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Logic-based artificial intelligence in systems for monitoring the enforcing traffic regulations

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Abstract. The paper touches upon the issues of monitoring and assessment of driver's actions during driving. Its key idea is to prove that currently there are all necessary conditions to develop control systems of traffic regulations based on artificial intelligence with logical reasoning. The article gives a detailed analysis of advanced driver-assistance systems from the world's leading companies and pays attention to the advantages and disadvantages of such solutions. As an engineering approach to solving the identified problems, it is proposed to use Mivar expert system. The purpose of this decision is to monitor the enforcing traffic regulations and inform the driver about violations. The article proposes the concept of practical implementation of Mivar system included in the driver assistance system. We conclude that Mivar approach provides excellent opportunities for creating the control system for monitoring the enforcing traffic regulations. The proposed solution can be used for reducing the number of accidents caused by drivers.

1. Introduction

The development of science and technology, the continuous improvement of technology and its distribution in industry and in society offer humanity a wide range of opportunities. However, despite the positive aspects, technological progress can have a negative impact on human security. For example, everyone knows the advantages of modern cars, but at the same time, according to The World Health Organization (WHO), car accidents are among ten most common causes of death in the world. In order to improve road safety indicators, various measures are applied, including the tightening of laws regulating the behavior of participants of traffic and the updating transport infrastructure. In Russia by the end of 2016, the number of road traffic accidents (RTA) was over 170 thousand. 90% of these cases were due to violation of traffic regulations by people (drivers and pedestrians). The total number of victims was about 220 thousand people. Improving traffic safety is a critical component to saving lives on the roads.

It is important to note that one of the most radical proposals to prevent accidents is the complete exclusion of people from the process of driving, i.e. the creation of a fully autonomous unmanned transport. Of course, people will design such cars and develop software for them, but they will not directly participate in the process of driving, except, perhaps, some exceptional cases and situations. Moreover, in some promising models of unmanned vehicles there is no steering wheel or pedals for a person.

In general, all specialists understand the way of creating unmanned vehicles, which will include various stages from full human control, through the joint interaction of a person with an automatic control system of the car and to a fully autonomous unmanned vehicle driving on highways (analogue of the "railway"), and secondary roads, and off-road in different weather conditions. And it is generally accepted that the system (complex of systems) of controlling a car should include, at least, an automatic system of trajectory control (holding in the lane, keeping the distance in the stream, etc.), a system of technical vision (collecting information about the road situation in real time), a navigation system (routing) and a Decision Support System to enforce traffic regulations. Of course, there are other important components and systems, for example, interaction of the car with the "intelligent road environment", which will inform about traffic signs, difficulties, weather, etc. via radio channels to an unmanned vehicle, and it will greatly facilitate the collection of information about the road situation and even could eliminate the need to create a complex system of technical vision. For example, in cities and major highways, instead of the usual traffic signs and traffic lights, radio transmitters which report on restrictions and possible routes, distances to obstacles, will be installed. They also will get data from stationary cameras about the road situation and emerging obstacles in real time. In any case, for an unmanned vehicle, it is necessary to create a Decision Support System to enforce traffic regulations. It is generally recognized that for some time the technology of unmanned vehicles will be used in a man-machine mode. For legal permission to use fully unmanned vehicles it is necessary to carry out testing in an automated mode, when a person at any time can interfere in driving. On the other hand, for example, DSS TR can be installed in conventional vehicles and help human driver enforce traffic regulations or monitor the driver's behavior. Many researchers believe that even now the electronic system of the car can "set fines" to their owners-drivers in case of violation of traffic regulations. It is only necessary to regulate the legal aspects, but there are already precedents with stationary automatic cameras, which monitor the enforcing traffic regulations, and "automatic" issuing of fines.

Thus, on the basis of DSS TR a new class of devices can be created– automatic autonomous control systems of enforcing traffic regulations. On the one hand, these control systems will monitor and assist drivers, and on the other hand, such control systems in real traffic conditions will be able to prove the possibility of creating and practical application of DSS TR for fully autonomous vehicles. From a scientific point of view, this is one technical system that will have two purposes:

1) Control system of traffic regulations and driver assistance;
2) DSS TR for fully autonomous cars.

Consequently, the subject of the development of control systems of enforcing traffic regulations based on technologies of logical artificial intelligence is relevant, feasible and practically useful [1].

2. Overview of existing solutions in the field of driver assistance system and AI

Automotive companies (Volkswagen, Tesla, Mercedes-Benz), engineering centers (Google, Siemens, Baidu), universities (Stanford University, Massachusetts Technological Institute, University of Minnesota) and many others are actively engaged in the development of intelligent control technologies for autonomous wheeled vehicles [2–4]. Active work is underway in the field of driver assistance systems, examples of which are intelligent driver assistance systems: Mobileye, Audi Driver assistance systems and Opel SAFETEC. The decision from Mobileye is a hardware and software complex that allows recognizing traffic signs and informing about exceeding the permitted speed. An audio Driver assistance system is a serial product of autopilot in road traffic, which is focused on helping a driver in everyday situations: holding the lane, adaptive cruise control and automatic traffic in traffic jams. Opel SAFETEC is the representative of the integrated security system that combines and coordinates all the systems of active and passive safety, which allows you to recognize traffic signs, monitor the surrounding traffic situation and warn about exceeding the permitted speed. To make driving comfortable, these systems continuously evaluate the road environment with the help of numerous sensors installed inside and around the vehicle. Navigation tools and computer vision are also used for the precise orientation in space.

