Mathematical Methods in Designing an Autonomous Means of Automating the Work of a Production Facility

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***Abstract*— A comparative analysis of various mathematical methods used in the design of specialized autonomous means of automation of transportation processes in the work of production facilities is carried out. The advantages of using machine learning are demonstrated. Attention is focused on the features of the use of machine learning in the design of autonomous vehicles. Examples of methods for evaluating the effectiveness (accuracy) of the results of machine learning are given. A practical example is considered, based on the results of which one can talk about the effectiveness and appropriateness of using machine learning to automate the work of a production facility.**

***Keywords*— mathematical methods; design; autonomous means; automation; automation of production; machine learning; efficiency; accuracy**

I. Introduction

Relatively recently various "smart" tools began to be introduced into the everyday life of a person. For example, smart systems work in smartphones and can give advice, for example, while planning routes. Trained software and hardware systems cannot only help any single person: they have long been used in industry. In the program code of complex production plants intellectual analysis tools are implemented to additionally control the technological process and prevent extraordinary emergencies. Despite the widespread use, such solutions are developed by single companies. The level of expertise of such companies is quite high; therefore, the cost of the tools they develop is unacceptably high.

The mathematical apparatus used in intelligent systems is hierarchically complicated with increasing complexity of the systems. Nowadays with accumulated information about intelligent systems, one can look at mathematical methods «from general to particular». Presented in the market of high-tech IT solutions, sophisticated "smart" systems can give an impetus for solving local problems. However, all the details of implementation, of course, are carefully concealed and sometimes constitute a trade secret.

Of particular interest at first glance is the simple task of designing autonomous tools. Such means may include the aforementioned production machines, conveyor production lines, means of monitoring processes (processes like technological, biological, economic, etc.). A large number of developments are carried out in the field of autonomous robotics. The geometric dimensions of robots vary from units to hundreds of centimeters.

The most popular are autonomous vehicles (vehicles or means of transportation). For example, autonomous cars are already used to transport people. A sufficient level of security is provided while transporting people. Only a few people can become users of such cars.

As for industry and the sphere of production, then autonomy is present not only in technological installations, but also in the process of transporting special cargoes. A big role is played by transportation of two types:

- Territory of the production premises, whether it is a warehouse, manufacturing facility, etc.
- Between the above-mentioned premises: only between warehouses, between warehouses and manufacturing facilities, etc.

A cargo can be considered not only as separately taken details, but also as an entire manufacture racks. Nuance in solving such problems is the choice of algorithmic, software and hardware implementation means.

In the next sections, we will try to answer the question: "What tasks are considered at all?"

II. Classical Problem of Managing the Production Process

Production site chief have a daily production plan. The plan is compulsorily developed based on any system of enterprise resource planning – *ERP-system*. ERP-systems have long been used in many enterprises and can manage resources for all manufacture processes, for example:

- administrative;
- economic;
- work with suppliers;

- human resources management.

Further, the daily plan is divided into executors by the production site. For each employee individual production plan is formed.

To implementation of the established production plan, in general case, the employee requires consumables, components or raw materials (depending on the type of production). Usually for getting the required amount of expendable material, either the employee personally need to receive them, or special people were engaged in the delivery of raw materials to the workplace.

Using a autonomous delivery tool for expendable material will lead to a useful effect (for example, [1]):

- reduction of transportation time and time of preparation for work;
- increase in the volume of work performed;
- minimization of the human factor.

What mathematical methods are needed to solve this problem?

- Optimization methods.

As for to resource planning, optimization methods are mainly incorporated in the ERP system. As for planning the trajectories of the movement of autonomous means, the optimization methods are implemented in logistics.

A large role is played by the methods of multi-purpose optimization [2], when it is necessary to seek compromises between several goals. For example between the complexity of the model and the accuracy, sensitivity and specificity.

- Methods of queuing theory for planning the provision of resources to several employees at the same time and planning the processing of several autonomous transporters.

III. Designing of autonomous mean

Autonomous various complexity tools are require not only well-considered technical solutions, but also the corresponding software. Very often developers try to reduce the cost of devices, saving on technical equipment.

Pursuing the goal of saving on technical equipment, have to solve complex tasks of selecting base of components. Sometimes, the simpler the technical solution seems, the harder in really is software.

When designing an autonomous device have to solve a number of specific software development problems. The following is a list of only some of them:

- Indoor navigation, for example, in the absence of GPS, GLONASS signals.
- Simultaneous localization and construction of the map, the so-called SLAM tasks (*SLAM – Simultaneous Localization and Mapping).* SLAM is a method used in mobile autonomous tools to build a map in an unknown space or to update a map in a previously known space while monitoring the current location and the distance traveled. Popular methods for the approximate solution of this problem include a particle filter and an extended Kalman filter.
- Reaction to obstacles.

The obstacles are divides into two types: static and dynamic. Static obstacles are those that already taken into account when building a map, dynamic ones are those that need to be analyzed in real time. For describing the reaction on obstacles in most cases the methods of machine learning are used.

To analyze dynamic obstacles it is not enough to have sufficiently sensitive sensors. Sensors allow only recording the appearance of an obstacle in time. It is necessary to analyze the obstacle that has arisen. The analysis can be aimed at classifying the obstacle. For unambiguous classification it is necessary to have information about existing classes of objects in the production premise. The object database should be relevant and updated on time.

When classifying obstacles, artificial neural networks can be used that can give as output a probability distribution. Probabilities at the outlet of the network will mean the probability of belonging to a particular class of objects. The use of classifying neural networks may not be sufficient. For example, the obtained probability of belonging to a certain class of objects is 65%. For special industries, such a probability may be the cause of an insufficient level of confidence in the result.

