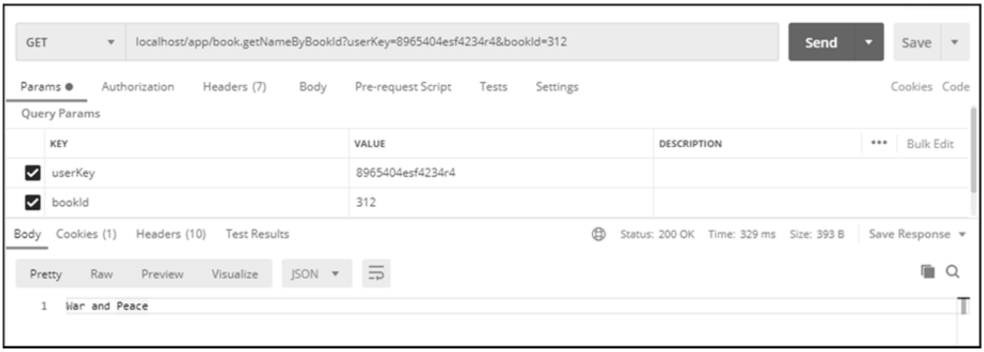

Fig. 3. An example of a GET request

In addition to executing requests, Postman allows you to automate the testing of API methods, which can significantly speed up the process of developing a software product.

To execute a request and an automated test, you must:

1. Take out the URL and token as environment variables.
2. Put down the method required for the request
3. Specify request parameters
4. In the Tests tab, enter the code that tests the method (its results).
5. Submit an inquiry.
6. After executing the request, view the results: response (Body) and test results (Test Results).

Consider creating and executing a test using the example of the previously considered getNameByBookId method.

One of the simplest and most understandable tests is to check the status of the completed request. If the request is successful, the response will contain a status code: 200.

Test listing:

pm.test(«Status code is 200», function () {
pm.response.to.have.status(200);
});

Upon successful completion of such a test, the user can see the status of the PASS test, as well as the message “Status code is 200”.

We specify the data listed in the Tests section of the request page in Postman and sends the request to the server. After running it, you can see that the Test Results tab highlights “(1/1)”, indicating that the test has been run. During the transition, you can see the result of a successful test (Fig. 4).

Consider the case where the test failed. To do this, we will change the test listing so that the test expects the request to return with an error code of 500. However, the request itself will return the code 200. The result of such a test is shown in Fig. 5.

In Fig. 5, you can see that the Test Results tab now highlights “(0/1)” indicating that the test failed, the test status changed to “FAIL”, and a comment can be seen next to the message indicating that the test was passed. And you can see in the report of error that prevented the test from running successfully.

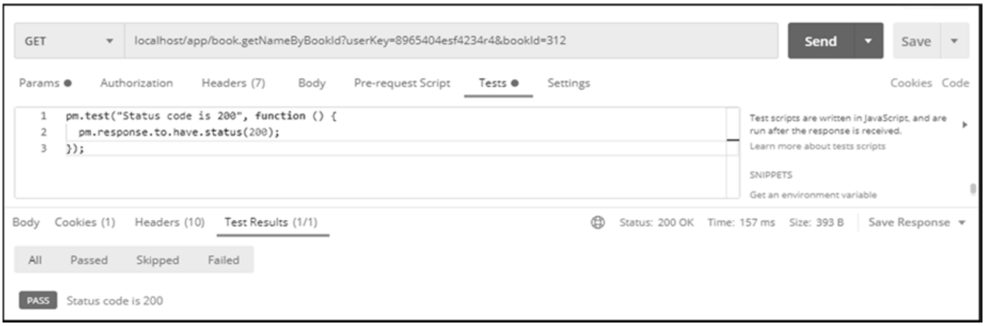

Fig. 4. The result of a successful test

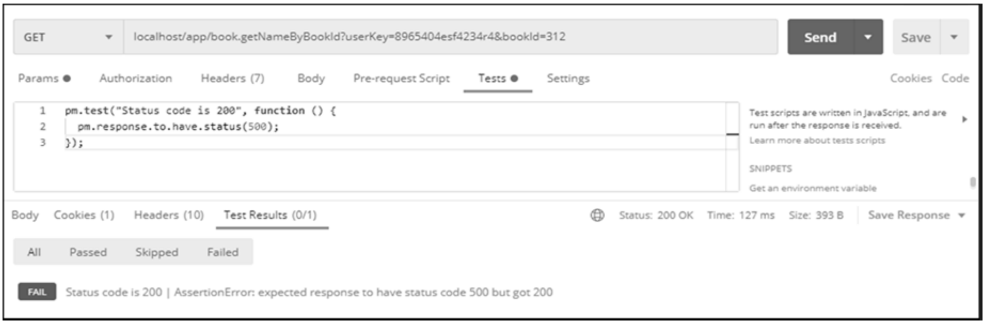

Fig. 5. View of the Postman window when the test fails

It is important to note that such tests in Postman can have a more complex structure. They can check several conditions, analyze data, etc. However, despite the complexity of compiling such tests, their important advantage is a significant acceleration of the development process, testing, as well as minimizing the human factor when checking errors.

Thus, we can conclude that automated API testing has more advantages than disadvantages, since its cost pays off quite quickly, and the speed exceeds the speed of manual testing. The only downside is that the tester needs to be able to code, but for this there are many tools that can help in creating tests. One of them is Postman, which helps you build, test, and document your application for a single resource.

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Формализованное представление угроз применения вредоносных программ в процессе противоправных действий в отношении сервиса платежных систем дистанционного банковского обслуживания

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Определены основные сервисы дистанционного банковского обслуживания, рассмотрены их преимущества и недостатки. Проведен анализ возможных источников угроз несанкционированного доступа к информационной системе сервиса платежных систем дистанционного банковского обслуживания. Разработана функциональная модель противоправных действий нарушителя, применяющего вредоносное программное обеспечение в отношении платежных систем (банкоматов) в целях хищения денежных средств.

Ключевые слова: *дистанционное банковское обслуживание, безопасность информации, сервис платежных систем, вредоносное программное обеспечение, модель злоумышленника*

Formalized Representation of Malicious Programs Threats in the Process of Illegal actions in Relation to the Service of Remote Banking Payment Systems

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The paper identifies the main remote banking services, considers their advantages and disadvantages. The analysis of possible sources of unauthorized access threats to the remote banking payment systems service is carried out. Presented developed by the author a functional model of illegal actions of a violator using malicious software against payment systems for with the purpose of stealing funds has been developed.

Keywords: *remote banking, information security, payment systems service, malicious software, model of an attacker*

Introduction

In recent years, the use of remote banking services (RBS) has become very common due to the speed, simplicity and reliability of transactions. The COVID-19 pandemic has also accelerated digitalization in banks around the world. As a result, the number of remote services for bank customers has also increased. RBS is a way for customers to interact with the bank on the basis of orders transmitted electronically via communication channels. Banks pay special attention to this method of interaction in order to expand the customer base.

DBO services based on the classification of service provision and typification of end devices used for banking operations can be divided into the following classes [1]:

1. “Client-Bank” services, which are divided into 2 types: “thin client” and “thick client”.
2. Telephone-Bank services.
3. Service services using payment systems (ATMs) and self-service banking devices.

ATMs and terminals fall into the category of remote banking, since they almost completely provide banking services remotely, without a client visiting a banking organization. In addition, an important factor for including them in this category is the possibility of duplicating the basic functions of a standard bank client that the bank provides to individuals for making payments.

The issues of security during banking operations through the service “Client's Personal account” using a home computer or smartphone are widely and in detail considered in the professional literature and are under the constant attention of developers of anti-virus software and security services of banks [2, 3]. At the same time, ensuring security in banking operations using ATMs, most of which are actually mini-offices, is often reduced to recommendations for the safety of Bank cards and pin-codes.

Today, the ATM is the most convenient means of RBS for individuals, allowing not only to withdraw or Deposit cash, but also to carry out such banking operations as the transfer of funds from one account to another (including interbank), making payments, repayment of loans, etc.However, the use of RBS technology along with the advantages has a number of negative consequences. The most significant of them are the possibility of gaining access to financial assets of users or to the ATM management system by intruders. This kind of criminal activity causes not only significant material damage to users, but also significant material and reputational damage to the credit and financial sector as a whole [4].

Thus, purposeful and systematic improvement of security technologies of payment systems and, in particular, ATMs is an urgent problem. This article is devoted to the analysis of possible threats to the security of the RBS environment during banking operations using the service of payment systems and the creation of a functional model of the offender, who uses malware to implement their illegal actions against payment systems (ATMs). On the basis of such a model it is possible to build a functional model of responses to these threats, and, as a consequence, the construction of mathematical models of the characteristics of these responses.

Sources of threats of unauthorized access to the ATM information system

The range of illegal actions against ATMs can be varied — from the theft of plastic cards or mechanical hacking of ATMs to the use of “ATM viruses” or embedded readers (skimmers). Traditionally, the security problems of the payment system service are reduced to ensuring the safety of Bank cards and protecting ATMs from mechanical hacking. At the same time, the secrecy of the introduction and implementation of malicious functions by “ATM viruses” puts them in the category of the most dangerous tools of illegal actions in relation to this RBS service. This determines the need to study the characteristics of such threats to information security in order to justify the requirements for methods and means of protection.

An objective classification basis for the classification of threats to the service of payment systems is the phasing of their manifestation. At the first stage, the attackers try to access the information resources of the payment system by infecting the ATM with the appropriate malicious software. For this the most often skimmers are used. In contrast to the traditional use of this device as a device for reading user identification data, in this case it is used as a container for the introduction of malware into the payment system software.

The most well-known malware of this kind is Trojan.Skimer [5]. Built on the technology of “Trojan” programs Trojan.Skimer allows you to form a kind of “back door” through the ATM, which allows an attacker to perform the following actions using the ATM keyboard:

• play the entered registration data;
• print the date on the ATM printer;
• display software version;
• distribute cash;
• uninstall an unwanted program;
• close (block) ATM.

At the second stage, the attackers, using the introduced malware, gain access to the ATM management and withdraw funds from the ATM dispenser or transfer them to the controlled accounts.

Functional model of the actions of the attacker

I present a description of this kind of action with respect to the payment systems service in the form of a composite structure of graphs, which contains only the minimum number of parameters. That parameters are necessary for the identification of functional States of the process under study, the order of their change, as well as generalizing features, in accordance with which the functional States of the subsequent composite levels are formed. All functional States at each level of the functional composition of the process under study are presented in the form of a graph.

Based on the specifics of the illegal actions functional model representation in relation to the service of payment systems in the form of a composite structure of the functional description of such actions form a set $\{\}$, $i = 1, 2, \ldots, 7$ the states (Table). The compositional feature for the first level of the compositional structure of the process under study is the actions of an attacker to access information resources of the RBS payment systems service.

The characteristics of the functional states of illegal actions in relation to the “Client-Bank” service

No.	The name of a characteristic	Identifying characteristics of the corresponding States	
		Name	ID
1	The fact of installation of skimming devices	Collection of credit card data for subsequent access to the Bank's customer account	$S_1^{(1)}$
2	The fact that the use of skimming devices		
3	The fact of introduction of malicious software on the server of the payment system service	Introduction of malicious software into the working environment of the payment system server — the object of fraudulent actions	$S_2^{(1)}$
4	The fact of malicious software initialization in the working environment of the payment system server	Initialization of malicious software in the production environment of the payment system server — the object of fraudulent actions	$S_3^{(1)}$

End of tabs

No.	The name of a characteristic	Identifying characteristics of the corresponding States	
		Name	ID
5	The fact that an attacker acquired ATM control codes on specialized sites	Obtaining access codes to the infected ATM	$S_4^{(1)}$
6	The fact of transfer to the attacker of ATM control codes directly from the installers of specialized or software equipment		
7	The fact that the ATM is infected with malicious software through a direct connection to the control computer	The results of the cash dispensers ATM using the obtained codes or commands ATM	$S_5^{(1)}$
8	The fact of getting access to the ATM management under the guise of service	Getting access to the infected ATM	$S_6^{(1)}$
9	The fact of gaining control of the ATM via the network connection		
10	The fact of the transfer of funds without withdrawal	Obtaining data and transferring funds to the attacker's account using an infected ATM	$S_7^{(1)}$
11	The fact of receipt of payment card credentials		
12	The fact of transfer of payment card credentials to the attacker		

At the second level of the composite functional structure, the set of states $\{S_i^{(1)}\}$ of the first level of the hierarchy are grouped on the basis of stages of fraudulent operation in relation to the payment system using malware. The result is two states

$$\{s_j^{(2)}\}, j = 1,2$$

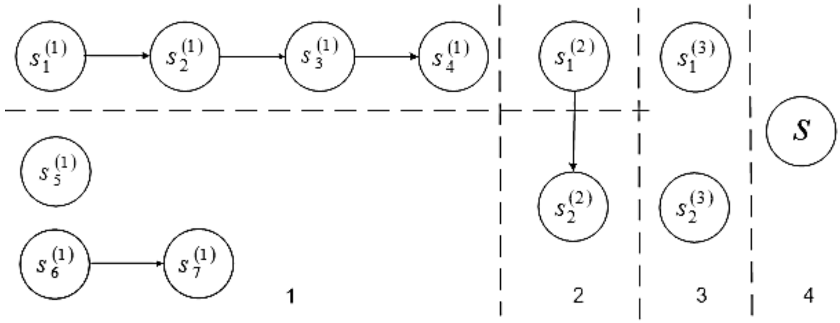
where $s_1^{(2)}$ is obtaining information by an attacker to access the information environment of the payment system; $s_2^{(2)}$ is serving an attacker in the information environment of the payment system as a legitimate user.

Third, the level of the hierarchy of functional representation of illegal actions against payment systems using malware are two States that characterize the target function S of this kind of action:

• state $s_1^{(3)}$ is illegal withdrawal of funds from ATM dispensers using received codes or management commands;

• state $s_2^{(3)}$ is illegal transfer of funds of the Bank's client to accounts controlled by intruders.

The functional model of the actions of criminals who use malicious programs in the implementation of illegal actions in relation to the ATMs is represented in Figure.



The functional model of the attacker actions in the process malicious program application in the implementation of illegal actions against the service of payment systems of remote banking

Conclusion

This functional model can serve as a basis for the development of a mathematical apparatus for an adequate assessment of the effectiveness of measures to respond to the security threats of this service.

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Диагностики заболеваний на основе медицинских карт пациентов с использованием машинного обучения

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Рассмотрены системы прогнозирования потенциальных заболеваний на основе исторических медицинских данных. Использована методология функционального моделирования для определения функциональной структуры проектируемой системы диагностики и прогнозирования заболеваемости. Определены основные функции разрабатываемой системы. Проанализированы методы машинного обучения, которые широко используются при диагностике заболеваний.

Ключевые слова: *информационная система, проектирование, машинное обучение, прогнозирование заболеваемости, медицинские карты пациентов, функциональная модель*

Disease Diagnosis Based on Patient Medical Records Using Machine Learning

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The article is devoted to systems for predicting potential diseases based on historical medical data. The methodology of functional modeling was used to determine the functional structure of the designed system for diagnosing and predicting morbidity. The main functions of the developed system are determined. The methods of machine learning, which are widely used in the diagnosis of diseases, are analyzed.

Keywords: *information systems, design, machine learning, patient medical records, disease prediction, functional model*

Введение

Анализ медицинских данных широко используется в области интеллектуальных консультаций, диагностики заболеваний и поддержки принятия решений врача. С быстрым развитием Интернета во всем мире стала популярной для исследований электронная медицинская информация такая, как электронные медицинские карты (electronic medical record, EMR), которые заменили традиционные бумажные медицинские карты, онлайн-записи на прием и онлайн-отчеты. Таким образом, накоплен большой объем медицинских данных здравоохранения, которые могут быть своевременно собраны, правильно сохранены и эффективно проанализированы. Это имеет большое значение для улучшения образа жизни [1], диагностики и эффективности лечения, качества медицинских услуг, ускорения исследований и разработок лекарственных средств и оптимизации медицинской системы. Прогнозирование возможных заболеваний поможет пациенту пройти профильные медицинские осмотры, указав на возможные признаки заболевания. Эти системы предсказывают возможные заболевания пациентов на основе анализа медицинских карт и позволяют уменьшить проблему задержки лечения из-за нечеткого описания симптомов или ограниченных профессиональных знаний. Если прогноз заболевания предоставить практикующему врачу, то необходимые медицинские исследования могут быть проведены раньше, а пациент может заранее правильно скорректировать образ жизни. Это приводит не только к улучшению качества жизни пациента, но и к снижению затрат на здравоохранение, в противном случае пациенты могут пропустить важные медицинские осмотры, что приведет к серьезным проблемам со здоровьем [2].

Методы решения

Статья посвящена применению методологии функционального моделирования [3] для анализа бизнес-процессов информационной системы в целях прогнозирования заболеваемости. Проектирование архитектуры информационных систем, основанное на тщательном системном анализе предметной области, имеет первостепенное значение для успешной разработки информационных систем в целом.

Контекстная диаграмма функциональной модели информационной системы диагностики и прогнозирования заболеваемости на основе анализа медицинской базы данных пациентов представлена на рис. 1. Опишем основные объекты этой диаграммы.

Входная информация: демографические данные пациента (возраст, дата рождения, пол и т. д.); неструктурные медицинские данные (рентгенографические изображения, биомедицинские сигналы и т. д.); клинические лабораторные результаты; информация о лекарствах, которые принимает пациент; исторические медицинские данные.

Управляющая информация: методы обработки данных; методы извлечения признаков; описания медицинских симптомов и алгоритмы машинного обучения.

Механизмы: врач, компьютер, разработчик и система управления базами данных (СУБД).

Выходная информация: предварительный диагноз; прогноз заболевания; план лечения и рецепт.

На рис. 2 представлена декомпозиция контекстной диаграммы функциональной модели. Рассмотрим более подробно основные функции системы.

Обработка данных. Эта функция занимается преобразованием необработанных данных для получения значимой информации. Обработка медицинских данных включает в себя повышение качества медицинских изображения, сегментацию медицинских изображений [4] и обработку биомедицинских сигналов.

Рис. 1. Контекстная диаграмма функциональной модели

Извлечение признаков. Функция преобразует исходные данные, такие как тексты, сигналы или изображения, в числовые характеристики, которые можно использовать для машинного обучения.

Диагностика и прогнозирование заболеваемости. Эта функция выполняется с использованием методов машинного обучения с учителем. Алгоритмы данного типа обучения требуют помеченного набора данных для обучения. Часто эти данные требуют ручного отбора или экспертной оценки, например, радиолог необходим для маркировки набора изображений сканирования МРТ, а невропатолог должен классифицировать набор изображений, полученных из образцов посмертных пациентов. После того, как этот эталонный набор данных был помечен, алгоритм машинного обучения строит модель взаимосвязи между входными функциями (например, размером области мозга на МРТ-сканировании) и меткой (например, диагностической категорией). Затем алгоритм классификации может применить эту модель к новым немаркированным наборам данных, чтобы предсказать метку на основе новых данных входных функций.

Принятие решений и предоставление информации: врач на этом этапе рассматривает полученные результаты и предоставляет пациенту план лечения и рецепт.

Проанализируем методы решения поставленной задачи (рис. 2, блок 3 «Диагностика и прогнозирование заболеваемости»). Машинное обучение с учителем [5] делится на алгоритмы классификации и регрессии. Алгоритмы классификации предсказывают категориальный вывод (диагностическую категорию) для каждой выборки данных пациента [6]. Напротив, алгоритмы регрессии предсказывают переменную с действительным знаком для каждой выборки данных (например, степень функционального ухудшения, измеренную по непрерывной шкале). Применительно к данным здравоохранения алгоритмы классификации и регрессии могут определять эндотипы пациентов, идентифицируя шаблоны в данных и группируя области сходства вместе. Практическим примером регрессионных подходов может быть подразделение пациентов на эндотипы прогрессирования на основе алгоритмов, которые моделируют снижение двигательной функции, продолжительность заболевания или наклон прогрессирования, чтобы сформировать нюансированные представления временных рядов прогрессирования.

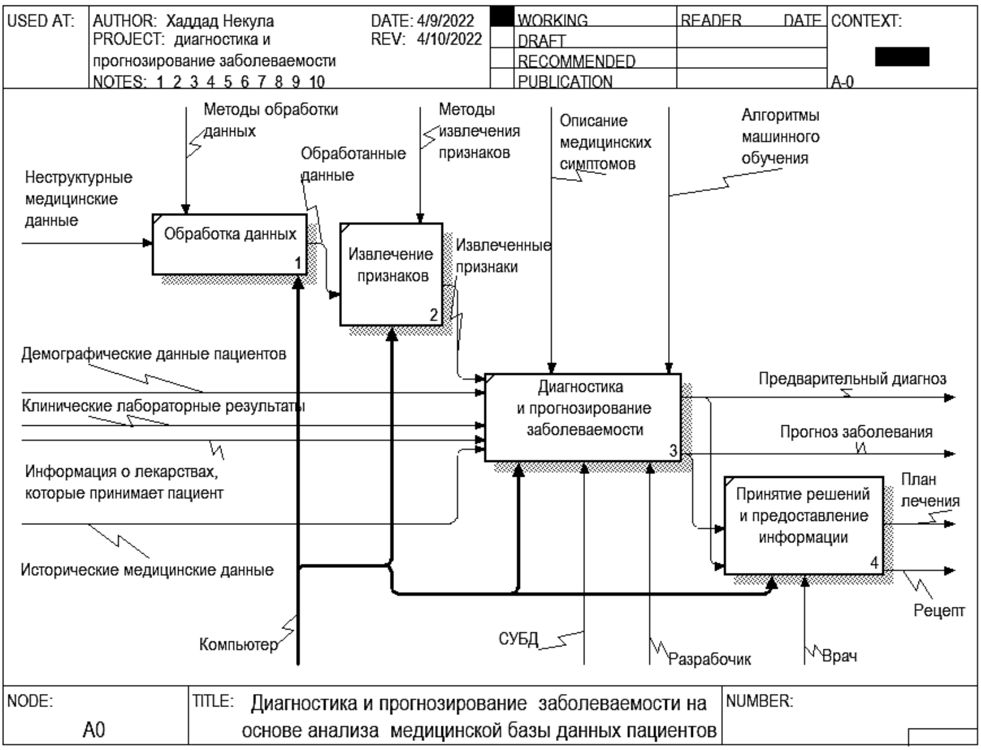

Рис. 2. Декомпозиция контекстной диаграммы модели

На данном этапе используются различные методы, которые варьируются по типу данных (структурные и неструктурные медицинские данные) и по типу задач, которые они предназначены решить [6]. Для настоящего исследования были выбраны сверточные нейронные сети в качестве классификатора для диагностики заболеваний по медицинским изображениям в дополнение к методу случайного леса (random forest) для диагностирования заболевания по структурным данным (клинические лабораторные результаты, демографические данные пациента и т. д.) [7, 8]. Для прогнозирования заболеваемости и ранней диагностики на основе исторических медицинских данных используются рекуррентные нейронные сети (recurrent neural network, RNN) и долгая краткосрочная память (long short-term memory, LSTM) [9, 10]. Выбор этих методов основывался на анализе статей, посвященных диагностике заболеваний с помощью методов машинного обучения.

Заключение

Разработана обобщенная функциональная модель информационной системы диагностики и прогнозирования заболеваемости на основе анализа медицинской базы данных пациентов. Определены основные функции разрабатываемой системы:

- обработка медицинских данных пациентов;
- извлечение признаков заболеваний;
- диагностика и прогнозирование заболеваемости;
- принятие решений;
- предоставление информации.

Для этих функций определены входная, управляющая, выходная информация и механизмы реализации. Проанализированы методы машинного обучения, которые широко используются при диагностике заболеваний. Методы машинного обучения, которые планируется использовать в разрабатываемой системе, были выбраны на основе анализа типов и особенностей входных и выходных данных. На следующих этапах работы планируется провести дальнейшую декомпозицию блоков функциональной модели (см. рис. 2), что даст детальное представление о функциях и связях разрабатываемой системы. При проектировании системы ранней диагностики заболеваний планируется использовать модели, методы и средства, описанные в работах [11, 12].

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УДК 004

Веб-скрейпинг

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Веб-скрейпинг — это технология получения веб-данных путем извлечения их со страниц веб-ресурсов. Веб-скрейпинг используют для синтаксического преобразования веб-страниц в более удобные для работы формы. Веб-страницы создают с использованием текстовых языков разметки и содержат множество полезных данных в коде. Загрузка и просмотр страницы — важнейшие составляющие технологии, они являются неотъемлемой частью выборки данных. Рассмотрены основные виды веб-скрейперов.

Ключевые слова: *интернет-технологии, веб-скрейпинг, интернет-исследования, парсинг, выборка данных*

Web-Scraping

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Web scraping is a technology for obtaining web data by extracting it from web resource pages. Web scraping is used to syntactically transform web pages into more usable forms. Web pages are created using text-based markup languages and contain a lot of useful data in the code. Loading and viewing a page are critical components of the technology, they are an integral part of the data sampling. This article will cover the main types of web scrapers.

Keywords: *internet technologies, web scraping, internet research, parsing, data set*

Web scraping is the process of collecting structured web data in an automated fashion. It's also called web data extraction. Some of the main use cases of web scraping include price monitoring, price intelligence, news monitoring, lead generation, and market research among many others [1].

Although web scraping can be done manually, in most cases, automated tools are preferred as they can be less costly and work at a faster rate. Websites come in many shapes and forms, as a result, web scrapers vary in functionality and features.

Web scraping works by way of two parts: a web crawler and a web scraper. The web crawler is the horse, and the scraper is the chariot [1].

A web crawler, which we generally call a "spider", is an artificial intelligence that browses the internet to index and search for content by following links and exploring. In many projects, you first "crawl" the web or one specific website to discover URLs which then you pass on to your scraper [2].

A web scraper is a specialized tool designed to extract data from a web page. Web scrapers vary in design and complexity, depending on the project. An important part of every scraper is the data selectors that are used to find the data that you want to extract from the HTML file [2].

Most web scrapers will output data to a CSV or Excel spreadsheet, while more advanced scrapers will support other formats such as JSON which can be used for an API.

There are 5 types of scrapers.

Self-built or Pre-built. Just like how anyone can build a website, anyone can build their own web scraper. However, the tools available to build your own web scraper still require some advanced programming knowledge. The scope of this knowledge also increases with the number of features you'd like your scraper to have.

Browser extension. Web scraping extensions have the benefit of being simpler to run and being integrated right into your browser. However, these extensions are usually limited by living in your browser. Meaning that any advanced features that would have to occur outside of the browser would be impossible to implement.

The user interface between web scrapers can vary quite extremely. For example, some web scraping tools will run with a minimal UI and a command line. On the other hand, some web scrapers will have a full-fledged UI where the website is fully rendered for the user to just click on the data they want to scrape. These web scrapers are usually easier to work with for most people with limited technical knowledge.

Local web scrapers will run on your computer using its resources and internet connection. This means that if your web scraper has a high usage of CPU or RAM, your computer might become quite slow while your scrape runs. With long scraping tasks, this could put your computer out of commission for hours.

Cloud-based web scrapers run on an off-site server which is usually provided by the company that developed the scraper itself. This means that your computer's resources are freed up while your scraper runs and gathers data. You can then work on other tasks and be notified later once your scrape is ready to be exported.

On average, 2 % of online revenue is lost as a result of web scraping. The key culprits behind web scraping are bots, a software application that runs automated scripts. Bots typically perform tasks at a much higher and faster rate than humans [3].

Because information on the Internet is public domain, web scraping is legal. However, it has a negative effect on content owners. Today's cybersecurity landscape is crawling with sophisticated bots doing the dirty work for hackers. Any content that can be viewed on a webpage can be scraped. There is an entire economy built around web scraping that only looks to grow in the future if malicious bots are not blocked and threats are not mitigated.

There are 6 main use cases for web scraping: content scraping, research, contact scraping, price comparison, weather data monitoring, and website change detection [3]. Content scraping is stealing original content from a legitimate website and posting it on another website without the knowledge or permission of the original content owner. Content scraping can come in the form of web mashups, using information from more than one source to create a new display of information, also known as web data integration. For example, users can build new aggregatorsand centralized job portals by using data from other websites. Content scraping is the top use of web scraping by customers, with 38% of companies who using it [4].

The second main use for web scraping is research. 26 % of companies that hire web scrapers use web scraping bots to gather research on listening services that monitor consumer opinions about products and companies. Companies also use web scraping bots for mass data collection for various projects. For example, users can get marketing intelligence by using bots to identify key market developments from various sources on the web [4].

19 % of companies use web scraping for contact scraping. These companies wish to gain access to customers' emails in order to obtain contact information for marketing

purposes or for background reports. Bots help generate leads from business directories and social media sites like Twitter and LinkedIn.

Consulting and marketing research firms, like the Nielsen Company, used web scraping to monitor online buzz for clients and get insights for their consumers until it decided web scraping was bad PR. E-commerce sites in various industries, such as fashion and ticket retailers use web scraping to compare prices and inventory and gather content. These are just a few examples of industries that use web scraping for personal revenue gain [4].

With a wide variety of web scraping customers, comes a wide variety of web scraping victims. If a website contains content that drives revenue for a business, that business is at risk. Many of these industries are being targeted by an influx in startups that are scraping information from industry leaders in order to compete.

Web scraping is readily available in a variety of forms, enabling the average person to obtain scraped data and content. These forms include both web scraping services and do-it-yourself web scraping software, making web scraping easily accessible. Additionally, a number of websites host ads providing freelance and company web scraping services, with new ads being posted every day.

The wide-scale costs of web scraping products and services also contribute to web scraping's accessibility.

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Мобильные приложения и языки программирования iOS

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Мобильное приложение — это программное обеспечение, которое работает на мобильном устройстве (смартфон, планшет и смарт-устройства). История мобильных приложений началась с выпуска первых телефонов в 1993 г., но всемирное распространение они получили с появлением первого iPhone. Для разработки мобильных приложений для устройств iOS используют два языка программирования: устаревший, но функциональный Objective-C и Swift.

Ключевые слова: *iOS, мобильные приложения, языки программирования, Objective-C, Swift, разработка приложений*

Mobile Anwendungen und iOS-Programmiersprachen

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Eine mobile App ist eine App, die auf einem mobilen Gerät wie Smartphone, Tablet und Smart-Geräte läuft. Die Geschichte der mobilen Apps beginnt mit der Herstellung der ersten Telefone im Jahr 1993, aber die weltweite Verbreitung hat mit der Erscheinung des ersten iPhons gewonnen. Für die Entwicklung von mobilen Apps für iOS-Geräte werden zwei Programmiersprachen verwendet: die veraltete, aber funktionierende Objective-C und Swift.

Keywords: *iOS, die Anwendung, Die Programmiersprachen, Objective-C, Swift, App-Entwicklung*

Mobile Anwendungen und iOS-Programmiersprachen

Die Beliebtheit und Relevanz der mobilen Webbesuche, das heißt des Gebrauchs vom mobilen Netz, ist nicht zu übersehen, das liegt vor allem an seiner leichten und schnellen Zugänglichkeit. Das ist der Grund, warum bereits im Herbst 2014 mehr als jeder zweite Webbesuch über Smartphones und Tablets erfolgte.

Im Allgemeinen kann eine App, kurz für Applikation, jede Art von Anwendung sein und gehört zur Software. Diese lässt sich nicht von der Hardware, den physischen Bestandteilen eines Computers oder anderen Gerätes, trennen und wird darauf ausgeführt. Auch umgekehrt ist Hardware auf Software angewiesen, welche sich in drei Bereiche unterteilen lässt.

Mobile Apps

Sprechen wir von Apps, sind zumeist mobile Apps gemeint, welche auf Mobilgeräten wie Smartphones, Tablets und “smarten” Geräten wie Smart TVs oder Autos mit integrierter Software ausgeführt werden.

Dabei handelt es sich um kleine Programme mit unterschiedlichen – mal mehr, mal weniger nützlichen — Funktionen. Apps haben in der Regel keine systemische Funktion. Das heißt, sie sind nicht relevant für das Funktionieren eines Systems.

Apps erweitern somit den Funktionsumfang eines Gerätes. So gibt es Apps zum Kommunizieren, Navigieren, Spielen, Online Nachrichten Lesen und vieles mehr. Im Gegensatz zu systemischen Anwendungen zielen Apps auf eine bestimmte Zielgruppe ab. Somit lässt sich durch eine App das Smartphone oder Tablet an die Bedürfnisse des Nutzers anpassen.

Die Geschichte der Apps

Entgegen der Annahme, dass Smartphones auf eine noch junge Geschichte zurückblicken, kam das erste Touchscreen-Telefon bereits im Jahre 1993 auf den Markt: Der IBM Simon war im Grunde ein Taschencomputer und hatte sogar eine E-Mail-Funktion. Im Jahre 1999 folgte dann das erste Blackberry 850 des Unternehmens Research In Motion mit einer physischen Computer-Tastatur.

Bei den ersten Smartphones wurden einige Software Apps bereits auf das Gerät vorinstalliert. Dinge wie ein Taschenrechner, ein Notizbuch, ein Diktiergerät oder der Internet Button waren bereit für die Nutzung. Die Anzahl der möglichen Anwendungen war noch sehr gering. Doch die jungen Unternehmen, die eine Vielzahl an tollen Smartphone Apps entwickelt haben, waren nicht weit entfernt. Die Suche und Installation einer App konnte zwar selbst ausgeführt werden, doch es war noch deutlich komplizierter als in der heutigen Zeit.

Die ersten Applikationen wurden schon im Jahr 2002 von dem Unternehmen RIM erstellt, z.B. ein Programm um E-Mails per Smartphone zu versenden. Diese Anwendungen sind fest an das Betriebssystem des Mobiltelefons gebunden und nicht löschbar. Mit der Erfindung von Java auf Mobiltelefonen änderte sich alles plötzlich: Anwendungen waren nicht mehr vom Betriebssystem abhängig und bereits vorinstalliert, sondern konnten heruntergeladen werden.

Die Smartphone-Welle wurde schließlich 2007 mit dem ersten iPhone von Apple ausgelöst. Dieses besaß verschiedene Apps, die allerdings vorinstalliert waren. Ein Jahr später erfolgte die Einführung des App Stores, mit dem es erstmalig möglich war, Apps über einen zentralen Store, also eine Art Management-Umgebung, herunterzuladen [1].

iOS-Apps

iOS, wobei das i ein Markenkennzeichen ist und OS für Operating System (Betriebssystem) steht, wurde von Apple entwickelt und wird nur für Apple-Geräte benutzt. Zusammen mit watchOS und tvOS ermöglicht es den Betrieb von iPhones und iPads, Apple Watches und Apple TVs.

Der Download von Apps ist über den App Store möglich. Für die App-Entwicklung kann die integrierte Entwicklungsumgebung XCode verwendet werden, die allerdings nur für den Mac erhältlich ist, weshalb Entwickler einen Mac benötigen, um entwickelte Apps zu kompilieren [2, 3].

Das User Interface von iOS Apps zeichnet sich meist durch eine minimalistische und elegante Benutzeroberfläche aus. Beim Nutzererlebnis steht vor allem eine hohe Konnektivität mit der Hardware und anderen Geräten des Apple-Universums im Vordergrund.

iOS-Programmiersprachen

Übliche Programmiersprachen für die Entwicklung von iOS Apps sind Swift und Objective-C, welche beide über das Framework Cocoa verwendet werden. Objective-C ist die ältere der beiden Sprachen, wird aber nach wie vor benutzt. Swift ist seit etwa 2013 auf dem Markt und gilt als schneller und performativer. Eine Kompilierung der Apps erfolgt direkt in Maschinencode. Auch C und C++ können für die App-Entwicklung verwendet werden, über Umwege sind auch Java, Ruby und andere verwendbar. Da Swift und Objective-C nur für iOS ausgelegt sind, ist es unter Entwicklern weniger verbreitet als beispielsweise Java, dafür wird für weniger Geräte, nämlich ausschließlich Apple-Geräte, aber damit auch gezielter programmiert und die Ergebnisse sind leichter zu überprüfen.

Lassen Sie uns im Detail einige grundlegende Unterschiede zwischen Swift und Objective-C betrachten [4]:

1. Swift ist die neueste Programmiersprache, die von Apple entwickelt wurde und auf verschiedenen plattformübergreifenden Betriebssystemen wie Linux, Darwin, Free BSD usw. ausgeführt werden kann, wohingegen Objective C eine allgemeine objektorientierte Programmiersprache ist, die von Apple verwendet wird.
2. Swift verfügt über verschiedene Programmierfunktionen wie sichere Programmiermuster, Syntax wie Objective C und vollständigen Zugriff auf Cocoa-Frameworks, während Objective C mit Ausnahme von STL dieselben Funktionen wie C ++ unterstützt und grundlegende Frameworks enthält.
3. Swift hat objektorientierte und prozedurale Merkmale in seiner Sprache und eingebaute Funktionen in seiner Bibliothek, wohingegen Objective C verschiedene Datentypen, Token zum Erkennen der Bezeichner, Deklarationen und Zuweisungen und Präprozessor zum Definieren von Konstanten hat.
4. Swift unterstützt verschiedene Operatoren wie arithmetische Operatoren, logische Operatoren, bitweise Operatoren, Vergleichsoperatoren, Zuweisungsoperatoren, Bereichsoperatoren und verschiedene Operatoren, während Objective C mit Ausnahme von Range und Preprozessoren, die nicht Teil der Kompilierung sind.
5. Swift unterstützt Wörterbücher, Funktionen, Abschlüsse, Aufzählungen, Strukturen usw., wohingegen Objective C Posieren, Erweiterungen, dynamische Bindung, Protokolle, zusammengesetzte Objekte, Speicherverwaltung und Aufzählungen unterstützt.
6. Swift unterstützt optional Verkettung, Typumwandlung, Generika, Protokolle, Indizes usw., wohingegen Objective C den dynamischen Versand und die automatische Generierung von Zugriffsmechanismen für den Zugriff auf Mitgliedsvariablen und-eigenschaften ermöglicht und es einer Methode und einem Namen ermöglicht, denselben Bezeichner zu verwenden.
7. In Swift wird der Aufruf einer Methode zur Kompilierungszeit entschieden und ähnelt der objektorientierten Programmierung, während in Objective C der Aufruf einer Methode zur Laufzeit entschieden wird und Objective C spezielle Funktionen wie das Hinzufügen oder Ersetzen von Methoden wie bei einer Klasse aufweist, die ist bereits vorhanden.
8. In Swift können Fehler mithilfe von Protokollen behandelt werden, um den unerwarteten Fluss der Programmsteuerung zu vermeiden, wohingegen Objective C den Wert «nil» hat, der auf leistungsstarke Weise sicher gehandhabt werden kann, indem Nachrichten sicher an keine Objekte gesendet werden.
9. In Swift wird das Überladen von Operatoren unterstützt und es ist in Bezug auf Umfang und Einfachheit global, wohingegen Objective C keine Standardparameter

unterstützt, sondern durch Manipulation mehrerer Methoden implementiert werden kann und auch keine privaten Mitglieder unterstützt.

10. In Swift ist Arc (Automatic Reference Counting) die Funktion, die die Garbage Collection verwaltet, bei der geleerter Speicher den erforderlichen Prozessen zugewiesen wird, wohingegen Objective C keine stapelbasierten Speicherobjekte unterstützt und das Zuweisen von Speicher in Objective C sehr kostspielig ist.

11. In Swift werden Klassenobjekte normal deklariert und ähneln den allgemeinen objektorientierten Programmiersprachen, wohingegen Objective C ein zusammengesetztes Objektfeature aufweist, in das ein Objekt eingebettet ist, d.h. ein privates Clusterobjekt wird in das Hauptobjekt eingebettet zusammen mit einigen primitiven Methoden.

12. In Swift gibt es erweiterte Operatoren, um die Manipulation komplexer Werte zu handhaben, während Objective C über die Funktion zur schnellen Aufzählung verfügt, bei der Auflistungen Kernkomponenten dieser Funktion sind.

Fazit

In den letzten Jahren ist die Nutzung von Smartphones und anderen Mobilgeräten immer mehr angestiegen. Selbst Anwendungen, die eine Internetverbindung erfordern, werden immer häufiger mobil genutzt. Deshalb ist für Unternehmen, die in der Lebenswirklichkeit potentieller Kunden mitspielen wollen, eine mobilfähige Website bzw. ein Responsive Design ein wichtiger Faktor, wenn nicht sogar die Mindestvoraussetzung, um gegen Mitbewerber mithalten zu können.

Die Bedürfnisse der Nutzer gehen aber meist über die Informationsbeschaffung hinaus und herkömmliche Websites bleiben hinter dem Potential zurück, was mit heutigen Technologien im Bereich Kommunikation möglich ist. Eine mobile App leistet weit mehr als eine Verbesserung der Unternehmenskommunikation bzw. -präsentation, welche zeigt, dass man heutigen Standards entspricht: Kunden können auch von unterwegs direkt in Interaktion treten oder sie offline nutzen. Zudem erhöht sich durch eine häufigere und verbindlichere Nutzung auch die Kundenbindung. So ist es nicht möglich, sich die Arbeit im Geschäftsbereich ohne mobile Anwendungen vorzustellen, so dass die mobile Entwicklung unbegrenzte Perspektiven hat und dem Nachwuchs enorme Chancen eröffnet.

Einer der großen Sprünge in der Entwicklung der iOS war die Einführung der neuen Programmiersprache Swift. Jetzt wird das neue SwiftUI Fraemwork eingeführt, das diese Entwicklung noch vereinfachen soll. Swift und Objective-C werden direkt zum Erstellen von Apple-Anwendungen verwendet. Objective-C wird weniger verwendet und durch Swift ersetzt, da es veraltet ist.

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Семантическая навигация роботов с использованием Mask-RCNN и обучения с подкреплением

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В современном мире, где интеллектуальный автономный робот необходим в различных областях применения (например, космос, транспорт, промышленность и оборона), потребность в точной навигации роботов стремительно растет. Для того чтобы ориентироваться в закрытой среде, заполненной объектами и движущимися людьми, робот должен избегать значительных препятствий и строить интеллектуальную траекторию движения к целевой точке. Поэтому в последнее время активно разрабатываются методы обучения робота навигации в неизвестных средах с помощью обучения с подкреплением. Рассмотрен процесс реализации программной модели для решения задачи семантической навигации робота в неизвестной среде с использованием алгоритма обучения с подкреплением для достижения конкретного объекта заданной категории.

Ключевые слова: *обучение с подкреплением, робот-навигация, избегание препятствий, семантическая навигация, обнаружение объектов*

Semantic Robot Navigation Using Mask-RCNN and Reinforcement Learning

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In our modern world, where an intelligent autonomous robot is required in various applications such as space, transportation, industry and defense, the need for accurate robot navigation is growing rapidly. To navigate in an enclosed environment filled with objects and moving people, the robot must avoid significant obstacles and construct an intelligent trajectory to the target point. Therefore, methods for teaching a robot to navigate in unknown environments using reinforcement learning have recently been actively developed. In this paper, we consider the process of implementing a software model to solve the problem of semantic navigation of a robot in an unknown environment using a reinforcement learning algorithm to reach a specific object of a given category.

Keywords: *reinforcement learning, robot navigation, obstacle avoidance, semantic navigation, object detection*

Введение

Автономная навигация является основным требованием при создании интеллектуальных агентов. Возможность автономной безопасной навигации особенно в динамических средах имеет первостепенное значение в промышленной мобильной робототехнике. Существующие методы навигации зависят от уже построенных статических карт, что приводит к многочисленным ошибкам в динамических средах [1].

В исследованиях роботизированная навигация рассматривалась с различных точек зрения, что привело к ее разделению на три основных подхода: геометрического, топологического и семантического. Геометрическое представление окружающей среды ближе к миру датчиков и исполнительных механизмов и лучше всего подходит для локальной навигации. Топологическое представление среды использует графы для ее моделирования и используется в задачах навигации большой размерности. Семантическое представление является наиболее абстрактной моделью и добавляет такие понятия, как служебные программы или значения элементов для карт, моделирующих среду [2].

Семантическая навигация

Семантическая навигация позволяет роботу соотносить то, что он воспринимает, с местом, в котором он находится. Таким образом, модель среды управляется с использованием объектов и концепций, которые они представляют. Вся эта информация используется для классификации мест, где расположены объекты, и для достижения заданного местоположения или конкретной цели. Таким образом, робот может находить места, семантически связанные с целью, даже если цель находится в малоизученной или неизвестной среде. Этот уровень навигации позволяет получить полную информацию, которая необходима при частичном знании окружающей среды [3].

Решаемая задача называется «Цель объекта», согласно которой необходимо перейти к экземпляру заданной категории объектов, например, «коробка» или «пакет». Агент инициализируется в случайном месте среды и получает в качестве входных данных категорию целевого объекта (G). На каждом временном шаге t агент получает визуальные наблюдения (s_t), показания датчика положения x_t и выполняет навигационные действия a_t [4]. Визуальные наблюдения состоят из RGB изображений и карт глубины. Область действия A состоит из четырех вариантов: движения вперед, поворота влево, поворота вправо, остановки. Агент должен предпринять действие «стоп», когда он считает, что приблизился к целевому объекту.

Семантическое отображение

Для создания семантического представления необходимо использовать матрицу каналов, где каждый канал соответствует категории, притом что первые два канала должны отображать препятствия и исследуемую область. Каждый элемент в матрице каналов показывает, является ли соответствующее местоположение препятствием, исследуемой областью или содержит объект соответствующей категории. Семантические категории определяются с помощью модуля семантического сопоставления, представляющего собой предварительно обученную сверточную нейронную сеть Mask R-CNN [5] для обнаружения объектов. Она обучается с использованием контролируемого обучения с кросс-энтропийной потерей.

Наблюдение глубины изображений используется для вычисления облака точек. Каждая точка в облаке точек ассоциируется с предсказанными семантическими категориями, а затем проецируется в трехмерное пространство для получения воксельного представления.

Последним шагом является преобразование представления вокселей в семантическую карту. Семантическая карта состоит и $K \times M \times M$ матрицы и обозначается как m_t, t обозначает временной шаг, так как семантическое представление обновляется на каждом временном шаге), где $M \times M$ обозначает размер карты и каждый элемент этой пространственной карты соответствует ячейке размером 25 см^2 (5×5 см) в физическом мире. $K = C + 2$ — это количество каналов в семантической карте, где C — общее количество семантических категорий. Первые два канала представляют препятствия и исследуемую область, а остальные каналы представляют категорию объекта. Каждый элемент в канале представляет, является ли соответствующее место препятствием, исследованной областью или содержит объект соответствующей категории. Карта инициализируется всеми нулями в начале эпизода, $m_0 = [0]^{K \times M \times M}$.

Целеориентированная семантическая политика

Необходимо определить ориентированную на цель навигационную политику, которая будет определять долгосрочную цель на основе текущей семантической карты для достижения данной цели как объекта (G). Если канал, соответствующий категории G, имеет ненулевой элемент, то это означает, что цель объекта соблюдается, и, согласно навигационной политике, все ненулевые элементы выбираются в качестве долгосрочной цели. В противном случае навигационная политика, ориентированная на цель, должна выбрать долгосрочную цель, где можно обнаружить объект, относящийся к категории цели. Навигационная политика, ориентированная на цель, использует обучение с подкреплением на основе уменьшения расстояния до ближайшего целевого объекта.

Детерминированная локальная политика

Локальная политика использует метод быстрого марша [6] для планирования пути к долгосрочной цели из текущего местоположения на основе канала препятствий семантической карты. Она просто предпринимает детерминированные действия на этом пути для достижения долгосрочной цели. На каждом временном шаге обновляется карта и перепланируется путь к долгосрочной цели.

Заключение

В статье представлена семантически ориентированная модель исследования для решения задачи навигации при частичном знании окружающей среды. Предложено использование Mask R-CNN для построения семантических карт среды и обучение с подкреплением для создания навигационной политики, которая выбирает долгосрочную цель и безопасно переходит к ней с учетом семантической карты.

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Идея нового алгоритма распознавания звездной карты

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Рассмотрены методы распознавания звездных карт при астроориентации и астронавигации космических аппаратов. Проанализированы текущие алгоритмы обработки звездных карт, полученные астрономическими датчиками зондов для исследования дальнего космоса. Сформулирована мысль о комбинации алгоритмов метода роя частиц и алгоритма муравьиной колонии для улучшения качества распознавания. По сравнению с существующими методами распознавания предлагаемый метод имеет высокую скорость распознавания, хорошую робастность, а требуемая емкость базовых данных навигационных звезд относительно невелика.

Ключевые слова: *идентификация звездной карты, база данных путеводных звезд, оптимизация роя частиц, алгоритм муравьиной колонии, комбинация алгоритмов*

The Idea of a New star Map Recognition Algorithm

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This article is devoted to methods for recognizing star charts in astroorientation and celestial navigation of spacecraft. The current algorithms for processing star maps obtained by astronomical sensors of deep space probes are considered. The idea of combining the algorithms of the particle swarm method and the ant colony algorithm in order to improve the quality of recognition is being clarified. Compared with the existing recognition methods, the proposed method has a high recognition rate, good robustness, the required capacity of basic nautical star data is relatively small.

Keywords: *star map identification, guidance star database, particle swarm optimization, ant colony algorithm, algorithm combination*

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Введение

Автономное управление пространственным положением космического аппарата с помощью системы астроориентации означает получение информации о космическом небесном теле через звездные датчики и выполнение автономной задачи ориентации космического аппарата без зависимости от использования наземных средств. Технология высокоточного автономного позиционирования космических аппаратов основана на автономном методе сопоставления и идентификации звездных карт. Процесс сопоставления и идентификации включает в себя следующие этапы:

- в соответствии с исходными данными звездной карты, полученными через звездный датчик, необходимо отметить все звездные точки;

• отмеченные звездные точки преобразуют и объединяют по определенным правилам для формирования информации, максимально отражающей звездную карту;

• проводят сравнение полученной и имеющейся в базе данных о навигационных звездах информации, после чего осуществляют завершающий этап по быстрому сопоставлению и идентификации звездной карты.

Спутник должен не только иметь возможность быстро определять свое положение в пространстве, но и обеспечивать быструю реконструкцию, когда ориентация теряется. Поэтому скорость распознавания и показатель успешности распознавания стали ключевыми показателями для измерения производительности алгоритма астронавигации и астроориентации.

Что касается сопоставления и распознавания звездных карт, существует много методов сопоставления и распознавания:

• алгоритм треугольного сопоставления [1];
• алгоритм четырехугольного сопоставления [2];
• алгоритм идентификации группы сопоставления [3];
• алгоритм разрезания триангуляции Делоне [4];
• распознавание на основе сетки [5];
• распознавание на основе созвездий [6];
• распознавание на основе статистических признаков [7];
• метод распознавания звездных карт на основе алгоритма пирамиды [8];
• метод распознавания звездных карт на основе нейронной сети [9];
• метод распознавания звездных карт на основе генетического алгоритма [10] и др.

Использование алгоритмов распознавания звездных карт дают относительно хорошие результаты, тем не менее у них есть преимущества и недостатки, например, в скорости распознавания, успешности распознавания, покрытии неба, размере базы данных и устойчивости к шуму. Но особенно в условиях большого поля и высокой чувствительности звездного датчика из-за большого искажения оптической системы, множества чувствительных звездных точек и сложности извлечения центра масс звездной точки скорость распознавания и вероятность успеха значительно снижаются.

Составной алгоритм, предложенный для распознавания

Метод роя частиц (МРЧ) — это метод типа эвристических алгоритмов для решения задач оптимизации. В 1995 г. Дж. Кеннеди (James Kennedy) и Р. Эберхарт (Russel Eberhart) предложили метод для оптимизации непрерывных нелинейных функций, названный ими алгоритмом роя частиц [11, 12] и изначально предназначался для имитации социального поведения. Первоначальная версия МРЧ была сформирована путем добавления согласования скоростей ближайших соседей, а также с учетом многомерного поиска и зависящего от расстояния ускорения. После этого был введен инерционный вес w для лучшего контроля эксплуатации и разведки и сформирован стандартный вариант. Чтобы улучшить производительность и осуществимость оптимизации роя частиц, университет Сунь Ятсена (Китай) и университет Глазго (Великобритания) разработали адаптивную версию [13] и дискретную версию МРЧ [14].

Базовая версия алгоритма МРЧ работает с понятиями «рой» и «частица». Рой означает семью пчел или других подобных насекомых, которые образуют отдельную группу, возглавляемую маткой. В методе МРЧ рой понимают как совокупность всех частиц, а сами частицы — это решения-кандидаты. Эти частицы перемещаются в пространстве поиска в соответствии с несколькими простыми формулами [15]. Движения частиц определяются их собственным наиболее подходящим положением в пространстве поиска, а также наиболее подходящим положением всего роя. Когда найдены улучшенные позиции, частицы сообщают друг другу эту информацию и направляются к новой точке, чтобы управлять движением роя. Этот процесс повторяется неоднократно с высокой вероятностью, однако не всегда находится удовлетворительное решение.

Алгоритм МРЧ основан на рое и перемещает особей роем в подходящее место в соответствии с их приспособленностью к окружающей среде. Однако метод не включает в себя применение эволюционных операторов для отдельной частицы, а трактует каждую частицу как точку без объема в D-мерном пространстве поиска, летящую с определенной скоростью. Скорость точки регулируется на основе собственного опыта самой частицы и опытов других частиц в рое динамически. Обозначена i-я частица как $X_i = (\chi_{i1}, \chi_{i2}, \chi_{i3}, \ldots, \chi_{iD})$, а $V_i = (v_{i1}, v_{i2}, v_{i3}, ..., v_{iD})$ наилучшее место, которое прошла данная частица, обозначается как $P_i = (p_{i1}, p_{i2}, p_{i3}, ..., p_{iD})$. Ее скорость является $V_i = (v_{i1}, v_{i2}, v_{i3}, ..., v_{iD})$. На следующей итерации движение частицы определяется следующим уравнением:

$$v_{id+1} = w \cdot v_{id} + c_1 \cdot rand1 \cdot (p_{id} - x_{id}) + c_2 \cdot rand2 \cdot \left(p_{gd} - x_{id}\right); \quad (1)$$

$$x_{id+1} = x_{id} + v_{id+1}. \quad (2)$$

Здесь w — инерционный вес одной частицы; c_1, c_2 — константы ускорения данной частицы; $rand1$ $rand2$ — случайные величины в диапазоне [0, 1].

Кроме этого, скорость частиц $\mathbf{V}_i$ (векторная величина) еще ограничена заданной максимальной скоростью $V_{\max}$, составляющей скалярными величинами по направлениям $v_{\max d}$ $(d = 1, 2, 3, ..., D)$. Если составляющая скорости по направлению v_{id} превышает соответственную максимальную по данной направлению $v_{\max d}$, то она ограничена максимальной векторной скоростью V_i.

Приведенная выше формула показывает, что есть три фактора, которые влияют на движение частиц:

• инерция предыдущего движения;

• познание самой частицы;

• «социальный» фактор, который представляет обмен информацией и взаимное сотрудничество между частицами.

Стандартный процесс алгоритма МРЧ выглядит следующим образом.

1. Инициализация группы частиц (размер группы M) со случайными положениями и скоростями.

2. Оценка пригодности каждой частицы.

3. Для каждой частицы сравнивают ее значение пригодности с лучшим положением p_{best}, которое данная частица испытала, и если текущее значение лучше, то заменять настоящим местонахождением лучшее положение p_{best}.

4. Сравнить для каждой частицыее значения пригодности с глобальным лучшим положением g_{best}, и, если текущее значение лучше, то принять его как новое глобальное лучшее положение g_{best}.

5. Определить скорость и положение частицы в соответствии с (1) и (2).

6. При невыполнении конечного условия необходимо вернуться к выполнению п. 2 и повторить алгоритм.

Конечным условием может быть нахождение достаточно хорошего значения или доведение до максимального числа итерации.

Алгоритм подражания муравьиной колонии — это интеллектуальный алгоритм, предложенный доктором наук М. Дориго (Marco Dorigo) в результате моделирования поведения популяции муравьев в поисках пищи [16]. При отсутствии зрительной функции муравьи могут начать передвижение с муравьиного гнезда и найти кратчайший путь к источнику пищи, даже при внезапном столкновении с препятствиями.

После тщательных исследований ученые-биомиметики обнаружили, что феромон является средством обмена информацией между муравьями. Муравьи общаются с другими особями в группе через феромон и, наконец, формируют групповое интеллектуальное поведение. Не все муравьи выбирают пути, основанные на феромонах, для поиска пищи, некоторые муравьи выбирают другие пути и одновременно выделяют феромоны. Концентрация феромона указывает на расстояние пути, и чем больше концентрация, тем ближе расстояние. С течением времени концентрация феромона медленно уменьшается и постепенно испаряется. Муравьи выберут путь с большей концентрацией феромонов, т. е. более короткий путь. Через некоторое время большинство муравьев выбирает кратчайший путь для поиска источника пищи.

Таким образом, МРЧ — это алгоритм случайного поиска с сильными возможностями глобального поиска. Преимущества его в скорости и краткости, но он легко попадает в локальный оптимум. Алгоритм муравьиной колонии является параллельным алгоритмом, обладающим положительной обратной связью, высокой точностью решения, медленной скоростью сходимости и т. д.

Для решения вышеуказанных проблем предложен усовершенствованный алгоритм оптимизации муравьиной колонии. Сначала следует выбрать набор относительно хороших путей алгоритм МРЧ, затем — наилучший оптимальный путь алгоритма муравьиной колонии, как показано на рис. 1.

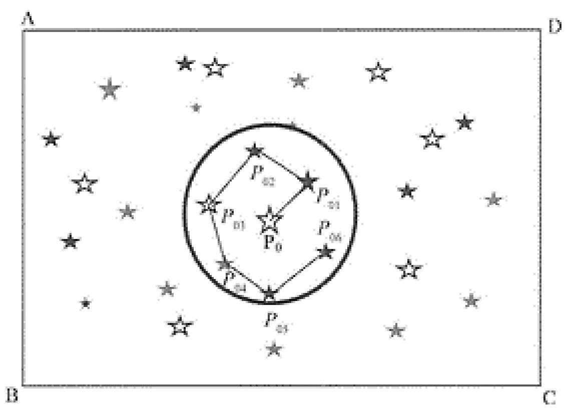

Рис. 1. Схема поиска пути на звездной карте

С помощью приведенного выше алгоритма можно быстро спланировать лучший путь вокруг навигационной звезды P_0 на звездной карте. Для того чтобы совершить операцию астроориентации, достаточно выбрать три звезды из всех звездных точек P_0, P_{01}, P_{02}. Пример параметров координат трех звезд в поиске приведен в таблице, где θ_1 — угловое расстояние между P_0 и P_{01}, θ_2 — угловое расстояние между P_{01} и P_{02}.

Параметры координат звезд

№	Угловое расстояние, град		Звездная точка, (прямое восхождение/ *h*; склонение/град)		
	θ_1	θ_2	1	2	3
⋮	⋮	⋮	⋮	⋮	⋮
1296	0,761741	3,286664	(14,90636; – 11,89833)	(14,94614; –11,40973)	(14,82197; –14,14899)
1297	1,022368	1,842572	(20,15712; 36,83959)	(20,24222; 36,80614)	(20,10609; 35,97348)
1298	1,478042	2,016786	(0,78990; 6, 74098)	(0,80627; 5,28325)	(0,80482; 7,29992)
⋮	⋮	⋮	⋮	⋮	⋮

В [17] рассмотрен алгоритм муравьиной колонии, приведены улучшенные результаты по сравнению с проанализированными алгоритмами (алгоритм разрезания триангуляции Делоне и алгоритм треугольного сопоставления). Новый алгоритм обеспечит более высокую скорость распознавания звездной карты и точность результатов распознавания. Общая вероятность успеха будет улучшаться на примере линии красного цвета D на рис. 2.

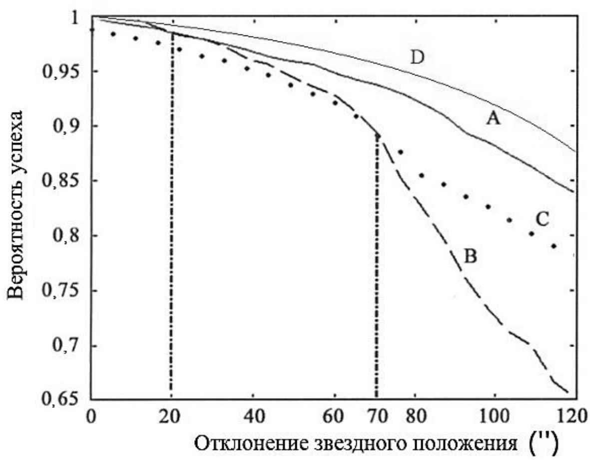

Рис. 2. Показатели различных алгоритмов:
A — алгоритм муравьиной колонии; B — алгоритм разрезания триангуляции Делоне;
C — треугольного сопоставления; D — спрогнозированные результаты по новым алгоритмам МРЧ и муравьиной колонии

Заключение

Рассмотрены проверенные алгоритмы распознавания звездных карт. Уделено внимание анализу алгоритмов МРЧ и муравьиной колонии. Предлагается новый путь комбинации алгоритмов в целях улучшения качества распознавания. В дальнейшем будет проведено моделирование процесса распознавания звездных карт и эмуляция рабочего состояния системы астронавигации.

Стипендия от Государственного комитета КНР
по управлению фондом обучения за границей

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Машиностроение

УДК 67.02

Математическое моделирование температурных полей при контактной точечной сварке

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Представлена математическая модель для моделирования тепловых процессов контактной точечной сварки в пакете ANSYS. Анализ кинетики изменения температурного поля в процессе сварки и на стадии охлаждения подтвердил ее адекватность. Модель может быть использована для оптимизации режимов и условий сварки однородных и разнородных конструкционных материалов различных толщин. Повышение точности и адекватности математических моделей позволяет снизить объем экспериментальных исследований, ускорить внедрение новых технологических процессов в производство.

Ключевые слова: *контактная сварка, точечная сварка, математическое моделирование, температурные поля, сварное соединение*

Mathematical Modeling of Temperature Fields in Contact Spot Welding

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The article presents a mathematical model for simulating thermal processes of resistance spot welding in the ANSYS package. The analysis of the kinetics of changes in the temperature field during welding and at the stage of cooling confirmed its adequacy. The model can be used to optimize welding modes and conditions of homogeneous and dissimilar structural materials of various thicknesses. Increasing accuracy and adequacy of mathematical models makes it possible to reduce the amount of experimental part of research and accelerate the introduction of new technological processes into production.

Keywords: *contact welding, spot welding, mathematical modeling, temperature fields, welded join*

Currently, one of the relevant and popular areas for improving resistance spot welding technologies is the mathematical modeling of physical processes occurring in the formation of a welded joint [1–3]. Increasing accuracy and adequacy of mathematical models makes it possible to reduce the amount of experimental part of research and accelerate the introduction of new technological processes into production. The existing mathematical models of resistance spot welding differ primarily in the design schemes of the process, which is caused by the variety of specific cases of practical use of this technology [4–6]. Due to this fact, the same case of resistance welding can be described using different boundary conditions. The assumptions accepted in the mathematical description of the process are widely varied. For example, the influence of temperature on the thermophysical properties of materials of welded parts and electrodes can be described by different dependencies, and the change in contact resistance during the welding cycle can be taken into account in different ways. These circumstances explain the ongoing development of this area of scientific research. This article presents a model for calculating temperature fields when welding two aluminum and steel sheet blanks 2 mm thick.

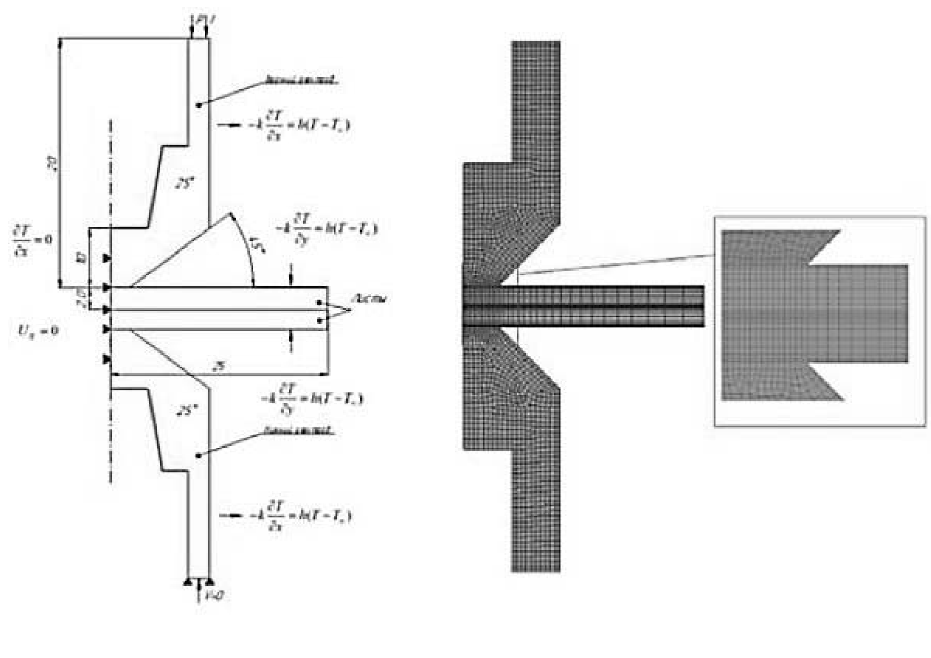
Termophysical properties of materials are given in Table 1.

Table 1

Termophysical properties of materials

Options	Melding temperature, °C	Thermai conductivity, W/(m·K)	Specitific electrical resistance, $\Omega m^2 \times 10^{-8}$	Specitific heat, J/(kg·K)
Al	660	205–255	2.85	900
Steel	1425–1550	45–55	14.5	460

The calculator model is explained in Fig. 1.



a *b*

Fig. 1. Calculator model:
a — accepted boundary conditions; *b* — generated mesh

Zirconium bronze with a specific heat capacity of 385 J/(kg·K), thermal conductivity of 367 W/(m·K), softening point of 1083 °C, and density of 8.89 g/cm^3 was taken as the electrode material. To set the electric fields, the potential difference between the nonworking ends of the electrodes was set. This makes it possible to determine the power field of heat sources used to solve the differential equation of non-stationary heat conduction;

$$q = \frac{1}{\rho}(\nabla\varphi)^2$$

where ρ is the electrical resistivity, φ is the electrical potential.

The accepted dependences of electrical resistivity on temperature are given in Table 2.

Table 2

Dependence of electrical resistivity on temperature

Temperature	Specitific electrical resistance bronze electrode, $\Omega m^2 \times 10^{-8}$	Specitific electrical resistance of steel, $\Omega m^2 \times 10^{-8}$	Specitific electrical resistance aluminum alloy, $\Omega m^2 \times 10^{-8}$
25	2.65	14.2	4.2
95	3.0	18.5	4.95
210	4.0	27.0	6.25
315	5.05	37.5	7.65
430	6.2	49.85	9.3
540	6.95	65.1	11.1
650	8.0	81.9	28.2
760	9.0	101	29.75
880	9.5	112	–
985	9.99	115	
1095	–	119	

When solving the heat equation, boundary conditions of the 3rd kind were adopted. Numerical calculations were performed in the Ansys package.

The model has a generated grid of 2166 elements (Fig. 1, *b*) with an element size of 0.85847 mm. For simulation, a welding cycle was adopted, shown in Fig. 2.

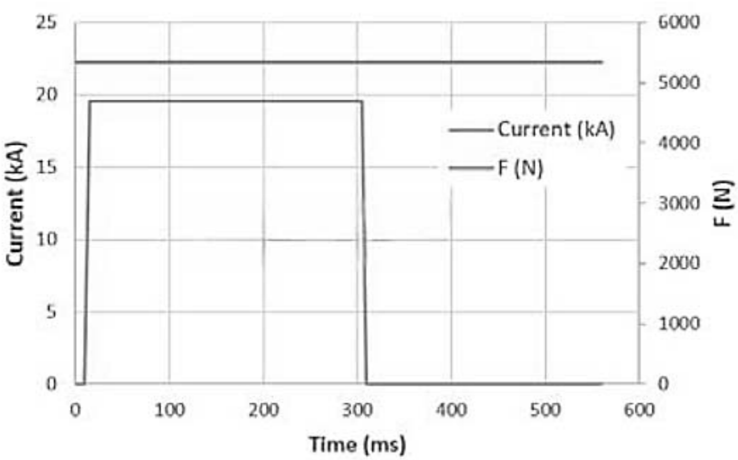


Fig. 2. Welding cycle

The duration of the welding current pulse corresponding to the cycle shown in Fig. 2 is 285 ms. The current strength was 19.9 kA. The electrode compression force is maintained constant throughout the entire welding process and amounts to 5335 N. Simulation modeling made it possible to trace the kinetics of temperature field changes both during welding and after switching off the welding current at the stage of welding joint cooling. It was revealed that at the initial moments of the welding cycle, the maximum temperatures are reached at the contact resistances of the electrode-part and part-part. Then the region of maximum temperatures shifts towards the contact axis and towards the steel sheet bar. The temperature field at the end of the welding current pulse is shown in Fig. 3.

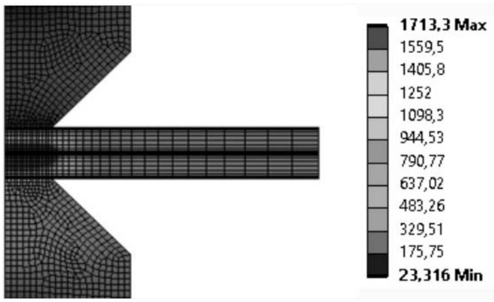


Fig. 3. Temperature field simulation results

The predicted kinetics of changes in the temperature field corresponds to existing theoretical ideas about thermal processes, occurring during resistance spot welding. The resulting model can be used to substantiate ways of optimizing modes and conditions of welding in order to control temperature fields when joining homogeneous and dissimilar structural materials.

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УДК 62

Усовершенствованные системы помощи водителю для общественного транспорта

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Представлен обзор усовершенствованных систем помощи водителю. Приведена информация о важности применения усовершенствованных систем помощи водителю, особенно для общественного транспорта, так как минимизируются различные риски. Отмечены уровни усовершенствованных систем помощи водителю, зависящие от автоматизации транспортного средства, которые были предоставлены «Обществом инженеров автомобильной промышленности». Рассмотрены датчики, используемые для обеспечения разных задач в системах помощи водителю и системах автономного вождения. Приведен обзор компаний усовершенствованных систем помощи водителю по всему миру, которые успешно разработали системы усовершенствованных систем помощи водителю. Показаны преимущества применения слияния датчиков по сравнению с использованием одного датчика для решения задач усовершенствованных систем помощи водителю. Изучены наиболее важные исследования и алгоритмы в области глубокого обучения для систем помощи водителю. Изучена схема планирования траектории для автономного вождения. Даны рекомендации по самым важным задачам для усовершенствованных систем помощи водителю и расположение датчиков на транспортном средстве.

Ключевые слова: *усовершенствованные системы помощи водителю, слияние датчиков, автономное вождение, навигация, машинное зрение, глубокое обучение*

Advanced Driver Assistance Systems for Public Transport

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This article provides an overview of Advanced Driver Assistance Systems (ADAS). The importance of ADAS systems is introduced, especially for public transport, for minimizing various risks. The levels of ADAS are defined, depending on the automation of the vehicle, which was provided by the Society of Automotive Engineers (SAE). In this paper, it was considered various sensors achieve tasks in driver assistance systems and autonomous *driving systems. After that, a review about the most important companies that successfully developed ADAS. The advantages of using sensor fusion in comparison with the use of a single sensor for solving ADAS tasks are presented. The most important studies and algorithms in the field of deep learning for driver assistance systems are studied. In addition, brake systems and their general scheme are being introduced. The trajectory planning scheme for autonomous driving is also considered. After that, frequently used control units in such systems are introduced. At the end of the article, recommendations of the most important tasks for ADAS and the location of sensors on the vehicle are indicated.*

Keywords: *advanced driver assistance systems, sensors fusion, autonomous driving, navigation, machine vision, deep learning*

Введение

По данным Всемирной организации здравоохранения, каждый год дорожно-транспортный травматизм становится причиной примерно более миллиона смертей во всем мире (рис. 1, 2) [1–4]. Причины дорожно-транспортных происшествий обусловлены несколькими факторами:

- самочувствие, внимательность и компетенции водителя;
- качество дорожного полотна;
- характер окружающей среды;
- наличие других транспортных средств на дороге.

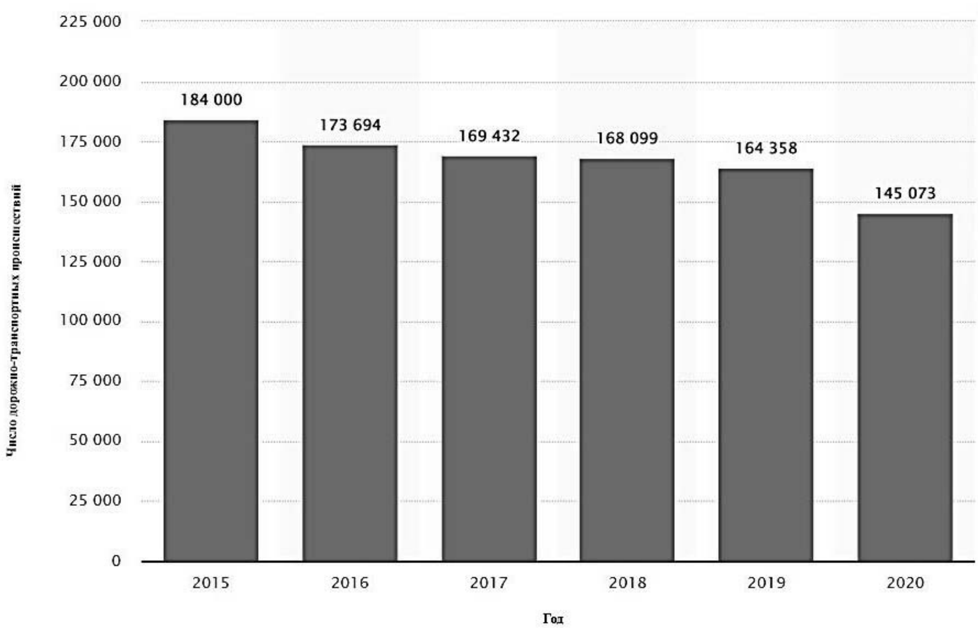

Рис. 1. Дорожно-транспортные происшествия в России в 2015–2020 гг.

Многие люди пользуются общественным транспортом таким, как автобусы. На автобусы приходится около 8,3 % дорожно-транспортных происшествий смертности (рис. 3) [2], для повышения безопасности этих средств изучается возможность оснащения их системами помощи водителю, что способствует повышению безопасности на дорогах, защите людей и сокращению несчастных случаев.

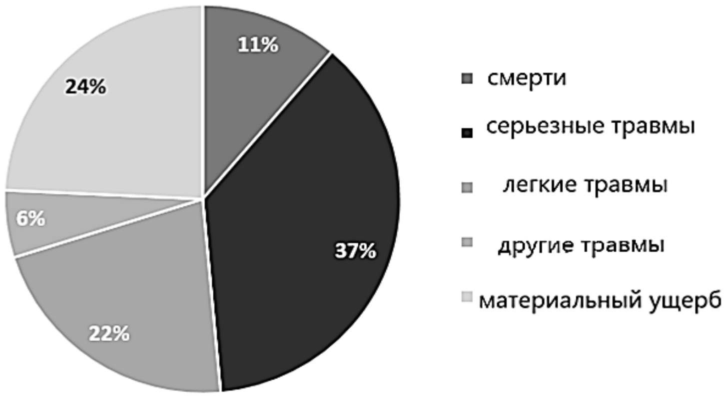

Рис. 2. Расходы на дорожно-транспортные происшествия

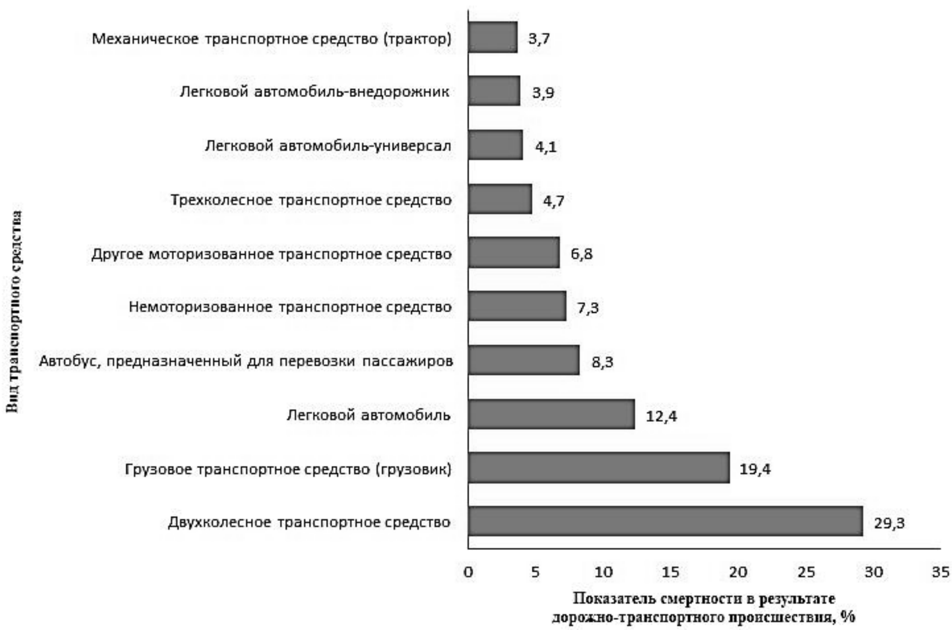

Рис. 3. Смертность в результате дорожно-транспортных происшествий в зависимости от вида транспорта

Чтобы свести к минимуму эти инциденты, транспортные средства были оснащены системами помощи водителю для наблюдения за водителем, за дорогой, другими транспортными средствами и даже людьми на дороге, а также за светофорами.

Эти системы работают для защиты водителя, защиты пешеходов и транспортных средств с дороги и значительно снижают риск дорожно-транспортных происшествий, уменьшая материальные потери и сохраняя человеческие жизни.

Усовершенствованная система помощи водителю (УСПВ) подразделяется на разные уровни в зависимости от степени автоматизации и масштаба, предоставленного Обществом инженеров автомобильной промышленности (Society of Automation Engineers, SAE). УСПВ можно разделить на несколько уровней (табл. 1) [5].

Таблица 1

Уровни усовершенствованной системы помощи водителю

Уровень	Определение	Принцип действия
0	Без автоматизации	Предупреждение водителя или минимальное вмешательство
1	Водитель осуществляет управление	Водитель и автомобильные системы совместно контролируют ситуацию
2	Водитель не осуществляет управление	Автоматическая система может полностью брать управление на себя. Водитель должен быть готов к немедленному вмешательству
3	Без зрительного контроля	Водитель может отвлечься от вождения. Водитель должен быть в состоянии взять на себя управление при условии заблаговременного уведомления от систем
4	Без участия человека	Водитель может заниматься другими делами, например, спать. Допускается использование только в предварительно геозонированных областях
5	Рулевое управление не требуется	Водитель не требуется

Методы и материалы

Развитие исследований в области автономного вождения и систем помощи водителю произошло быстро. Были разработаны различные алгоритмы, связанные с компьютерным зрением и нейронными сетями. Были изучены алгоритмы планирования траектории и тормозной системы на транспортных средствах, которые можно рассматривать как нелинейные системы. Для получения наилучших результатов были проведены исследования в области оптимального управления. Кроме того, на заводах было разработано множество блоков управления для мониторинга и управления транспортным средством. Во многих исследованиях работа проводилась с использованием моделирования, например, в таких программах, как MATLAB и CARLA. Были использованы системы RObot Operating system (ROS). Стоит отметить, что программирование может выполняться с использованием таких языков, как C, C++ и Python. После тестирования алгоритмов и тестов на симуляторах тесты могут быть проведены в реальных сценариях. Приведем краткий обзор связанных с этим работ, систем управления и интерфейсов, датчиков, а также наиболее известных исследований и алгоритмов в области автономного вождения и систем помощи водителю.

Обзор литературы

В настоящее время в мире существует несколько компаний, которые уже выпустили на рынок автобусы с автономным управлением:

- Apollo Baidu (Байду, Китай) [5];
- Легкая миля EZ10 (Легкая миля, Тулуза, Франция) [6];
- Навья Арма (Навья, Лион, Франция) [7];
- Олли (Local Motors, Национальная гавань, Мэриленд, США) [8].

Эти компании сначала разработали пилотные программы, проверили свои продукты и теперь могут тиражировать их в больших масштабах.

В марте 2021 г. Honda стала первым производителем, предоставившим легально одобренный автомобиль третьго уровня [9] и в декабре 2021 г. Mercedes-Benz стал вторым производителем, соответствующим требованиям законодательства [10], получившим юридическое одобрение на третий уровень.

Подавляющее большинство этих компаний возникли из стартапов, и их опыт тесно связан с исследованиями и разработками. Что касается исследований, то несколько научных обзоров посвящены этой теме.

В [11] представлено автономное вождение с точки зрения распознавания пешеходов и велосипедов. В [12] показаны текущие последствия использования автономных автобусов на основе нескольких проектов и их результатов. В [13] авторы сообщают об исследовании интеграции автономного вождения в инфраструктуру умного города. В [14] авторы сосредоточены на датчиках и восприятии объектов в качестве источника информации для алгоритмов автономного управления движением. В [15] приведено исследование по интеграции автономного вождения в современные транспортные средства и его влияние на текущие транспортные стратегии. В [16] авторы сосредоточили свои исследования на кибербезопасности AVS (Autonomous Vehicle Systems) и ее влиянии на конфиденциальность пользователей этих технологий. В [17] представлен ряд методологий, связанных с картами и дорогами в качестве путей движения для AVS.

Локализация и картографирование обычно используют комбинацию различных датчиков таких, как GPS, IMU, Лидар и камеры для получения точных и надежных результатов. Несмотря на наличие высокоточных и надежных GPS-датчиков, часто бывает так, что сигналы GPS обычно сталкиваются с блокировками или перебоями в работе в определенных условиях окружающей среды. Следовательно, для компенсации потерь сигнала GPS система локализации скорее всего будет соединена с другими датчиками, например, IMUs [18].

Кроме того, высокоточные измерительные устройства, как правило, очень дорогие, что делает их непригодными для использования в приложениях, отличных от точных наземных показаний для оценки и проверки качества и производительности алгоритма. Снижение стоимости технологий зондирования при сохранении эффективной производительности является одним из приоритетов в системах AVS, поэтому объединение недорогих данных IMU и сигналов GPS может обеспечить непрерывную и точную оценку состояния транспортных средств [19]. Кроме того, камеры и лидар [20, 21] используют в конфигурации, которая позволит извлечь данные по конкретной среде (примитивы — дорожная разметка и статические процентного пункта) для использования либо в заданной карте благодаря одновременной локализации и сопоставления алгоритмов (SLAM) [22] или сопоставляя их с уже существующей в высокой четкости (HD-high definition) карте [23], а затем получить точную позицию для транспортного средства и окружающих предметов.

В табл. 2 приведен полный перечень различных комбинаций, соединений и методов объединения наиболее распространенных датчиков, используемых в самоуправляемых транспортных средствах. В таблице также приведена информация о датчиках ограничения, если они должны использоваться индивидуально. Кроме того, в ней перечислены преимущества объединения подходящего набора датчиков для достижения желаемого результата.

Таблица 2

Краткое описание приложений AV, ограничений датчиков и преимуществ слияния датчиков

Статья	Приложение	Датчики	Ограничения без слияния	Преимущества слияния
[24–26]	Обнаружение пешеходов	Зрение и лидар	Чувствителен к качеству освещения; трудности с ночным видением только с помощью камеры ночного видения; низкое разрешение лидарной 3D-конструкции сцены при использовании в одиночку	Возможность измерения глубины и дальности с меньшей вычислительной мощностью; улучшения в экстремальных погодных условиях (туман и дождь)
[27–32]	Обнаружение пешеходов	Зрение и ИК-датчик	Проблемы с ночным видением только с камерой ночного видения; тепловизионные камеры теряют мелкие детали объектов из-за их ограниченного разрешения	Устойчивость к световым эффектам и обнаружению в ночное время; ИК-камера обеспечивает четкие силуэты объектов; возможность работы в плохих погодных условиях
[33–36]	Обнаружение дороги	Зрение и лидар	Освещение и условия освещения; высокие вычислительные затраты для измерения глубины обзора; ограниченное разрешение и дальность измерений с помощью лидара; разреженные и неорганизованные данные лидара	Измерения геометрии дорожной сцены (глубины) при сохранении богатой цветовой информации; калибровка рассеянного облака точек лидара с изображением
[37–39]	Обнаружение транспортного средства и определение полосы движения	Зрение и радар	Низкое разрешение радара; для измерения расстояния камере требуются специальные объективы, устройства и сложные вычисления	Точность измерения расстояния; хорошо работает в плохих погодных условиях; камера хорошо подходит для приложений определения полосы движения

Окончание табл. 2

Статья	Приложение	Датчики	Ограничения без слияния	Преимущества слияния
[40]	Визуальная одометрия	2D-лазерный сканнер и зрение	2D-сканнеры могут пропускать обнаружение объектов в сложных средах; 2D-изображений недостаточно для того, чтобы запечатлеть все особенности 3Dмира-	Слияние визуальных и 2D-сканнеров может заменить потребность в 3D-лидаре и снизить цену и вычислительную нагрузку
[41–42]	SLAM	Зрение и IMU	Освещение и условия освещения камерой; камера страдает от размытия из-за быстрого движения; ошибка при составлении IMU	Повышенная точность при меньшей вычислительной нагрузке; устойчивость к помехам в поле зрения и корректировка смещений IMU
[43]	Навигация	GPS and INS	Отключение GPS в районах ущелий и каньонов; дрейф в показаниях INS	Непрерывная навигация; коррекция показаний INS

Наблюдается заметный рост объема исследований, связанных с алгоритмами слияния датчиков глубокого обучения в автономном вождении. CNN и RNN являются одними из наиболее часто используемых алгоритмов в AVS [44]. На рис. 4 показаны различные варианты CNN и RNN, которые использовались в приложениях AV.

Торможение

Системы торможения и ABS (Anti-Lock Braking System) [45] являются одной из наиболее важных систем для автономного вождения. Основная идея заключается в том, что транспортное средство всегда должно достигать желаемого уровня замедления. Проблема заключается в распределении замедления по расстоянию и том, как пассажиры транспортного средства испытывают это замедление, особенно несидящие и несмотрящие на дорогу пассажиры. Чтобы распознать процесс торможения, алгоритм, управляющий замедлением, должен быть адаптируемым и способным различать нормальное торможение, плавное замедление и торможение и экстренное торможение [46].

В соответствии с требуемым замедлением и расстоянием между транспортным средством и требуемым маневром алгоритм управления торможением может решить использовать гидравлическую систему, систему рекуперативного торможения, систему противоточного торможения или первую и вторую параллельно.

Возможное управляющее решение для управления торможением AV представлено в [47]. На рис. 5 показана структура контура управления транспортным средством для торможения.