To clarify the questionable results contextual analysis of the premises taking into account the properties of objects can be used. In this case, a prerequisite is the availability of a priori information, how objects are interrelated with each other. A priori information can be represented in a matrix form, where the columns and rows are objects, and at the intersection the characteristics of the objects interrelationships indicated. This information is most conveniently kept in the database of objects together with a description of the properties of objects.

Context analysis can be implemented both based on neural networks, and based on methods and models of fuzzy logic. When developing algorithms for contextual analysis, it is necessary to consulting with expert group. Experts will help to form a correct idea about the objects of the production premises.

It is necessary to highlight an important point, which is a particular danger for an autonomous transporter is the loose obstacles. The open question is how accurate should the sensors be to reliably determine the radius of danger depending on the loose material.

The state of the surrounding objects, their geometric parameters and other similar information can be adjusted and updated using the data from several sensors. Algorithms for data merging from different sensors are a task for separate consideration.

Moreover, for successful deployment of autonomous transport on the territory of a production facility it is required:

1. Develop and implement standardized racks.
2. To develop a system of control points. It is important to determine the possibility of applying visual markers or installing radio or RFID tags indoors.
3. To implement a system of control points.
4. Allocate working time for approbation of the test sample, etc.

IV. Autonomous Transportation by the Example of Amazon Robotics Company

To describe the engineering of the company Amazon Robotics need introduce the generally accepted notions. Automated Guided Vehicle – AGV is a mobile robot used in the industry for the movement of cargoes, commodities and materials in the production process or in the warehouse household [3]. The device is equipped with a special system that allows navigating in space. Such robots can be used in medical institutions to serve patients with limited mobility.

Since 2003 Amazon has been developing robotic storage facilities. A fundamentally new approach was developed in comparison with conveyors and loaders.

In addition to the already mentioned ERP system, the company uses a modern WMS system (Warehouse Management System) of its own development [4]. Based on the above systems, a Flexible Manufacturing System (FMS) is built [5], [6].

A. A informative description of the solution

Units of storage (raw materials, components, etc.) are in special storage modules. Each storage module has an identification number.

The task is to deliver a certain module to a given place. A request for transportation is sent to the database of the system. The program finds the nearest transport device and directs it to the storage module.

With the help of special visual markers deposited on the floor of the warehouse, the devices can navigation and transport. Collisions of robots are excluded by means of special sensors and software algorithms.

Upon reaching the storage module, the robot is should be located in a certain way under the module and lift it up. The robot then moves the module to a predetermined location for further processing.

B. Some used mathematical methods

In the program code of autonomous transporters the storage module identification algorithms, [7] such as the Principal Component Analysis (PCA) method and the Support Vector Method (SVM) are used.

Q-learning is used as routing algorithms. Q-learning is a method of machine learning with reinforcement in conditions of environmental uncertainty [8], [9]. The main problem to be solved is the routing of the shortest routes. In [8], [9] the route is defined as the shortest route based on the amount of travel time and the amount of time the autonomous device waits.

If consider the shortest route as a distance, then we can use a specialized procedure for problem solving which is named as the branch and bound method [10]. The method is used to minimize the total distance traveled by vehicles in accordance with the constraints (under the assumption that the resulting network has only one connected component).

Technical systems tend to failure at an inopportune moment. Even in abnormal situations the ability of the automated system to work properly should be preserved. To prevent emergencies, operative control measures should apply. For such purposes expert systems are used based on heuristic output rules [11], [12].

An important task is to determine the behavior of an individual device in the flow with other devices [13]. Other important tasks, such as designing the direction tracks, determining the requirements for vehicles, positioning in standby mode, battery management and resolving the deadlock situation, are considered in [14].

It is sufficient effectively to use several mathematical methods at once. For example methods for pattern recognition, construction of expert systems, artificial neural networks, fuzzy systems and modern hybrid methods of artificial intelligence (AI) in [15] are considered as successive elements of the production process.

A detailed description of the theory of AGVs can be found in the [16], [1].

The accuracy of robot positioning is considered in [17]. In [17] said about the high level of accuracy of the device with sufficient level of autonomy. Autonomy is achieved through the introduction of forecasting modules, environmental perception, path planning and additional tracking of own path. At the same time, the amount of manual work required in establishing a priori knowledge of the environment is decreasing.

V. Conclusion

The present state of the matter was investigated. The urgency of developing independent means of transporting production facilities was determined. A thorough review of the subject area which is the task of automating the work of production facilities is considered. The main points of view on the corresponding process of developing autonomous means are considered.

Various mathematical methods used in the design of specialized autonomous means were proposed. Special attention was paid to the applicability of AGV-tools for automation of transportation processes in the work of production facilities. The main advantages of using machine learning were demonstrated. The means of refinement of the results of intellectual analysis of surrounding objects were proposed. It is noted that when developing a database of objects it is necessary to conduct active work with subject area experts.

An example of the advanced use of autonomous transporters for warehouse automation was considered. Based on the results of the considered example, one can talk about the effectiveness and appropriateness of using machine learning to automate the work of a production facility.

It should be noted that not only the Amazon project considered in the work is known to the world, for other examples see [19]. Other reviews on the design of stand-alone automation devices for industrial premises can be found in [18], [14].

The authors have received a scientific background for further specific scientific development. The immediate task for future consideration is the selection of scientific and technical equipment and software development planning.

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