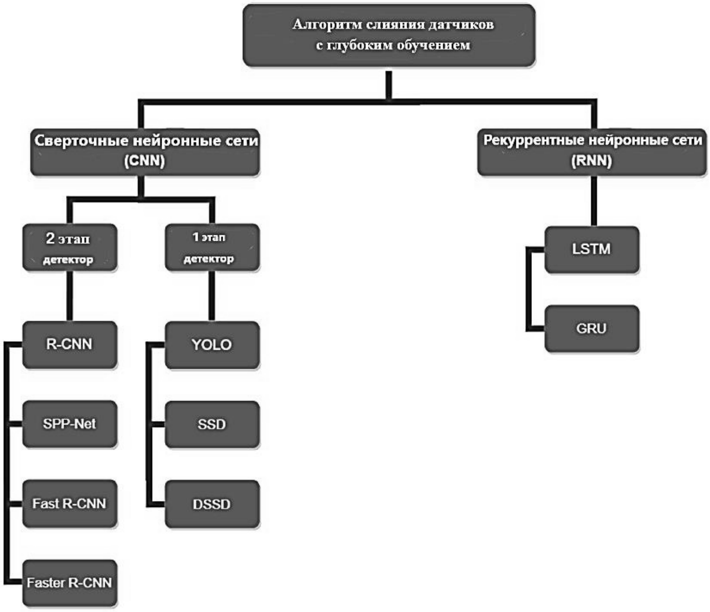

Рис. 4. Распространенные алгоритмы слияния датчиков с глубоким обучением, используемые в приложениях для автономных транспортных средств: R-CNN —на основе региона; SPP-сеть — сеть объединения пространственных пирамид; YOLO — вы смотрите только один раз; SSD — детектор мультибоксов с одним выстрелом; DSSD — деконволюционный мультибокс с одним выстрелом детектор; LSTM — долговременная и кратковременная память; GRU — закрытый повторяющийся блок

Рис. 5. Структура контура управления для торможения

Интерфейсы и блоки управления

Было разработано множество блоков управления и интерфейсов для таких транспортных средств: ADAS ECU Veoneer, AVL Ajunic, Aptiv, ADCU.

ADAS ECU Veoneer — открытая масштабируемая платформа, основанная на проектировании аппаратного обеспечения и архитектуре программного обеспечения ISO 26262, в которой размещаются алгоритмы от Veoneer, заказчиков или третьих сторон. В настоящее время Veoneer работает с NVIDIA над вариантами повышения производительности [48].

AVL Ajunic предлагает интерфейсы для камер, лидаров и других устройств, необходимых для функциональности УСПВ. Десятки датчиков могут быть подключены, чтобы обеспечить полный обзор вокруг автомобиля. Он также обеспечивает вычислительную мощность, необходимую для автономного управления движением [49].

Платформа Aptiv для Audi A8 является первой системой автономного вождения третьего уровня, разработанной Audi и изготовленной Aptiv (Delphi), интегрирует высокопроизводительные процессоры от Nvidia (Tegra K1), Altera (Cyclone V), Infineon (Aurix) и Mobileye (процессор обработки изображений EyeQ3) [50].

Вспомогательный и автоматизированный блок управления (ADCU) вождением обеспечивает от Continental безопасную и надежную многофункциональную платформу обработки, идеально подходящую для приложений в области высокоавтоматизированного вождения.

Это достигается за счет интеграции выбранных оборудования и программного обеспечения, которые отслеживают движение транспортного средства и определяют его состояние маршрута во время выполнения. Кроме того, ADCU выполняет модель окружающей среды на основе сигналов, полученных от бортовых датчиков наблюдения, и дополнительной информации. Это передается в алгоритмы планирования траектории для определения оптимального (экологичного, безопасного, удобного) пути и координации множества исполнительных механизмов (например, тормозов, подвески и т. д.) [51].

Планирование пути

Задача управления и планирования траектории (рис. 6) состоит в том, чтобы сравнить текущее положение AV с выравниванием запланированной траектории. В зависимости от других аспектов (комфорт и текущая скорость AV) контроллер генерирует управление системой рулевого управления в зависимости от скорости автомобиля.

Централизованная структура управления основана на характеристиках динамики транспортного средства, а подсистемы управляются непосредственно централизованным контроллером. Конструкция контроллера, как правило, на основе линейных или нелинейных моделей и метода проектирования системы с несколькими выходами и несколькими входами (MIMO) используется для решения проблем, связанных с продольной и поперечной динамикой транспортного средства Общую абстракцию иерархической схемы автономных транспортных средств можно найти в [52–55].

Результаты

На основании расмотреных исследований можно разделить задачи в уровни 0–2 на 4 группы.

1. Система предупреждения о столкновении (CWS):

• предупреждение о прямом столкновении (FCW);
• предупреждение о столкновении пешеходов и велосипедистов (PCW).
2. Система мониторинга дорог (RMS):
• предупреждение о выезде с полосы движения (LDW);
• система виртуальных коридоров (VCS);
• система распознавания дорожных знаков (TSR).
3. Системы помощи при принятии решений о смене полосы движения (LCDMS):
• мониторинг слепых зон (BSM);
• помощь при повороте на дороге (TAS);
• предупреждение об уменьшении бокового интервала (LCW).
4. Система мониторинга водителя (DMS):
• распознавание усталости водителя;
• распознавание эмоциональной ситуации водителя.

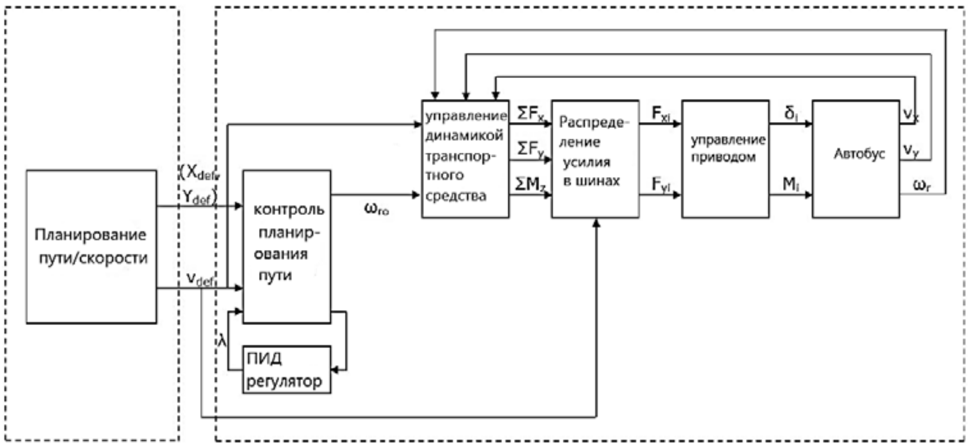

Рис. 6. Система рулевого управления

С третьего уровня и выше будут поставлены и выполнены задачи навигации, а также планирования пути и SLAM. Для достижения этих задач необходимо использовать несколько датчиков, которые расположены на автобусе (рис. 7).

Обсуждение полученных результатов

Для системы предупреждения о столкновении используется камера и радар дальнего действия (Long Range Radar, LRR), расположеные в передней части автобуса. Обычно у этого радара есть два режима: дальний и ближний. Для системы мониторинга дорог также используется камера для распознавания дорожных знаков и разметки. Для системы мониторинга водителя используют камеры, расположенные внутри траспортного средства у водителя. Для системы помощи при принятии решений о смене полосы движения используют два радара ближнего действия в передней боковой части транспортного средства. Эти датчики могут достигать всех задач во всех уровнях, но для будущей работы, когда необходимо использовать систему навигации, при необходимости используется лидар.

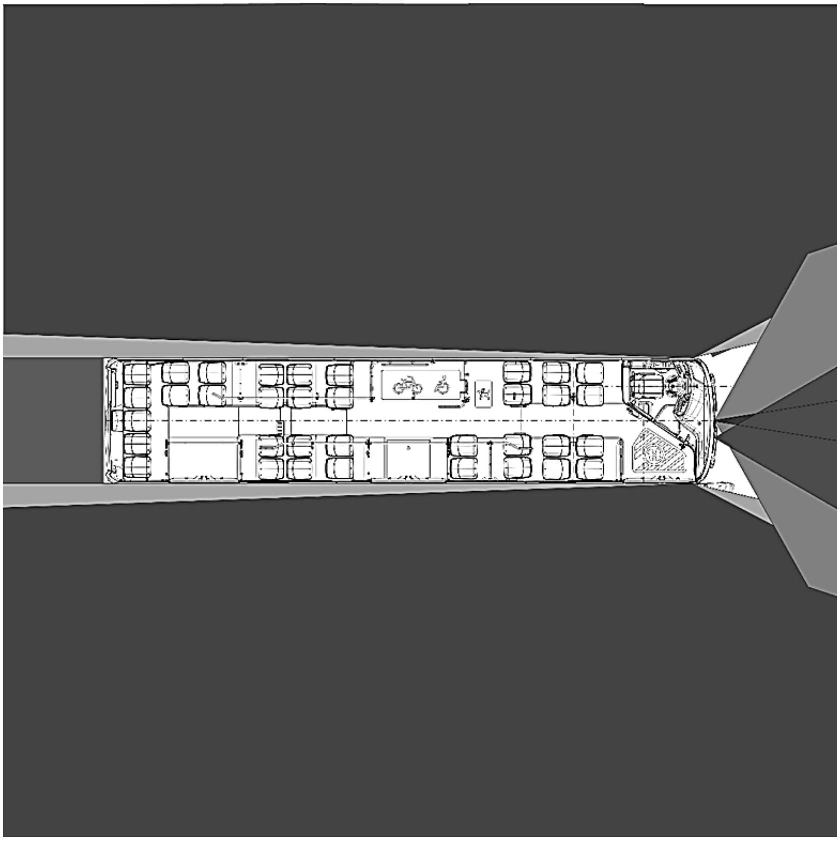

Рис. 7. Схема зон покрытия сенсорами:
темно-синий цвет — радар дальнего действия (дальний режим); голубой цвет — радар дальнего действия (ближний режим); зеленый цвет — радар ближнего действия (режим измерения); светло-зеленый цвет — радар ближнего действия в режиме детекции; темно-фиолетовый цвет — зона камеры; красный цвет — непокрытые слепые зоны

Заключение

В рамках статьи было достигнуто несколько задач.

1. Проведен обзор литературы.
2. Рассмотрены самые важные задачи в система УСПВ.
3. Рассмотрены общие схемы систем торможения и планирования пути.
4. Представлены датчики и их примениния в системах УСПВ.
5. Предложена архитектура системы и зона покрытия сенсорами.

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УДК 536.2

Сравнение двух расчетных моделей для определения температурного состояния теплозащитного экрана выполненного из анизотропного материала

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При спуске в плотных слоях атмосферы поверхность теплозащиты космических аппаратов подвергается сильному нагреву. Для снижения риска повреждения покрытия или разрушения покрытия в зонах, испытывающих наибольшие тепловые нагрузки, целесообразно применение в качестве внешнего слоя теплозащиты материала с высокой степенью анизотропии теплопроводности. Проведено сравнение двух моделей проведения расчета температурного состояния теплозащитного покрытия из такого материала для аппарата, возвращающегося с низкой опорной орбиты Земли.

Ключевые слова: *теплозащитное покрытие, анизотропия теплопроводности, аналитическая модель для расчета поля температур, нагрев в плотных слоях атмосферы, теплозащитный экран*

Two Analytical Models for Calculating Temperature Conditions of Heat Shield from Anisotropic Material

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Surface of thermal protection coating of space vehicles suffers from significant heating during re-entry. Risk of damage or destruction of coating in regions with maximum thermal stresses can be lowered by using materials with high anisotropy of thermal conductivity as outer layer of thermal protection coating. In this paper is presented the comparison of two analytic models for calculating temperature conditions of thermal protection coating manufactured of such material for re-entry from the Low Earth orbit.

Keywords: *thermal protection coating, anisotropy of thermal conductivity, analytical model for calculating temperature field, re-entry heating, heat shield*

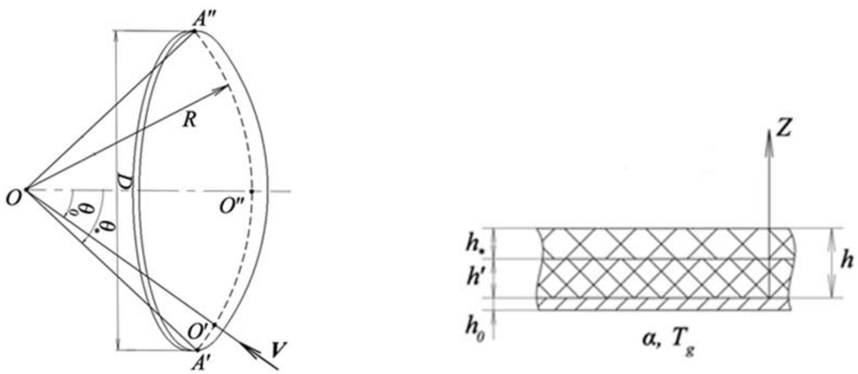
Introduction

During re-entry spacecrafts, like ballistic capsules of automatic interplanetary stations or cargo returning capsules, suffer from significant thermal stresses. These stresses can cause severe damage to surface of vehicle or even its destruction. To reduce thermal stress of re-entry vehicle specialized thermal protection coating can be used. Conventional materials used in such coatings have low thermal conductivity, thus persist the risk of surface damage or destruction in critical, most loaded points. To counter that, materials with high anisotropy of thermal conductivity can be used, which make possible to reduce value of temperature distribution due to greater value of thermal conductivity in tangential direction to the surface comparing to its value in normal direction [1–4].

In this paper comparison of two analytic models for calculating temperature field of thermal protection coating is presented. The first model (Model A) is based on explicit finite-difference method programmed using PTC Mathcad software. The second model (Model B) is based on transient thermal solver of ANSYS finite-elements system using stand-alone program for calculating heat flux $q(\theta, \varphi, t)$ which used as a boundary condition.

Problem statement

As analytical model, spherical segment of heat shield shown in Fig. 1, a is used. Composition of multilayer thermal protection coating used in said heatshield, consists of three layers, as provided in Fig. 1, b. The outer layer made of pyrolytic graphite has high anisotropy of thermal. The middle layer made of TZMK has low thermal conductivity and serves as isolator. The inner layer made of titanium alloy OT-4 models structural wall of the re-entry vehicle. Existence of reinforcing structural elements is taken into account by using effective thickness of the inner layer.



a *b*

Fig. 1. Analitycal model of heatshield (*a*) and multilayer thermal protection coating (*b*)

Labelings used in Fig. 1: θ_* — central half-angle of spherical segment; θ_0 — angle coordinate of critical point; h_0 — effective thickness of OT-4 layer which has thermal conductivity λ_0 and specific heat c_0; h' — thickness of TZMK layer which has thermal conductivity λ' and specific heat c'; h_* — thickness of pyrolytic graphite layer which has thermal conductivity λ_n and λ_t in normal and tangential directions respectively and specific heat c ; α — heat transfer coefficient for convection with environment inside shell with temperature of T_g.

Differential heat equations of pyrolytic graphite and TZMK can be written as follows respectively

$$\frac{c'}{\partial T'}\frac{\partial t}{\prime} = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^{\cdot 2}\frac{\partial T'}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial T'}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 T'}{\partial \varphi^2}, \quad z \in (0, h'), \qquad (1)$$

$$c\frac{\partial T}{\partial t} = \frac{\lambda_n}{r^2}\frac{\partial}{\partial r}\left(r^2\frac{\partial T)}{\partial r}\right) + \frac{\lambda_t}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial T}{\partial \theta}\right) + \frac{\lambda_t}{r^2\sin^2\theta}\frac{\partial^2 T}{\partial \varphi^2}, \quad z \in (h', h), \qquad (2)$$

with initial condition

$$T'(r,\theta,\varphi,0) = T(r,\theta,\varphi,0) = T_0, \quad r \in [R-h], \quad \theta \in [0,\theta_*], \quad \varphi \in [0,2\pi],$$

where T_0 — initial temperature of thermal protection coating.

Boundary conditions for equations (1) and (2) with heat balance equation on outer surface of coating can be written as

$$\left.\frac{\partial T'}{\partial \theta}\right|_{\theta=0} = \left.\frac{\partial T}{\partial \theta}\right|_{\theta=0} = \left.\frac{\partial T'}{\partial \theta}\right|_{\theta=\theta_*} = \left.\frac{\partial T}{\partial \theta}\right|_{\theta=\theta_*} = \left.\frac{\partial T'}{\partial \varphi}\right|_{\theta=0} =$$

$$= \left.\frac{\partial T}{\partial \varphi}\right|_{\phi=0} = \left.\frac{\partial T'}{\partial \varphi}\right|_{\varphi\to 2\pi} = \left.\frac{\partial T}{\partial \varphi}\right|_{q\to 2\pi} = 0,$$

$$\left|\lambda_n\frac{\partial T}{\partial r}\right|_{r=R} = q(t,\theta) - \varepsilon\sigma_0\big(T(R,\theta,\varphi,t)\big)^4\Big|_{r=R}.$$

Perfect thermal contact conditions between layers of pyrolitic graphite and TZMK and TZMK and OT-4 with heat balance equation for inner layer can be written as respectively,

$$T'(R-h_*,\theta,\varphi,t) = T(R-h_*,\theta,\varphi,t), \left.\frac{\lambda'}{\lambda_r}\frac{\partial T'(r,\theta,\varphi,t)}{\partial}\right|_{r=R-h_*} = \left.\frac{\partial T(r,\theta,\varphi,t)}{\partial r}\right|_{t=R-h_*},$$

$$c_0 h_0\frac{\partial T'(R-h,\theta,\varphi,t)}{\partial t} = \lambda'\left.\frac{\partial T'(t,r,\theta,\varphi)}{\partial r}\right|_{l=R-h} + \alpha\left(T_g - T'(R-h,\theta,\varphi,t)\right) +$$

$$+\frac{\lambda_0 h_0}{r_0^2\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\frac{\partial T'(R-h,\theta,\varphi,t)}{\partial\theta}\right) + \frac{\lambda_0 h_0}{r_0^2\sin^2\theta}\frac{\partial^2 T'(R-h,\theta,\varphi,t)}{\partial\varphi^2}.$$

Calculating boundary conditions

Axisymmetric behavior is used. Therefore, heat flux $q(\theta,\varphi,t)$ is being calculated in the form of $q(t,\theta)$. First step in determination of heat flux is finding trajectory parametrs. Equations used for this purpose can be written as follows:

$$\dot{V_x} = -\frac{\mu}{r^3}x - C_{xa}\cdot\frac{\rho V^2}{2m}S_m\cdot\frac{V_x}{V},$$

$$\dot{V_y} = -\frac{\mu}{r^3}y - C_{xa}\cdot\frac{\rho V^2}{2m}S_m\cdot\frac{V_y}{V},$$

$$\dot{x} = V_{x'},$$

$$\dot{y} = V_y,$$

where V_x and V_y — projections of velocity vector on Ox and Oy axys of coordinate system with initial point positioned in centre of the Earth respectevily; ρ— density of air; S_m — frontal area; μ — dynamic viscosity; C_{xa} — drag coefficient; m — vehicle mass; r — module of vector $\overline{r}$ that determine position of vehicle relative to centre of the Earth.

After calculating trajectory parameters they are used in determination of $q(t,\theta)$ in various conditions. Knudsen number is used as main parameter for determination of current flow conditions. Transition points for mentioned conditions are Kn = 0,01 and Kn = 10 [5].

For Kn > 10 thermal flux can be found as follows:

$$q_c'(\theta) = 0{,}5\rho V^3 \cos^3\theta, \tag{3}$$

where θ — angle between re-entry vehicle velocity vector and normal vector to surface in a current point of the surface.

For Kn < 0,01 thermal flux can be calculated as:

$$q_l(\theta) = 3.3 \cdot 10^{-5} V^{3.2} (\rho / r_1)^{0.5} \cdot (0.1 + 0.9\cos^2\theta), \tag{4}$$

$$q_t(\theta) = 1.06 \cdot 10^{-4} V^{3.19} (\rho^4 / r_1)^{0.2} \cdot (15 - 14\sin^2\theta)\sin^2\theta, \tag{5}$$

$$q_c^*(\theta) = q_l(\theta) \text{ при } q_l(\theta) > q_t(\theta), \tag{6}$$

$$q_c^*(\theta) = q_t(\theta) \text{ при } q_t(\theta) > q_l(\theta), \tag{7}$$

where $q_l(\theta)$ and $q_t(\theta)$ — heat fluxes for laminar and turbulent conditions respectively.

For 0,01 < Kn < 10 thermal flux can be found as follows:

$$q_c(\theta) = \left(q_c^*(\theta) + Kn \cdot q_c'(\theta)\right) / (1 + Kn). \tag{8}$$

Radiation heat flux can be calculated as:

$$q_r^0(\theta) = 2.195 \cdot 10^{-22} V^{7.9} \rho^{1.2} r_1^{0.49}. \tag{9}$$

Summary heat flux $q(t,\theta)$ comes out by summing up values of $q_r^\circ(\theta)$ and $q_c(\theta), q_c^*(\theta)$ or $q_c'(\theta)$ depending on the value of Knudsen number.

In both models trajectory parameters are calculated before staging main analitical model, but determination of heat flux values differs. In Model A heat flux is calculated on each timestep during main procedure of determenation temperature field using equations (3)–(9). However, in Model B for same purpose stand-alone program is used. Interface of mentioned program is shown on Fig. 2.

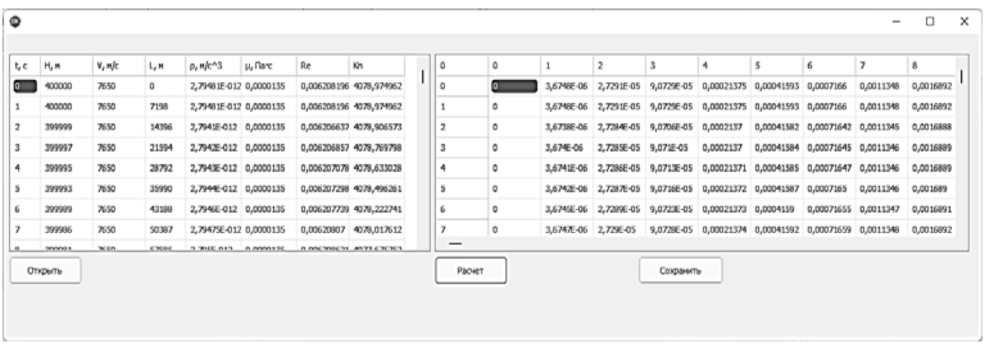
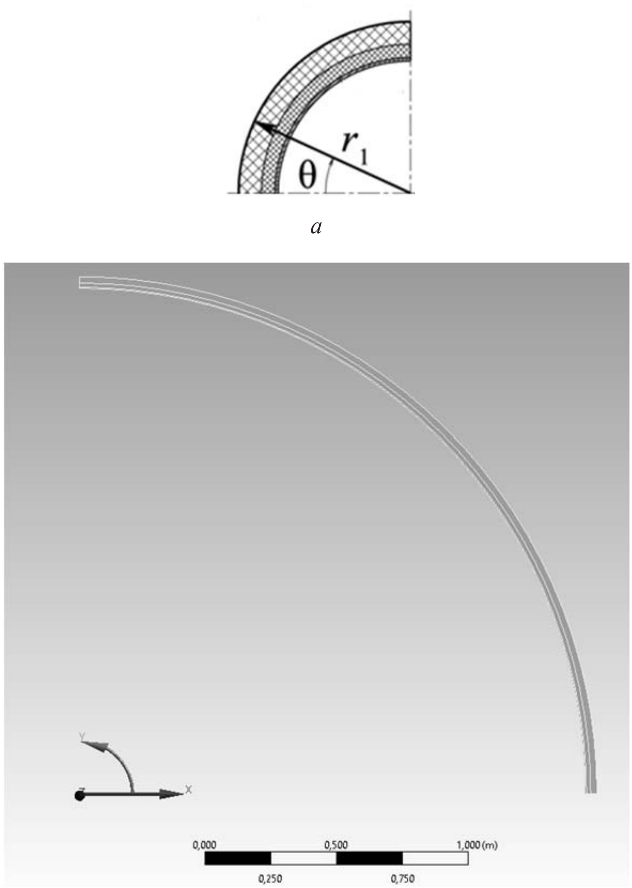


Fig. 2. Interface of program for calculating heat flux

While calculation type used in Model A is simpler and has no need for using some third-party tools, Model B's type is more flexible, providing opportunity to use nonuniform time or coordinate steps. That flexibility allows to use ANSYS transient thermal solver's built-in approximation methods to reduce calculation time by increasing timestep value when loads are low. Also, this method allows to reduce project files' size when analyzing re-entry vehicles with various geometry because there is no need to have a heat flux calculating procedure for every analysis.

Model task and analysis results

For model task the segment of spherical heat shield with outer radius of 1,96 m used. Thicknesses of multilayer thermal protection coating are 24, 16 and 4 mm for pyrolytic graphite, TZMK and OT-4 layers respectively. Trajectory is ballistic decent from orbit straight to surface of Earth. Starting point of trajectory for heat flux calculation is 400 km high with starting velocity of 7650 m/s. Initial temperature of thermal protection coating is set to 240,8 K while inner wall of OT-4 layer is specified as perfectly insulated. As Model A has no visual representation of analitycal model, principal scheme is shown in Fig. 3, a. Analitycal model for Model B is shown on Fig. 3, b. Forward stagnation point for Model A is located at θ = 0 and at θ = y = 90° for Model B.



a

b

Fig. 3. Analytical models for Model A (*a*) and Model B (*b*)

Most critical and stressed points of surface are forward stagnation point and point, located approximately 45° from it that has maximum temperatures during the turbulent flow conditions. Therefore, comparison of results for these points is best-suited for comparing Models A and B. Temperature chart for these points for re-entry time within 2655 s is shown on Fig. 4. On Fig. 5 time region when highest temperatures occur is presented.

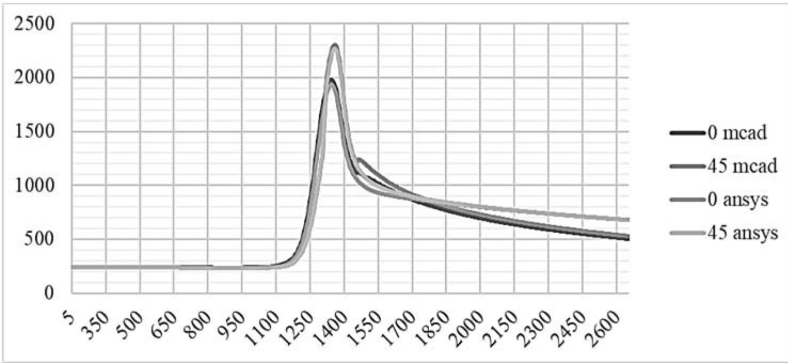


Fig. 4. Temperature chart for most stressed points

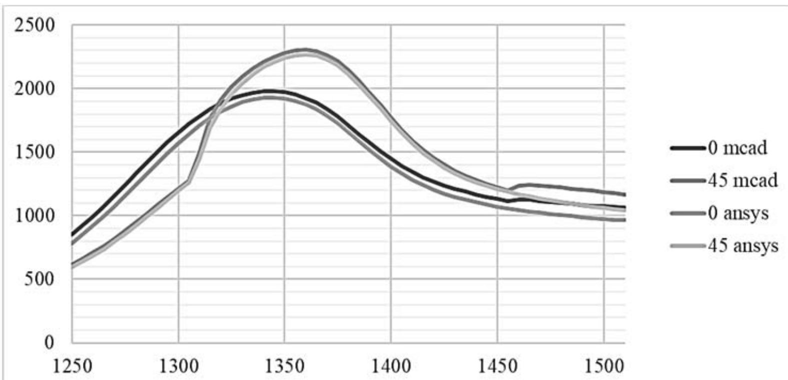


Fig. 5. Temperature chart for most stressed points, highest temperatures time region

Analyzing charts shown on Fig. 4 and Fig. 5 it can be noted that results for both models have little difference which come up to 1,5 % at time point of 1360 s which corresponds to maximum temperature value occurred during the re-entry. Slightly lesser values obtained using Model B can be explained by finer mesh and more accurate calculation method used in ANSYS transient thermal solver.

Conclusion

Comparison of used analytic models shows low difference in calculated temperature values, especially at critical most stressed points of surface. Therefore, both of the presented models can be used for calculating temperature field of thermal protection coating with acceptable accuracy. But it should be noted that Model B has some crucial advantages before Model A. First and foremost, Model B has much less calculation time, about 4 times lower for the task. Second, use of ANSYS transient thermal solver and ANSYS finite-element system in general provides more flexibility and simplicity in making amendments to analytical models. Third and most significant for further research of thermal protection coating manufactured of materials with high anisotropy of thermal and structural characteristics is ability to solve coupled thermal and structural problems without need of considerable modifications of the existing code which occur in case of Model A. Therefore, using Model B for further cases seems more appropriate.

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УДК 533.6.011

Влияние перфорации поверхности на аэродинамические характеристики плоских пластин

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Тесис

Одной из основных задач аэродинамики является определение аэродинамических характеристик. Зачастую аэродинамические характеристики ухудшаются из-за вихрей вблизи поверхности самолета. Поэтому очень важно создавать хорошо обтекаемые объекты с хорошими аэродинамическими характеристиками. Перфорация стабилизирующих поверхностей может быть использована как один из способов устранения нежелательного периодического срыва вихрей. Рассмотрены аэродинамические характеристики перфорированных пластин при скорости набегающего потока $V = 25$ м/с и углах атаки $0 < \alpha < 90°$, а также проанализировано влияние степени перфорации на аэродинамические характеристики и структуру течения. Исследование включало эксперимент в дозвуковой трубе МГТУ им. Н.Э. Баумана и численное моделирование. Экспериментальные и расчетные данные сравнивались между собой, было получено удовлетворительное совпадение результатов вихрей.

Ключевые слова: *аэродинамические характеристики, перфорированная пластина, дозвуковой поток, аэродинамическая труба, обтекаемый объект*

Surface Perforation effect On the Aerodynamic Characteristics of a Flat Plate

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Tesis

One of the main tasks of aerodynamics is to determine the aerodynamic characteristics. Often the aerodynamic characteristics deteriorate due to vortices near the surface of the aircraft. Therefore, it is very important to create well streamlined objects with good aerodynamic characteristics. The perforation of stabilizing surfaces can be used as one of the ways to eliminate the undesirable periodic disruption of vortices. The aerodynamic characteristics of the perforated plates at the incident flow velocity $V = 25$ m/s and angles of attack $0 < \alpha < 90°$ have been considered, and the effect of the perforation degree on the aerodynamic characteristics and flow structure has been analyzed. The study included an experiment in a subsonic tube of the BMSTU and numerical simulation. The experimental and calculated data were compared with each other and a satisfactory agreement between the results was obtained.

Keywords: *aerodynamic characteristics, perforated plate, subsonic air flow, wind tunnel, streamlined object*

Introduction

During the past decade there has been increasing research in the field of control and stabilization of the gas flow around various configurations bodies. The main objective of research in this ашудв is associated with shaping the appearance of a promising high-performance aircraft. Structural elements of such vehicles must have the requiered aerodynamic characteristics in accordance with the functional area of an aircraft. The field of our research is well-streamlined surfaces that prevent the nucleation and subsequent separation of vortices aimed at eliminating undesirable effects caused by the detachable flow around an aircraft. A method of using perforation of aerodynamic surfaces is proposed [1].

Perforation is widely used in aviation, hydraulics, engineering and construction. There is a lot of literature which suggests that use of perforated permeable surfaces should be effective. Windbreaks can be perforated and the articles [2, 3] present the analysis and search for the optimal configuration of holes in such structures to minimize the wind speed. The homogenizing perforated membranes in pipelines are described by P. Tanner et al. [4]. K. Steiros, N. Bempedelis, L. Ding discuss the wake behind perforated plates of an infinite span located perpendicular to the flow [5]. F.C. Bossi et al. considered the flow around perforated plates located at a zero angle of attack to the flow [6].

In the construction, energy and technology iindustries it is possible to use not only flat, but also cylindrical surfaces. The authors [7] have analyzed the complex nature of the flow around a rotating permeable cylinder, which provides additional lifting force in the structure of a wind turbine. Perforation can also be used to control unsteady vortex flow arising behind a circular cylinder [8, 9].

In the aviation industry, perforated surfaces can be used to solve a wide range of tasks. To reduce the excess noise from an aircraft engine caused by localized strong turbulence, the authors of [10, 11] have proposed to use a perforated deflector with a wedge shape. The perforation of the wing airfoil skin has been considered as a way of passive control of the flow processes in article [12]. The sensitivity of the aerodynamics of a perforated wing to acoustic disturbances has been considered in [13]. A number of works [14, 15] have been investigated the use of permeable flaps and the effect of their perforation on aerodynamics and the near wake behind the wing.

The review of literary sources has shown that permeable surfaces can be effectively used to solve a wide range of hydro- and aerodynamic problems, most often flat perforated surfaces are used. Unfortunately, there is a limited number of research papers focused on a comprehensive analysis of the perforated bodies aerodynamics performance. Therefore, in this study we organize experimental and computational studies of perforation influence on the aerodynamic characteristics and flow structures.

Methods

The most common ways to determine the aerodynamic characteristics of an aircraft or its structural element are an experiment or a numerical simulation. The main advantages of the numerical simulation are the clarity of the results, the possibility to change the aircraft and flow parameters in a wide range. However, the results of the numerical simulation must be compared with experimental data in order to assess the correctness of the selected mathematical models and calculation schemes. This work deals wit the comparison analysis of the results obtained during experimental and numerical studies of a subsonic air flow around flat perforated plates.

Experimental Research. Experimental studies were carried out in a subsonic wind tunnel at Bauman Moscow State Technical University at free stream velocity $V = 25$ m/s. We have a closed-circuit wind tunnel in our laboratory. The air in the wind tunnel is driven by an electric motor and an axial fan.

The aerodynamic forces acting on the flat plate models were measured with the strain gage. Experimental models were fixed on a thin holder, which was attached to the strain gage piston. During the experiment, the strain gages were covered with a fairing and installed in the pylon of the device for changing the angles of attack. This device was located on the experimental table in the working part of the wind tunnel. The signal from the strain gage was transmitted to the MGCPlus digital data acquisition system. Obtained experimental results were processed and analyzed on a PC. The angle of attack α during the experiment varied from 0 to 90° with a variable step. The blocking efficiency of the wind tunnel working part did not exceed 5 %.

The flow structure visualization in the experiment was carried out by the smudge. The smokescreen was created using a specialized “fishing rod” that generates intense wisps of smoke. The smoky liquid was pumped by a pump through a supply hose into a reservoir, where it was heated and converted into smoke. Smoke was introduced into the air flow in the working part of the wind tunnel through a small hole with a circular cross section using a thin probe.

Mathematical Modeling. Mathematical modeling of the flow beyond the plates was carried out in the Flow Simulation Computing Module of Solid Works. The Flow Simulation is based on the finite volume method. The previously created computational domain is divided into finite volumes (cells) to perform spatial discretization. A system of equations that expresses the conservation laws is written and solved for each cell.

The RANS (Reynolds Averaged Navier Stokes) approach was used in the simulation, the k-ε turbulence model was used to determine the Reynolds stress tensor and close the system of equations.

The process of numerical simulation was conditionally divided into four stages:

• construction of computational domain and grid;
• setting general calculation settings;
• calculation;
• processing of the received results.

The computational domain was a parallelepiped 1.8×1.6×1.6 m in size. Initially, a basic computational grid was built with a 600.000 number of cells, the grid was refined near the surface of the plate to resolve the features of near-wall flow and structures inside perforations. During the calculation, at the 50, 100, and 150th step, the grid was adapted: in the regions with the highest-pressure gradient, the computational cells were refined. The total number of grid cells reached 1.5 million.

The speed of the oncoming flow during numerical simulation was also $V = 25$ m/s, pressure $p = 101325$ Pa, density $\rho = 1.225$ kg/m^3, similarly to the experiment, the angle of attack varied from 0 to 90°.

Results and discussion

We obtained the aerodynamic coefficients of perforated plates. The dependences of the normal force coefficient cy and the pitching moment mz on the angle of attack α were received (Fig. 1).

The degree of perforation has a significant impact on the aerodynamic characteristics of the plates. Dependence cy(α) increases almost linearly up to α = 70°, and then reaches the "shelf" similarly to a solid plate. With an increase in the degree of perforation, the value of the normal force coefficient and the pitching moment coefficient decrease.

Flow structures around perforated plates with different degrees of perforation were obtained as a result of numerical simulation (Fig. 2).

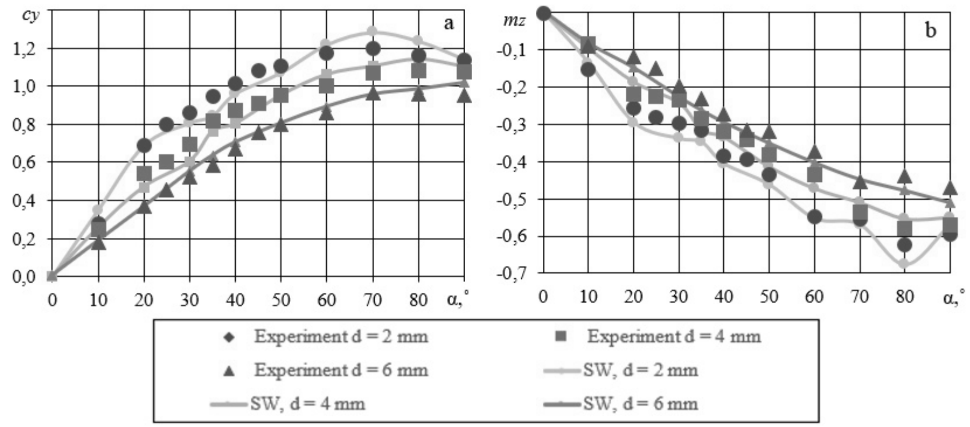

Fig. 1. Aerodynamic coefficients:
a — normal force coefficient; *b* — pitching moment coefficient

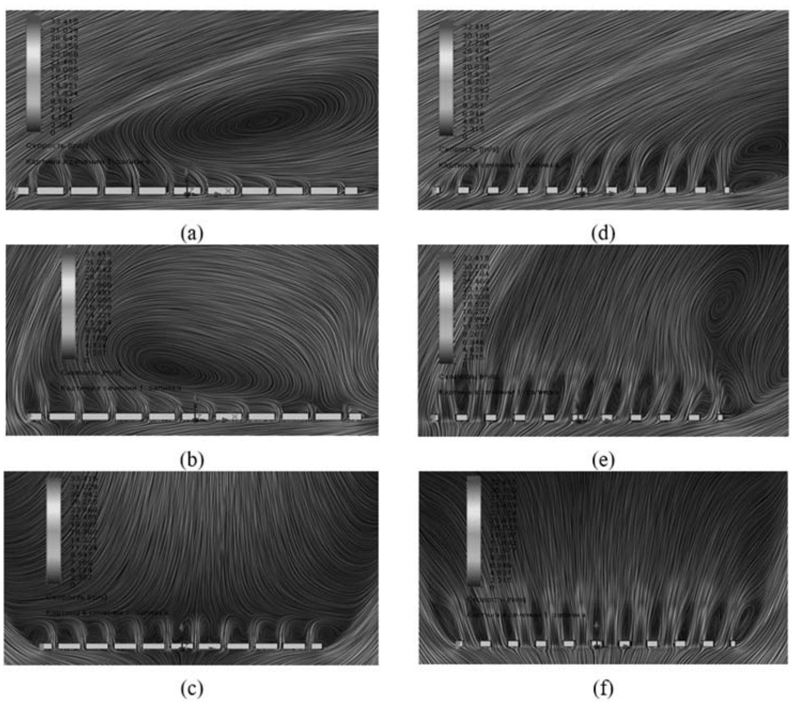

Fig. 2. Flow structures:
(*a*)–(*c*) — σ = 3.1 %; (*d*)–(*f*) σ = 28.3 %; (*a*), (*d*) — α = 30°; (*b*), (*e*) — α = 60°; (*c*), (*f*) — α = 90°

A large vortex with one core appears on the leeward side of the plate with the minimum degree of perforation (Fig. 2, *a*, *b*). When air flows through the perforation holes, streams are formed. These streams are deflected by the return flow in the separation region in the direction opposite to the oncoming flow.

With an increase in the diameter of the holes, air streams transform the flow structure on the leeward side of the plate at $\alpha = 0\ldots\ 70^{\circ}$: at $\sigma = 3.1$ %, the emerging single vortex becomes less intense and moves away from the surface of the plate, at $\sigma = 28.3$ % (Fig. 2, *d*, *e*) the region of the return flow is almost completely eliminated due to the greater air mass transfer, leaving only local separation zones near the trailing edge of the plate. Air streams are carried away in the direction of the oncoming flow, and a local separation zone is formed behind each stream.

At $\alpha = 90^{\circ}$, air flows through the perforations. The air streams are low-intense when the plate has a small hole's diameter. These air streams are carried away by the flow in the bottom wake in different directions (Fig. 2, *c*). With an increase in the perforation diameter, the amount of passing gas increases. The air streams are more intense and significantly transform the separation flow in the bottom region of the plate.

Conclusion

We carried out a series of experimental and numerical research. As a result, we obtained aerodynamic characteristics. Satisfactory agreement between the calculated and experimental data was obtained with the accuracy of 5 %. Results can be used for selection of stabilizers and flaps. Further, we plan to continue the study of the flow around such perforated bodies as cylinders, cones, spheres and etc.

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УДК 621.6

Применение эндохронной теории пластичности для проведения поверочного расчета при проектировании композитного баллона давления с металлическим лейнером

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Приведены уравнения для расчета напряженно-деформируемого состояния многозонного композитного баллона высокого давления с металлическим лейнером. Рассмотрено применение эндохронной теории пластичности, учитывающей нелинейное деформирование изотропного материала лейнера при интенсивном нагружении. Выполнен численный пример расчета цилиндрической части баллона давления с проверкой полученных результатов расчета в программе MSC Nastran.

Ключевые слова: *эндохронная теория пластичности, металлокомпозитный баллон давления, композиционные материалы, прочность, металлический лейнер*

Endochronic Theory of Plastic Deformation for the Verification Calculation in Metal-Composite Pressure Vessels Design

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The equations for calculation of the stress-strain state of a multi-zone composite high-pressure cylinder with a metal liner are given. The application of the endochronic theory of plasticity, taking into account the nonlinear deformation of the isotropic material of the liner under intense loading, is considered. A numerical example of stress calculation for the cylindrical part of a metal-composite pressure vessel is performed.

Keywords: *endochronic theory of plastic deformation, metal-composite pressure vessel, composite materials, strength, metal liner*

Introduction

Currently, there is a worldwide replacement of metal pressure vessels with modern composite pressure vessels containing a metal or polymer liner. They have a number of advantages which include high strength-to-weight ratio exceeding the specific strength of steel and titanium alloys, shatterproof destruction and explosion safety when exposed to flame and bullet, corrosion resistance and weight perfection. In this regard, the creation of such civil pressure vessels is an actual applied task.

When such pressure vessels are intensively loaded, plastic deformations will occur in the metal liner. They must be taken into account in order to obtain reliable results when calculating strength.

In this paper, we will show the application of the endochronic theory of plasticity, which allows us to take into account the nonlinear behavior of the material under intense loading of composite pressure vessels.

Endochronic theory of plasticity

The endochronic theory is one of the variants for the theory of plasticity. It establishes a connection between increments of deformations and stress increments as well as the classic theories of plasticity. Unlike them, it does not use the concept of the yield surface, and there is also no division of deformation into elastic and plastic components. The endochronic theory of plasticity uses a non-decreasing scalar quantity called “a measure of intrinsic time” to account for the irreversible material deformation. This quantity is an analog of the Odquist parameter for classic theories of plasticity.

This approach has a number of advantages over traditional approaches based on the relations of the nonlinear theory of elasticity, in particular, it allows calculations under any types of loading, including cyclic loading and loading with unloading. At the same time, the relations obtained by the endochronic theory are simple and convenient. The material parameters α and β used in the model for isotropic solids are determined by experimental data. The global search method is used to find them. The optimality criterion is the minimum function of the mean deviation of the deformation curve from the experimental curve

$$f(\alpha,\beta)=\frac{1}{n}\left|\varepsilon_{test}-\varepsilon_{calc}\right|,$$

where n is number of experimental points.

The main relations of the endochronic theory of plasticity for isotropic solids

The relationship between strain increments and stress increments can be written as [1]:

$$d\{\sigma_m\}=[D_m]d\{\varepsilon_m\}-[A]\frac{d\xi}{\sigma_T(\xi)}\{\sigma_m\}$$

where $d\{\varepsilon_m\}=(d\varepsilon_{11m},d\varepsilon_{22m},d\gamma_{12m})^T$ is vector of deformation increment; $d\{\sigma_m\}=$ $=(d\sigma_{11m},d\sigma_{22m},d\sigma_{12m})^T$ is vector of stress increment; $\{\sigma_m\}=(\sigma_{11m},\sigma_{22m},\sigma_{12m})^T$ is vector of stress; $\sigma_T(\xi)=\frac{3G}{\alpha}f(\xi)$; $f(\xi)=1+\beta\xi$;

$$[A]=\begin{bmatrix}\frac{E(2-\nu)}{2(1-\nu^2)} & -\frac{\nu E(1-2\nu)}{2(1-\nu^2)} & 0\\ -\frac{\nu E(1-2\nu)}{2(1-\nu^2)} & \frac{E(2-\nu)}{2(1-\nu^2)} & 0\\ 0 & 0 & 3G\end{bmatrix};\ [D_m]=\begin{bmatrix}\frac{E}{(1-\nu^2)} & \frac{\nu E}{(1-\nu^2)} & 0\\ \frac{\nu E}{(1-\nu^2)} & \frac{E}{(1-\nu^2)} & 0\\ 0 & 0 & G\end{bmatrix}.$$

Measure of intrinsic time $d\xi$, calculated as

$$d\xi_m=\frac{\sqrt{2}}{3}\sqrt{(d\varepsilon_{11m}-d\varepsilon_{22m})^2+(d\varepsilon_{11m}-d\varepsilon_{33m})^2+(d\varepsilon_{33m}-d\varepsilon_{22m})^2+\frac{3}{2}d\gamma_{12m}^2}.$$

The increment of the deformation $d\varepsilon_{33m}$ can be found as

$$d\varepsilon_{33m}=-\frac{\nu}{1-\nu}(d\varepsilon_{11m}+d\varepsilon_{22m})-\frac{1-2\nu}{2(1-\nu)}\frac{\sigma_{11m}+\sigma_{22m}}{\sigma_T(\xi)}d\xi.$$

The method of calculating the strength of composite pressure vessels containing a metal liner

When performing the verification calculation of the pressure vessel, the following assumptions were carried out [2–4]:

• the calculation method is based on the membrane theory of shells of rotation;

• the nonlinear behavior of the composite material is neglected;

• a metal liner to be an incompressible isotropic material with a nonlinear deformation curve. It is set as the zero layer of the composite laminate.

It is advisable to start the calculation by determining the linear force in the cylindrical part and bottoms. On the cylindrical part, the meridional and circumferential linear forces T_1 and T_2 are constant and equal

$$T_2 = 2 \cdot T_1 = pR.$$

On the bottoms of the vessel, the linear forces T_1 and T_2 are equal

$$T_1 = \begin{cases} -\dfrac{p}{2}\dfrac{\sqrt{1+y'^2}}{y'}, & \text{if } r > b, \\ \sigma_m h_m - \dfrac{pb^2 - 2b\sigma_m h_m \sin\theta_b}{b^2 - r_{01}^2}\dfrac{r^2 - r_{01}^2}{2r}\dfrac{\sqrt{1+y'^2}}{y'}, & \text{if } r \le b, \end{cases}$$

$$T_2 = \begin{cases} T_1\left(2 - \dfrac{ry''}{y'(1+y'^2)}\right), & \text{if } r > b, \\ \sigma_m h_m - \dfrac{pb^2 - 2b\sigma_m h_m \sin\theta_b}{b^2 - r_{01}^2}\dfrac{r\sqrt{1+y'^2}}{y'} - \dfrac{ry''(T_1 - \sigma_m h_m)}{y'(1+y'^2)}, & \text{if } r \le b. \end{cases}$$

where r is radius of the vessel generatrix; r_{01} is radius of the pole hole; b is radius of the flange; y' is first derivative of the generatrix; y'' is second derivative of the generatrix; p is internal pressure, σ_m is tensile strength of the isotropic material; h_m is thickness of the liner; θ_b is angle of slope of the generatrix at $r = b$.

The average meridian and circumferential stresses σ_X and σ_Y are defined as

$$\sigma_X = \frac{T_1}{h_m + \sum_{i=1}^{n} h_i}; \sigma_Y = \frac{T_2}{h_m + \sum_{i=1}^{n} h_i},$$

where n is number of layers of the laminate; i is layer number; h_i is thickness of the power shell.

The composite deformations are determined in accordance with the matrix equality [5]:

$$d\{\varepsilon_{XY}\} = [S_{XY}]\left(d\{\sigma_{XY}\} + [A]\frac{d\xi}{\sigma_T(\xi)}\{\sigma_m\}\delta_m\right),$$

where $d\{\varepsilon_{XY}\} = d\{\varepsilon_X, \varepsilon_Y, \gamma_{XY}\}$ is vector of deformation increment of the laminate; $d\{\sigma_{XY}\} = d\{\sigma_X, \sigma_Y, \sigma_{XY}\}$ is vector of stresses increment of the laminate; $\{\sigma_m\}$ is stress vector of the liner in the coordinate system of the layer; δ_m, δ_i are relative thickness of the liner and power shell respectively; $[S_{XY}]$ is compliance matrix of laminate equal to

$$[S_{XY}] = (\sum_{i=1}^{n}[T_1]_i[D]_i[T_1]_i^T\delta_i + [D_m]\delta_m)^{-1},$$

where $[D]_i$, $[D_m]$ are the stiffness matrix of the power shell and liner respectively.

The $[T_1]_i$ matrix is

$$[T_1]_i = \begin{bmatrix} \cos^2\varphi_i & \sin^2\varphi_i & 2\sin\varphi_i\cos\varphi_i \\ \sin^2\varphi_i & \cos^2\varphi_i & -2\sin\varphi_i\cos\varphi_i \\ -\sin\varphi_i\cos\varphi_i & \sin\varphi_i\cos\varphi_i & \cos^2\varphi_i - \sin^2\varphi_i \end{bmatrix},$$

where φ_i is layer reinforcement angle.

The deformation and stress increments of power shell in the material coordinate system can be found as

$$d\{\varepsilon\}_i = [T_1]_i^T d\{\varepsilon_{XY}\}; d\{\sigma\}_i = [D]_i d\{\varepsilon_i\}.$$

In the difference formulation

$$\Delta\{\varepsilon_{XY}\}_k^{(p+1)} = [S_{XY}]\left(\Delta\{\sigma_{XY}\}_k + [A]\frac{d\xi_k^{(p)}}{\sigma_T(\xi_{k-1})}\{\sigma_m\}_{k-1}\delta_m\right),$$

$$\Delta\xi_k^{(p)} = \frac{\sqrt{2}}{3}\sqrt{\left(\Delta\varepsilon_{11m}^{(p)} - \Delta\varepsilon_{22m}^{(p)}\right)^2 + \left(\Delta\varepsilon_{11m}^{(p)} - \Delta\varepsilon_{33m}^{(p)}\right)^2 + \left(\Delta\varepsilon_{33m}^{(p)} - \Delta\varepsilon_{22m}^{(p)}\right)^2 + \frac{3}{2}\Delta\gamma_{12m}^{2(p)}},$$

$$\Delta\varepsilon_{33m}^{(p)} = -\frac{\nu}{1-\nu}\left(\Delta\varepsilon_{11m}^{(p)} + \Delta\varepsilon_{22m}^{(p)}\right) - \frac{1-2\nu}{2(1-\nu)}\frac{\sigma_{11m_{k-1}} + \sigma_{22m_{k-1}}}{\sigma_T(\xi_{k-1})}\Delta\xi_k^{(p)},$$

where k is step number of the iterative procedure; p is iteration number.

The numerical procedure continues until the condition is satisfied

$$\Delta\{\varepsilon_{XY}\}_k^{(p+1)} - \Delta\{\varepsilon_{XY}\}_k^{(p)} \le \mu \cdot \Delta\{\varepsilon_{XY}\}_k^{(p)},$$

where μ is small number equal to $\mu = 0.001$.

The current values are given by the formulas

$$\{\sigma_{XY}\}_k = \{\sigma_{XY}\}_{k-1} + \Delta\{\sigma_{XY}\}_k; \{\varepsilon_{XY}\}_k = \{\varepsilon_{XY}\}_{k-1} + \Delta\{\varepsilon_{XY}\}_k,$$

$$\xi_k = \xi_{k-1} + \Delta\xi_k.$$

Numerical example

As an example, consider the cylindrical part of a metal-composite pressure vessel with a radius of 159 mm, consisting of two layers with a total thickness H = 14.05 mm, loaded with internal pressure (Fig. 1). The solution to this problem is given in the book [4].

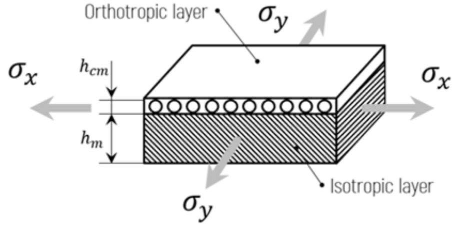

Fig. 1. The cylindrical part of a metal-composite pressure vessel

The first layer is an isotropic material with linear hardening: h_m = 12.75 mm, E = 69 GPa, ν = 0.3, σ_T = 276 MPa, σ_V = 324 MPa, α = 301.5, β = 3.45. The second layer is an orthotropic material (monotropic model): h_{cm} = 1.3 mm, E_1 = 72.4 GPa, E_2 = 0.1 GPa, G_{12} = 0.1 GPa, ν_{12} = 0.3.

Program “MSC Nastran” was used to check the calculation results. In order to avoid bending stress in the plate, a symmetrical reinforcement scheme was used (Table). The isotropic layer was defined as “Nonlinear Elastic”, the solution was performed out in SOL 400. The boundary conditions and the load are shown in the figure below (Fig. 2).

Reinforcement scheme of the composite laminate

No. layer	Model of material	Reinforcement angle, degrees	Thickness, mm
1	Orthotropic, Linear Elastic	90	0.65
2	Isotropic, Nonlinear Elastic	0	6.375
3	Isotropic, Nonlinear Elastic	0	6.375
4	Orthotropic, Linear Elastic	90	0.65

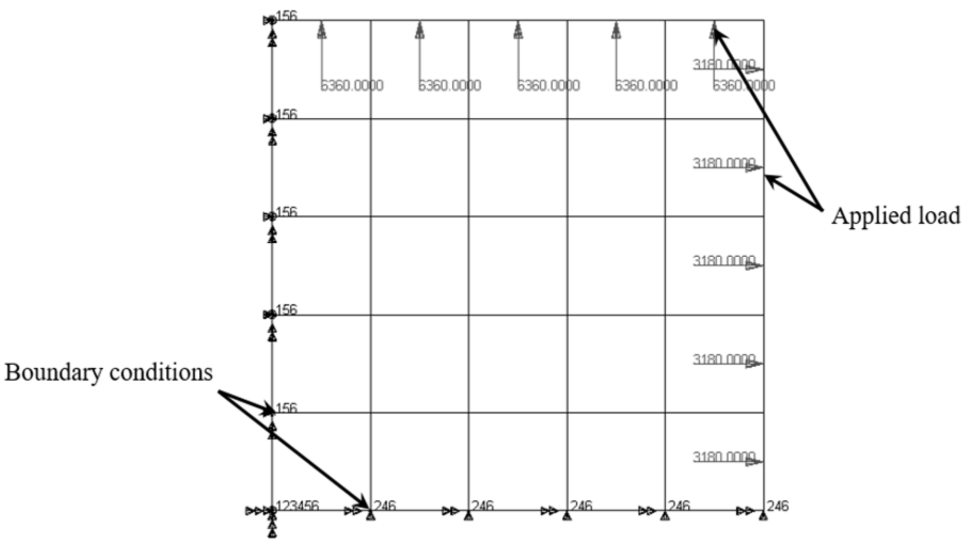

Fig. 2. Boundary conditions and load applied to the plate

To compare the results obtained, graphs of the dependence of the meridian and circumferential stresses in the layers of the laminate on the applied pressure are shown on Fig. 3–5, respectively.

From these graphs it can be seen that the results calculated according to the endochronic theory are close to the results obtained by the finite element method in the MSC Nastran program.

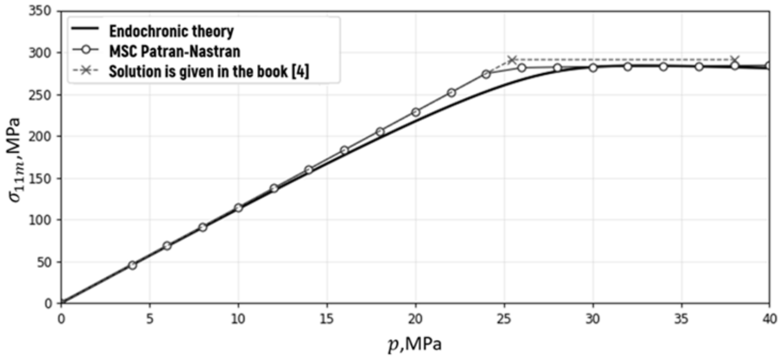

Fig. 3. Dependence of meridian stresses in the metal layer on pressure

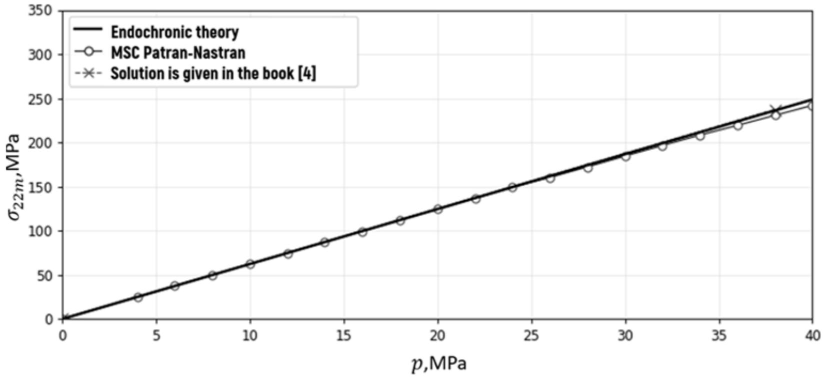

Fig. 4. Dependence of the circumferential stresses in the metal layer on the pressure

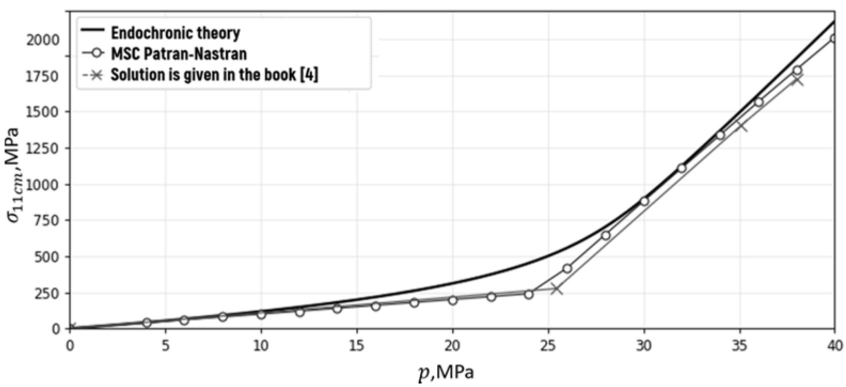

Fig. 5. Dependence of stresses along the fibers in the composite layer on pressure

Conclusion

This article discusses the application of the endochronic theory of plasticity to calculate the stress-strain state of a composite high-pressure vessel containing metal liner.

Satisfactory results of calculation for the strength of the cylindrical part of the pressure cylinder are shown.

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Робототехника и комплексная автоматизация

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Исследование методов трехмерной реконструкции для робота-марсохода

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Проанализирована проблема автономной визуальной навигации роботов-марсохода. Приведена классификация методов 3D-реконструкции, рассмотрены их характеристики, показаны преимущества и недостатки различных методов и исследованы проблемы, с которыми может столкнуться каждый метод при реконструкции в сочетании с топографическими изображениями марсианской поверхности. Заложена основа для дальнейшей разработки системы визуальной навигации для роботов-марсохода.

Ключевые слова: *3D-реконструкция, автономная навигация, структура на основе движения, визуальная навигация, марсоход*

3D Reconstruction Methods for Mars Rovers

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This paper focuses on the problem of autonomous visual navigation of robotic rovers. It gives a classification of 3D reconstruction methods, discusses their characteristics, compares advantages and disadvantages of different methods and analyses the problems that each method may face when reconstructed in conjunction with topographic maps of the Martian surface. Providing a basis for further development of a visual navigation system for robotic Mars rovers.

Keywords: *3D reconstruction, autonomous navigation, structure from motion, visual navigation, Mars Rover*

Введение

В XXI в. страны запускают программы по исследованию дальнего космоса. Марс как планета, наиболее похожая на Землю, был в центре внимания исследователей. На протяжении десятилетий Национальное управление по аэронавтике и исследованию космического пространства (NASA) запустило к Марсу несколько космических аппаратов, включая искусственные спутники, посадочные аппараты и марсоходы, а первый китайский марсоход успешно приземлился на Марс в 2021 г.

Являясь важным средством исследования внеземных тел, планетоходы обеспечивают гарантию выполнения миссии. На рис. 1 показан марсоход Perseverance в кратере Jeaero Crater. Столкнувшись со сложной, неизвестной средой марсианской поверхности, планетарные марсоходы должны обладать высокой степенью автономной навигационной способности и уметь выполнять следующие функции:

- восприятие местности;
- автономное позиционирование и навигация;
- планирование пути;
- обход препятствий.

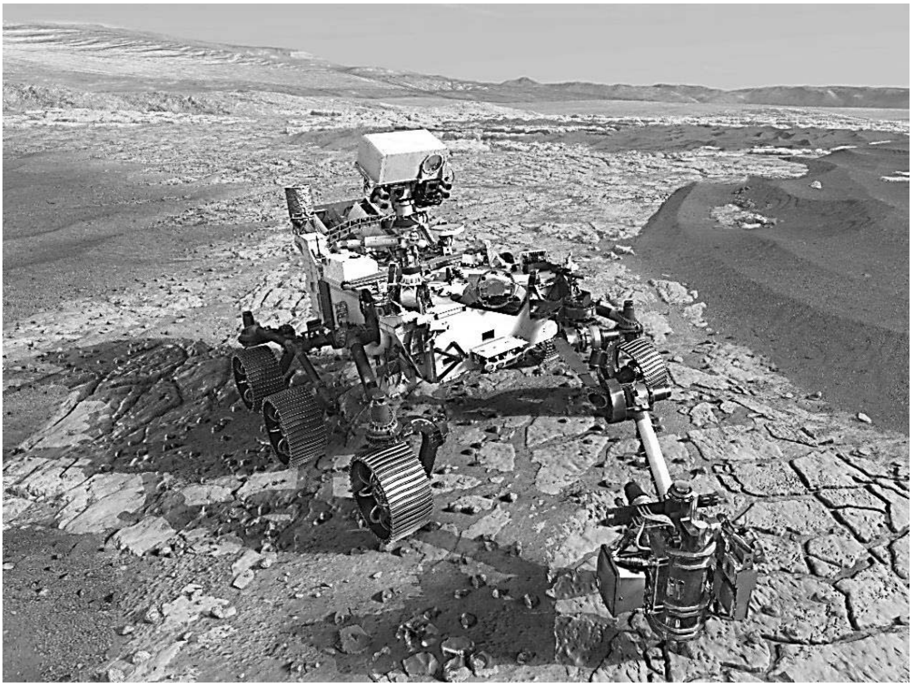

Рис. 1. Марсоход Perseverance

Планетоход использует экологическую осведомленность для получения и анализа информации о своем окружении, определения геометрии местности вокруг него, определения ее проходимости, принятия решений и разработки маршрута на основе этой информации. Способ получения точной трехмерной информации о рельефе из серии изображений Марса имеет решающее значение для миссий по исследованию Марса.

Приведены итоги технологии трехмерной реконструкции, сравниваются преимущества и недостатки различных методов и анализируются проблемы, с которыми может столкнуться каждый метод при реконструкции в сочетании с топографическими изображениями марсианской поверхности.

Марсианская поверхностная среда

На рис. 2 показана топография марсианской поверхности, сделанная марсоходом. В отличие от наземных мобильных роботов, планетарные роверы часто подвергаются воздействию более сложной земной среды. Планетарная поверхность может содержать сложные прерывистые формы рельефа: хребты, овраги, склоны, скалы и кратеры [1]. На рис. 1 показаны условия рельефа на поверхности Марса.

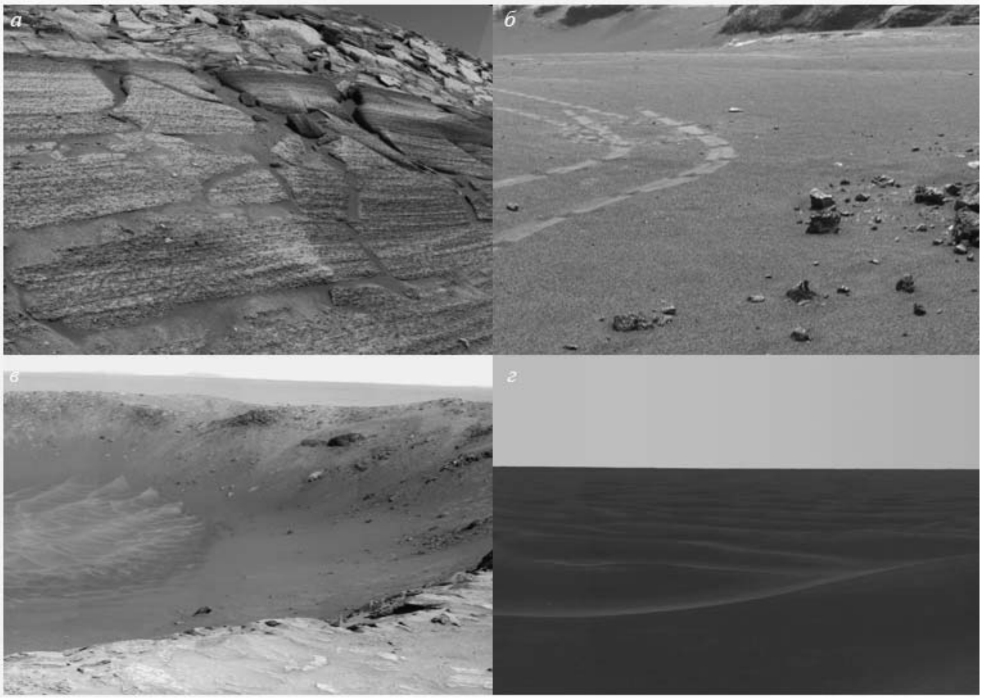

Рис. 2. Марсианская топография:
а — обрыв Бернса (Burns Cliff); *б* — плато Меридиана (Meridiani Planum);
в — кратер Санта-Мария (Santa Maria crater); *г* — пустынный регион

При столкновении с такими сложными ландшафтами результаты наблюдений, полученные планетарным ровером, могут значительно отличаться. Кроме того, на поверхности планеты могут быть, например, большие участки пустыни, что может привести к соскальзыванию или опрокидыванию ровера. Непрерывные, но разреженные ландшафты, например, пустыни, трудно квалифицировать с точки зрения их особенностей, что может вызвать сложности для задач реконструкции поверхности, выполняемых ровером.

Методы трехмерной реконструкции

Существует множество методов 3D-реконструкции (рис. 3) и алгоритмы 3D-реконструкции можно разделить на контактные и бесконтактные методы. Контактные методы получают трехмерную информацию о сцене путем прямого воздействия измерительного инструмента (например, руки манипулятора) на объекты сцены, но он не может получить информацию об удаленных объектах — ориентирах или препятствиях. Поэтому в настоящей статье рассмотрены только бесконтактные методы.

Рис. 3. Таксонометрия существующих подходов к задаче реконструкции сцены

На рис. 3 приведены категории бесконтактных методов. Они не повреждают сцену, поскольку не находятся в непосредственном контакте с ней и являются достаточно точными: лазерное сканирование, время полета, структурированный свет, структура на основе движения и т. д. Большинство из них могут достичь 3D-реконструкции в реальном времени, но все вышеперечисленные бесконтактные методы имеют некоторые недостатки, когда речь идет о 3D-реконструкции. Например, структурированный свет относится к активной проекционной технологии и подходит для использования при слабом освещении, имеет высокую точность на близком расстоянии (в пределах одного метра), вплоть до уровня миллиметра, с увеличением расстояния проекционный рисунок становится больше и менее точным, а также подвержен помехам от яркого света.

Время полета измеряют на больших расстояниях, он не подвержен влиянию серых оттенков или особенностей поверхности. По сравнению со статическими сценами технологии структурированного света этот метод больше подходит для динамических сцен. Однако данный метод требует высокого уровня оборудования для измерения времени и не очень точен для сцен с близкого расстояния.

Метод бинокулярного зрения основан на биологической аналогии со зрением человека. В этом методе используют две камеры для получения воспринимаемого изображения объекта с двух разных ракурсов, этот метод иногда называют стереоскопическим зрением. Стереовидение имеет преимущества при оценке местности вблизи, и работа в этой области включает в себя основанную на стереоснимках цифровую карту рельефа, разработанную Лабораторией реактивного движения США для оценки опасного рельефа и получения таких характеристик распределения, как высота, плотность и наклон облака точек вблизи планетарных марсоходов [2]. Для миссии марсохода ExoMars ученые Европейского космического агентства также предложили использовать стереоизображения для измерения протяженности холмов [3].

Для удаленных сред, где трудно получить точную трехмерную информацию, местность обычно оценивают на основе двухмерных изображений, и обычно рассматривают методы монокулярного зрения. Монокулярное зрение получает изображения двумя способами: используя камеру для получения одного или нескольких изображений из одной точки, или получая несколько изображений из нескольких точек. Однако использование только камер имеет некоторые потенциальные последствия, поскольку методы, основанные на зрении, чувствительны к свету, что может привести к относительно большим ошибкам в 3D-реконструкции, поэтому в некоторых исследованиях также используют лазеры или радары для расширения масштабов восприятия окружающей среды. В то же время 3D-реконструкция, основанная на традиционной многоракурсной геометрии, часто опирается на формулы, которые не очень хорошо работают в экстремальных ситуациях. Однако в некоторых экстремальных условиях глубокое обучение может обеспечить хорошие результаты реконструкции.

С развитием технологии искусственного интеллекта большое значение для завершения миссии по исследованию Марса имеет то, как объединить технологию искусственного интеллекта с традиционной технологией многоракурсной геометрии для повышения возможностей автономной интеллектуальной разведки марсохода.

Подходы к автономной технологии восприятия окружающей среды для планетохода

В зависимости от способа получения многомасштабной экологической информации вблизи планетарного аппарата и сценария применения, существующие технические подходы для автономного экологического зондирования планетарных аппаратов, как правило, следующие.

1. Для ближнего окружения: местность оценивается на основе стереозрения.
2. Для дальних сред: местность оценивается на основе двухмерных изображений.
3. Для улучшения восприятия окружающей среды используется лазер или радар.
4. Используется глубокое обучение для разрешения экстремальных ситуаций.

В этих решениях необходимо сначала найти трехмерную информацию о точках, т. е. получить информацию об облаке точек. Принцип стереоскопического зрения показан на рис. 4.

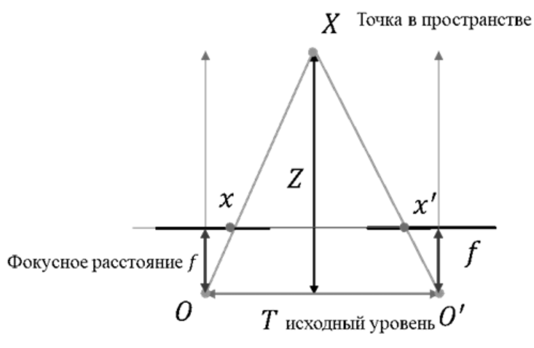

Рис. 4. Принцип стереоскопического зрения

На рис. 4 показано: O, O' — левый и правый центры камеры, x, x' — координаты плоскости съемки, а поскольку $\Delta Xxx'$ аналогично $\Delta XOO'$:

$$(T - x + x')/(Z - f) = T/Z,$$

$$Z = fT/(x - x'),$$

$$d = x - x'.$$

Разница d между горизонтальными координатами левой и правой диаграмм называется параллаксом.

Структуру на основе движения (Structure from motion, SFM) используют для реализации 3D-реконструкции x, x' по движению. Входными данными этого метода является группа двухмерных графиков движения или временного ряда. Путем нахождения совпадающих точек на движущемся 2D-изображении затем устанавливают соответствие признаков в сочетании с принципом триангуляции, чтобы получить трехмерную информацию. Точки соответствия могут быть получены с помощью масштабно-инвариантной трансформации признаков (scale-invariant feature transform, SIFT) [4] или метода Speeded Up Robust Features (ускоренные надежные функции, SURF) [5], а параметры камеры могут быть известны заранее, принцип триангуляции заключается в следующем.

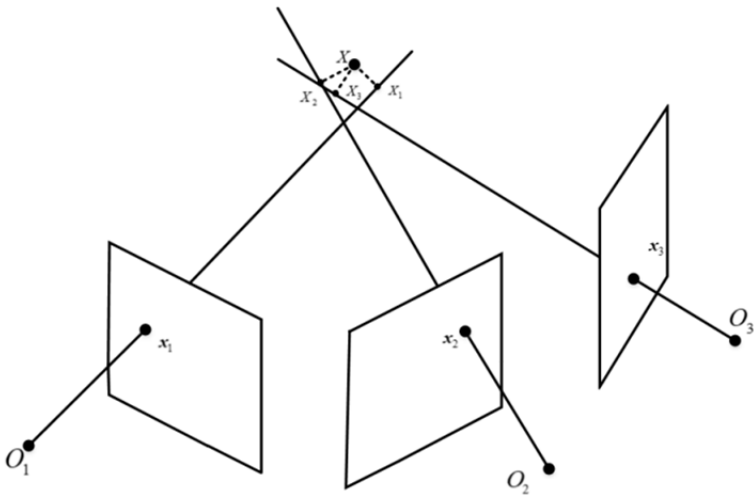

Рис. 5. Принцип триангуляции

Как показано на рис. 5, X — координаты трехмерных точек в пространстве, x_i — X проецируется на i-ю точку зрения, O_i — центр i-й камеры.

Дана матрица проекции i-й камеры:

$$P_i = k_i[R_i, t_i] = \begin{bmatrix} P_{i1} \\ P_{i2} \\ P_{i3} \end{bmatrix}.$$

Координаты трехмерных точек в пространстве:

$$X = [x, y, z, 1]^T.$$

Координаты изображения, проецируемого в i-й точке обзора:

$$\begin{bmatrix} x_i P_{i3} - P_{i1} \\ y_i P_{i3} - P_{i2} \end{bmatrix} X = 0.$$

Так что

$$\begin{bmatrix} x_i P_{i3} - P_{i1} \\ y_i P_{i3} - P_{i2} \end{bmatrix} X = 0.$$

Одно наблюдение обеспечивает два ограничения,X имеет три степени свободы и решает уравнение по крайней мере для двух пар точек:

$$A = \begin{bmatrix} x_1 P_{13} - P_{11} \\ y_1 P_{13} - P_{12} \\ \dots \\ x_i P_{i3} - P_{i1} \\ y_i P_{i3} - P_{i2} \\ \dots \\ x_K P_{K3} - P_{K1} \\ y_K P_{K3} - P_{K2} \end{bmatrix} X = 0, K \geq 2.$$

После получения 3D-точек необходимо выполнить регулировку связки для оптимизации координат 3D-точек и параметров камеры. Структура на основе движения может реализовать самокалибровку камеры в процессе реконструкции и может удовлетворить потребности крупномасштабной 3D-реконструкции сцены, а эффект реконструкции лучше, когда ресурсы изображения в изобилии.

Выводы

Окружающая среда на поверхности Марса очень сложна. Классификация местности с использованием только одного датчика, например, изображение или лазер, имеет недостатки, присущие классификации местности. Учитывая, что планетарные аппараты часто оснащены несколькими камерами технического зрения и недавно были сделаны значительные достижения в области машинного зрения для задач 3D-реконструкции, автономная навигация планетарных аппаратов на основе визуальной информации имеет большое исследовательское значение в будущем.

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УДК 004

Использование искусственного интеллекта в прикладных областях

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Рассмотрено применение технологий искусственного интеллекта в прикладных технических областях. Доказана актуальность использования искусственного интеллекта и практического использования технологий искусственного интеллекта. Дано объяснение концепции искусственного интеллекта, приведена информация об истории возникновения этой концепции. Указан основной принцип работы искусственного интеллекта. Показаны примеры практического применения искусственного интеллекта в прикладных областях науки и техники. При этом особое внимание уделено определенным продуктам или практикам, в которых искусственный интеллект уже используется сегодня. Названы преимущества, которые дает активное использование искусственного интеллекта. Подчеркнута актуальность темы и затронута тема целесообразности использования искусственного интеллекта. Рассматриваемая тема полезна специалистам в области информационных технологий, техники и автоматизации процессов.

Ключевые слова: *искусственный интеллект, нейронная сеть, искусственный интеллект в технике, история искусственного интеллекта, искусственный интеллект в дизайне*

Der Einsatz von kALSnstlicher Intelligenz in angewandten Bereichen

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In diesem Artikel wird die Anwendung von künstlichen Intelligenztechnologien in angewandten technischen Bereichen untersucht. Es handelt sich ebenfalls um die Aktualität vom Einsatz der künstlichen Intelligenz und dessen Auswirkungen bei der Einführung in die Praxis. Der Artikel erläutert das Konzept der künstlichen Intelligenz und berichtet auch über die Entstehungsgeschichte dieses Konzepts. Das Grundprinzip der künstlichen Intelligenz wird ebenfalls beschrieben. Es werden mehrere Beispiele für die praktische Anwendung künstlicher Intelligenz in den angewandten Bereichen von Wissenschaft und Technologie angeführt. Dabei wird besondere Aufmerksamkeit auf bestimmte Produkte oder Praktiken gelenkt, bei denen künstliche Intelligenz heute bereits angewandt wird. Es werden Vorteile genannt, die der aktive Einsatz von KI bietet. Der Autor betont die Relevanz des Themas und schneidet das Thema der Machbarkeit vom KI-Einsatz an. Das betreffende Thema wird für Spezialisten auf dem Gebiet der Informationstechnologien, der Technik und der Prozessautomatisierung nützlich sein.

Keywords: *Künstliche Intelligenz, neuronales Netzwerk, künstliche Intelligenz in der IT, künstliche Intelligenz in der Technik, künstliche Intelligenz im Design, die Geschichte der künstlichen Intelligenz*

Das Konzept der künstlichen Intelligenz

Künstliche Intelligenz (KI) ist ein System oder eine Maschine, die in der Lage ist, menschliches Verhalten zu simulieren, um bestimmte Aufgaben zu erfüllen, und kann schrittweise mit den erhaltenen Informationen trainiert werden. Es ist wichtig zu sagen, dass KI kein einzelner Algorithmus oder keine Maschine ist. KI ist eine Sammlung verschiedener Algorithmen. Das ist ein ganzes System, das der Maschine ermöglicht, Daten zu analysieren.

Der Anfang der Entwicklung von künstlichen Intelligenztechnologien

Die Anfangsphase der Entwicklung von KI-Technologien gilt als die 40er Jahre des 20. Jahrhunderts. Damals fragten sich die Wissenschaftler: "Kann eine Maschine denken? Wie kann das erreicht werden?". Aber sie wählten die falsche Strategie: Alle bereits vom Menschen erworbenen Kenntnisse an den Computer zu übertragen. Natürlich ist die Menge an Informationen riesig. Und diese Idee musste aufgegeben werden, weil es viel Zeit und Arbeit erforderte.

In den 80er Jahren wurde ein anderes Konzept vorgeschlagen. Der Sinn der neuen Technologie bestand darin, dass Maschinen Informationen im Selbstlernprozess verarbeiten. Das heißt, ohne menschliche Hilfe. Das Konzept hat einen uns bekannten Namen — maschinelles Lernen. Diese Technologie ermöglichte es dem Computer, Datensätze zu analysieren und korrekte und falsche Informationen zu identifizieren. Ein solcher Algorithmus wird als neuronales Netzwerk bezeichnet. Diese Technologie ist sehr vielversprechend und wird bisher verwendet.

Der Algorithmus des neuronalen Netzwerks

Das neuronale Netzwerk (NN) ermöglicht es Ihnen, die Arbeit des menschlichen Gehirns zu simulieren. NN wird verwendet, um die künstliche Intelligenz von Maschinen zu entwickeln [1]. Ein Neuron ist eine Recheneinheit eines neuronalen Netzwerks. Die Arbeit eines neuronalen Netzwerks basiert auf der Interaktion solcher Neuronen. Jedes Neuron führt Berechnungen durch und überträgt die Ergebnisse weiter. Basierend auf den Berechnungen aller Neuronen im Netzwerk wird eine endgültige Lösung erstellt. Ein neuronales Netzwerk ist eine sehr komplexe Struktur. Eine solche Komplexität und Vernetzung der Elemente ähnelt tatsächlich der Arbeit des menschlichen Gehirns [1].

Angewandte Nutzung künstlicher Intelligenz

Die Software. Der Einsatz von KI ist aus folgenden Gründen notwendig geworden: Erstens ist es mit der Zunahme der Rechenleistung und des Informationsvolumens nicht möglich, Daten nur durch menschliche Arbeit zu verarbeiten. Es war notwendig, diese Prozesse zu automatisieren. Zweitens erweitert künstliche Intelligenz die Fähigkeiten des Menschen, da die KI Berechnungen und Analysen genauer durchführt. Dadurch wird der Einfluss des menschlichen Faktors reduziert, wenn Fehler auftreten. Im Bereich der Software werden am häufigsten neuronale Netze verwendet.

Der Entwurf und der Design. Es ist erwähnenswert, dass künstliche Intelligenz auch bei der Konstruktion im Maschinenbau, im Bauwesen und in der Architektur verwendet wird. In diesen Bereichen fungiert die KI als Projektanalysator. Die Analyse besteht darin, die besten Lösungen für die Form und die Parameter eines Teils zu finden oder beispielsweise den Lebenszyklus eines Produkts zu modellieren [2]. Die Implementierung künstlicher Intelligenz in die Designsoftware ermöglicht es Ingenieuren, die genaueste Lösung für ihre Entwicklung zu finden, und erleichtert ihnen den Designprozess selbst [3].

Die Robotik und die Fertigung. Künstliche Intelligenz erweitert die Möglichkeiten der Produktion, des Transports und der Robotik. In Fabriken haben Maschinen den Menschen längst in Prozessen ersetzt, die durch einen Algorithmus beschrieben werden können. Aber heute ist KI notwendig, um die Produktqualität zu kontrollieren, um die entscheidenden Produktionszahlen zu überwachen [4]. Beispielsweise misst die KI die Luftfeuchtigkeit oder die Luftverschmutzung. In der Robotik und im Transport steuert künstliche Intelligenz eine Maschine oder einen Roboter, d.h. sie macht das Gerät autonom. Schon heute können Sie unbemannte Taxis oder Lieferroboter auf den Straßen beobachten. Um dies zu tun, ist es notwendig, Computer Vision-Technologien anzuwenden, deren Entwicklung jetzt sehr schnell stattfindet.

Fü r welche Aufgaben und Bereiche gilt Kü nstliche Intelligenz?

Medizin. Im Bereich der Medizin werden intelligente Roboter eingesetzt, die mit Ärzten an Operationen arbeiten, sowie Programme zum Scannen von Bildern, die helfen, Tumorherde und ihre Größe genauer zu bestimmen.

Produktionen. In den Produktionen KI löst mehr mechanische Probleme. Hier, wie in der Medizin, hilft es, die Genauigkeit der Arbeit zu verbessern. KI in den Produktionen erschien nach der Robotisierung von Unternehmen.

Technik. KI kann in vielen Geräten, Autos und anderen Geräten gefunden werden. Heute sind die am häufigsten verwendeten Technologien das Spracherkennungssystem und das Bilderkennungssystem. Spezifische Beispiele könnten Face ID, Sprachassistenten (Alice von Yandex und Siri von Apple) sein. Im Maschinenbau werden Computer Vision verwendet. Auf diese Weise kann das Auto Umgebungshindernisse erkennen, da es mit einer Vielzahl von Kameras ausgestattet ist. Schon heute können Bewohner von Großstädten die Tests von unbemannten Fahrzeugen beobachten. Die Inbetriebnahme ist in Kürze geplant.

Die Algorithmen in Diensten

In den letzten Jahren wurde der aktive Einsatz von KI-Technologien in Online-Diensten wie Youtube, Netflix, Tiktok, Spotify usw. In der Regel sind dies Angebote für den Verkauf von Waren, Streamingdienste, soziale Netzwerke. Unternehmen verwenden intelligente Empfehlungsalgorithmen, die das Angebot für jeden Benutzer personalisieren (z. B. ein bestimmtes Musikgenre oder eine bestimmte Produktkategorie auswählen).

Wird KI den Menschen vollstä ndig ersetzen kö nnen?

Ich möchte darauf hinweisen, dass die Entwicklung künstlicher Intelligenz ein unglaublich umfangreiches und komplexes Gebiet ist. Viele fragen sich vielleicht: “Kann künstliche Intelligenz die menschliche vollständig ersetzen? Wie schnell wird das passieren?” Diese Fragen sind logisch, denn KI hat eine Reihe von Vorteilen gegenüber dem Menschen: kreativen Ansatz, Geschwindigkeit, Multifunktionalität. Aber die Meinung der Wissenschaftler und Forscher ist ermutigend. Sie argumentieren, dass die KI heute noch nicht ausreichend entwickelt ist. Zweitens hat KI nicht die menschlichen Eigenschaften, die uns bei der Arbeit helfen: liebe zum Detail, Sinnlichkeit, Emotionalität. Daher sind die

Argumente, die menschliche Intelligenz vollständig durch künstliche Intelligenz zu ersetzen, nichts anderes als Fiktion.

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Технология дополненной реальности в современной промышленности и проектировании модульных конвейерных систем

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Дополненная реальность — это новая технология, нашедшая применение в различных областях промышленности. Данная технология позволяет вводить в поле зрения пользователя виртуальные объекты, таким образом, дополняя реальность виртуальными составляющими. Представлен краткий обзор применения технологии дополненной реальности в современной промышленности. Проанализированы ключевые тенденции и запрос на развитие данной технологии среди современного научного сообщества. Приведены результаты проведенного исследования, посвященного возможности внедрения технологии дополненной реальности на практике в области модульного проектирования конвейеров.

Ключевые слова: *индустрия 4.0, визуализация, дизайн, модульный дизайн, информационные технологии*

The Augmented Reality Technology in Modern Industry and Modular Conveyor Design

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The augmented reality is a new technology that has found application in various fields of industry. This technology allows virtual objects to be introduced into the user's field of view, thus supplementing reality with virtual components. A brief overview of the application of augmented reality technology in modern industry is presented. The key trends and the request for the development of this technology among the modern scientific community are analyzed. The results of the conducted research devoted to the possibility of implementing augmented reality technology in practice in the field of modular conveyor design are presented.

Keywords: *industry 4.0, visualization, design, modular design, information technologies*

Introduction. The concept of augmented reality technology

The core principle of the augmented reality technology or the AR-technology, is defined as adding different virtual objects such as text, 3D models or information into the field of view of the user, thus enhancing their perception the real environment, surrounding them. The main difference between AR and the virtual reality (or VR) that we can experience by using computers or other devices is that in the latter case, the user is being immersed into the simulated synthetic environment where they can interact with the virtual objects while in the former case, the surroundings stays real and the virtual objects are just “augmented” into them.

The AR technology does not only let the user see the virtual objects in the real, it can give the user the ability to directly interact with them while also modelling their responsive actions. For example, the user may change their point of view or turn, rotate and move the objects and the objects would behave as they would do in the real life [1].

The concept of the augmented reality was born way ahead of any technologies that could make it possible to implement this theoretical concept in practice. The first mentions of similar concepts can be traced dating back to the beginning of the XXth century, such as the concept introduced by Lyman Frank Baum in his 1901 book "The Master Key An Electrical Fairy Tale" that features the magic glasses that could define a person's personality and mark them accordingly with a letter on their forehead when the one wearing the device would look at them. These early concepts were very far from any implementation, however, but that might be a sign, that a technology of this kind was already on someone's mind.

The first early real examples of the AR technology implemented in the real life started to emerge in the 1960s–1980s and were generally used in some specific areas such as aerospace industry. One of the examples may be considered the head-up display or the HUD used in various aircraft since the late 1950s. The HUD is a transparent display right in front of the pilot's head used to provide the pilot with the most valuable information without making them look away to read it elsewhere. In this case the virtual object in form of the text and graphical symbols, containing the information is added into the user's field of view.

Although the first implementations were limited to different specific areas, the rapid development of the computer and mobile smartphone technologies in the beginning of the XXIst century finally let the AR technology be implemented without the use of expensive and complex special equipment.

In 2010s the AR technology first emerged on the entertainment market. In 2016 the famous game featuring AR technology, the Pokemon GO was first released. Very soon it got extremely popular with over 100 million downloads over the course of the first year [2]. The example of the Pokemon GO shows that today the technology level of electronic devices makes the AR technology accessible by the wide range of users without using any special equipment.

In order to analyze and illustrate the current demand and interest for the AR technology within the scientific society, an analysis of the publication activity in this field over the past twenty years has been carried out based of the catalog of scientific and technical literature of the All-Russian Institute of Scientific and Technical Information of the Russian Academy of Sciences (VINITI RAS) [3]. The results of the analysis in the form of a graph are shown in Fig. 1.

The graph shows two waves of growth of interest to the topic of the AR technology among the scientific community. The first one taking place between the years of 2006 and 2013 may be attributed to the development of new technologies that would make the implementation of AR more convenient. The second and larger wave that started in 2016, culminating in 2018 may be a result of popularization of AR in public and success of different projects such as Pokemon GO, proving that the AR technology can be profitable and accessible by ordinary smartphone users. Even though there is still some decline in publication activity on related to the this topic since 2019, the trend (pictured by the green and red lines) is still positive, meaning that the overall interest to the topic is still rising and research and development of projects in this field is likely to be demanded in the future.

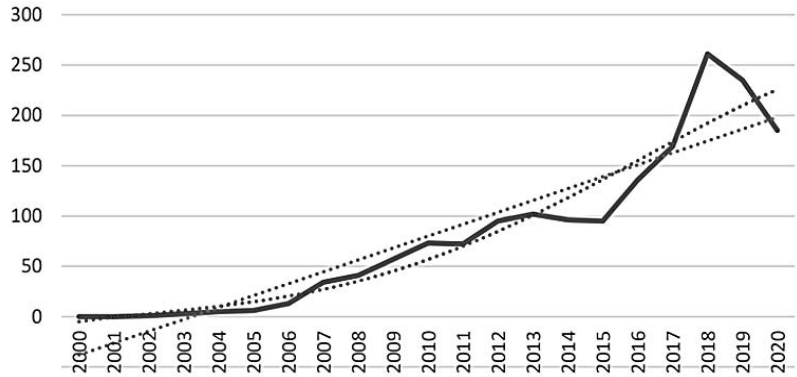

Fig. 1. Graph of publication activity in the field of AR technology

The augmented reality technology in modern industry

As of today, the AR technology is getting more and more implementation in various fields apart from just entertainment. For example, AR started to get implemented in the field of education and in medicine [4, 5]. However, one of the fields that utilizes the AR the most is modern industry.

Today AR technology is used in architecture as a mean of visualizing a building that is currently under development in it's final form or on the different stages of construction in it's real surroundings. Also, AR can be used in construction for performing accurate measurements with high precision [6].

Recently, AR technology found implementation in logistics and warehouse management. According to some estimates, the cost of warehouse operations is about 20 % of logistics total expenses, while the costs of picking up the ordered goods range from 55 % up to 65 % of the total cost of warehouse operations [7]. In this field the AR technology is used to assist the warehouse workers to navigate through their working space, choose and pick the required items. The system that uses AR-based devices to assist workers this way is called Pick-by-Vision, highlighting the way that the user is gets guided to the required location or item by visual reference. The system uses special devices in shape of glasses that provide user with necessary information and visual guidance for the current task in text or graphic format. The system also allows to scan the barcode of the product without using hands by just looking at the code [8].

The prospects of using the augmented reality technology in future industry

To understand the place of AR technology in future industry, it's necessary to understand what are the key trends that the industry is likely to follow in the nearest future. Modern trends in the development and introduction of new, high-tech systems and technologies that can radically affect the industry are often combined under the general name of The Fourth Industrial Revolution, which is predicted to result in automation and the implementation of digital technologies at all stages of production within the transition to Industry 4.0 [9]. However even with the introduction of complex automation it is not possible to completely get rid of the human labor, replacing it with automated complexes.

In areas where human labor will be indispensable, new technologies can be used to help workers. To implement these principles, the use of modern technologies, including AR technology, is considered.

For example, according to the article by the scientists of the University of Turin it is possible to identify several main areas of application of AR technologies in the future industry: the joint work of humans and robotic complexes, the tasks of maintenance, assembly and repair, the learning process and production quality control [10].

The augmented reality technology in the design of modular conveyor systems

With the general trends, mentioned above in mind and over the course of the university program the research the was conducted on the prospects of implementation of the AR technology in the field of modular conveyor systems.

As in architecture, in this field the visualization plays a major role during the design stage of the project. It is crucial to give both the customer and the engineers, that work on the project the clear picture on how the finished product would look like. The main difference between this case and the experience of using AR in architecture is that conveyors consist of different specific modules that are connected into one system so for the visualization it is necessary to have different modules that would be able to connect into one system similar to puzzle pieces connecting into an image. The purpose of the research was to find the way to get this picture while still leaving the ability to change it to find the best system configuration.

In this case AR technology would become useful as the AR technology provides a better visualization then both traditional blueprints and 3D images as the user is able to interact with objects directly, but the most challenging part was to create the system that would work with multiple 3D objects at once that are not connected with each other and are moved separately.

The research started with the analysis of different ways of implementing the AR system. In this case it was a choice between two ways:

• the marker based AR system, where a virtual object is connected to a special marker (also called ‘tag’) that is mostly an image on a piece of paper that is being tracked by the system so that by moving the marker around the user is able to manipulate the related object;

• the markerless AR system, where the virtual object is connected to some point, usually some flat surface.

The analysis was also based on the article “Comparison of marker-based AR and markerless AR: a case study on indoor decoration system”, presented in the “Lean & Computing in Construction Congress (LC3), vol. 2.” [11]. It showed that the marker-based AR technology allows to create a more simple and reliable system that could simultaneously track several different objects.

After determining the AR system type it was necessary to find the software required to work with application based on AR technologies. Fortunately, a number of Software Development Kits or SDK that allow users to create such software is available. The analysis of those available SDKs was conducted to determine the best software for the current task based on the software information and different articles, dedicated to this topic. The analysis showed that the best way to create the AR-based application to work with multiple markers would be to use two SDKs: Vuforia software for multi marker system and AR-media for studying markers on single marker systems.

On the following step a research was conducted on the configuration of the markers to determine what features of the marker make the system more or less reliable. The research consisted of creating and testing various markers of different configuration using the AR-media SDK. Some rules for the markers were determined such as: the markers need to have a frame that the camera would track, the image has to be asymmetrical so the program would be able to determine it's position, the image should be as contrasting as possible and should not consist of thin lines that the camera would have trouble identifying.

The next step was to create a working multimarker AR system using the selected SDK and considering the rules mentioned above (Fig. 2). As it was still a test, the simple figures were used as placeholders for the models. The system was created using Vuforia software and custom markers. Vuforia SDK used black images with text as markers. The system worked as intended, providing reliable connection between the markers and the 3D objects. When markers were moved or rotated, the objects moved correspondingly.

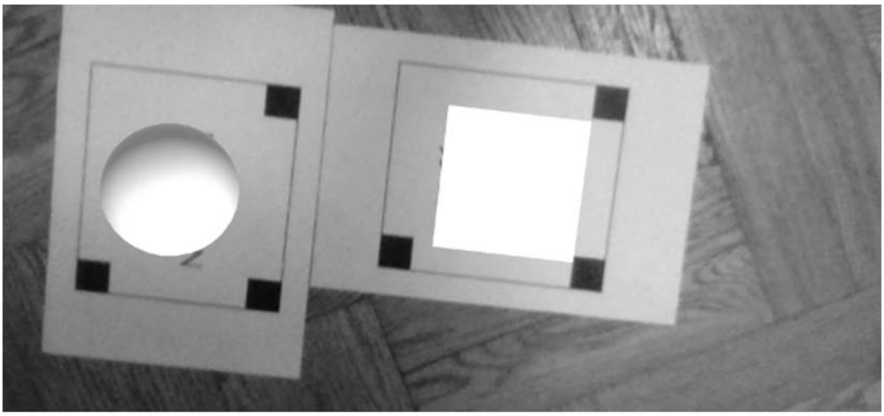

Fig. 2. Working multimarker AR system with a sphere and a cube as placeholders

This research serves as a demonstration proving that it is indeed possible to create a reliable multiple marker based AR system to create a visualization for a modular system such as a modular conveyor. The next step will be to assign 3D models of real conveyor modules that are required instead of the placeholders, creating the fully functional visualization. As for now, the models are still in the process of creation and the work on the fully functional visualization is still in process.

Conclusion

The AR technology is proved to be on the rise of it's popularity. The analysis shows that there is a lot of interest for the AR technology in the modern scientific community and there are a lot of possible ways to implement the technology in future industry as the more developed the industry becomes, the higher the demand for such new technology will become.

One of the examples of the implementation is demonstrated based on the conducted research. While shows one of the possible ways of enhancing the visualization of the project by using AR technology, it also demonstrates that a user without any special programming skills is able to create such a system using modern development tools.

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Гидроакустическая сеть для навигационного и информационного обеспечения подводных работ

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Гидроакустическая сеть предназначена для определения местоположения входящих в нее устройств и передачи данных между этими устройствами. Представлен подход к выбору структуры и алгоритмов функционирования гидроакустической сети малых размеров, построенной на гидроакустических устройствах, позволяющих определять координаты получателя гидроакустического сигнала относительно отправителя. Этот подход основан на выделении в гидроакустической сети пяти типов носителей гидроакустических устройств по критериям мобильности, возможности управления отправкой гидроакустических сообщений, наличием бортовой навигационной системы, числу гидроакустических устройств на борту. Предложена структура гидроакустической сети, состоящей из последовательности шагов, выполняемых всеми устройствами в сети одновременно и синхронно. Описаны процедуры решения проблем обрыва связи и потери синхронизации между устройствами. Предложены варианты схем опроса в гидроакустической сети по заданным критериям минимизации. Описаны процедуры передачи пользовательских сообщений по гидроакустической сети.

Ключевые слова: *гидроакустическая сеть, гидроакустическая навигационная система, гидроакустическое устройство, обмен данными, подводный аппарат*

A Hydroacoustic Network for Navigation and Information Support of an Underwater Work

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A hydroacoustic network is used for location determination and data transmission between underwater vehicles. This work presents a structure and algorithms of a small size hydroacoustic network based on hydroacoustic devices capable to determine coordinates of remote devices relative to a local one. To determine a structure of the underwater hydroacoustic network, vehicles were divided into six groups according to their mobility, ability of hydroacoustic device control, availability of an onboard navigation system, a number of hydroacoustic devices on board. A hydroacoustic network algorithm is based on synchronous steps performed by every vehicle in the network. The algorithm for proceeding disconnections and synchronization failure caused by transition errors is presented. Procedures for user's specified data transmission throw hydroacoustic network are developed and described in this work, as well as schemas for the order of the vehicle transmission determination.

Keywords: *hydroacoustic network, hydroacoustic navigation system, hydroacoustic device, data translation, underwater vehicle*

Introduction

Underwater vehicles are widely used in oceans depth for varies types of work. They need information on their location and possibility of data exchange with an operator for a work control and correction as well as every autonomous device for successful operation. The underwater navigation and data transmission are strong signal attenuation that make it impossible to use traditional navigation and data transmission systems based on high frequency signals such as global positioning system, Wi-Fi and radio transmission. Because of this, systems based on hydroacoustic signals are widely used by underwater robotics. They are able to transmit data at huge distances (kilometers), but with strong limitations on a message size and transmission speed [1].

A hydroacoustic navigation system is based on location determination of one hydroacoustic device relative to another one by a hydroacoustic message exchange. There are two types of hydroacoustic navigation systems. The first type is based on hydroacoustic devices capable only to measure a distance to a hydroacoustic message sender. This type is based on triangulation methods of location determination. Another type is based on hydroacoustic devices with a phased antenna array capable to determine the direction of the received hydroacoustic message [2]. The way of hydroacoustic network organization presented in this work is based on the second type of hydroacoustic devices.

A hydroacoustic network is a set of hydroacoustic devices, which exchange messages to determine their location and transmit specific data. The known ways of hydroacoustic network organization are mostly focused on data transmission between remote devices which can’t exchange data directly [3–5], or on the location determination of a big number of devices [6–8]. These works describe algorithms for big size hydroacoustic networks with dozens of devices, majority of which don’t change their location. This work proposes a hydroacoustic network for up to ten devices (this number of underwater devices is used more often). The presented algorithm is based on classification of underwater vehicles caring hydroacoustic devices, and the types of hydroacoustic messages they transmit.

The work has the following structure. At the first paragraph the method of network underwater vehicle classification is presented, and vehicle’s main characteristics are introduced. The second paragraph deals with the hydroacoustic messages content and the transmission order. The third paragraph contains the algorithm of disconnecting and synchronization lost preventing. At the fourth paragraph recommendations for choosing data messages transmission order in the hydroacoustic network are done.

Hydroacoustic Network Vehicles Parameters

For every kind of work, different types of vehicles involved in the underwater network are used. Autonomous underwater vehicles can do some works, such as specified object search and monitoring of water area without an operator support. Remote operated and towed underwear vehicles are controlled by humans. Hydroacoustic devices can be mounted on the sea floor or can drift on the surface and can be used in these cases for navigation support of underwater work. Underwater doc stations are used for charging and storage of underwater vehicles. Support vessels do not only carry underwater vehicles to the work location but provide some technical and information support by hydroacoustic devices.

Classification of these underwater and support vehicles is done by their mobility, ability to manage their onboard hydroacoustic devices, availability of navigation information onboard. In addition, some vehicles can carry more than one hydroacoustic device, e.g. a support vessel or an underwater vehicle, to expand the area of hydroacoustic signal reception, as it is usually restricted by a part of sphere.

All vehicles can be divided into active and passive by the ability of managing their onboard hydroacoustic devices. Active vehicles are able to initiate hydroacoustic message transmission. Passive vehicles can only automatically respond to hydroacoustic messages.

Passive vehicles can be static (bottom hydroacoustic transponders) or mobile (remote operated vehicles). Active vehicles with an onboard navigation system are usually mobile and ones without it are static. As passive vehicles can't transmit data on their desire, they don't have onboard navigation systems but their coordinates can be known.

In the hydroacoustic navigation system, vehicle's coordinates are calculated basing on the information about the determined location of the remote vehicle with the respect to the local one and considering its absolute location. So, absolute coordinates of one vehicle should be known to another vehicle to calculate its own coordinates. According to this, hydroacoustic network vehicles can be divided into two groups. The first group includes vehicles which can be used to calculate absolute coordinates of another vehicles (coordinates+). The second group includes vehicles which can't be used in the same way (coordinates).

Due to the mentioned parameters hydroacoustic network vehicles can be divided into six types (Table).

Types of hydroacoustic network vehicles

No.	Static / mobile	Single / group	Coordinates+ / Coordinates-	Active / passive
1	Static	Single	Coordinates+	Passive
2	Mobile	Single	Coordinates-	Passive
3	Static	Single	Coordinates+	Active
4	Static	Group	Coordinates+	Active
5	Mobile	Single	Coordinates+	Active
6	Mobile	Group	Coordinates+	Active

Hydroacoustic Network Messages

The process of measuring a remote vehicle's coordinates with relative to a local one used in hydroacoustic devices is following: a local vehicle sends a hydroacoustic message to a remote vehicle and measure a time from the moment of sending to the moment of receiving an automatic immediate response from the remote vehicle. The remote vehicle calculates its coordinates using this time, the information on the sound speed in the water and the direction of the received signal [2]. Absolute coordinates of a remote vehicle are calculated by adding absolute coordinates of a local vehicle.

Since the response to a hydroacoustic message is always sent automatically and immediately, its content can't be changed. Such way of a message exchange is used in many real hydroacoustic systems. This cycle of hydroacoustic message sending and automatic response receiving (Fig. 1) is a step of a hydroacoustic network.

The hydroacoustic network consists of series of steps performed by active vehicles which send hydroacoustic messages with desired data. A receiver of the message can be a passive or active vehicle which response with a fixed data immediate message. To calculate coordinates of the remote vehicle, the local vehicle needs one step. The own local vehicle coordinates can be calculated by one step if the remote vehicle is static and has the known coordinates, and by two steps if the remote vehicle is mobile and active. In this case one step is used to determine relative coordinates of the remote vehicle and another step is used to send absolute coordinates of the remote vehicle to the local one.

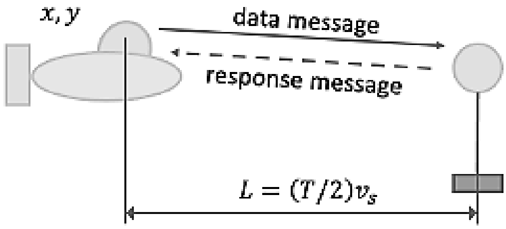

Fig. 1. A hydroacoustic network step:
L — distance between vehicles; *T* — time to receiving hydroacoustic response; v_s — speed of sound in the water

The steps order determines time and precision of the coordinates' calculation. If the first step is used to calculate coordinates of the remote vehicle relative to the local one and the second step is used to transmit the absolute coordinates of the remote vehicle to the local one, an error of the coordinate calculation will be proportional to the travel length of the remote vehicle with relative to the local one during one hydroacoustic message transmission (Fig. 2, *a*). If steps are performed in the opposite order, an error of coordinate calculation will be proportional to the travel distance of the remote vehicle relative to the local one during transmission of three hydroacoustic messages (Fig. 2, *b*). So, the first variant of the steps order is more precise then the second one.

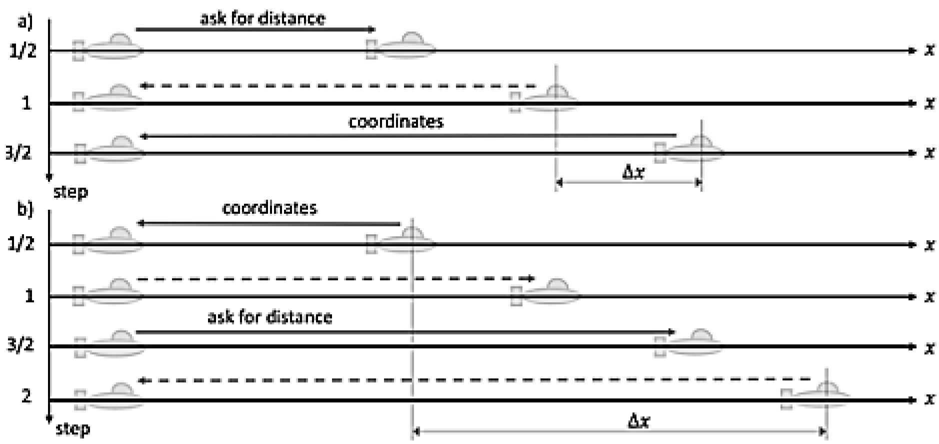

Fig. 2. Hydroacoustic network step order:
a — when relative coordinates are calculated by the first step;
b — when absolute coordinates of the remote vehicle are transmitted by the first step

Disconnection and Synchronization Failure Repairing

A hydroacoustic network consists of steps ordered by all active vehicles at the same time. On the same step one active vehicle sends hydroacoustic message, another vehicle waits for this message and sends response while other vehicles wait for their turn to do the same. Only a pair of underwater vehicles can exchange hydroacoustic messages at one time. That's why waiting steps are included in the hydroacoustic network.

To ensure that all vehicles are at the same step, its maximum duration is limited. The maximum step duration calculation is based on the known maximum communication distance of hydroacoustic devices and methodological, hard and soft delays. If a massage transmission failure is occurred due to the aggravation of hydrological situation or vehicle exceedance the communication distance of hydroacoustic devices, the same step of the hydroacoustic network can be repeated. The number of the step repetition should be limited to prevent a hydroacoustic network from locking on the one step. If a hydroacoustic network vehicle equipped with more than one hydroacoustic device, it can change the device which repeat the message on the same step.

When the step was repeated maximum number of times and the hydroacoustic link was not established the vehicle starts the next step. Also, a different time of a message transmission could lead to the situation when more the one hydroacoustic network vehicles will try to send a message. This will result in all messages transmission failure. To solve this problem all active hydroacoustic network vehicles are organized in the hierarchical structure. When the conflict of a message transmission occurred each vehicle repeats the transmission after a delay which duration is proportional to the vehicle's place in the hierarchical structure. Because of this all vehicles repeat a message transmission at different times.

A step order control on the board of hydroacoustic network vehicles is based on steps counters for every pair of active vehicles. Every exchange step in the hydroacoustic network has a number, which is transmitted in a hydroacoustic message. If the step number in a hydroacoustic message is not equal to one on the board of a vehicle which received this message, vehicle changes its current step in the hydroacoustic network on one, that was in the message and continue the hydroacoustic exchange from the new step. So, to repair a synchronization failure between two vehicles only one step repetition is needed.

Hydroacoustic Network Step Order

A hydroacoustic network structure depends on purposes of vehicles which are used in the network. According to a wide variety of underwater vehicles and hydroacoustic devices they can be provided with some schemes of the hydroacoustic network organization :

• *a fast scheme* characterized by the minimum duration of a hydroacoustic network cycle which includes all vehicles (Fig. 3, a). On this scheme an active vehicle sends hydroacoustic messages to all other vehicles in preset order. Then next active vehicle in the hydroacoustic network does the same. The active vehicles' sending messages order affects only the frequency of an active vehicle coordinates calculations. The highest frequency will be achieved when the active vehicle exchanges with a coordinates+ and coordinates- vehicles in turns;

• *a precise scheme* characterized by the highest frequency of coordinates calculation of every active vehicle (Fig. 3, b). On this scheme every active vehicle sends messages to a pair of vehicles: one coordinate+ and one coordinate-. Then next active vehicle does the same. Vehicles should be divided into pairs so that to make the duration of message exchange cycles of all pairs approximately equal. If the number of vehicles in the hydroacoustic network doesn't allow to divide all vehicles into pairs, some pairs could be extended by one extra vehicle. In this case, the order of sending messages remains the same as for ordinary pairs: the coordinates+ and coordinates- vehicles receive messages in turns;

• *a priority scheme* characterized by the preset frequency of every vehicle coordinate calculation (Fig. 3, c). On this scheme every active vehicle sends one message to another vehicle at a time. Then next vehicle in the hydroacoustic network does the same. Every vehicle receives a message as often as it set in the hydroacoustic network parameters.

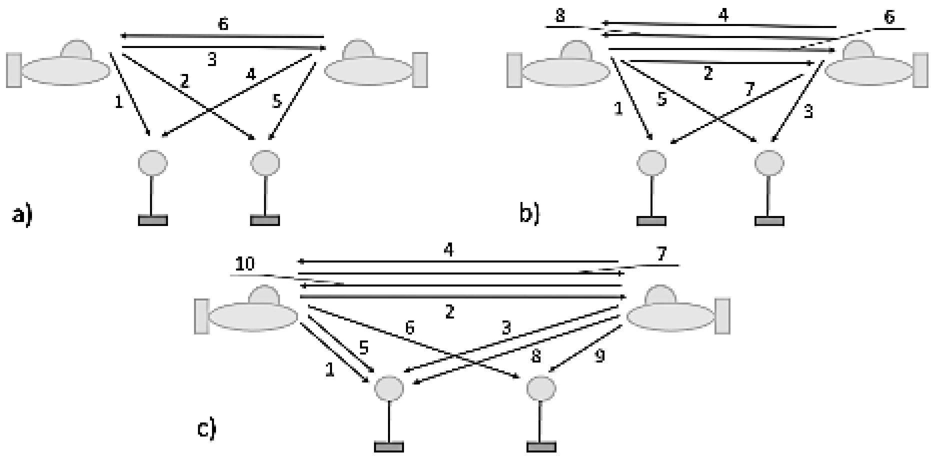

Fig. 3. Hydroacoustic network schemas:
a — a fast schemas; *b* — a precise schema; *c* — a priority schema
(numbers are determine the order of message exchange)

A hydroacoustic network is also used for a data messages transmission from one vehicle to another. All data messages could be divided into two groups. The first group includes cyclic data messages which are usually used for the work control. The second group includes commands, which are used for a vehicle and a hydroacoustic network control. Every message in the hydroacoustic network contains data used for vehicles' coordinate calculations. It can also contain a specific user data added to the tail of a message. This way of a user data transmission between vehicles does not interrupt the hydroacoustic network cycle. The limitation of this way of a data transmission is a small size of a message, which could be sent by the hydroacoustic device because a half of it is used for the coordinate calculation data. On the other hand, commands are usually used to change the hydroacoustic network scheme, so they could be sent as individual hydroacoustic messages. The hydroacoustic network vehicle should send this message only instead of the usual hydroacoustic message with a data for coordinates calculations to avoid transmission failure described earlier in this work. Individual messages could also be used to transmit a cyclic control data, but the effect on coordinate calculations should be taken into account.

Conclusion

The authors have described and presented the hydroacoustic network organization. It contains the algorithms of vehicles coordinate calculations and data transmission from one hydroacoustic network vehicle to another. We have also analysed the impact of the hydroacoustic messages order on the precision of vehicles' coordinate calculations.

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Фундаментальная математика и физика

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Эффективность Евро-Азиатской сети детекторов гравитационных волн: регистрация чирп-сигналов и сигналов от коллапса сверхновых

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Приведена оценка эффективности предлагаемой Евро-Азиатской сети интерферометров гравитационных волн, которую планируют с учетом строительства одного из детекторов в Новосибирском научном центре РАН. Евро-Азиатская сеть образована четырьмя детекторами: VIRGO, KAGRA, LIGO India и детектором в Новосибирске. Эффективность такой конфигурации рассчитывают на основе типичных численных критериев для глобальных сетей. Одним из ключевых показателей эффективности сети является точность восстановления параметров гравитационных волн, что связывает расчет соответствующего критерия с конкретным классом астрофизических источников. Приведены результаты расчетов, выполненных для чирп-сигналов релятивистских двойных систем и сигналов от вращающихся коллапсирующих звезд. Максимизацией интегрального критерия найдена оптимальная ориентация новосибирского детектора, которая задается углом между южным направлением и биссектрисой плеч интерферометра Майкельсона.

Ключевые слова: *гравитационные волны, сети детекторов, гравитационный коллапс, слияние двойных систем, эффективность сетей*

Efficiency of Euro-Asian Network of Gravitational Wave Detectors: Registration of Chirp Bursts and Signals of Collapsing Stars

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In this report, we evaluate the performance of the proposed Euro-Asian network of gravitational wave interferometers. Euro-Asian network consists of four detectors: VIRGO, KAGRA, LIGO India and the planned detector at the Novosibirsk Scientific Center of the Russian Academy of Sciences. The efficiency of Euro-Asian network is calculated based on typical numerical criteria for wide area networks. Accuracy of reconstructing the parameters of gravitational wave bursts is one of the main criteria and it depends on the particular form of gravitational wave signal. We calculate the efficiency of Euro-Asian network for the chirp signals from the relativistic binaries inspiral and for signals from rotating collapsing stars. Maximizing the integral criterion we find the optimal orientation of the Novosibirsk detector, which is specified by the angle between the south direction and the bisector of the Michelson arms of the gravitational wave interferometer.

Keywords: *gravitational waves, network of detectors, gravitational collapse, binary star merger, network efficiency*

Introduction

In September 2015, the first direct registration of a gravitational-wave burst from the merger of a relativistic binary, whose components were evaluated as black holes (BH), took place [1]. The detection of this event was carried out using LIGO detectors [2]. After there were several other similar registrations. A qualitative step was the registration by three detectors (including a similar interferometer VIRGO in Europe) GW170814 burst from the merger of BH binary ($M = 30M_{\odot}$) from the distance of 540 Mps [3], which allowed to reduce the localization zone of the source on the celestial sphere by an order of magnitude, up to $\sim 60deg^2$. A gravitational wave (GW) signal from neutron stars (NS) merger was registered, coinciding with GRB170817A gamma burst (with 1.7 sec delay) [4]. One of the most recent significant steps is the registration of GW from the neutron star — black hole binaries coalescence [5].

All these facts allow to claim confidently real occurrence of a new gravitational-wave channel of astrophysical information and heuristic value of multi-messenger astronomy, i.e. strategy of parallel observation of transients on detectors of different physical nature. However, there is still no observation of GW from supernova as well as significant coincidence between LIGO/VIGRO data and neutrino detectors like NOvA [6] and IceCube [7] experiments. GW from core-collapse supernovae can serve as an important source of information about the processes occurring during a given event [8].

In this context, we continue the discussion of a European-Asian network (EAN) [9] which consists of four antennas in the northern hemisphere: VIRGO in Italy, KAGRA in Japan, LIGO-India in India and the planned new additional antenna in Novosibirsk. In order to assess the scientific feasibility and efficiency of such a network the calculation of its main characteristics was performed in the approach developed in Refs. [1, 10].

Here we consider two sources of GW signals: inspiral of a relativistic binary and collapsing stars at the protoneutron star stage which is subjected to rotational instabilities. For both sources we define the optimal orientation angle of possible detector in Novosibirsk by maximizing the integral efficiency criteria.

Table shows the coordinates of the detectors in question. The detector orientation angle γ is defined as the angle between the southward direction at the detector location and the bisector of the angle formed by its arms, measured counterclockwise.

Detector data (all angles given in degrees)

Detector	Latitude ll	Longitude LL	Orientation γ\gamma
VIRGO	43.6	–10.5	206.5
KAGRA	36.4	–137.3	163.3
LIGO India	19.6	–77.0	254.0
Novosibirsk	55.0	–82.9	To be defined

It is worth noting that in addition to the planning Novosibirsk interferometer, today a project of search for neutrino and gravitational correlations using the OGRAN gravitational detector and the BUST neutrino telescope is being developed in Russia [11].

Criteria of a network

To estimate efficiency of a network of ground based detectors it is necessary to construct power patterns of individual components and the whole network. Here we review the basic information necessary for construction of the pattern and calculation of the criteria.

In the long wavelength approximation (the GW wavelength is much larger than the interferometer arm length L) the detector response can be evaluated as

$$h(t) = \frac{\delta L}{L} = F_+(\theta, \varphi, \psi) h_+(t) + F_\times(\theta, \varphi, \psi) h_\times(t),$$

where $F_+(\theta, \varphi, \psi), F_\times(\theta, \varphi, \psi)$ are the antenna pattern functions for the two polarizations, which are functions of the polar angle θ and the azimuth angle φ of the spherical coordinate system (*XY* is the detector plane) and the polarization angle of the GW ψ.

Antenna pattern functions have the following form (in the coordinate frame, which basis vectors, coincide with the direction of the detector arms):

$$F_+ = \frac{1}{2}(1 + \cos^2\theta)\cos 2\varphi \cos 2\psi - \cos\theta \sin 2\varphi \sin 2\psi,$$

$$F_\times = \frac{1}{2}(1 + \cos^2\theta)\cos 2\varphi \sin 2\psi + \cos\theta \sin 2\varphi \cos 2\psi.$$

In Ref. [12] it's shown that for a network of Ndetectors network antenna power pattern P^N:

$$P^N = \sum_{k=1}^{N} \left(F_{+,k}^2 + F_{\times,k}^2\right).$$

In order to choose the optimal detector angle in Novosibirsk, we use 3 independent criteria presented in Refs. [1, 10]. These three criteria form an integral criterion, which is to be maximized by changing the orientation of the Novosibirsk detector, to find the most effective angle.

Polarization criterion I. Criterion I characterizes ability of the network to assess the polarization of the received GW. Following Ref. [10] we define $+$ and $\times$ integral functions for a network of four detectors:

$$F^N = \frac{1}{2}\sqrt{F_1^2 + F_2^2 + F_3^2 + F_4^2},$$

where N stands for a network function and $F_1 \ldots F_4$ all either correspond to the $+$ or $\times$ polarization. Obviously F^N depend on the polarization angle of ψ.

Calculation of *I* is carried out in dominant polarization frame (DPF) [13]. In DPF for each point on the celestial sphere $(\alpha; \delta)$ (in equatorial coordinate system point is defined by right ascension $\alpha \in [-\pi; \pi]$ and declination $\delta \in [-\frac{\pi}{2}; \frac{\pi}{2}]$) a polarization angle that maximizes the network factor F_+^N and minimizes $F_\times^N$ is chosen. Consequently, for this direction $(\alpha; \delta)$ the condition $F_+^N \geq F_\times^N$ is valid. The condition of approximate equality of factors $F_\times^N$ and F_+^Nhas to be kept, i.e. $\frac{F_\times^N}{F_+^N} \approx 1$. This means that the gravity detector network will be sensitive to both gravity wave polarizations. It follows that a minimum difference of $|F_\times^N - F_+^N|$ should be sought for all $(\alpha; \delta)$. This leads to the quantitative formulation of the polarization criterion *I* [1]:

$$I = \left(\frac{1}{4\pi} \oiint |F_+^N(\alpha; \delta) - F_\times^N(\alpha; \delta)|^2 d\Omega\right)^{-1/2},$$

where averaging of $|F_{\times}^N - F_{+}^N|$ over celestial sphere takes place ($d\Omega$ is solid angle).

Localization criterion D. Criterion D characterizes the ability of a network to define angular position of a source. In astrometry the problem of a source localization on celestial sphere of a radiation source is solved by a method of triangulation.

Triangulation is based on the difference in time between the registration of signals by network detectors. The further apart the detectors are, the greater the time delay is. To maximize the source location accuracy on the celestial sphere, the telescopes should be placed as far apart from each other as possible. According to Ref. [1], for a network of four detectors D is calculated as the area of the triangle formed by the three detectors in the network, which has the largest area among all possible combinations. If O is the center of the Earth, A, B, C are points where the detectors are located, the area of the corresponding triangle:

$$S_{ABC} = 1/2\left|[\vec{AC},\vec{AB}]\right| = 1/2\left|[\vec{OC}-\vec{OA};\vec{OB}-\vec{OA}]\right|.$$

Parameters reconstruction criterion R. Criterion R characterizes the possibility of reconstruction the parameters of the signal of a known analytical form. According to the Maximum likelihood estimation in the additive Gaussian noise background model, the parameters of the received signal are evaluated by the Rao-Cramer bound. The best possible estimates are obtained using the Fisher information matrix $\Gamma_{\alpha\beta}$ [14] in accordance with the formula

$$\Gamma_{\alpha\beta} = Re\left\{4\int_{f_{min}}^{f_{max}} \frac{\partial_\alpha \bar{\tilde{h}}(f)\,\partial_\beta \tilde{h}(f)}{S_n(f)}df\right\},$$

where $\tilde{h}(f)$ is the Fourier image of response of the detector, the line above the Fourier image of response represents the complex conjugate, and $S_n(f)$ is the spectral noise density of a single detector. In this paper we assume for simplicity that all detectors have the same noise properties presented in [14].

Rao-Cramer bound determines the best possible accuracy of parameter$P$ estimation [14]:

$$\delta P^2 = (\Gamma_N^{-1})_{PP},$$

where $\Gamma_N = \sum_{i=1}^{N}\Gamma_i$, i. e. the Fisher information matrix for detector network, is the sum of the corresponding detector matrices constituting the network. The inverse value of the celestial-averaged relative error is a numerical expression of criterion R:

$$R = \left(\frac{1}{4\pi}\oiint\left(\frac{\delta P}{P}\right)^2 d\Omega\right)^{-1/2} =< \frac{\delta P}{P}^{-1} >.$$

Maximization of criterion R leads to the minimum relative error averaged over the celestial sphere in the estimation of the parameter.

IIntegral criterion C. ntegral criterion C is used to compare different configurations of a network:

$$C = \sqrt{\left(\frac{I}{I_{max}}\right)^2 + \left(\frac{D}{D_{max}}\right)^2 + \left(\frac{R}{R_{max}}\right)^2}.$$

Maximization of C by orientation angle of the detector in Novosibirsk gives the optimal orientation angle and leads to values $I(\gamma_{Nsk}^{max}) = I_{max}, D(\gamma_{Nsk}^{max}) = D_{max}$, and $R(\gamma_{Nsk}^{max}) = R_{max}$.

Sources

Binary inspiral. As a first typical source of gravitational radiation, we consider inspiral of a relativistic binary. For our purposes a rather simplified Newtonian form of gravitational chirp signal, which does not take into account post-Newtonian corrections is sufficient [16]:

$$h(t) = \frac{4}{d_L}\sqrt{F_+^2 + F_\times^2}\frac{G^{5/3}}{c^4}\mathcal{M}^{5/3}(\pi f)^{2/3}cos(\Phi + \Psi),$$

where $\mathcal{M}$ is the chirp mass of a system, d_L is the distance to the source, Φ is the phase,f is the frequency, Ψ is the initial phase.

Collapsing star. As a second source of gravitational radiation, we consider a core-collapse supernovae. During the core-collapse there exist many mechanisms of GW radiation on different stages of the process [17]. As Fisher matrix approach requires analytical form of the signal we have considered GW from long-lived rotational instabilities of a proto-neutron star. If the key result of this instabilities is bar deformation that the radiation can be simulated by radiation from a rotating cylinder (axis of rotation is a bisector of the cylinder axis) with a Gaussian exponent which is introduced phenomenologically to take into account finiteness of the signal:

$$h(t) = \sqrt{F_+^2 + F_\times^2}\frac{GM\omega^2L^2}{3c^4r}(1 - 3\varepsilon^2)e^{-\frac{4(t-t_0)^2}{t_0^2}}cos(2\omega t + \phi), \phi = \pi + \tan^{-1}\frac{F_+}{F_\times},$$

where G is Newtonian constant of gravitation, c is speed of light, M is mass of the source, L is length of the cylinder, R is radius of the cylinder, ω is source angular frequency, t_0 is characteristic signal length and parameter $\varepsilon = \frac{R}{L}$ characterizes the degree of deformation and is used for calculation of criterion R. Gravitational radiation carries away energy from the system so ω decreases over time. Typical values of source parameters [17] are $\omega =$ $= 2\pi \times 700 rad/s, L = 20km, R = 5km, M = M_\odot$ and $t_0 = 1$ sec and we use Einstein's formula [18] for calculation of GW luminosity (we consider ω to be constant).

Numerical results

To define the optimal orientation angle of possible Novosibirsk detector for the to sources in question we maximize the integral criterion C.

We have chosen the following typical values for the first source parameters: a binary neutron star with masses of $1.4M_\odot$, without spins, located at a distance of $1Gpc$ from the Earth and with an orbital plane perpendicular to the line-of-sight. The results of numerical integration are presented in Fig. 1. Criterion D in our approximation does not depend on the orientation angle of the detector in Novosibirsk. The most sensitive to changes in orientation angle is criterion I . The maximum value of integral criterion C is achieved at $\gamma_{Nsk}^{max} = 13°$.

In the case of gravitational collapse, the strain $h(t)$ is expected to be several orders of magnitude less than for binary coalescence ($h \sim 10^{-22} - 10^{-20}$ at 10 kpc) so we cannot assume isotropic distribution of sources over the celestial sphere. Instead, we integrate over the Milky Way disk (neglecting the fact that the sensitivity may be sufficient for detection of the signal from several nearby galaxies). Due to rotation of the Earth antenna pattern functions depend on time, thus we average functions of time over 24 hours which also makes analytical calculation of Fourier image $\tilde{h}(f)$ possible.

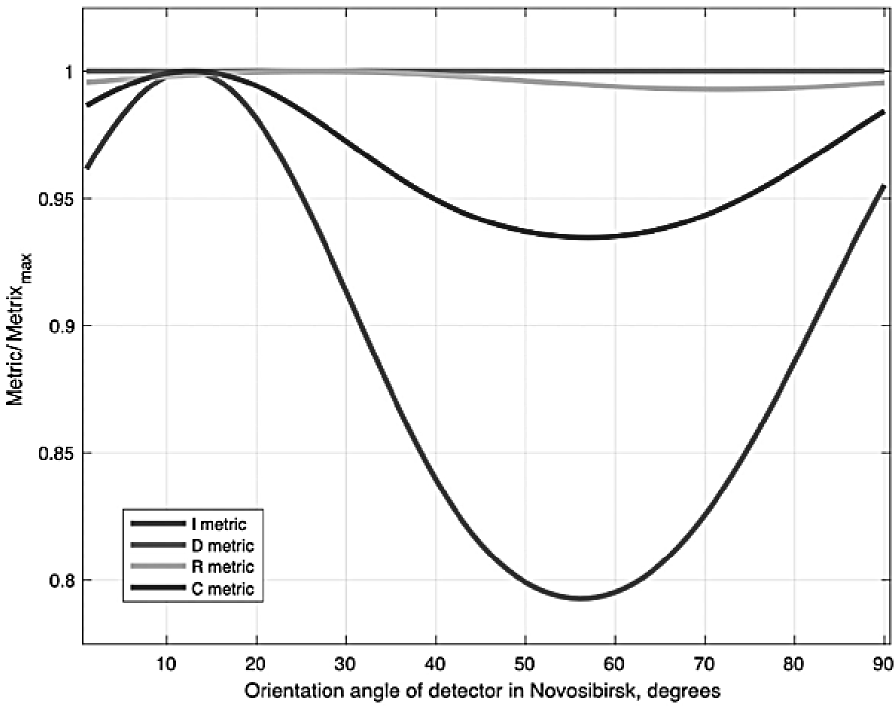

Fig. 1. Dependence of all criteria on orientation angle of detector in Novosibirsk for binary inspiral

The parameters of a source are those ones from Section *Collapsing star*.

The calculation results are shown in Fig. 2. Again I is again the most sensitive criterion to changes of orientation angle. The maximum value of integral criterion C is achieved at $\gamma_{Nsk}^{max} = 40°$.

The final choice of the orientation depends on the most topical problems at the time of the detector construction in Novosibirsk. To conclude, we notice that the choice of the source is a limitation of this work, because more significant physics is encrypted in a more complex structure of the signal from the core collapse, but such signals are model-dependent and do not have an analytical form (e.g. [19]), which does not allow using them within the framework of this approach.

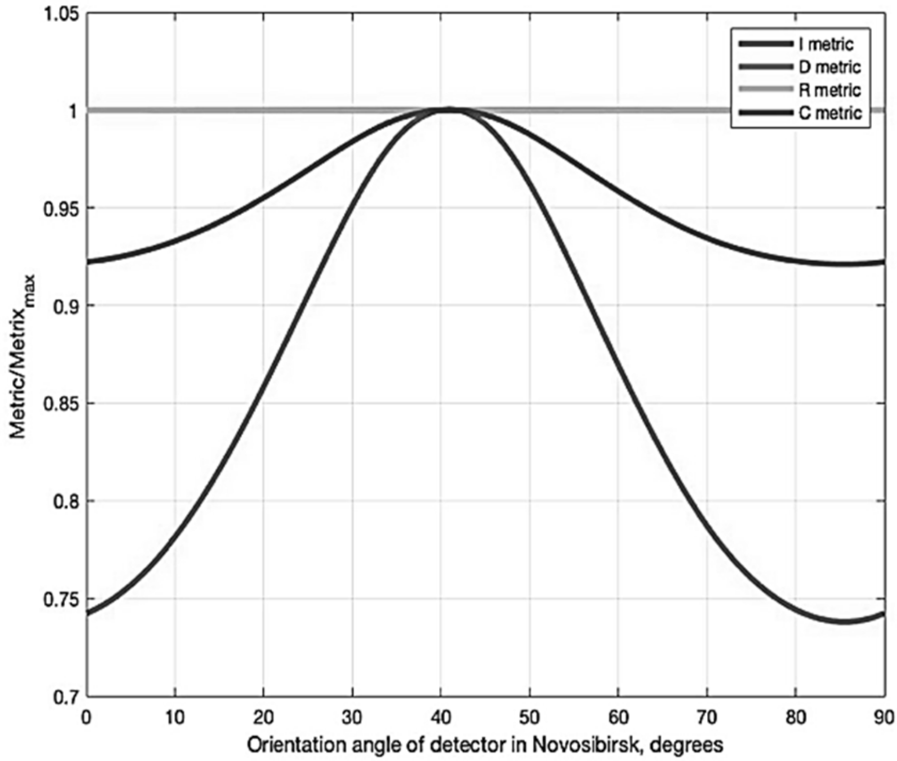

Fig. 2. Dependence of all criteria on orientation angle of detector in Novosibirsk for gravitational collapse

Conclusions

The obtained result shows that in one specific network it is impossible to indicate the orientation of the interferometer in Novosibirsk, which would be optimal both for GW signals from the coalescence of relativistic binaries and for signals from collapses. This is despite the fact that the collapse model with the stage of rotating cylindrical bar instability is closest to the picture of a merging binaries at the inspiral stage. At the moment, it is possible to recommend the choice of an averaged orientation with an appropriate estimate of the loss in the accuracy of estimating the parameters of the received signals.

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УДК 51.76

Моделирование передачи вирусной инфекции в небольшой группе людей

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Приведены результаты численного моделирования нестационарных эффектов при распространении вирусной инфекции в небольшой группе людей. Рассмотрен случай распространения вирусной инфекции воздушно-капельным путем. Показано, что колебания концентрации вирионов в атмосфере приводят к качественному изменению роста вирионов по сравнению с детерминированной ситуацией. Основная цель настоящей статьи — проиллюстрировать качественно новые эффекты, возникающие в нелинейных системах в случайной среде.

Ключевые слова: *вирусная инфекция, концентрация вируса, стохастические дифференциальные уравнения, случайный гауссовский процесс, случайная флуктуация, метод Лагранжа, алгоритм Эйлера — Маруямы*

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Simulation of Viral infection Transmission in a Small Group of People

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The paper is devoted to the results of numerical modelling of non-stationary effects during the spread of a viral infection in a small group of people. The case of a viral infection spread by airborne droplets is considered. It is shown that fluctuations in the concentration of virions in the atmosphere lead to a qualitative change in the growth of virions compared to the deterministic situation. The main purpose of our work is to illustrate qualitatively new effects that occur in nonlinear systems in a random environment.

Keywords: *viral infection, concentration of virus, stochastic differential equations, random Gaussian process, random fluctuation, Lagrange approach, Euler — Maruyama algorithm*

Inroduction

Many viral diseases that lead to the development of massive epidemics are transmitted by airborne droplets. As an example, we will point to Covid-19 [1], which has affected most of the world's population, and African swine fever, which poses a threat to pig farming in entire countries [2]. As a result of accidental contacts of individuals, some of whom may be infected with the virus, the concentration of the virus in the atmosphere changes. The variation of virion concentration near the isolated individual is a random process. The diffusion of virions from the atmosphere into the body and the transfer of blood flow to organs, where there is an active increase in the concentration of pathogens, are the initial stages of infection. An active increase in the concentration of virions in organs can lead to serious damage to the body and the death of an individual. The immune response attenuates the degree of infection. The paper proposes a qualitative mathematical model that takes into account the transfer and increase in the concentration of pathogenic cells when the concentration of virions in the atmosphere near an individual changes randomly. The method of direct numerical modeling is used, based on the solution of stochastic ordinary differential equations system (SODE) [3], describing both random fluctuations in the concentration in the atmosphere and the dynamics of the pathogens concentration growth in the body. It is shown that the dynamics of pathogen replication in the body with deterministic and random virion concentrations in the atmosphere are qualitatively different [4].

Main equations

The dynamics of virion concentration taking into account the immune response and the transfer of virions from the atmosphere to the affected organs is modeled as follows

$$\frac{dX}{dt} = \left[\alpha X\left(\frac{X}{X_{cr} + \gamma X} - 1\right) + \frac{X_{atm}}{T_{\mathrm{in}}}\right]\left(1 - \frac{X}{X_{\max}}\right), \quad X(0) = X_0.$$

Here X_{cr} is critical concentration; α is rate of cells degradation; $X_{\max}$ is the limiting concentration, the achievement of which leads to the death of an individual, $X_{\max} \gg X_{cr}$; γ is degree of immune response, $0 \le \gamma \le 1$; X_{atm} is virion concentration in atmosphere; T_{in} is the characteristic time of virions transportation in the body to the area of their intensive reproduction.

We reduce the equation to a dimensionless form

$$X^* = \frac{X}{X_{cr}}, X^*_{\max} = \frac{X_{\max}}{X_{cr}}, t^* = \alpha t, X^*_{atm} = X_{atm}/X_{cr}, T^*_{in} = \alpha T_{in}$$

$$\frac{dX^*}{dt^*} = \left[X^*\left(\frac{X^*}{1+\gamma X^*} - 1\right) + \frac{X^*_{atm}}{T^*_{in}}\right]\left(1 - \frac{X^*}{X^*_{\max}}\right), \quad X^*(0) = X^*_0. \tag{1}$$

Equation (1) has an analytical solution that allows us to qualitatively investigate the influence of parameters on the dynamics of pathogenic virus concentration growth in the organs and virus intensive replication. Fig. 1, *a* shows the dynamics of virion concentration with the direct introduction of the initial mass of pathogens into the body. In the absence of an immune response

In the case of a constant concentration of virions in the atmosphere below a certain critical level, a stable concentration of the pathogen is established in the body (Fig. 1, *b*). Exceeding the critical level in the atmosphere leads to a monotonous increase in the concentration of virions. This trend persists in the case of a high degree of immunity.

Results of calculating the random concentration of virions in the atmosphere

For a random concentration of virions in the atmosphere, equation (1) takes the form

$$\frac{dX^*}{dt^*} = \left[X^*\left(\frac{X^*}{1+\gamma X^*} - 1\right) + \frac{\langle X^*_{atm}\rangle + x^*_{atm}}{T^*_{in}}\right]\left(1 - \frac{X^*}{X^*_{\max}}\right), \quad \langle x^*_{atm}\rangle = 0. \tag{2}$$

Here $\langle X^*_{atm} \rangle$ is the average value of virion concentration in the atmosphere; x^*_{atm} is fluctuations in concentration; $\langle \cdots \rangle$ angle brackets denote the result of averaging over an ensemble of random realizations.

Random fluctuations of concentration in the atmosphere are modeled as a random Gaussian process, the implementation of which is the solution of an equation of the form

$$\frac{dx^*_{atm}}{dt} = \frac{1}{T^*_{atm}} (\eta^*_{atm} - x^*_{atm}), \tag{3}$$

where T^*_{atm} is integral time scale of concentration fluctuations in the atmosphere; η^*_{atm} is a source of fluctuations modeled by a random Gaussian process with delta-time correlation (white noise)

$$\langle \eta^*_{atm}(t^{*\prime}) \eta^*_{atm}(t^{*\prime\prime}) \rangle = \langle \eta^{*2}_{atm} \rangle \delta \left(t^{*\prime\prime} - t^{*\prime} \right).$$

Here $\langle \eta^{*2}_{atm} \rangle$ is dispersion of source fluctuations; $\delta(t)$ is Dirac delta function.

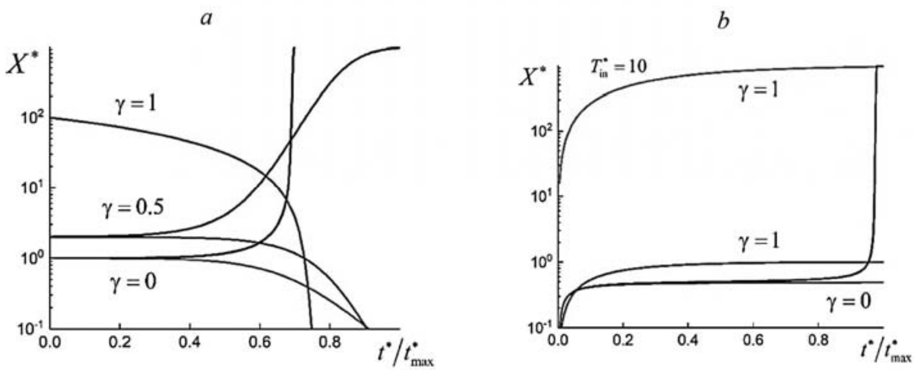

Fig. 1. Dynamics of the pathogens concentration in the body:
a — at zero concentration in the atmosphere and a given concentration in the body;
b — at zero concentration in the body and a given constant concentration of virions in the atmosphere

Note that the concentration fluctuations described by equation (3) have an exponentially decreasing autocorrelation function.

The SODE system (2) and (3) are integrated numerically based on the Euler — Maruyama algorithm.

Fig. 2 illustrates the effect of virion concentration fluctuations in the atmosphere on the explosive growth of the pathogen in an infected organism. The presented random implementations show a qualitative difference in the development of infection in a deterministic case and a random atmosphere. In the deterministic case, when the average concentration of virions in the atmosphere is below the critical level, the explosive development of infection will not occur. However, with the same average concentration value, the presence of fluctuations in the pathogen concerntations in the atmosphere will inevitably lead to an explosive increase in the concentration of pathogenic cells in the body. Thus, the average concentration cannot serve as an unambiguous criterion for the stable course of the disease. Without an immune response (Fig. 2, *a*) the delay time of explosive growth is noticeably less than taking into account immunity (Fig. 2, *b*).

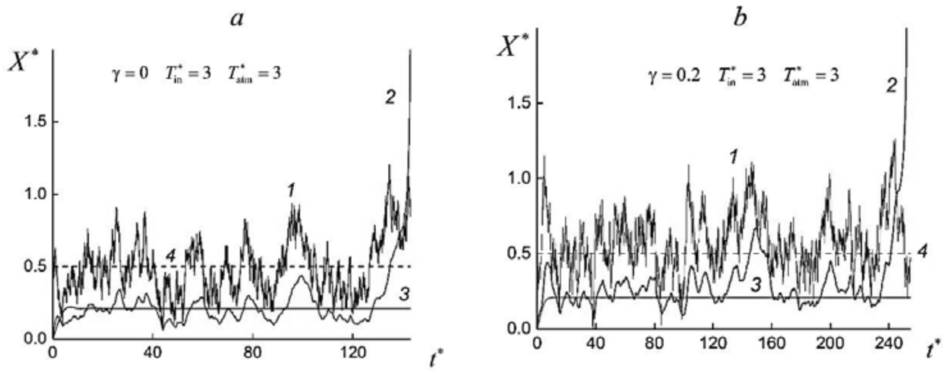

Fig. 2. An increase in the concentration of pathogenic microorganisms in an infected organism in the presence of fluctuations in the virus concentration in the atmosphere: *a* — without an immune response; *b* — considering immunity

Fig. 3 shows the effect of atmospheric concentration fluctuations when the average atmospheric concentration level exceeds the critical value. In this deterministic case, an explosive increase in the pathogens concentration in the body is realized. At the same time, fluctuations in concentration can lead to a delay in the explosion compared to the deterministic case (Fig. 3, *a*). Note that a random trajectory of concentration growth is presented. In most implementations, taking into account fluctuations in concentration, an earlier explosive growth of pathogens is observed compared to the case of a constant concentration (Fig. 3, *b*).

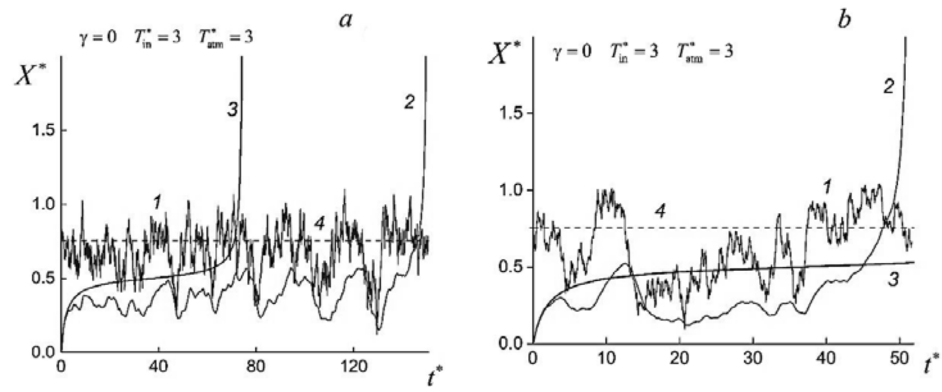

Fig. 3. Illustration of pathogen growth in an infected organism at a constant virion concentration in the atmosphere above a critical level: *a* — increasing the delay time of explosive growth; *b* — reducing the start time of explosive growth

Conclusions

The paper presents the results of numerical simulation of pathogenic cells concentration growth in an infected organism in the atmosphere with a randomly varying concentration of virions in the atmosphere near an isolated individual. The study was implemented within the framework of the Lagrange approach, in which an ensemble of random virion concentrations in the body of a selected individual is modeled. Fluctuations in the concentration of virions in the atmosphere are caused by accidental contacts of individuals as a result of their chaotic movement.

It is shown that fluctuations in the concentration of virions in the atmosphere lead to a qualitative change in the growth of virions compared to the deterministic situation. Random trajectories cross the critical level of critical concentration, even if in the deterministic case of explosive growth of pathogens in the body is not observed.

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УДК 533:519.6

Сравнительный анализ результатов газодинамических расчетов валидационной задачи с применением российского и зарубежного комплексов вычислительной гидродинамики

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При расчете различных процессов гидрогазодинамики с использованием кодов вычислительной гидродинамики необходимо определить область применения различных моделей турбулентности. Приведены расчеты в российском программном комплексе и в ANSYS Fluent при теплообмене газа с плоской пластиной для различных моделей турбулентности с использования функций стенок, а также без их учета. Показано, что в результатах, полученных для различных численных моделей турбулентности, имеются расхождения. Все результаты в разной степени отличаются от известных экспериментальных данных в аналогичной задаче. В качестве критерия при сравнительном анализе использовалось число Нуссельта. Приведены результаты расчета и максимальные погрешности.

Ключевые слова: *код вычислительной гидродинамики, модели турбулентности, функции стенок, теплообмен с плоской пластиной, валидация, российский код вычислительной гидродинамики*

Comparative Analysis of Fluid-Dynamic Calculations of the Validation Problem Using Russian and Foreign Computational Fluid Dynamics Codes

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When calculating various fluid dynamics processes using computational fluid dynamics codes, it is necessary to determine the scope of different turbulence models. Calculations in the Russian software package and in ANSYS Fluent at gas heat exchange with a flat plate for different turbulence models with the use of wall functions as well as without taking them into account are given. It is shown that there are discrepancies in the results obtained for different numerical models of turbulence. All the results differ in different degrees from the *known experimental data in a similar problem. Nusselt number was used as a criterion for comparative analysis. Calculation results and maximum errors are given.*

Keywords: *computational fluid dynamics, turbulence models, wall functions, forced convection over a flat plate, validation, Russian computational fluid dynamics codes*

Intoroduction

As part of the import substitution policy, the issue of replacing foreign software systems with Russian software is relevant. When introducing a new CFD (Computation Fluid Dynamics) complex into the calculation practice, it is necessary to determine the errors of the calculation results and the degree of their reliability for a number of typical validation problems. ANSYS Fluent R2 2021 was adopted as a reference foreign CFD complex, which is widely used in the international market and in Russia.

In this paper, the authors examine a typical problem of forced convection of a flat plate by fluid.

When solving the problem in Russian software, the following three turbulence models were chosen for analysis [2–4]:

- k-Omega SST (Shear Stress Transport);
- k-Omega BSL (Baseline);
- EARSM (Explicit Algebraic Reynolds Stress Model).

When solving the problem numerically in ANSYS Fluent, the following seven turbulence models were used to compare the results with [5–13]:

- k-epsilon Standart;
- k-epsilon RNG;
- k -epsilon Realizable;
- k -omega Standart;
- k -omega BSL;
- k -omega SST
- RSM* (* — this model is based on k-epsilon, k-omega BSL, k-omega SST models).

In the comparative analysis of the results obtained, the differences in the accepted wall functions for the viscous sub-layer, logarithmic profile, and the universal wall functions (taking into account the buffer zone) were considered.

Problem formulation

To solve the problem of forced convection of a flat plate by fluid the following assumptions were made:

- fluid flow is turbulent from the edge of the plate (x = 0 m), the length of the laminar zone and the laminar-turbulent transition is negligible;
- Archimedean forces are negligible;
- the fluid is incompressible, the ideal fluid law is used;
- the problem is solved in 2D.

A comparative analysis of the calculation results was carried out at Reynolds numbers ranging from 0.5×10^6 to 1.5×10^6.

Fig. 1 shows the problem formulation, whereU_∞ = 1 m/s is free stream velocity; T_p = 413 K is plate temperature; L = 1 m is plate length.

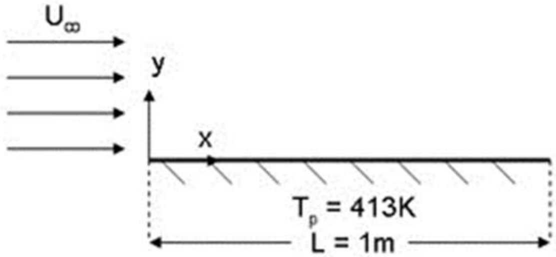


Fig. 1. Problem formulation

For the problem we use the following thermophysical properties of the incoming medium:

Dynamic viscosity, kg/(m×s) .... $6.667e^{-7}$
Thermal conductivity, W/(m×K) .... $.9.4505e^{-4}$
Specific heat capacity at constant pressure, J/(kg×K) 1006.43
Free stream temperature of the fluid, K 353
Free stream pressure, Pa 101 325

To recalculate the obtained results and compare them with experimental data, the following dependence of the Nusselt number on the heat transfer coefficient is used

$$Nu_{CFD} = \frac{\alpha \cdot x}{\lambda};$$

$$\alpha = \frac{q}{T_p - T_\infty};$$

$$Nu_x = 0.0285 Re_x^{0,8} Pr^{0,4}. \quad (1)$$

Here Nu_{CFD} is Nusselt number (dependent on x-coordinate) calculated using CFD; αis heat transfer coefficient calculated using CFD, $W/m^2 \times K$; x is plate length coordinate, m; λ is thermal conductivity coefficient, W/(m×K); where q is heat flux density between the wall and the flow, calculated using CFD, W/m^2; T_∞ is free stream temperature of the fluid, K; where Nu_x is experimental Nusselt number; Re_x is Reynolds number from plate length; Pr*is* Prandtl number.

For comparative analysis, the calculated values of the Nusselt number are used as theoretical data. The calculated values of the Nusselt number were obtained using the formula (1), which is a generalization of the experimental data [1].

Computational fluid dynamics codes

A feature of the Russian software package is the presence of separated and coupled solver types, as well as a large selection of wall functions. This paper considers a separated solver and its wall functions (Table 1).

Table 2 shows the used turbulence models and their wall functions from ANSYS Fluent 2021 R2.

Table 1

Turbulence models and wall functions of the Russian software package

Turbulencemodel	Solver	Wall functions
k-Omega, SST [2]	Separated (Single)	High-Re Low-Re All-Re All-Re (Smirnov) All-Re (Smirnov, Rotation)*
k-Omega, BSL [3]		
EARSM [4]		

*The All-Re (Smirnov, Rotation) wall function is not tested in this work due to the problem statement.

Table 2

Turbulence models and wall functions in ANSYS Fluent analyzed in the paper

Turbulencemodel	Type of turbulence model	Solver	Wall functions / Additional turbulence model options
k-epsilon	Standart [5]	Separated (PISO)	Standard Wall Functions Scalable Wall Functions Non-Equilibrium Wall Functions EWT-e ML-e
	RNG [6]		
	Realizable [7]		
k-omega	Standart [8]		Without Low-Re Corrections With enabled Low-Re Corrections
	BSL [9]		
	SST [9]		
RSM* [10–13]	Linear Pressure-Strain		Linear (Standard; Scalable; Non-Equilibrium; Enhanced) Quadratic (Standard; Scalable; Non-Equilibrium) K-omega (Without Low-Re Corrections; With enabled Low-Re Corrections) BSL
	Quadratic Pressure-Strain		
	Stress-Omega		
	Stress-BSL		

*The RSM turbulence model is based on other turbulence models therefore it can use all the given wall functions [10].

Mesh convergence was carried out along the x-axis; in the normal direction, the mesh division was determined by the near-wall function and the required value of $y+$. The same mesh files were used for calculations in two different software. For universal near-wall functions, the study was carried out for three zones $y+$ ($y+ < 5$; $5 < y+ < 30$; $30 < y+ < 200$).

The relative error in the calculation of the Nusselt number relative to the values taken as theoretical (1) is calculated using the following formula:

$$\Delta(x) = \left(\frac{Nu_x - Nu_{CFD}}{Nu_x}\right) 100\%.$$

Fig. 2 shows the calculated values of the Nusselt number in the studied range of the Reynolds number for various models of turbulence and wall functions for the Russian software package (*a*)–(*c*) and the relative calculation errors (*d*)–(*f*).

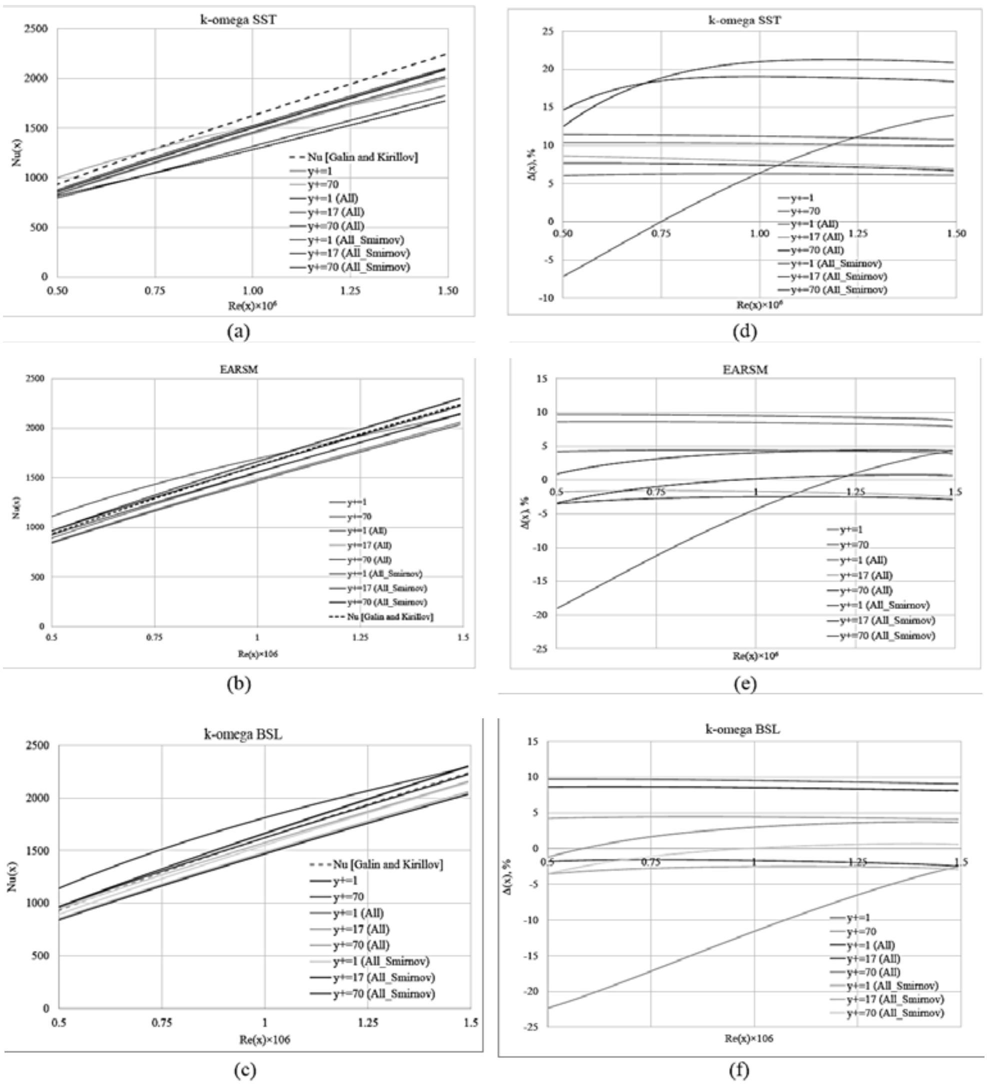
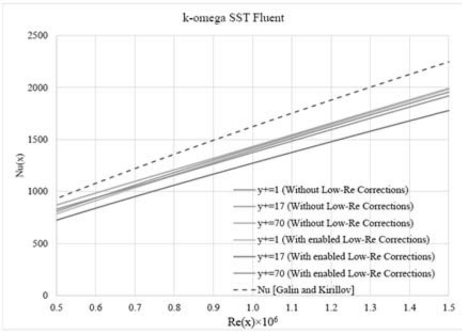


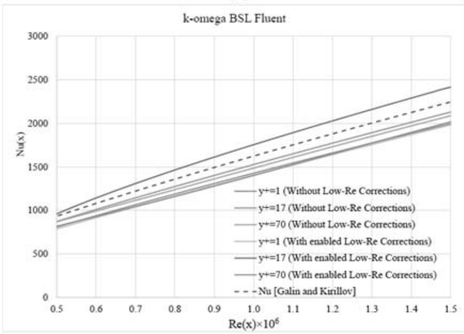
Fig. 2. Calculated values of the Nusselt number in the studied range of the Reynolds number for various models of turbulence and wall functions for the Russian software package (*a*)–(*c*) and relative calculation errors (*d*)–(*f*)

The calculated values of the Nusselt number in the studied range of the Reynolds number for various models of turbulence and wall functions for ANSYS Fluent (*a*)–(*g*) and the relative calculation errors (*h*)–(*n*) are shown in Fig. 3.

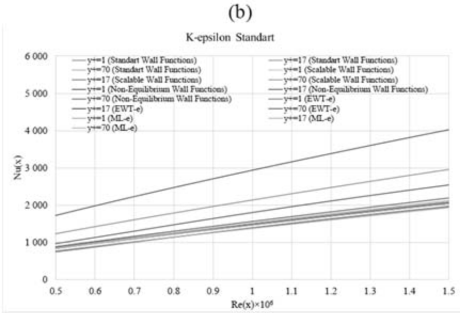
Table 3 shows the maximum relative deviations of the calculated values of the Nusselt number relative to the theoretical ones (1) for the Russian CFD complex (Table 3) and ANSYS Fluent 2021 R2 (Table 4).


k-omega SST Fluent
Nu(x)
Re(x)×10⁶
y+=1 (Without Low-Re Corrections)
y+=17 (Without Low-Re Corrections)
y+=70 (Without Low-Re Corrections)
y+=1 (With enabled Low-Re Corrections)
y+=17 (With enabled Low-Re Corrections)
y+=70 (With enabled Low-Re Corrections)
Nu [Galin and Kirillov]

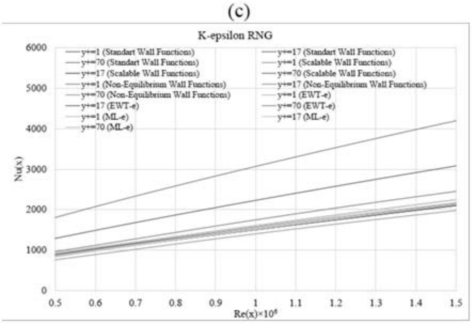
(a)


k-omega BSL Fluent
Nu(x)
Re(x)×10⁶
y+=1 (Without Low-Re Corrections)
y+=17 (Without Low-Re Corrections)
y+=70 (Without Low-Re Corrections)
y+=1 (With enabled Low-Re Corrections)
y+=17 (With enabled Low-Re Corrections)
y+=70 (With enabled Low-Re Corrections)
Nu [Galin and Kirillov]

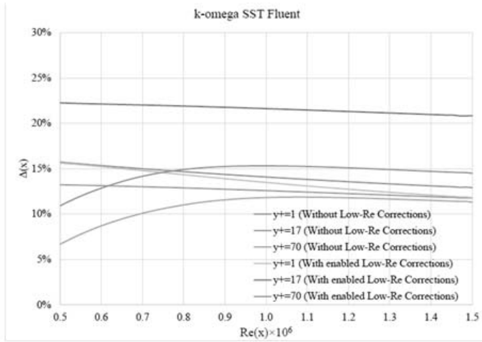
(b)


K-epsilon Standart
Nu(x)
Re(x)×10⁶
y+=1 (Standart Wall Functions)
y+=17 (Standart Wall Functions)
y+=70 (Standart Wall Functions)
y+=1 (Scalable Wall Functions)
y+=17 (Scalable Wall Functions)
y+=70 (Scalable Wall Functions)
y+=1 (Non-Equilibrium Wall Functions)
y+=17 (Non-Equilibrium Wall Functions)
y+=70 (Non-Equilibrium Wall Functions)
y+=1 (EWT-e)
y+=17 (EWT-e)
y+=70 (EWT-e)
y+=1 (ML-e)
y+=17 (ML-e)
y+=70 (ML-e)

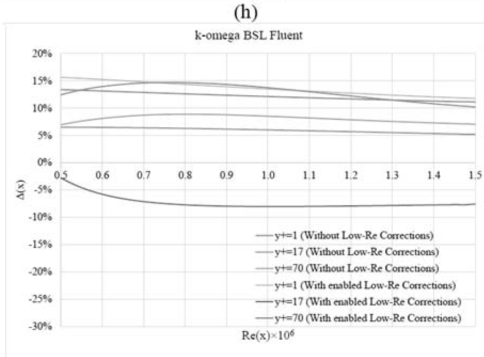
(c)


K-epsilon RNG
Nu(x)
Re(x)×10⁶
y+=1 (Standart Wall Functions)
y+=17 (Standart Wall Functions)
y+=70 (Standart Wall Functions)
y+=1 (Scalable Wall Functions)
y+=17 (Scalable Wall Functions)
y+=70 (Scalable Wall Functions)
y+=1 (Non-Equilibrium Wall Functions)
y+=17 (Non-Equilibrium Wall Functions)
y+=70 (Non-Equilibrium Wall Functions)
y+=1 (EWT-e)
y+=17 (EWT-e)
y+=70 (EWT-e)
y+=1 (ML-e)
y+=17 (ML-e)
y+=70 (ML-e)

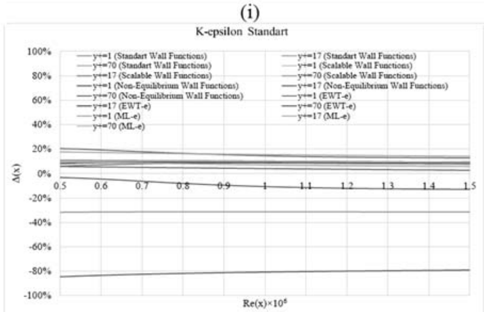
(d)


k-omega SST Fluent
Δ(x)
Re(x)×10⁶
y+=1 (Without Low-Re Corrections)
y+=17 (Without Low-Re Corrections)
y+=70 (Without Low-Re Corrections)
y+=1 (With enabled Low-Re Corrections)
y+=17 (With enabled Low-Re Corrections)
y+=70 (With enabled Low-Re Corrections)

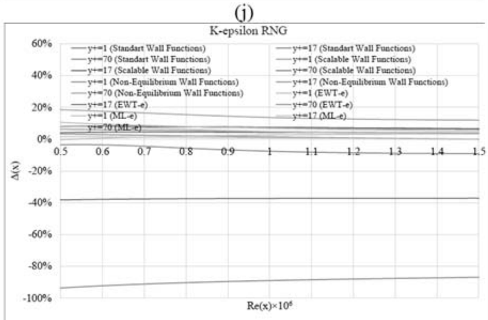
(h)


k-omega BSL Fluent
Δ(x)
Re(x)×10⁶
y+=1 (Without Low-Re Corrections)
y+=17 (Without Low-Re Corrections)
y+=70 (Without Low-Re Corrections)
y+=1 (With enabled Low-Re Corrections)
y+=17 (With enabled Low-Re Corrections)
y+=70 (With enabled Low-Re Corrections)

(i)


K-epsilon Standart
Δ(x)
Re(x)×10⁶
y+=1 (Standart Wall Functions)
y+=17 (Standart Wall Functions)
y+=70 (Standart Wall Functions)
y+=1 (Scalable Wall Functions)
y+=17 (Scalable Wall Functions)
y+=70 (Scalable Wall Functions)
y+=1 (Non-Equilibrium Wall Functions)
y+=17 (Non-Equilibrium Wall Functions)
y+=70 (Non-Equilibrium Wall Functions)
y+=1 (EWT-e)
y+=17 (EWT-e)
y+=70 (EWT-e)
y+=1 (ML-e)
y+=17 (ML-e)
y+=70 (ML-e)

(j)


K-epsilon RNG
Δ(x)
Re(x)×10⁶
y+=1 (Standart Wall Functions)
y+=17 (Standart Wall Functions)
y+=70 (Standart Wall Functions)
y+=1 (Scalable Wall Functions)
y+=17 (Scalable Wall Functions)
y+=70 (Scalable Wall Functions)
y+=1 (Non-Equilibrium Wall Functions)
y+=17 (Non-Equilibrium Wall Functions)
y+=70 (Non-Equilibrium Wall Functions)
y+=1 (EWT-e)
y+=17 (EWT-e)
y+=70 (EWT-e)
y+=1 (ML-e)
y+=17 (ML-e)
y+=70 (ML-e)

(k)

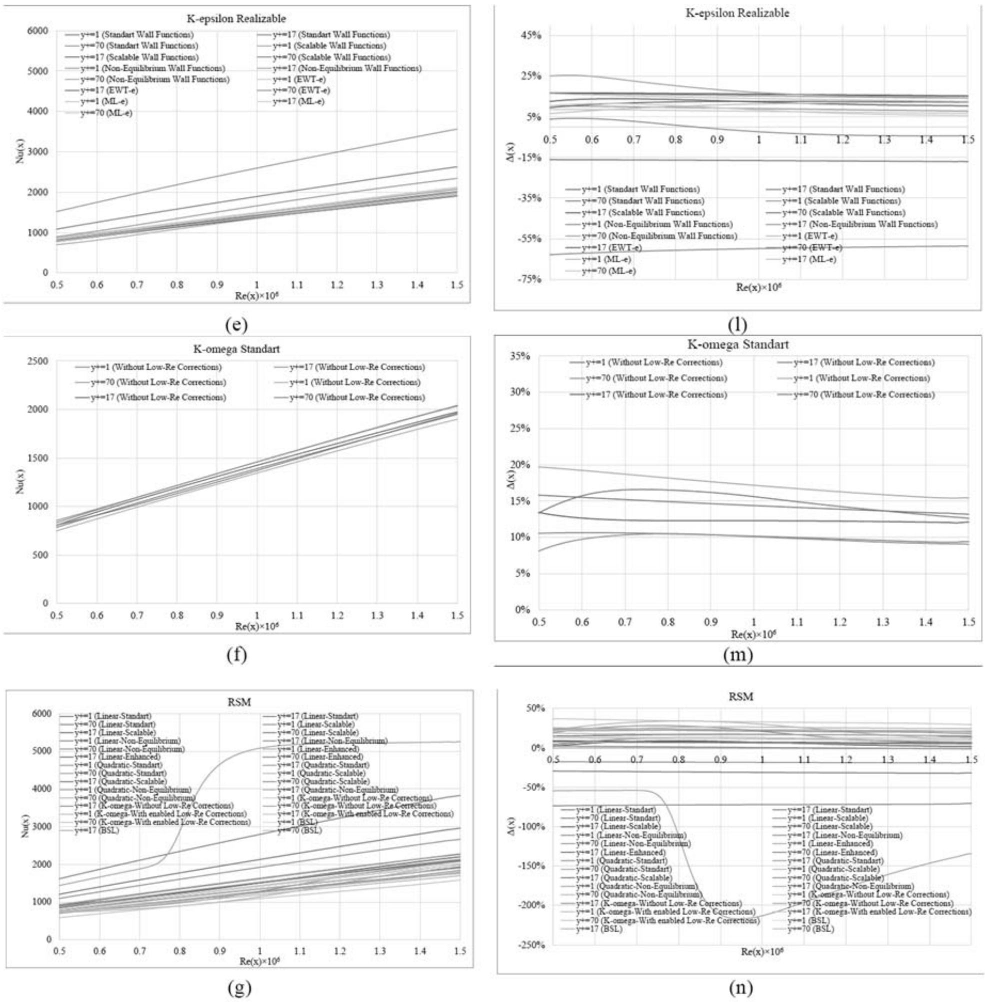


Fig. 3. Calculated values of the Nusselt number in the studied range of Reynolds number for various models of turbulence and wall functions for ANSYS Fluent (*a*)–(*g*) and relative calculation errors (*h*)–(*n*)

Table 3

Russian Computational Fluid Dynamics complex validation results

No.	Settings			Maximum relative error, %
	Turbulence model	Wall function	*y*+	[1]
1	k-omega SST	Low-Re	1	11.4
2		High-Re	70	14.0
3		All	1	10.4
4			17	8.6
5			70	21.3

End of tabs 3

No.	Settings			Maximum relative error, %
	Turbulence model	Wall function	$y+$	[1]
6	k-omega SST	All Smirnov	1	6.3
7			17	7.7
8			70	19.0
9	EARSM	Low-Re	1	9.7
10		High-Re	70	19.0
11		All	1	8.6
12			17	2.5
13			70	4.4
14		All Smirnov	1	4.4
15			17	3.5
16			70	3.4
17	k-omega BSL	Low-Re	1	9.7
18		High-Re	70	22.3
19		All	1	8.6
20			17	2.5
21			70	3.7
22		All Smirnov	1	4.4
23			17	3.6
24			70	3.5

Table 4

ANSYS Fluent validation results

No.	Settings			Maximum relative error, %
	Turbulence model	Wall function / Additional turbulence model options	$y+$	[1]
1	k-epsilon Standard	Standard Wall Functions	1	31.7
2			17	10.7
3			70	9.7
4		Scalable Wall Functions	1	8.8
5			17	10.7
6			70	9.7
7		Non-Equilibrium Wall Functions	1	84.4
8			17	5.6
9			70	20.2
10		EWT-e	1	9.4
11			17	9.0
12			70	13.1

Continuation of tabs 4

No.	Settings			Maximum relative error, %
	Turbulence model	Wall function / Additional turbulence model options	$y+$	[1]
13	k-epsilon Standard	ML-e	1	17.6
14			17	10.3
15			70	9.2
16	k-epsilon RNG	Standard Wall Functions	1	38.2
17			17	8.1
18			70	8.0
19		Scalable Wall Functions	1	6.2
20			17	8.1
21			70	8.0
22		Non-Equilibrium Wall Functions	1	93.5
23			17	3.2
24			70	18.4
25		EWT-e	1	3.2
26			17	4.5
27			70	9.2
28		ML-e	1	10.4
29			17	1.6
30			70	8.1
31	k-epsilon Realizable	Standard Wall Functions	1	17.0
32			17	16.7
33			70	14.0
34		Scalable Wall Functions	1	16.7
35			17	16.7
36			70	14.0
37		Non-Equilibrium Wall Functions	1	62.7
38			17	10.5
39			70	25.6
40		EWT-e	1	12.2
41			17	12.7
42			70	4.3
43		ML-e	1	16.4
44			17	8.7
45			70	11.6
46	k-omega Standard	Without Low-Re Corrections	1	15.8
47			17	10.6
48			70	10.5

Continuation of tabs 4

No.	Settings			Maximum relative error, %
	Turbulence model	**Wall function / Additional turbulence model options**	*y+*	**[1]**
49	k-omega Standard	With enabled Low-Re Corrections	1	19.7
50			17	13.3
51			70	16.6
52	k-omega BSL	Without Low-Re Corrections	1	13.3
53			17	6.5
54			70	8.9
55		With enabled Low-Re Corrections	1	15.6
56			17	8.0
57			70	14.7
58	k-omega SST	Without Low-Re Corrections	1	15.7
59			17	13.2
60			70	11.9
61		With enabled Low-Re Corrections	1	15.6
62			17	22.2
63			70	15.3
64	RSM	Linear-Standart	1	32.2
65			17	8.5
66			70	8.8
67		Linear-Scalable	1	9.1
68			17	8.5
69			70	8.8
70		Linear-Non-Equilibrium	1	73.6
71			17	2.3
72			70	28.2
73		Linear-Enhanced	1	1.7
74			17	16.6
75			70	17.5
76		Quadratic-Standart	1	19.1
77			17	13.6
78			70	13.2
79		Quadratic-Scalable	1	18.3
80			17	13.6
81			70	13.2
82		Quadratic-Non-Equilibrium	1	217.2
83			17	7.0
84			70	33.9

End of tabs 4

No.	Settings			Maximum relative error, %
	Turbulence model	Wall function / Additional turbulence model options	$y+$	[1]
85	RSM	k-omega-Without Low-Re Corrections	1	12.4
86			17	23.7
87			70	23.2
88		k-omega-With enabled Low-Re Corrections	1	24.7
89			17	36.9
90			70	26.7
91		BSL	1	13.9
92			17	25.3
93			70	26.7

As can be seen from Fig. 2, 3 and Tables 3, 4 the most accurate solution in Russian software is achieved using the following settings: EARSM/k-omega BSL; All and $y+ = 17$ (i.e. in the range $5 < y+ < 30$) according to the criterion of relative error between the calculated values of the Nusselt number according to the formula (1) and using a numerical model with the given settings in Russian software. The maximum relative error of the values for these settings are modulo about 2.5 %, respectively.

For the ANSYS Fluent 2021 R2 software package, the k-epsilon RNG turbulence model with the wall function Menter-Lechner (ML-e) and $y+ = 17$ has shown the best results (i.e. in the range $5 < y+ < 30$), the maximum relative error of the values for these settings are modulo about 1.6 %.

Conclusion

Thus, the validation carried out on the example of a typical problem of forced convective heat transfer of a fluid with a flat plate showed excellent convergence on various turbulence models and with different wall functions with respect to the local Nusselt number, obtained experimentally in [1] at Reynolds numbers ranging from 0.5×10^6 to 1.5×10^6. The achieved relative calculation error is about 2.5 %.

A comparative analysis of the results obtained on Russian software and the foreign software package ANSYS Fluent 2021 R2 showed similar values of the relative error, which proves the possibility of using Russian software to solve problems of this type.

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УДК 539.37

Принцип Сен-Венана в задачах нелокальной упругости

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На примере задачи о растяжении вытянутой прямоугольной пластины показано, что для задач нелокальной упругости в плоском напряженном состоянии выполняется принцип Сен-Венана. Проведено сравнение полученных решений с решениями аналогичных задач в классической постановке. Показаны качественные и количественные отличия полученных результатов. Выписаны основные соотношения и кратко описан метод решения задач в нелокальной постановке методом конечных элементов.

Ключевые слова: *нелокальная упругость, принцип Сен-Венана, метод конечных элементов, уравнение равновесия, кромочный эффект*

Информация о гранте

Работа выполнена в рамках государственного задания Министерства науки и высшего образования Российской Федерации (тема № 0705-2020-0032).

Saint-Venant Principle in Problems of Nonlocal Elasticity

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Using the example of the problem of stretching an elongated rectangular plate, it is shown that for problems of nonlocal elasticity in a plane stressed state, the Saint-Venant principle is fulfilled. The solutions obtained are compared with the solutions of similar problems in the classical setting. The qualitative and quantitative differences of the results obtained are shown. The basic relations are written out and the method of solving problems in a nonlocal setting by the finite element method is briefly described.

Keywords: *nonlocal elasticity, Saint-Venant principle, finite element method, equilibrium equation, edge effect*

Introduction

When considering structurally sensitive materials with micro- and nanostructures, it becomes necessary to develop new mathematical models, since classical models do not take into account the scale and edge effects arising in such materials [1].

The paper considers Eringen's nonlocal elasticity model [2], which generalizes the classical Hooke elasticity model. The main advantage of this model is its simplicity, the basic relations remain unchanged, however, the equations take on a more complex integro-differential form. Such a method of spreading the views of classical mechanics of a continuous medium in a medium with a micro- and nanostructure is sometimes called the method of continuous approximation [3]. Due to the continuity of the model, well-studied numerical methods are applicable to it, in particular, the finite element method, which, in relation to problems of this kind, is also called the nonlocal finite element method [4–6]. There are other solution methods based on radial basis functions [7] and the search for solutions in the form of series [8], but we will not consider these methods in this article.

Currently, active work is also underway on models of thermal conductivity of structurally sensitive materials [9–11]. Numerical study of thermal conductivity models [12, 13].

Since the classical elasticity model is a special case of the nonlocal model, it is important to rely on the principles of the classical elasticity theory in the study of the nonlocal model. One of the most important principles of the elasticity classical theory is the Saint-Venant principle, according to which different but statically equivalent loads cause identical stress states in the rod far from the points of application. This phenomenon has not been proven in the general case, but it is confirmed by many theoretical and experimental studies. The aim of this work is to study the stresses arising in a plate when it is stretched by various loads in a nonlocal setting and to compare the results obtained with the results received by using the classical theory of elasticity.

Formulation of the problem

Let us onsider a two-dimensional Euclidean space $\mathbb{R}^2$ with an arbitrarily chosen rectangular Cartesian coordinate system $O\mathrm{x}_1\mathrm{x}_2$, in which the position of each point is fixed by the radius vector $\mathbf{x} = x_i\mathbf{e}_i$, $i = 1,2$, where $\mathbf{e}_i$ are unit vectors of the coordinate axes; x_i are vector components $\mathbf{x}$. In an arbitrary domain $S \subset \mathbb{R}^2$ with a piecewise smooth boundary ∂S the equilibrium equation for a continuous medium has the form

$$\nabla \cdot \hat{\boldsymbol{\sigma}} = \mathbf{b}$$

where $\nabla = \partial/\partial x_i \mathbf{e}_i$, is differential operator nabla; $\mathbf{b} = b_i\mathbf{e}_i$ is body force vector; $\hat{\boldsymbol{\sigma}} = \sigma_{ij}\mathbf{e}_i \otimes \mathbf{e}_j$ is stress tensor, which is defined as follows

$$\hat{\boldsymbol{\sigma}} = p_1 \hat{\mathbf{C}} \cdot\cdot\, \hat{\boldsymbol{\varepsilon}} + p_2 \iint\limits_{S'(\mathbf{x}) \cap S} \varphi\,(|\mathbf{x} - \mathbf{x}'|) \hat{\mathbf{C}} \cdot\cdot\, \hat{\boldsymbol{\varepsilon}} dS'(\mathbf{x}), \quad \mathbf{x}' \in S'(\mathbf{x})$$

where $p_1 > 0$ and $p_2 \geq 0$ are weight fractions of local and nonlocal laws such that $p_1 + p_2 = 1$; φ is nonlocal influence function, some normalized positive function in the domain $S'(\mathbf{x})$; $S'(\mathbf{x})$ is the area of nonlocal influence; $\hat{\boldsymbol{\varepsilon}} = \varepsilon_{ij}\mathbf{e}_i \otimes \mathbf{e}_j$ is tensor of small deformations, the components of which can be determined using the Cauchy relation

$$\varepsilon_{ij} = \frac{1}{2}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right),$$

$\hat{\mathbf{C}} = C_{ijkl}\mathbf{e}_i \otimes \mathbf{e}_j \otimes \mathbf{e}_k \otimes \mathbf{e}_l$ is tensor of elasticity coefficients, the components of which, for the case of a linear elastic isotropic body in a plane stress state, are determined as follows

$$C_{ijkl} = \frac{\nu E}{1 - \nu^2}\delta_{ij}\delta_{kl} + \frac{E}{2(1+\nu)}\left(\delta_{ik}\delta_{jl} + \delta_{il}\delta_{jl}\right)$$

where ν is Poisson's ratio; E is Young's modulus; δ_{ij} is Kronecker's delta.

We will consider the kinematic and force boundary conditions

$$\mathbf{u}\big|_{\Gamma_1} = \mathbf{d}(\mathbf{x}), \quad \hat{\boldsymbol{\sigma}} \cdot \mathbf{n}\big|_{\Gamma_2} = \mathbf{p}(\mathbf{x}),$$

where $\mathbf{u} = u_i\mathbf{e}_i$, $i = \overline{1,2}$ is displacement vector; $\mathbf{d}(\mathbf{x}) = d_i(\mathbf{x})\mathbf{e}_i$ and $\mathbf{p}(\mathbf{x}) = p_i(\mathbf{x})\mathbf{e}_i$ are some functions that define displacement and pressure at the boundaries Γ_1 and Γ_2, respectively; $\Gamma_1, \Gamma_2 \subset \partial S$, $\Gamma_1 \cap \Gamma_2 = \varnothing$.

Numerical solution algorithm

As a numerical method for solving the equilibrium equation we have chosen the finite element method. To do this, in the region S we introduce the mesh of the finite element model S_h. Each element $(e) \in S_h$ contains the sets of nodes $\{\mathbf{x}_i\}_{i\in I^{(e)}}$ and basis functions $\{N_i^{(e)}\}_{i\in I^{(e)}}$, where $I^{(e)}$ is the set of node indices of the element (e).

Applying the standard finite element procedure to the equilibrium equation, substituting stress definition into it and going to the index notation, we can get [14, 15]

$$p_1 \iint\limits_S N_{n,i}^{(e)} C_{ijkl}\varepsilon_{kl} dS + p_2 \iint\limits_S N_{n,i}^{(e)} \iint\limits_{S'(\mathbf{x})\cap S} \varphi\,(\mathbf{x},\mathbf{x}') C_{ijkl}\varepsilon_{kl} dS'(\mathbf{x}) dS$$

$$= \oint\limits_{\Gamma_2} N_n^{(e)} p_j d\Gamma + \iint\limits_S N_n^{(e)} b_j dS,$$

$$i,j,k,l = \overline{1,2},\ n \in I^{(e)},\ (e) \in S_h.$$

After quadrature integration the final equation is [5]:

$$(p_1\mathbf{K}^L + p_2\mathbf{K}^{NL}) \cdot \mathbf{U} = \mathbf{B} + \mathbf{P},$$

where $\mathbf{K}^L$, $\mathbf{K}^{NL}$ are stiffness matrices of the classical and nonlocal elasticity laws, respectively;$\mathbf{U}$ is the vector of the sought nodal displacements; $\mathbf{P}$ and $\mathbf{B}$ are discretization of density vectors of surface and volume forces, respectively.

Calculations results

To simplify further research of the model, we turn to dimensionless parameters

$$\bar{\boldsymbol{\sigma}} = \frac{\hat{\boldsymbol{\sigma}}}{\sigma_0}, \quad \bar{E} = \frac{E}{\sigma_0}, \quad \bar{\mathbf{x}} = \frac{\mathbf{x}}{L}, \quad \bar{\mathbf{u}} = \frac{\mathbf{u}}{L}, \quad \bar{r} = \frac{r}{L},$$

where L is characteristic area size; σ_0 is normalization factor for loads; r is radius of nonlocal influence; the bar above the variables means they are dimensionless. In the calculations, we will assume that Poisson's ratio is $\nu = 0.3$, and the dimensionless Young's modulus is $\bar{E} = 210$. We will assume that the nonlocal influence function φ has the following form

$$\varphi(|\mathbf{x}-\mathbf{x}'|) = \begin{cases} \dfrac{1}{\pi r^2}\left(1 - \dfrac{|\mathbf{x}-\mathbf{x}'|^2}{r^2}\right), & |\mathbf{x}-\mathbf{x}'| \le r, \\ 0, & |\mathbf{x}-\mathbf{x}'| > r. \end{cases}$$

Thus, the geometry of the region of nonlocal influence $S'(\mathbf{x})$ is a circle with a radius of r.

Consider the Neumann problem on the domain $S = [0,10] \times [0,1]$, with a uniform mesh S_h introduced on it, consisting of 1000×100 quadratic serendipity elements. We set the following boundary conditions

$$\bar{\sigma}_{1j} \cdot n_j \Big|_{\bar{x}_1=0} = -f\left(\bar{x}_2\right), \quad \bar{\sigma}_{1j} \cdot n_j \Big|_{\bar{x}_1=10} = f\left(\bar{x}_2\right),$$

where f is some loading function. To obtain the uniqueness of the solution to the problem, we add two geometric conditions, which will also give us the symmetry of the solution and fix it relative to the center of mass of the region along each of the axes

$$\bar{u}_1 \Big|_{\bar{x}_1=5} = 0, \quad \bar{u}_2 \Big|_{\bar{x}_2=0.5} = 0.$$

Note that in the local formulation of the problem, due to symmetry, it was possible to dispense with considering only a quarter of the region S.

Consider three cases of loading with the same normalization to the region $A = \{x \mid 0 \leq \leq x \leq 1\}$:

$$f_1(x) = 1, \quad f_2(x) = \begin{cases} 4x, & x \leq 0.5, \\ 4 - 4x, & x > 0.5, \end{cases} \quad f_3(x) = \begin{cases} 2 - 4x, & x \leq 0.5, \\ 4x - 2, & x > 0.5. \end{cases}$$

The Fig. 1 illustrates the loads applied to the plate.

Fig. 1. Loads applied to a rectangular plate

On the Fig. 2 shows stresses $\bar{\sigma}_{11}$ along the loading axis in different sections. Despite the different nature of the loads, with distance from them the stresses take on the same form, which in the nonlocal setting, in contrast to the classical one, is not constant along the $\bar{x}_2$ axis. Model parameters and selected sections are shown in the figures.

Considering the central section along the other axis (see Fig. 2), we can be sure that in the nonlocal setting the stress surface $\bar{\sigma}_{11}$ has a more complex shape. Variation in the weight parameter p_1 affects the deviation of stress values at the boundaries, while variation in the radius of nonlocal influence $\bar{r}$ affects the range of the edge effect (Fig. 3). It is important to note that the integral load in each section is equal to the applied one, which tells us about the fulfillment of the Saint-Venant principle.

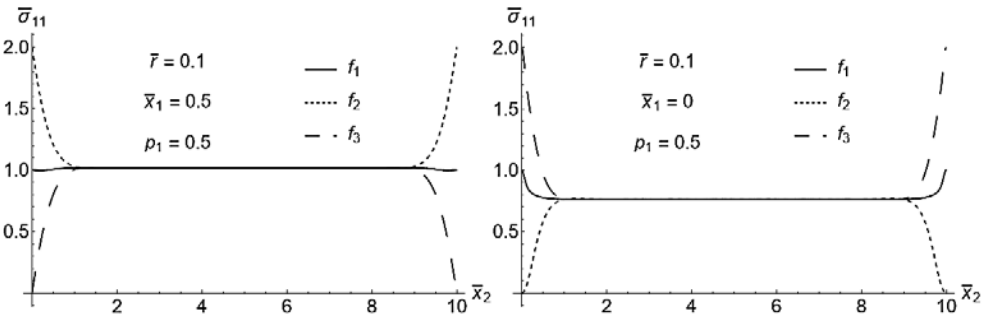

Fig. 2. Stress distribution along the tensile axis in different sections

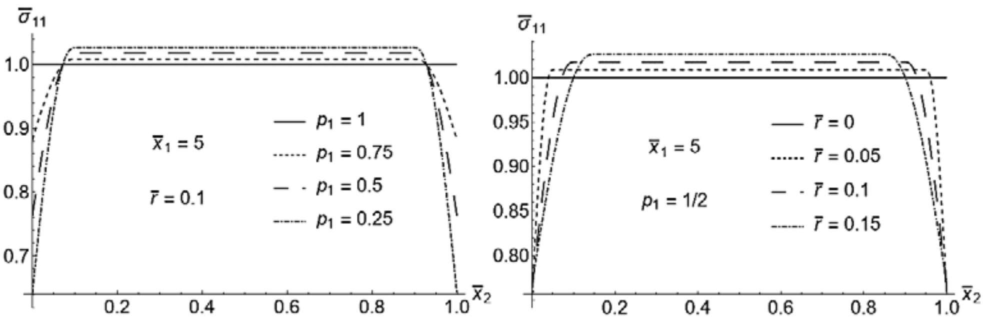

Fig. 3. Stress distribution along the central section with variation of the main parameters of the model

Conclusion

This study has demonstrated that such an important principle as the Saint-Venant principle is fulfilled in problems of nonlocal elasticity. These results prove that in the nonlocal formulation, as well as in the classical one, the balance relations are satisfied.

Information about the grant

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УДК 519.21

Марковский процесс гибели в квадранте плоскости

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Получено решение системы уравнений Колмогорова для двухмерного марковского процесса гибели. Проведено исследование фундаментальной системы решений, в соответствии с теоремой о структуре решений системы линейных дифференциальных уравнений с постоянными коэффициентами. В результате исследования выяснено, что в теореме о структуре решений константные значения выражаются через определители, и собственные вектора также выражаются через определители.

Ключевые слова: *марковский процесс, двухмерный процесс гибели, переходные вероятности, система обыкновенных дифференциальных уравнений, уравнение Колмогорова*

Markov Death-Process in the Plate Quadrant

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The solution of the Kolmogorov system of equations for two-dimensional Markov death-process is obtained. A study of the fundamental solution system is conducted in accordance with the theorem of the solutions structure in the system of linear differential equations with constant coefficients. As a result of the study, it was found that in the theorem of the structure of solutions, constant values and eigenvectors are expressed through determinants.

Keywords: *Markov process, two-dimensional death-process, transition probabilities, system of ordinary differential equations, Kolmogorov equation*

Introduction

Markov random processes are often used as probabilistic models of physical processes. Markov processes are widely used in physics, chemistry, biology, etc. For example, we can use Markov processes for mathematical modeling of the chemical reaction kinetics, when reaction occurs and new chemicals are formed. Models of the volume change or reagents concentration in time can be obtained through the use of mathematical tools.

In the paper we consider the Markov process of a system with interaction with a discrete set of states and continuous time. This Markov process is determined by the densities of transition probabilities and the starting distribution. The state of the Markov process 5×5 means the presence of particles 5 in the system. When particles interact, there is a transition to other state with a new particle quantity.

Analytical methods of studying of Markov processes with a countable number of states are based on the consideration of the first and second Kolmogorov systems of differential equations for transition probabilities. Explicit expressions for transition probabilities are lengthy and unsuitable for studying the asymptotic properties of a stationary process. In this paper, the methods of solving ordinary differential equations and the solution structure theorem are applied to the second Kolmogorov system of differential equations for the two-dimensional death-process on the plane quadrant.

Methodology and results

Let us consider a temporally homogeneous Markov two-dimensional process $\xi(t) = = \left(\xi_1(t), \xi_2(t)\right), \quad t \in [0, \infty)$, on a set of states $N^2 = \{(\alpha_1, \alpha_2), \alpha_1, \alpha_2 = 0,1,2, \dots\}$.

Transition probabilities from the starting point with coordinates (α_1, α_2) to the point with coordinates $(\beta_1, \beta_2)$are $P_{(\beta_1,\beta_2)}^{(\alpha_1,\alpha_2)}(t) = P\{\xi(t) = (\beta_1, \beta_2) \mid \xi(0) = (\alpha_1, \alpha_2)\}$.

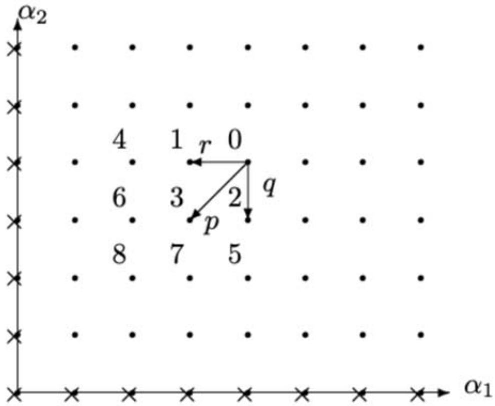
We consider the case of the death-process with an interaction $T_1 + T_2 \to 0, T_1, T_2$ [1], when the jump occurs either to the left with a probability r, or down with a probability q, or to the left lower diagonal with a probability p, and $q \geq 0, r \geq 0, p \geq 0, p + q + r = 1$. Boundary points are absorbing state points or breakpoints.

Transition probabilities are represented with $t \to 0+$ in the form of [2]:

$$P_{(\alpha_1-1,\alpha_2)}^{(\alpha_1,\alpha_2)}(t) = r\varphi_{\alpha_1,\alpha_2}t + o\,(t), P_{(\alpha_1,\alpha_2-1)}^{(\alpha_1,\alpha_2)}(t) = q\varphi_{\alpha_1,\alpha_2}t + o\,(t), P_{(\alpha_1-1,\alpha_2-1)}^{(\alpha_1,\alpha_2)}(t) = \\ = p\varphi_{\alpha_1,\alpha_2}t + o\,(t), P_{(\alpha_1,\alpha_2)}^{(\alpha_1,\alpha_2)}(t) = 1 - \varphi_{\alpha_1,\alpha_2}t + o\,(t),$$

where $\varphi_{\alpha_1,\alpha_2} > 0$, $\varphi_{\alpha_1,\alpha_2}$are different; at breakpoints $\varphi_{i0} = 0$ and $\varphi_{0i} = 0$.

Let the point be *0* the point of the beginning of the death-process. We began the study by looking at jumps inside the square 2×2 in the plane quadrant: when the jump starts at point *0* and ends at point *3*. The numbered points are shown in Figure. Then we considered rectangles 2×3 and 3×2.



Markov process jumps. Breakpoints are indicated by a sign x

Let the starting and finishing points of the jumps be inside the square on the plane quadrant. Let us write down the second Kolmogorov system of equations for the transition probabilities of the death-process in matrix form

$$\frac{dP_{0j}(t)}{dt} = A^T P_{0j}(t), \quad j = 0,1,2,\ldots,$$

where $P_{0j}(t) = (P_{00}, P_{01}, P_{02}, P_{03}, P_{04}, P_{05}, P_{06}, P_{07}, P_{08}, \ldots)^T$ is the transition probability consisting of the densities of the transition probabilities, initial data are $P_{00}(0) = 1; P_{0k}(0) = 0, k = 1,2,\ldots$, A is the matrix of infinitesimal characteristics.

The matrix of infinitesimal characteristics has the form

$$A = \begin{pmatrix} -\varphi_0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\ r\varphi_0 & -\varphi_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\ q\varphi_0 & 0 & -\varphi_2 & 0 & 0 & 0 & 0 & 0 & 0 & \ldots \\ p\varphi_0 & q\varphi_1 & r\varphi_2 & -\varphi_3 & 0 & 0 & 0 & 0 & 0 & \ldots \\ 0 & r\varphi_1 & 0 & 0 & -\varphi_4 & 0 & 0 & 0 & 0 & \ldots \\ 0 & 0 & q\varphi_2 & 0 & 0 & -\varphi_5 & 0 & 0 & 0 & \ldots \\ 0 & p\varphi_1 & 0 & r\varphi_3 & q\varphi_4 & 0 & -\varphi_6 & 0 & 0 & \ldots \\ 0 & 0 & p\varphi_2 & q\varphi_3 & 0 & r\varphi_5 & 0 & -\varphi_7 & 0 & \ldots \\ 0 & 0 & 0 & p\varphi_3 & 0 & 0 & q\varphi_6 & r\varphi_7 & -\varphi_8 & \ldots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \ddots \end{pmatrix},$$

where $\varphi_k > 0$.

With the help of a symbolic calculator, we obtained the transition probabilities for the points of square 3×3.

Through the transforming of the formulas, it became possible to find out that in the formula of transition probabilities at the transition from point *0* to point *n*, the densities of transient probabilities of only those points through which the paths pass are involved. For example, we can get from point 0 to point *3* in three ways: *0-1-3, 0-2-3, 0-3*. So, the transient probability $P_{03}(t)$ will consist of three additive components.

Through the analyzing the possible paths of the Markov process and using the induction method, we obtained transition probabilities for points of an arbitrary square. According to the theorem of the solutions structure, the solution of the system is presented as a linear combination of arbitrary constants and eigenvectors. To find the fundamental system of solutions, we write the secular equation

According to the structure theorem, the solution of the system has the form

$$P_0(t) = \sum_{k=0}^{\alpha_1\alpha_2} C_k X^{(\lambda_k)} e^{\lambda_k t},$$

where C_k is an arbitrary constant, $X^{(\lambda_k)}$ s the eigenvector corresponding to the eigenvalue λ_k.

$$P_0(t) = C_0 \begin{pmatrix} 1 \\ \dfrac{r\varphi_0}{(\varphi_1 - \varphi_0)} \\ \dfrac{q\varphi_0}{(\varphi_2 - \varphi_0)} \\ \dfrac{qr\varphi_0\varphi_1}{(\varphi_1 - \varphi_0)(\varphi_3 - \varphi_0)} + \dfrac{qr\varphi_0\varphi_2}{(\varphi_2 - \varphi_0)(\varphi_3 - \varphi_0)} \\ \vdots \end{pmatrix} e^{-\varphi_0 t} +$$

$$+C_1\begin{pmatrix}0\\1\\0\\\frac{q\varphi_1}{(\varphi_3-\varphi_1)}\\\vdots\end{pmatrix}e^{-\varphi_1 t}+\ \dots$$

Let us write expressions for arbitrary constants using matrix determinants

$$C_0=1,\ C_1=\frac{r\varphi_0}{(\varphi_0-\varphi_1)},\ C_2=\frac{q\varphi_0}{(\varphi_0-\varphi_2)},\ C_3=\frac{qr\varphi_0\varphi_1}{(\varphi_1-\varphi_3)(\varphi_0-\varphi_3)}+\frac{qr\varphi_0\varphi_2}{(\varphi_2-\varphi_3)(\varphi_0-\varphi_3)}+\frac{p\varphi_0}{\varphi_0-\varphi_3}=$$

$$=\begin{vmatrix}r\varphi_0 & -\varphi_1+\varphi_3 & 0\\ q\varphi_0 & 0 & -\varphi_2+\varphi_3\\ p\varphi_0 & q\varphi_1 & r\varphi_2\end{vmatrix}\frac{1}{\prod_{i=0}^{2}(\varphi_i-\varphi_3)},$$

$$C_4=\frac{r^2\varphi_0\varphi_1}{(\varphi_1-\varphi_4)(\varphi_0-\varphi_4)}=\begin{vmatrix}r\varphi_0 & -\varphi_1+\varphi_4\\ 0 & r\varphi_1\end{vmatrix}\frac{1}{\prod_{i=0,1}(\varphi_i-\varphi_4)},\dots$$

Components of the first eigenvector $X^{(\lambda_0)}$

$$x_0^{(\lambda_0)}=1,\ x_1^{(\lambda_0)}=\frac{r\varphi_0}{(\varphi_1-\varphi_0)},\ x_2^{(\lambda_0)}=\frac{q\varphi_0}{(\varphi_2-\varphi_0)},\ x_3^{(\lambda_0)}=\frac{qr\varphi_0\varphi_1}{(\varphi_1-\varphi_0)(\varphi_3-\varphi_0)}+\frac{qr\varphi_0\varphi_2}{(\varphi_2-\varphi_0)(\varphi_3-\varphi_0)}+$$

$$+\frac{p\varphi_0}{\varphi_3-\varphi_0}=\begin{vmatrix}r\varphi_0 & -\varphi_1+\varphi_0 & 0\\ q\varphi_0 & 0 & -\varphi_2+\varphi_0\\ p\varphi_0 & q\varphi_1 & r\varphi_2\end{vmatrix}\frac{1}{\prod_{i=1}^{3}(\varphi_i-\varphi_0)},$$

$$x_4^{(\lambda_0)}=\frac{r^2\varphi_0\varphi_1}{(\varphi_1-\varphi_0)(\varphi_4-\varphi_0)}=\begin{vmatrix}r\varphi_0 & -\varphi_1+\varphi_0\\ 0 & r\varphi_1\end{vmatrix}\frac{1}{\prod_{i=1,4}(\varphi_i-\varphi_0)},\dots$$

In the paper [3], expressions of arbitrary constants and eigenvectors were obtained through the square permanents 3×3. Analysis of the Markov process showed that the structural form of transition probabilities does not change if the square is moved. After analyzing the expressions of arbitrary constants and eigenvectors, it was found that these expressions can be written through matrix determinants for an arbitrary number of jumps. Matrix determinants are written as follows. Let the jump start at the point *0* and end at the arbitrary point *n*. Then we cross out the first line with the element $(-\varphi_0+\varphi_n)$ from the matrix $(A+\varphi_n E)$. Then we cross out lines and columns that contain $(-\varphi_k+\varphi_n)$, where *k* is the numbers of points through which the path from point *0* to point *n* does not pass. The determinant of the resulting matrix is a numerator of arbitrary constant C_n. The eigenvector has similar matrix compiling, but instead φ_n is φ_0.

Thus, the following theorem is established by the moving from point (α_1,α_2) to point (β_1,β_2).

Let's consider the theorem. The transition probabilities of the two-dimensional Markov death-process have the form, $\alpha_1\ge\beta_1\ge 1,\alpha_2\ge\beta_2\ge 1$,

$$P_{(\beta_1,\beta_2)}^{(\alpha_1,\alpha_2)}(t)=\sum_{\gamma_1=\beta_1}^{\alpha_1}\sum_{\gamma_2=\beta_2}^{\alpha_2}C_{\gamma_1\gamma_2}\,x_{\beta_1\beta_2}^{(\gamma_1,\gamma_2)}e^{-\varphi_{\gamma_1\gamma_2}t},$$

where arbitrary constants are

$$C_{\alpha_1\alpha_2} = 1,\ C_{\alpha_1-1,\alpha_2} = \frac{r\varphi_{\alpha_1\alpha_2}}{(\varphi_{\alpha_1\alpha_2}-\varphi_{\alpha_1-1,\alpha_2})},\ C_{\alpha_1,\alpha_2-1} = \frac{q\varphi_{\alpha_1\alpha_2}}{(\varphi_{\alpha_1\alpha_2}-\varphi_{\alpha_1,\alpha_2-1})},\ C_{\alpha_1-1,\alpha_2-1} =$$

$$\begin{vmatrix} r\varphi_{\alpha_1\alpha_2} & -\varphi_{\alpha_1-1,\alpha_2}+\varphi_{\alpha_1-1,\alpha_2-1} & 0 \\ q\varphi_{\alpha_1\alpha_2} & 0 & -\varphi_{\alpha_1,\alpha_2-1}+\varphi_{\alpha_1-1,\alpha_2-1} \\ p\varphi_{\alpha_1\alpha_2} & q\varphi_{\alpha_1-1,\alpha_2} & r\varphi_{\alpha_1,\alpha_2-1} \end{vmatrix} \times$$

$$\frac{1}{\prod_{i,j=0,i\neq j\neq 1}^{1}(\varphi_{\alpha_1-i,\alpha_2-j}-\varphi_{\alpha_1-1,\alpha_2-1})},$$

$$C_{\alpha_1-2,\alpha_2} = \begin{vmatrix} r\varphi_{\alpha_1\alpha_2} & -\varphi_{\alpha_1-1,\alpha_2}+\varphi_{\alpha_1-2,\alpha_2} \\ 0 & r\varphi_{\alpha_1-1,\alpha_2} \end{vmatrix} \frac{1}{\prod_{i=0}^{2}\left(\varphi_{\alpha_1-i,\alpha_2}-\varphi_{\alpha_1-2,\alpha_2}\right)}, \ldots,$$

and eigenvectors are

$$x_{\gamma_1\gamma_2}^{(\gamma_1,\gamma_2)} = 1,\ x_{\gamma_1-1,\gamma_2}^{(\gamma_1,\gamma_2)} = \frac{r\varphi_{\gamma_1\gamma_2}}{(\varphi_{\gamma_1-1,\gamma_2}-\varphi_{\gamma_1\gamma_2})},\ x_{\gamma_1,\gamma_2-1}^{(\gamma_1,\gamma_2)} = \frac{q\varphi_{\gamma_1\gamma_2}}{(\varphi_{\gamma_1,\gamma_2-1}-\varphi_{\gamma_1\gamma_2})},\ x_{\gamma_1-1,\gamma_2-1}^{(\gamma_1,\gamma_2)} =$$

$$\begin{vmatrix} r\varphi_{\gamma_1\gamma_2} & -\varphi_{\gamma_1-1,\gamma_2}+\varphi_{\gamma_1\gamma_2} & 0 \\ q\varphi_{\gamma_1\gamma_2} & 0 & -\varphi_{\gamma_1,\gamma_2-1}+\varphi_{\gamma_1\gamma_2} \\ p\varphi_{\gamma_1\gamma_2} & q\varphi_{\gamma_1-1,\gamma_2} & r\varphi_{\gamma_1,\gamma_2-1} \end{vmatrix} \frac{1}{\prod_{i,j=0,i\neq j\neq 0}^{1}(\varphi_{\gamma_1-i,\gamma_2-j}-\varphi_{\gamma_1\gamma_2})},$$

$$x_{\gamma_1-2,\gamma_2}^{(\gamma_1,\gamma_2)} = \begin{vmatrix} r\varphi_{\gamma_1\gamma_2} & -\varphi_{\gamma_1-1,\gamma_2}+\varphi_{\gamma_1\gamma_2} \\ 0 & r\varphi_{\gamma_1-1,\gamma_2} \end{vmatrix} \frac{1}{\prod_{i=1}^{2}\left(\varphi_{\gamma_1-i,\gamma_2}-\varphi_{\gamma_1\gamma_2}\right)}, \ldots$$

Representation of the theorem summarizes the expression for the transition probabilities of the one-dimensional death-process [4].

Conclusion

For the two-dimensional Markov death-process on the plane quadrant, formulas of transition probabilities are obtained according to the solution structure theorem of linear differential equations systems with constant coefficients for arbitrary constant and eigenvectors through matrix determinants. A process of a matrix determinant construction for arbitrary number of jumps. The obtained linear structure of the formulae for transition probabilities has a similar form for the two-dimensional birth-process and the two-dimensional death-process. We suppose that the similar form of transition probabilities will be for the three-dimensional birth-death process.

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УДК 51

Моделирование краевого эффекта в композитах на основе метода асимптотического осреднения

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Цель настоящей статьи — разработать численный алгоритм решения задачи краевого эффекта в пространственно-армированных композиционных материалах. Решение задачи краевого эффекта осуществляется с помощью коррекции в микрорешении, учитывающее сформулированное граничное условие. Данная формулировка приводит к задачам пограничного слоя, которые быстро затухают при удалении от границы, но добавляют существенные вклад вблизи нее, учет которых позволяет получить правильное представление глобального поля напряжений. Показано, что данная коррекция является существенной и влияет на прогнозы локальных напряжений и деформаций, которые упускаются классическими решениями микрозадач.

Ключевые слова: *композиционные материалы, асимптотическое осреднение, макроанализ, микроанализ, гомогенизация*

Modeling the Edge Effect in Composites Based on Asymptotic homogenization Method

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The purpose of this work is to develop a numerical algorithm for solving the problem of calculating the stress-strain state of composite materials structures, taking into account edge effects. The solution to the problem is solved by modifying the asymptotic averaging method by taking into account an additional solution of the boundary layer type, which quickly fades away from the boundary. This solution makes a significant contribution to the neighborhood of the composite surface itself. A numerical example of calculating an element of a composite structure with holes is given and this example showed the feasibility of the proposed method. The calculations are compared with a three-dimensional finite element solution in the ANSYS software package.

Keywords: *composite materials, asymptotic method, macroanalysis, microanalysis, homogenization*

Introduction

Existing research in the theory of composite materials is based on the homogenization approach, which consists of replacing a heterogeneous medium with a homogeneous one with certain effective properties. These effective properties are derived from internal asymptotics, which excludes boundary layer effects. However, at the boundary of the construction, the periodic solution is violated. This loss of periodicity of the internal asymptotic solution must be taken into account.

From a mathematical point of view, homogenization theory is a limiting theory that uses asymptotic expansion and the assumption of periodicity to replace differential equations with rapidly oscillating coefficients [1–3]. In elementary cell models, global properties are determined considering the conditions of macroscopic periodicity. Local problems are solved for specific representative load cases, thus representing the actual interaction between macro and micro-scale deformations.

Currently, there are some approaches to modeling edge effects in the literature [1, 4], however, as a rule, model problems are considered, without taking into account the real curvilinear shape of the surface of structures. The purpose of this work is to develop a variant of the asymptotic averaging method, which allows calculations of the stress-strain state of composite structures regarding the edge effect with an arbitrary shape of the surface of the structure.

Asymptotic solutions to the problem of elasticity theory regarding the boundary effect for a near-periodic composite

Let us consider a composite V with a periodic structure, the outer boundary $\Sigma = \Sigma_\sigma + \Sigma_u$ which has the equation following:

$$\Sigma:, f(x^i) = 0.$$

Regarding the quasi-periodicity of the composite [5, 6], the surface equation can be considered as function of two variables $\overline{x}^i$ and ξ^i (Fig. 1):

$$f\left(\overline{x}^i, \xi^j\right) = 0,$$

where x_i is the Cartesian coordinates for the characteristic size of the structure and the local system ξ_i is the “fast” (local) coordinates for the representative volume element (RVE):

$$\overline{x}_i = \frac{x_i}{L}, \quad \xi_i = \frac{\overline{x}_i}{\kappa} = \frac{x_i}{\ell}.$$

Here $\kappa = l/L$ is a small parameter, L is the global scale of the length L of the area V of the entire composite, l is the local scale of the length.

boundary Σ:. the solution of this problem of linear elasticity theory for the composite materials according to the method of asymptotic averaging [5, 9, 10], is sought in the form

$$u_k = u_k^{(0)}\left(\overline{x}^i\right) + \sum_{n=1}^{\infty} \kappa^n \tilde{u}_k^{(n)}, \tag{1}$$

where u_k are the components of the displacement vector, and

$$\tilde{u}_k^{(n)} = u_k^{(n)}(\overline{x}_i, \xi_j) + \hat{u}_k^{(n)}(\overline{x}_i, \xi_j),\ n > 0,\ \hat{u}_k^{(0)} \equiv 0. \quad (2)$$

Functions $u_k^{(n)}(\overline{x}_i, \xi_j)$ are 1-periodic in all ξ_j 3 coordinates: $u_k^{(n)}(\overline{x}_i, \xi_j + 1) = = u_k^{(n)}(\overline{x}_i, \xi_j)$, as result, the domain of definition of these functions are: $\xi_i \in V_\xi, \overline{x}_i \in \overline{V}$. Here V_ξ is one complete periodicity cell, and $\overline{V}$is the average are of the composite material structure, its equation $\overline{V} = \left\{\overline{x}_i : f\left(\overline{x}^i, \xi_j^*\right) < 0\right\}$, where ξ_j^* is some fixed set of values of local coordinates corresponding to the surface Σ, for example $\xi_j^* = 0$.

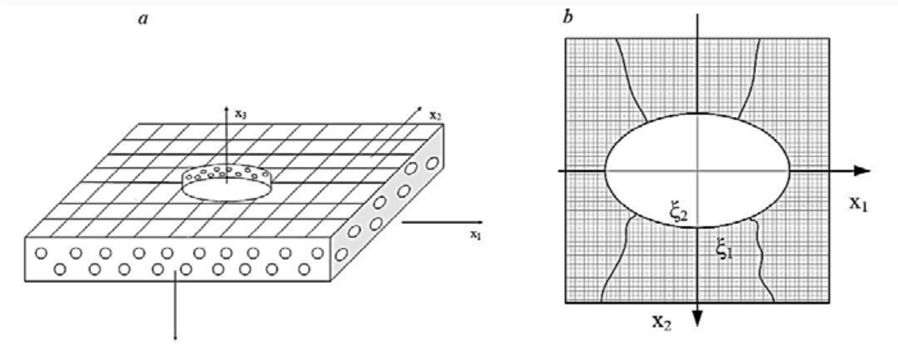

Fig. 1. A geometric model of a composite for constructing a solution taking into account the edge effect:
a — a general composite model; *b* — areas *Va*, where the frequency of functions *u* and the direction of attenuation of the solution for the boundary layer problem change

Let us consider the problem of linear elasticity theory [7, 8] in the domain V with a

The functions $\hat{u}_k^{(n)}\left(\overline{x}_i, \overline{\xi}_j\right)$ in (2) are 1-periodic in two coordinates: ξ_3, ξ_α, and decaying in the third coordinateξ_β, where $\alpha, \beta = 1,2$, $\alpha \neq \beta$. The area $V$is divided into subdomain V_α, where: 1) $\hat{u}_k^{(n)}$ are periodic by ξ_1, ξ_3, and 2) $\hat{u}_k^{(n)}$ by ξ_2, ξ_3

The attenuation of functions $\hat{u}_k^{(n)}(x_i, \xi_j)$ by coordinate ξ_β, when moving away from the surface Σ follows the expression:

$$\left|\hat{u}_k^{(n)}\right| \to 0, \quad \left|\xi_\beta\right| \to \infty.$$

Based on formula (1), we obtain an asymptotic expansion for deformations:

$$\varepsilon_{ij} = \sum_{n=0}^{\infty} \kappa^n \tilde{\varepsilon}_{ij}^{(n)};$$

$$\tilde{\varepsilon}_{ij}^{(n)} = \varepsilon_{ij}^{(n)}(x_k, \xi_m) + \hat{\varepsilon}_{ij}^{(n)}(x_k, \xi_m), \quad n \geq 0;$$

where

$$\varepsilon_{ij}^{(n)} = \frac{1}{2}\left(u_{i,j}^{(n)} + u_{j,i}^{(n)}\right) + \frac{1}{2}\left(u_{i/j}^{(n+1)} + u_{j/i}^{(n+1)}\right),$$

$$\varepsilon_{ij}^{(n)} = \frac{1}{2}\left(u_{i,j}^{(n)} + u_{j,i}^{(n)}\right) + \frac{1}{2}\left(u_{i/j}^{(n+1)} + u_{j/i}^{(n+1)}\right).$$

Here the derivatives are denoted by $u_{i,j}^{(n)} = \partial u_i^{(n)} / \partial x_j$ and $u_{i/j}^{(n)} = \partial u_i^{(n)} / \partial \xi_j$.

Using the generalized Hooke's law, we find the asymptotic expansion for stresses:

$$\sigma_{ij} = \sum_{n=0}^{\infty} \kappa^n \tilde{\sigma}_{ij}^{(n)}, \tag{3}$$

$$\tilde{\sigma}_{ij}^{(n)} = \sigma_{ij}^{(n)}(x_k, \xi_m) + \hat{\sigma}_{ij}^{(n)}(x_k, \xi_m), \quad n \geq 0;$$

where

$$\sigma_{ij}^{(n)} = C_{ijkl}\varepsilon_{kl}^{(n)}.,\ \hat{\sigma}_{ij}^{(n)} = C_{ijkl}\hat{\varepsilon}_{kl}^{(n)}.$$

Here $C_{ijkl}(\xi_k)$ are the tensor components of the composite elastic modules [11], which are functions of ξ_k.

Formulations of local and averaged problems

Substituting decomposition (9) into the equilibrium equation for the composite $\sum_\sigma$ and $\sum_u$ the boundary conditions on part of the surface and taking into account the conditions on the interface of the phases of the composite $\sum_S$: we obtain:

$$\frac{1}{\kappa}\left(\sigma_{ij/j}^{(0)} + \hat{\sigma}_{ij/j}^{(0)}\right) + \sum_{n=0}^{\infty} \kappa^n \left(\sigma_{ij,j}^{(n)} + \sigma_{ij/j}^{(n+1)} + \hat{\sigma}_{ij,j}^{(n)} + \hat{\sigma}_{ij/j}^{(n+1)}\right) = 0,$$

$$\sum_{\sigma}: \quad n_i\left(\sigma_{ij}^{(0)} + \hat{\sigma}_{ij}^{(0)} + \sum_{n=1}^{\infty} \kappa^n \left(\sigma_{ij}^{(n)} + \hat{\sigma}_{ij}^{(n)}\right)\right)$$

$$= S_{ie}, \quad \sum_{u}: \quad u_i^{(0)} + \sum_{n=1}^{\infty} \kappa^n \left(u_i^{(n)} + \hat{u}_i^{(n)}\right) = u_{ie},$$

$$\sum_{S}: \quad n_i\left[\sigma_{ij}^{(0)} + \hat{\sigma}_{ij}^{(0)} + \sum_{n=1}^{\infty} \kappa^n \left(\sigma_{ij}^{(n)} + \hat{\sigma}_{ij}^{(n)}\right)\right] = 0, \quad \sum_{n=1}^{\infty} \kappa^n \left[u_i^{(n)} + \hat{u}_i^{(n)}\right] = 0.$$

Here $[u_i^{(n)}]$ is a jump of functions at the component interface.

From the system of asymptotic equations we obtain 2 types of recurrent sequences of local problems:

type 1 tasks

$$\begin{gathered} \sigma_{ij/j}^{(n)} + \sigma_{ij,j}^{(n-1)} = h_i^{(n-1)}, \quad V_\xi \\ \sigma_{ij}^{(n)} = C_{ijkl}\varepsilon_{kl}^{(n)} \qquad \varepsilon_{ij}^{(n)} = \tfrac{1}{2}\left(u_{i,j}^{(n)} + u_{j,i}^{(n)}\right) + \tfrac{1}{2}\left(u_{i/j}^{(n+1)} + u_{j/i}^{(n+1)}\right) \\ \textstyle\sum_s: \quad n_i\left[\sigma_{ij}^{(n)}\right] = 0, \quad \left[u_i^{(n+1)}\right] = 0, \\ \left\langle u_i^{(n+1)}\right\rangle_{V_\xi} = 0, \quad n = 0,1,2\ldots \end{gathered} \tag{4}$$

tasks of the 2nd type

$$\hat{\sigma}_{ij/j}^{(n)} + \hat{\sigma}_{ij,j}^{(n-1)} = 0 \qquad \hat{V}_\xi$$

$$\hat{\sigma}_{ij/j}^{(n)} = C_{ijkl}\hat{\varepsilon}_{kl}^{(n)}, \qquad \hat{\varepsilon}_{ij}^{(n)} = \frac{1}{2}\left(\hat{u}_{i,j}^{(n)} + \hat{u}_{j,i}^{(n)}\right) + \frac{1}{2}\left(\hat{u}_{i/j}^{(n+1)} + \hat{u}_{j/i}^{(n+1)}\right),$$

$$\textstyle\sum_s: \quad n_i\left[\hat{\sigma}_{ij}^{(n)}\right], \quad \left[\hat{u}_i^{(n+1)}\right] = 0 \tag{5}$$

$$\sum_{\xi\sigma}: \quad n_i\hat{\sigma}_{ij}^{(n)} = -n_i\sigma_{ij}^{(n)} + S_{ie}^{(n)}$$

$$\hat{u}_i^{(n+1)} \to 0, \quad |\xi_\beta| \to \infty \; n = 0,1,2\ldots$$

Here are indicated:

$$h_i^{(-1)} = 0 \;\; h_i^{(n)} =< \sigma_{ij}^{(n)} >_{,j}, \; n \geq 0, S_{ie}^{(0)} = S_{ie}, S_{ie}^{(0)} = 0 \; n > 0,$$

where $< \sigma_{ij}^{(n-1)} >= \int_{V_\varsigma} \sigma_{ij}^{(n-1)} dV_\xi$ are averaging by RVE. In the task (13) $\hat{\varepsilon}_{ij}^{(0)} = = \frac{1}{2}\left(\hat{u}_{i/j}^{(1)} + \hat{u}_{j/i}^{(1)}\right)$.

Tasks of type 1 (4) are classical tasks on the periodicity cell. To achieve an acceptable accuracy of the solution, it is sufficient to consider only problem (4) at $n = 0$ — the zero approximation problem. Its solution is the functions $u_i^{(1)}$ and $\sigma_{ij}^{(0)}$, parametrically dependent on the average deformations $\overline{\varepsilon}_{ij} = \frac{1}{2}\left(u_{i,j}^{(0)} + u_{j,i}^{(0)}\right)$

$$u_i^{(1)} = \sum_{p,q=1}^{3} U_{ipq} \overline{\varepsilon}_{pq}, \sigma_{ij}^{(0)} = \sum_{p,q=1}^{3} \sigma_{ij(pq)} \overline{\varepsilon}_{pq},$$

where U_{ipq} and $\sigma_{ij(pq)}$ are some functions defined in the process of solving the problem on RVE.

To calculate displacements $u_i^{(0)}$ and deformations $\overline{\varepsilon}_{ij}$ we have the following averaged problem

$$\left\langle \sigma_{ij}^{(0)} \right\rangle_{,j} = 0,$$

$$\left\langle \sigma_{ij}^{(0)} \right\rangle = \overline{C}_{ijkl} \overline{\varepsilon}_{kl}, \quad \overline{\varepsilon}_{ij} = \frac{1}{2}\left(u_{i,j}^{(0)} + u_{j,i}^{(0)}\right), \tag{6}$$

$$\overline{\sum}_\sigma: \quad n_j \left\langle \sigma_{ij}^{(n)} \right\rangle = \langle S_{ie} \rangle, \quad \sum_u: \quad u^{(0)} = \langle u_{ie} \rangle.$$

The tensor of effective elastic modulus of a composite material is calculated by the formula [5]

$$\overline{C}_{ijpq} = \frac{<\sigma_{ij(pq)}>}{\overline{\varepsilon}_{pq}}.$$

Type 2 problems (5) are problems on a semi-infinite domain $\hat{V}_\xi$, with periodicity conditions in 2 directions ξ_3, ξ_α, and infinite in coordinate ξ_β. To achieve an acceptable accuracy of the solution, it is sufficient to consider only problem (5) at $n = 0$ — the zero approximation problem. Its solution is the functions $\hat{u}_i^{(1)}$ and $\hat{\sigma}_{ij}^{(0)}$, depending on the input data: functions $\hat{S}_{ie} = -n_i \sigma_{ij}^{(0)} + S_{ie}$, defined on a part of the surface $\sum_{\xi\sigma} = \sum_\sigma \cap V_\xi$.

The resulting stresses and deformations in the zero approximation have the form

$$\tilde{\sigma}_{ij} = \sigma_{ij}^{(0)} + \hat{\sigma}_{ij}^{(0)}, \quad \tilde{\varepsilon}_{ij} = \varepsilon_{ij}^{(0)} + \hat{\varepsilon}_{ij}^{(0)}.$$

Numerical simulation of micro stresses and effective elastic characteristics of composites for type one problem

The numerical implementation of the developed method was considered in the example of the problem of structure stretching in the form of a joint of 2 composite plates with holes in the joint zone (Fig. 2). The case of a fabric composite was considered, the periodicity cell of which is shown in Fig. 2, *b*. The same figure shows the finite element grid used to solve the problem (4). The results of solving local problems on RVE were discussed in detail in [5], so we will not consider them in detail. The calculations considered a glass/epoxy composite.

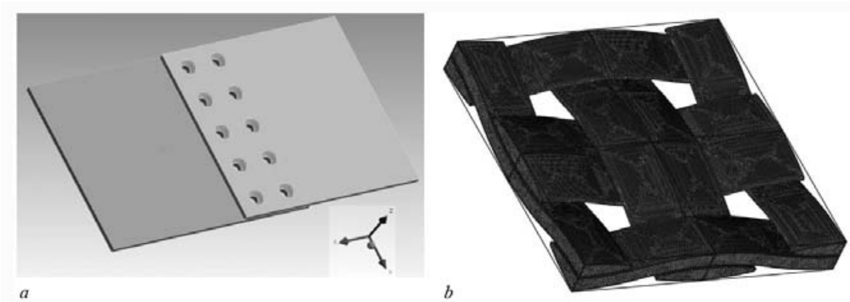

Fig. 2. Composite plate with holes (*a*) and finite element mesh for composite RVE (*b*), which were used in the calculations

Tetrahedral finite elements with linear approximation were used in the calculations. The number of finite elements was 282266, and the number of nodes was 46397.

Some results of solving the averaged problem (6) are shown in Fig. 3. Loading the structure of 2 plates was carried out by longitudinal force, while the holes of the plates were supposed to be free from loading. A tetrahedral grid with linear approximation was used for calculations, the number of elements was 2.086.414. The number of holes varied during the calculations.

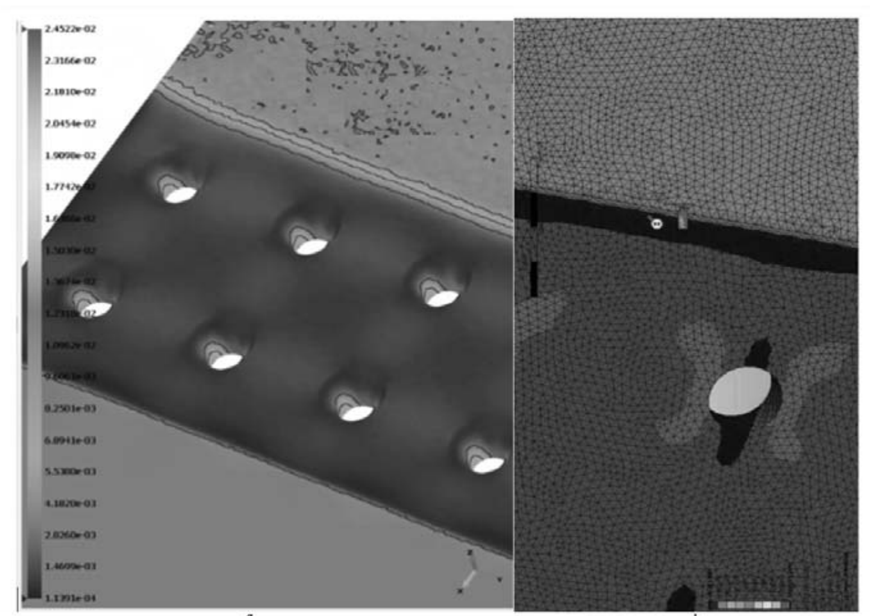

Fig. 3. Distribution of the stress field in the composite plate, obtained using the SMCM PC (*a*) and ANSYS PC (*b*)

Finite element calculations were carried out using the SMCM software package developed at the Scientific and Educational Center "Supercomputer Engineering Modeling and Development of Software Complexes" of Bauman Moscow State Technical University [12] (SIMPLEX), as well as using the ANSYS software package. Comparative results of calculations for the maximum value of the normal stress along the longitudinal axis of tension OX $\left\langle \sigma_{xx}^{(0)} \right\rangle$ are shown in Fig. 2.

Two types of finite element grids were used for calculations: 300 thousand finite elements with 2 FE in plate thickness, and 15 million FE with 4 FE in plate thickness (Table).

Values of maximum stresses in the vicinity of holes, depending on their number

Number of holes	max $\langle \sigma_{xx}^{(0)} \rangle$ ANSYS, MPa	max $\langle \sigma_{xx}^{(0)} \rangle$ SMCM, MPa
4	25.76	25.73
6	26.46	26.39
8	27.05	27.09
10	28.52	28.43

It was found that the results of calculations using the ANSYS and SMCM PCs coincide quite well σ_{xx}, both on a coarse grid (300 thousand finite elements, 2 FE in thickness) and on a fine grid (4 FE in thickness, 15 million FE). In the zone of rigid pinching, a state of pure bending is realized when σ_{xx} the linear depends on the transverse coordinate of the plate, because of this, the maximum values σ_{xx} are realized in the zone of load application at the ends of the plate. Local stress maxima max$\left\langle \sigma_{xx}^{(0)} \right\rangle$ are also reached in the vicinity of the holes, the values of which are presented in Table.

Calculations have shown that with an increase in the number of holes in the connection, the stresses max$\left\langle \sigma_{xx}^{(0)} \right\rangle$ increase.

Conclusions

A method for modeling the edge effect in composite materials based on the method of asymptotic averaging is proposed. Three types of problems arising in this method are formulated: problems on the periodicity cell, an averaged problem for a composite with effective characteristics, and an additional local problem with a decaying solution at a distance from the boundary of the body surface.

An example of numerical simulation of the stress-strain state of a composite structure with holes is given, which demonstrated the fundamental feasibility of the proposed calculation method. A comparison of the averaged problem solution of the composite plate stress-strain state obtained using the SMCM software package developed at BMSTU and using the ANSYS complex showed high accuracy of the numerical method and the software package.

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Электроника и лазерная техника

УДК 621.391

Алгоритм автоматического защитного переключения при резервировании линейного тракта ВОЛС

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ООО «Т8»

Разработан алгоритм автоматического защитного переключения при резервировании линейного тракта волоконно-оптической линии связи. Время защитного переключения сокращено до 10 мс. Предложенный алгоритм позволяет своевременно предупредить о деградации основного канала и выполнить быстрое переключение на резервный до достижения предела прямой коррекции ошибок (forward error correction, FEC). Быстрое переключение позволяет минимизировать и предотвратить потерю пакетов данных.

Ключевые слова: *защитное переключение, волоконно-оптические линии связи, резервирование, надежность, линейный тракт*

An Algorithm for Automatic Protective Switching during Redundancy of the Fiber-Optic Communication Line

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An algorithm for automatic protective switching during redundancy of the fiber-optic communication line was developed. The time of protective switching is reduced to 10 ms. The proposed algorithm allows timely warning of the main channel degradation and performing fast switching to the backup channel before the forward error correction limit is reached. Fast switching allows to minimize and prevent loss of data packets.

Keywords: *protective switching, fiber-optic communication lines, linear redundancy, reliability, linear tract*

Introduction

At present, the volume of data transmitted via optical networks is increasing by 20...30 % annually [1]. With the growth of transmitted data, the requirements for the reliability of fiber-optic communication lines (FOCL) increase as well. The reliability of FOCL is understood as the ability to provide the transfer of information with a given quality during a certain period of time [2]. One of the effective ways to improve the reliability of modern optical communication networks is linear redundancy.

Emergencies in the linear part of the network occur when the line is damaged (fiber breakage, failure of equipment: transponder, optical amplifier or other components). The obvious solution to this problem is to increase the number of available physical transmission paths, which will be switched to when a fault occurs.

Linear redundancy

The linear redundancy can be organized by different schemes “1+1”, “1:1”, “1:N” [1]. When using the “1+1” redundancy, the switching to another line is carried out only at the point of signal reception. When using the redundancy “1:1” it is required to perform switching both at the reception and at the transmission of the signal. For this purpose, it is necessary to coordinate the work of the equipment used in the receiving and transmitting so that at deterioration of the received signal quality switching to another line takes place. The operation of matching the operation of transponders increases the time of transition of the system to a working condition. Therefore, other things being equal, the scheme “1+1” is the most preferable. It provides greater reliability and better quality of the transmitted signal in comparison with the scheme “1:1”. Let's consider the algorithm of fast automatic protective switching at “1+1” redundancy.

In case of redundancy, “1+1” the transmitted signal is duplicated in the transponder at the OTN-container level and is transmitted over two independent optical channels [3]. After reception, each of the received signals is analyzed for possible errors. The signals are then sent to a protective switch. The protective switch connects to the client side only one stream in the best condition (Fig. 1).

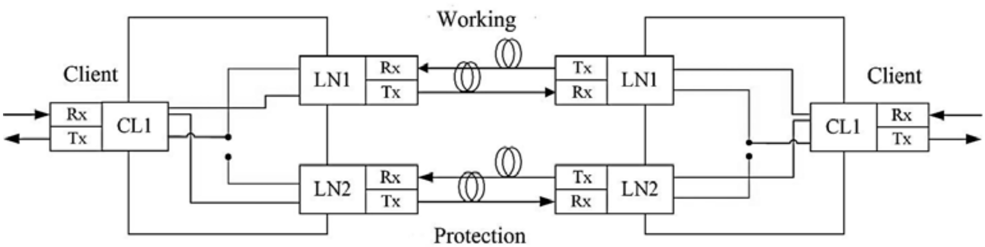

Fig. 1. The “1+1” redundancy scheme

The total recovery of protected traffic T (1) according to ITU-T G.808.1 is defined as

$$T = T_1 + T_2 + T_3, \tag{1}$$

where T_1 is acknowledgement time (time interval between the appearance of a network fault and the moment when it is confirmed that the generated signals require protection switching operation); T_2 is transmission time (time interval between the confirmation that the SF and SD signals require protection switching operation and the execution of protection switching operation); T_3 is time interval between the execution of protection switching operation and full restoration of the protected traffic.

Protection switching algorithm

To reduce the fault detection time, an automatic protection switching algorithm has been developed. The algorithm analyzes the state of the line according to the value of Pre-FEC BER (Pre-forward Error Correction BER), i.e. before the application of coding. BER (bit-error-rate) is an integral indicator of the quality of digital communication systems [4]. The coefficient (2) is defined as

$$BER = \frac{N_1}{N_2}, \qquad (2)$$

where N_1 is the number of received bit errors; N_2 is the total number of transmitted bits.

All errors are successfully identified and corrected in the system as long as the BER is below the forward error correction (FEC) limit. When the limit is exceeded, the FEC cannot handle the number of errors and data packets are lost.

The main task of the protection algorithm is to execute an early warning of line degradation, allowing proactive action to be taken before the FEC limit is reached. This way, packet loss can be minimized. The signal degradation means the state of a significant number of errors in the signal.

The following parameters are set in the system to detect faults on the line channel: polling interval, signal degradation threshold and threshold for register clearing.

The interval defines the minimum duration during which the BER must exceed the threshold. The threshold defines the BER level for setting the signal degradation state. An additional register clearing threshold is specified to eliminate chattering in the system.

The algorithm counts the total number of errors during the specified interval. When you exceed the threshold of deterioration of the signal Pre-Fec BER in the register is written to the appropriate alarm bit FASTDEG and traffic is redirected to the protective line. If during the interval the BER on the main line falls below the level of clearing the register, the alarm is reset, the register is cleared bit FASTDEG and return to the main line. The principle of the algorithm is shown in Fig. 2.

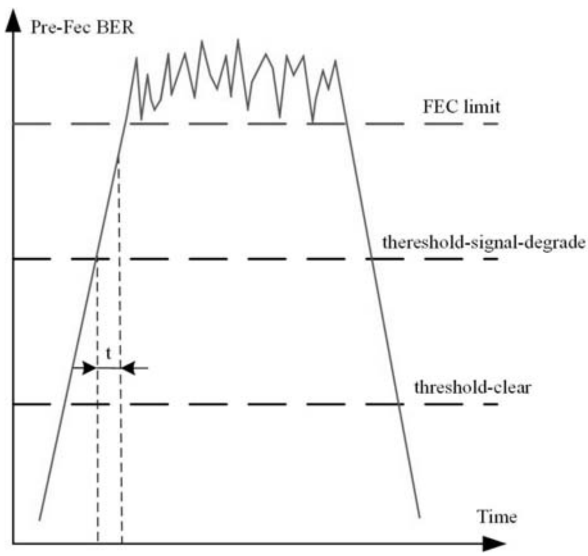

Fig. 2. Protection switching algorithm

Results

The developed algorithm is successfully applied on the two-channel transponder with linear interfaces OTU2e. The following error correction algorithms can be used on the transponder: G.709, EFEC. To study the protection switching time the scheme, presented in Fig. 3, is used.

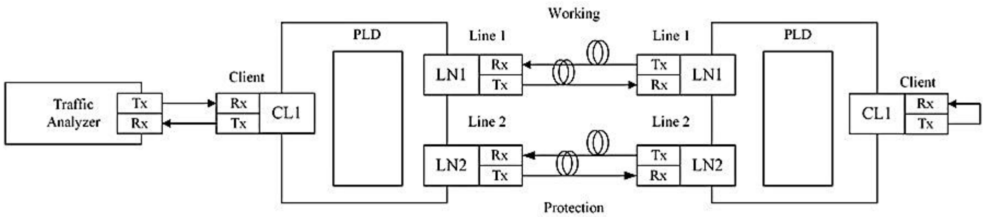

Fig. 3. Scheme for measuring the protection switching time

The flow analyzer sends the signal to the optical modules of the client interfaces. The optical modules convert the optical signals into electrical signals and transmit them to the Framer. The Framer generates linear streams, encodes the signal and transmits to the linear optical modules. Linear optic modules convert the streams into OTN channel signals (ITU-T G.694.1 standard DWDM frequency grid) and transmit them into the line. On the remote side there is a responder device that receives linear optical streams and converts them into electrical. The electrical signals are sent to the Framer. The framer decodes and corrects bit errors and directs the streams to the client optical modules. On the client module, a physical wrap of the traffic is installed with the help of a patch cord. Thus, the traffic is reversed and transmitted back to the protocol analyzer. In order to measure the switching time, the main line is cut in the opposite direction. Table shows the switching time values for G.975.1 I.3 (EFEC) and G.709 FEC. According to the results of the performed measurements, the maximum switching time does not exceed 10 m/s for each FEC type.

Measurement results

FEC type	Number of measurements, pcs.	Maximum switching time, ms
G.975.1. I.3	50	< 10
G709		< 10

Conclusion

An algorithm for automatic protective switching during redundancy of the fiber-optic communication line (FOCL) was developed. The proposed algorithm makes it possible to warn in time about the degradation of the main line and perform timely protective switching to a backup line. The maximum switching time for different FEC types (G.975.1 I.3 and G.709) is reduced to 10 ms. Reduced error detection time prevents data loss during transmission and increases the reliability of the system as a whole.

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Энергетика

УДК 629.038

Синтетическое топливо

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Представлена информация о синтетических топливах и об их использовании в транспортных двигателях. Указаны основные преимущества и недостатки этого вида топлива. Рассмотрена возможность использования синтетического топлива на транспорте в качестве альтернативы электрическому транспорту, оценены перспективы развития данного топлива в качестве замены бензина, дизеля и природного газа в целях уменьшения негативного влияния на экологию.

Ключевые слова: _автомобильная техника, транспортное средство, топливо, экология, двигатель внутреннего сгорания, электричество, источник энергии_

Synthetic Fuels

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The article describes information about synthetic fuels and their usage in transport engines. The main advantages and disadvantages of this art of fuels are indicated. Considered the opportunity of usage synthetic fuel on vehicles as alternative to electric vehicles. The development prospects of this fuel as the alternative to gasoline, diesel, gas in order to reduce negative affect on the environment are assessed.

Keywords: _auto, vehicle, fuel, ecology, internal combustion engine, electricity, energy sourse_

Synthetische Kraftstoffe

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Es werden Informationen über synthetische Kraftstoffe und ihre Verwendung in Verkehrsmotoren vorgestellt. Die wichtigsten Vor- und Nachteile dieser Art von Kraftstoff werden aufgezeigt. Die Möglichkeit der Verwendung synthetischer Kraftstoffe im Verkehr als Alternative zum Elektroantrieb wird geprüft, und die Aussichten für die Entwicklung dieser Kraftstoffe als Ersatz für Benzin, Diesel und Erdgas werden bewertet, um die negativen Auswirkungen auf die Umwelt zu verringern.

Keywords: _Kraftfahrzeugtechnik, Fahrzeug, Kraftstoff, Umwelt, Verbrennungsmotor, Strom, Energiequelle_

Sind synthetische Kraftstoffe die bessere Alternative zur Elektromobilität?

Elektroautos gelten als die Fahrzeuge der Zukunft, wobei sie nicht zwingend klimafreundlich sind. Synthetische Kraftstoffe hingegen können durch erneuerbare

Energien hergestellt und wie Benzin oder Diesel einfach getankt werden. Der Verbrennungsmotor könnte so überleben.

Das Auto der Zukunft stößt kein CO_2 aus und tankt Strom statt Benzin oder Diesel: Elektroautos sollen den Verbrennungsmotor ablösen und das Klima schonen. Dabei sind sie in der Regel (noch) gar nicht richtig klimafreundlich. Denn der genutzte Strom stammt lange nicht immer aus erneuerbaren Energien. Außerdem sind die verwendeten Batterien in der Herstellung und Entsorgung bisher durchaus klimaschädlich [1–3].

Synthetische Kraftstoffe, auch PtX-Kraftstoffe oder E-Fuels genannt, sind im Optimalfall hingegen annähernd zu 100 Prozent klimaneutral und können wie Benzin oder Diesel in Verbrennungsmotoren zum Einsatz kommen. Sind synthetische Kraftstoffe damit eine realistische Alternative zur Elektromobilität?

Was sind E-Fuels?

Der Name "E-Fuels" steht für "Electrofuels", also "Elektro-Treibstoff"- und dürfte etwas verwirren. Denn eFuels tankt man wie normalen Sprit an der Zapfsäule und nicht an der Steckdose. Aber: Bei der Herstellung kommt Strom zum Einsatz. Und zwar grüner Strom aus Sonnen- und Windenergie [4].

Für die E-Fuels Herstellung (abb. 1) braucht man regenerativen Strom, am besten überschüssigen Wind- oder Solarstrom, den das Netz nicht aufnehmen kann. Damit wird Wasser per Elektrolyse in Sauerstoff (O_2) und Wasserstoff (H_2) gespalten – das ergibt als ersten Grundstoff Wasserstoff. Im zweiten Arbeitsschritt wird dieser Wasserstoff mit Kohlendioxid (CO_2) verbunden, das zum Beispiel als Abfallprodukt aus anderen industriellen Prozessen abfällt oder aus der Umgebungsluft extrahiert wird.

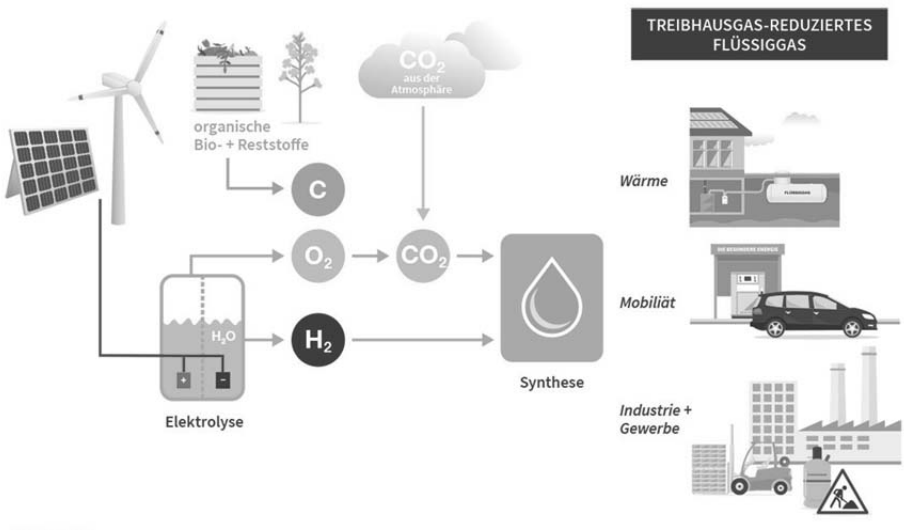

Abb. 1. E-Fuel Herstellung

Mögliche Endprodukte sind synthetischer Diesel, synthetisches Benzin und synthetisches Gas. Die Herstellung erfolgt derzeit noch in geringen Mengen, etwa in Forschungs- und Pilotprojekten. Die bekannteste Anlage steht im norddeutschen Werlte (abb. 2), wo Audi mit Industriepartnern klimaneutrales, synthetisches E-Gas produziert.

Dieses wird in das normale Erdgasnetz eingespeist und mit den Mengen verrechnet, die Kunden von Audi bzw. vom VW-Konzern in ihren Erdgasfahrzeugen tanken. Strombasiertes Benzin und strombasierter Diesel werden derzeit noch nicht in den Verkehr gebracht.

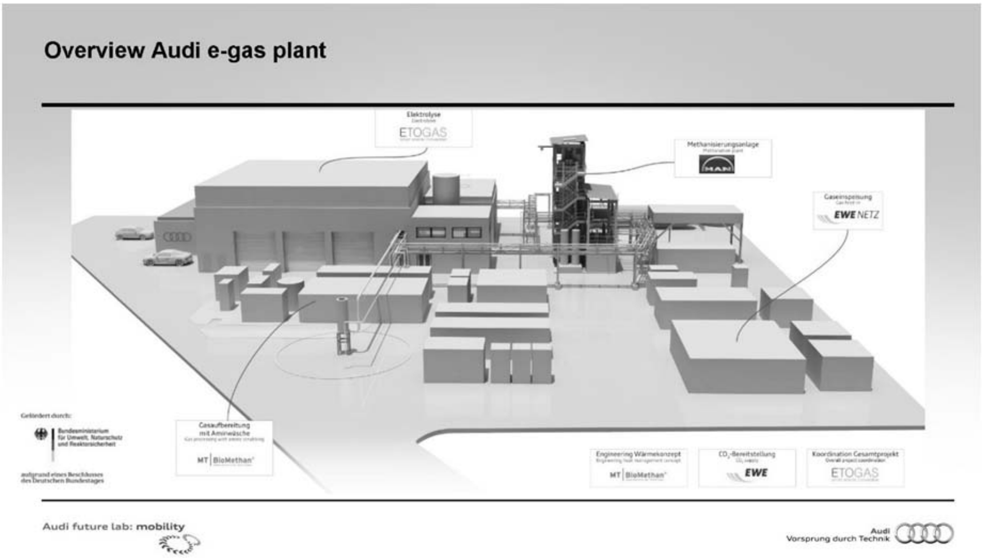

Abb. 2. Audi E-Gas Anlage (Wertle)

Der Nachteil von E-Fuels ist der folgende: der grüne Sprit ist zu ineffizient. So reicht die gleiche eingesetzte Menge Strom bei E-Fuels für 100 Kilometer, bei batterieelektrischen Autos für 700 Kilometer; der Wirkungsgrad von E-Fuels liegt bei etwa 15 Prozent. Der von E-Autos bei etwa 80 Prozent. Die Befürworter von E-Fuels entgegnen, die Effizienz ist gar nicht so entscheidend – da die eingesetzte Sonnen- und Windenergie ja ohnehin anfalle. E-Fuels sollen dort hergestellt werden, wo es Wind und Sonne satt gibt. Etwa in Afrika.

Außerdem haben E-Fuels andere Vorteile: sie besitzen eine viel höhere Energiedichte als Auto-Akkus oder gasförmig gespeicherter Wasserstoff. Das macht sie sehr ähnlich zu fossilen Kraftstoffen. Was bedeutet das? E-Fuels lassen sich über lange Distanzen kostengünstig transportieren, etwa von Tankschiffen und gut lagern – was mit Strom schwierig ist.

Synthetische Kraftstoffe sind noch weit von einer Markteinführung entfernt, jedoch laufen Forschungen dazu. Der Entwicklungschef von Porsche, Michael Steiner, sagt dem RND: “Wenn man die Bestandsflotte perspektivisch nachhaltig betreiben will, dann sind E-Fuels ein elementarer Bestandteil”. Porsche hat zusammen mit Siemens Energy den Bau der nach eigenen Angaben weltweit ersten kommerziellen Pilotanlage zur Herstellung von E-Fuels in Chile begonnen, wie die beiden Unternehmen im September mitteilten. Die Fabrik soll nahezu CO_2-neutrale synthetische Kraftstoffe herstellen. 2022 sollen erstmals rund 130.000 Liter erzeugt werden, welche in den eigenen Fahrzeugen mit Verbrennungsmotoren eingesetzt werden sollen. Die Wahl fiel auf den Standort in Chile, weil dort gute Windbedingungen herrschen.

Die Herstellung von synthetischen Kraftstoffen ist allerdings sehr aufwendig und teuer. Der aufwendige Herstellungsprozess wirkt sich allerdings auf den Preis aus. Ein Liter synthetischer Kraftstoff würde in der Herstellung momentan etwa 4.50 Euro kosten. Obwohl es schon viele Forschungen und Studien sind, die beweisen, dass es möglich ist, das Wirkungsgrad deutlich zu erhöhen, und der Preis in der Zukunft zwischen 1.20 und 1.70 Euro pro Liter sein könnte, bis jetzt eine Nutzung wohl im Flugzeug- und Schiffsverkehr wahrscheinlicher ist. Neben der Möglichkeit, CO_2 aus der Umgebung aufzunehmen sowie der klimaneutralen Herstellung und Verwendung (abb. 3), liegt in der Lagerung von synthetischen Kraftstoffen ein weiterer Vorteil: Sie könnten über das bestehende Tankstellennetz vertrieben werden und benötigen nicht mehr Raum als Kerosin oder Diesel. Damit kann der herkömmliche Tank genutzt werden.

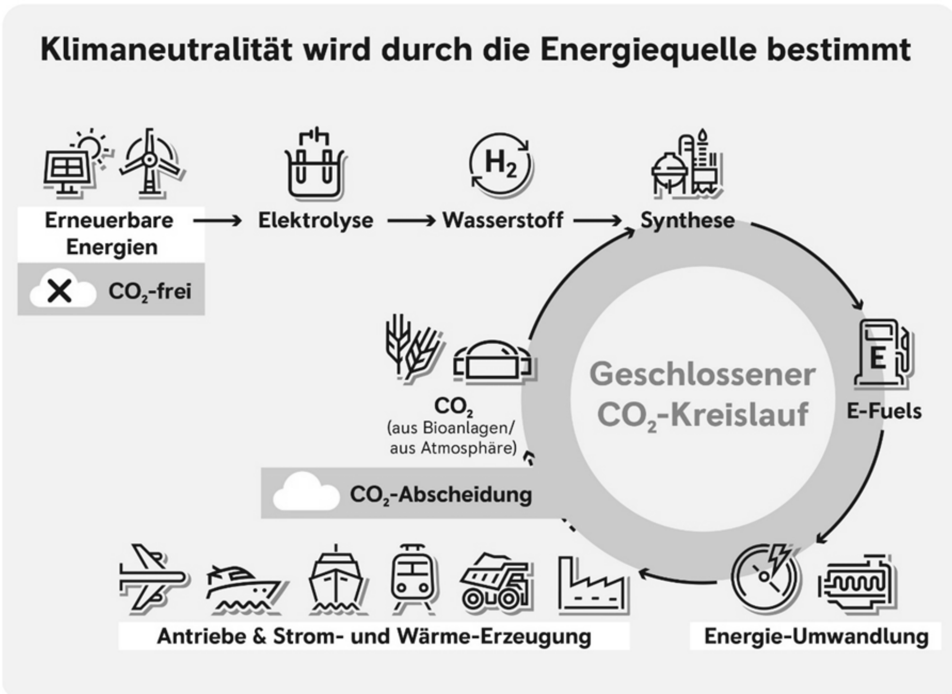

Abb. 3. CO_2 Kreislauf

Das Gewicht eines Elektrofahrzeugs nimmt mit einer ansteigenden Reichweite zu, da die Batterie entsprechend schwerer wird. Ein Elektromotor etwa bei einem Schiff oder Flugzeug ist also bisher eher undenkbar, da eine gewaltige Batterie nötig wäre, um eine übliche Reichweite zu erzielen. Das Gewicht von mit synthetischen Kraftstoffen betriebenen Fahrzeugen nimmt hingegen in Abhängigkeit von der Reichweite nicht wesentlich zu. Somit sind synthetische Kraftstoffe im Schiffs- und Flugverkehr denkbar, welcher kaum mit Elektromotor auskommen würde.

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Кавитация в центробежных насосах

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Кавитацией (или образованием полостей) называют процесс, когда в определенных местах рабочей жидкости образуются пузырьки пара. Они возникают, когда в жидкостной среде статическое давление, температура и давление насыщенного пара не соответствуют друг другу. После того, как статическое давление поднимается выше давления насыщенного пара в направлении потока жидкости, пузырьки пара сжимаются и лопаются — происходит имплозия.

Ключевые слова: *кавитация, центробежный насос, напорно-расходная характеристика, имплозия, пузырьки пара*

Kavitazion in den Kreiselpumpen

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Wenn sich in einer Flüssigkeit an bestimmten Stellen der Anlage Dampfblasen bilden, dann spricht man von Kavitation (Hohlraumbildung). Die Dampfblasen entstehen, wenn der statische Druck in einer Flüssigkeitanlage, die Temperatur und der Dampfdruck nicht zueinander passen. Nach dem Ansteigen des statischen Druckes über den Dampfdruck in der Strömungsrichtung, kommt es zu einer Implosion der Dampfblasen.

Keywords: *Kavitation, Kreiselpumpe, Netto-Positivsaugkopf, Imploion, Dampfblasen*

Kavitation oder Hohlraumbildung

Wenn sich in einer Flüssigkeit an bestimmten Stellen der Anlage Dampfblasen bilden, dann spricht man von Kavitation (Hohlraumbildung). Die Dampfblasen entstehen, wenn der statische Druck in einer Flüssigkeitanlage, die Temperatur und der Dampfdruck nicht zueinander passen. Nach dem Ansteigen des statischen Druckes über den Dampfdruck in der Strömungsrichtung, kommt es zu einer Implosion der Dampfblasen.

Zwei Grundtypen der Pumpenkavitation

Saugkavitation oder auch klassische Kavitation tritt auf, wenn sich eine Pumpe unter Niederdruck- oder Hochvakuumbedingungen befindet. Wenn die gepumpte Flüssigkeit in das Auge einer Kreiselpumpe gelangt, wird der Druck erheblich reduziert. In einigen Fällen ist der Druckabfall groß genug, um zu bewirken, dass die Flüssigkeit zu Dampf aufblitzt, wenn der lokale Druck unter den Sättigungsdruck für die zu pumpende Flüssigkeit fällt. Am Auge des Laufrads bilden sich Blasen oder Hohlräume, und anschließend bewegen sich die gebildeten Dampfblasen in Bereiche mit höherem Druck, wenn sie sich in Richtung des Pumpenauslasses bewegen. Im Hochdruckbereich wird die Dampfblasen fallen plötzlich an den äußeren Teilen des Laufrads zusammen. Dies kann zu erheblichen Schäden an allen beweglichen Teilen einer Kreiselpumpe führen.

Um diese Art von Kavitation zu vermeiden, muss der im System verfügbare Netto-Positivsaugkopf (NPSHa) höher sein als der erforderliche NPSH der Pumpe. Dieses Problem ist typisch für Saugkavitation und daher wird diese Art der Kavitation auch als unzureichende NPSHa-Kavitation bezeichnet.

Entladungs Kavitation tritt auf, wenn der Pumpenabgabedruck ist sehr hoch oder wenn die Entladungsströmung beschränkt und die Pumpe nicht verlassen kann (zB durch geschlossene Auslassventil verursacht). Ein extrem hoher Förderdruck führt dazu, dass der Großteil des gepumpten Fluids in der Pumpe zirkuliert.

Diese Art der Kavitation stammt aus zwei Quellen. Erstens wird diese innere Zirkulation (von Hochdruckzonen in Niederdruckzonen) mit hoher Geschwindigkeit durch das Spiel zwischen dem Laufrad und dem Pumpengehäuse gedrückt, was zur Bildung eines Niederdruckbereichs (aufgrund des Bernoulli-Prinzips) in welche Kavitation auftreten kann. Zweitens zirkuliert die Flüssigkeit in der Spirale der Pumpe und überhitzt sich schnel.

In beiden Fällen hat Kavitation ähnliche Folgen. Die Implosion von Blasen löst starke Stoßwellen aus, die zu vorzeitigem Verschleiß der Laufradspitzen und des Pumpengehäuses führen. Im Extremfall kann durch Ausstoßkavitation die Laufradwelle brechen [1].

Typische Ursachen fü r Kavitation

Im Folgenden werden die typischen Ursachen für Kavitation aufgeführt:

1. Die Pumpe läuft zu weit rechts oder links auf der Pumpenkurve im Diagramm.
2. Schlechte Saugbedingungen.
3. Verstopfung im Rohr auf der Saugseite.
4. Unangemessenes Rohrleitungsdesign.
5. Verstopfte Filter oder Siebe.

Kavitationsnummer

Die Kavitationszahl (Ca) oder der Kavitationsparameter ist eine dimensionslose Zahl, die bei Durchflussberechnungen verwendet wird. Es ist üblich, anhand der Kavitationszahl zu charakterisieren, wie nahe der Druck im Flüssigkeitsstrom am Dampfdruck (und damit am Kavitationspotential) liegt.

Die Kavitationszahl kann ausgedrückt werden als [2]:

$$Ca = \frac{p - p_v}{\frac{1}{2}\rho v^2},$$

wo: Ca = Kavitationsnummer p = lokaler Druck, Pa; p = Dampfdruck der Flüssigkeit, Pa; ρ = Dichte der Flüssigkeit, kg / m; v = Flüssigkeitsgeschwindigkeit, m / s.

Ein anderes Kriterium ist der NPSH-Wert (Net Positive Suction Head). Der NPSH-Wert entspricht der Energie einer Flüssigkeitssäule bei den vorliegenden Betriebbedingungen am Anschlussflansch. Der Wert ist immer positiv.

Es wird zwischen zwei NPSH-Werten unterschieden: NPSHA (Net Positive Suction Head Available): Dies ist der vorhandene Druck der Anlage bei Betriebsbedingungen als Höhendifferenz. NPSHR (Net Positive Suction Head Required): Dies ist der für den Betrieb der Pumpe erforderliche Druck als Höhendifferenz. Hierbei muss der NPSHA-Wert der Anlage immer ober halb des erforderlichen NPSHR-Wertes der Pumpe liegen.

Mechanismus und Gegenmaß nahmen

Wie man sich vorstellen kann nützt die Installation von Entlüftern oder ähnlichen Komponenten nicht zur Vermeidung von Kavitation, da solche nur das von außen eingedrungene Gas ausschleusen können, nicht aber die Ursache von Kavitation beheben können. Um die Enstehung von Kavitation zu vermeiden muss dafür Sorge getragen werden, dass die Bildung von Dampfblasen in der Pumpe ausgeschlossen wird.

Selbst wenn die Kondensattemperatur am Pumpeneintritt zunächst deutlich unter dem Siedepunkt liegt besteht immer noch die Gefahr von Kavitation, indem ein Teil der Flüssigkeit verdampfen kann. Die Verdampfung von Kondensat kann auftreten bei leichtem Temperaturanstieg oder Druckabfall, wenn der Dampfdruck schwankt, wenn verschiedene Verbraucher in einen gemeinsamen Kondensatsammler entwässern, wenn Bypassventile geöffnet sind oder wenn Leckagen in Kondensatableitern bestehen.

Um Kavitation zu vermeiden, ist die Kavitationszahl σ so groß wie möglich zu halten. Andererseits ergibt eine kleine Kavitationszahl eine hohe Energieausnutzung und kleine Abmessungen der Strömungs maschine. Folgende Maßnahmen verringern die Kavitationsneigung:

- niedrige Drücke vermeiden;
- Temperaturen nahe des Siedepunktes des Fluids vermeiden;
- dünne Schaufelprofile verwenden;
- kleine Anstellwinkel der Schaufeln wählen;
- abrupte Umlenkungen der Strömung vermeiden;
- Anströmkante abrunden.

Kavitationsschä den

Kavitation ist in vielen Fällen ein unerwünschtes Ereignis. Bei Kreiselpumpen verursacht Kavitation Schäden an Bauteilen (Erosion des Materials), Vibrationen, Geräusche und einen Wirkungsgradverlust.

Vielleicht das wichtigste durch Kavitation verursachte technische Problem ist die materiellen Schäden, dass Kavitationsblasen verursachen kann, wenn sie zusammenbrechen in der Nähe einer festen Oberfläche. Das Zusammenfallen von Kavitationsblasen ist ein heftiger Prozess, der stark lokalisierte Stoßwellen und Mikrojets erzeugt. Sie zwingen energetische Flüssigkeit in sehr kleine Volumina, wodurch Flecken hoher Temperatur entstehen, und diese intensiven Störungen erzeugen stark lokalisierte und vorübergehende Oberflächenspannungen auf einer festen Oberfläche. Anzeichen von Erosion treten aufgrund der Wasserschlagwirkung der kollabierenden Dampfblasen als Lochfraß auf. Es wurde festgestellt, dass die Kavitationsschadensraten schnell ansteigen mit der Erhöhung des Volumenstroms.

Weichere Materialien können auch durch kurzfristiges Auftreten von Kavitation beschädigt werden. Einzelne Gruben können nach einem einzelnen Blasenkollaps beobachtet werden. Daher werden für Kreiselpumpen härtere Materialien verwendet. Bei den härteren Materialien, die in den meisten Anwendungen verwendet werden, kann die zyklische Beanspruchung aufgrund wiederholter Zusammenbrüche zu einem lokalen Versagen der Oberflächenermüdung führen. Kavitationsschäden an Metallen haben daher normalerweise den Anschein eines Ermüdungsversagens [3].

Implosion

Eine Implosion ist im Gegensatz zur Explosion ein Zusammenbrechen nach innen. Wenn die Kavitationsblasen zusammenfallen, zwingen sie energetische Flüssigkeit in sehr kleine Volumina, wodurch Flecken mit hoher Temperatur erzeugt werden und Stoßwellen emittiert werden, von denen letztere eine Geräuschquelle sind. Obwohl das Zusammenfallen eines kleinen Hohlraums ein Ereignis mit relativ niedriger Energie ist, können stark lokalisierte Zusammenbrüche Metalle wie Stahl im Laufe der Zeit erodieren. Die durch das Zusammenfallen von Hohlräumen verursachte Lochfraßbildung führt zu einem starken Verschleiß der Bauteile und kann die Lebensdauer eines Propellers oder einer Pumpe erheblich verkürzen.

Auch in einer Umwälzpumpe kann es aufgrund einer Kavitation zu einer schlagartige Kondensation der entstandenen Dampfblasen (Mikroblasen aus Luft und Dampf) kommen. Diese Hohlraumbildung führt zum Abtrag des Materials an den betroffenen Stellen. Durch die Implosionen kann es auch zu einer Leistungsminderung in der Förderhöhe, zu unruhigen Laufeigenschaften, zum Abfall des Wirkungsgrades und zu Geräuschen kommen. Die gleichen Effekte können auch an Schiffsschrauben und Hochleistungsventilatoren auftreten [4].

Nü tzliche Anwendung der Hohlraumbildung in Technik

Bei der Reinigung von Gegenständen in sogenannten Ultraschallbädern, in denen durch Kavitation Oberflächenschmutz entfernt wird. Die Kavitation wird hierbei durch Ultraschall. Durch den Einsatz speziell abgestimmter Reinigungsflüssigkeiten und eine höhere Temperierung des Bades kann der mechanische Reinigungseffekt des Ultraschalls noch verstärkt werden.

Im militärischen Bereich werden Torpedos eingesetzt, die sich mit sehr hoher Geschwindigkeit unter Wasser in einer künstlich erzeugten Kavität bewegen. Diese Technologie wurde zuerst von der russischen Marine zur Anwendungsreife entwickelt und ist unter dem Begriff Superkavitation bekannt geworden.

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