Now the existing driver assistance systems are quite expensive and therefore they are not installed on all vehicles. But such systems implement mechanisms to maintain a safe distance to the car in front, hold the lane and prevent violations of the speed limit. However, they do not fully solve the problem of preventing traffic violations. First of all, this is due to the fact that these systems do not have modules for assessing the driver's actions for consistency with traffic regulations. Firstly, we are talking about the control of the sequence of actions of the driver and his making difficult decisions, because “simple” traffic violations: journey on prohibited signal of a traffic light or sign; speeding, etc. are easily detected at the “reflex” level of AI systems, for example, with the help of different neural networks or methods of “comparison with decision templates”. When making decisions on some sequence of actions (driving through the intersection, overtaking and lane change, interaction with other drivers, decision-making in non-standard situations, etc.), the driver actually builds an algorithm of his actions in real time and in a specific traffic situation. These processes are already being investigated at the “logical” level of AI. It is known that the task of constructing algorithms of actions is complex, important for robots and depends on the computational complexity of the methods of logical inference based on the production rules of the “If – Then” format. In addition, the lack of driver assistance systems of “logical” level is largely due to the fact that the creation of such systems must take into account the following requirements:

- The possibility to adapt the product to the legislation of the countries in which the vehicle is planned to operate;
- The flexibility of updates when changes are made by the regulatory authority in the legislative framework;
- Economic accessibility of the technical platform for the owner of the vehicle.

The developers plan to solve the above-mentioned requirements during the implementation of unmanned vehicles. However, it is now possible to create modules that meet the above requirements and implement them into existing driver assistance platforms. Mivar approach can be the beginning for the creation of a logic-based intelligent system of monitoring the enforcing traffic regulations.

3. Mivar approach to the creation of logical AI

Mivar approach is implemented at the logical level of AI and is based on the idea of combining products and Petri nets. In 2002, it was theoretically shown that the logical inference on products presented in the format of Mivar bipartite oriented networks is performed with linear computational complexity. In 2007, the transition from poorly formalized anthropomorphic terms of artificial intelligence to active reflection theory was substantiated, in which a qualitative scale of “intelligence” of a human and self-organizing software and hardware complexes was proposed. It is important to note sufficient versatility of Mivar technologies that solve problems at a qualitatively new level in the field of AI [5], and a patent on a logical inference in Mivar knowledge base [6] with linear computational complexity was obtained. Autonomous vehicles deal with the problem of creating autonomous intelligent robots for which Mivar technologies were proposed to apply even in 2004 [7], and later the possibility of creating autonomous intelligent robotic systems (IRS) was shown [8].

For further study, it is important to emphasize that in January 2017, in practice, an unmanned autonomous car with a logical AI was demonstrated [2, 9], in which, on the basis of three laptops, it was assembled:

1) a reflex trajectory control system;
2) a simplified system of technical vision;
3) Mivar decision support system with a fairly simple logical model of traffic in the city.

Russian scientists from Moscow Automobile and Road Construction State Technical University take active part in Mivar DSS studies, they developed algorithms for driving an autonomous car as part of intelligent transport systems [10], also, the choice of key technologies for the functioning of the system of inter-object interaction of intelligent vehicles was validated, the problems of determining the mutual position of moving vehicles were investigated, a system of inter-object interaction of intelligent cars was developed, the possibilities of using onboard multiplex networks of motor vehicles by means of road tests and automation of traffic control were shown [11].

Thus, proper intelligent autonomous robots and unmanned vehicles have become a reality through the use of Mivar decision support systems. For example, to calculate the algorithms of service robots [12] and to plan the movement of mobile robots [13] Mivar models, which contain from 250 to 350 production rules, are applied. According to the experts, the model of a journey of a crossroad for an unmanned vehicle will exceed 300 regulations in Mivar network.

Currently, Mivar approach is developing in Bauman Moscow State Technical University as a part of the study of hybrid intelligent information systems [14] with the description of the subject domain in the formalism of the metagraph data model [15] and intelligent systems [16]. Structural development of Mivar approach using the classes and relations was performed, the advantage of Mivar approach over ontologies and cognitive maps was shown [17], Mivar logical inference machine [18] was implemented for the development of various systems using automatic routing of logical inference in Mivar knowledge base [19] on the basis of the logically critical systems (Razumator) [5].

The subject domain of the enforcing traffic regulations is closely related to the analysis of various road accidents, so it is important to note the work of D.A. Chuvikov about the creation of Mivar expert system (ES) “Accident motor vehicle accidents” [20-21], the use of expert modeling in obtaining new knowledge by a person, the practical use of ES “Accident Analysis” for accident analysis and solving the tasks assigned to the forensic center [22-27]. The versatility of Mivar ES shows the possibility of modeling the behavior of an autonomous robot-guide in the environment of V-REP, analytical modeling of a distributed system of data processing method in a background thread and rationale for the selection of software tools for solving problems of mass service [28].

Thus, Mivar technologies allow creating algorithms based on active learning evolutionary bipartite network, controlled by the input data stream. This makes it possible to present the accumulated knowledge in the form of sets of modules, services and procedures, thereby ensuring the properties of scalability, adaptability and flexibility which are necessary for the construction of control system of enforcing traffic regulations. Let us turn to the description of the conceptual model of Mivar system of enforcing traffic regulations.

4. The concept of creation of Mivar control systems for monitoring the enforcing traffic regulations

To solve the problem of informing the driver in real time about the violation of the provisions of the traffic regulations there is an offer to implement Mivar control system (MCS) based on a software product “Razumator” [5]. The MCS is an integral component of the driver assistance system. Mivar system storage is a set of models. Each model describes a relatively simple subject domain: movement in residential areas, passing crossroads, crossings, etc. The structure of the MCS is shown in Figure 1.

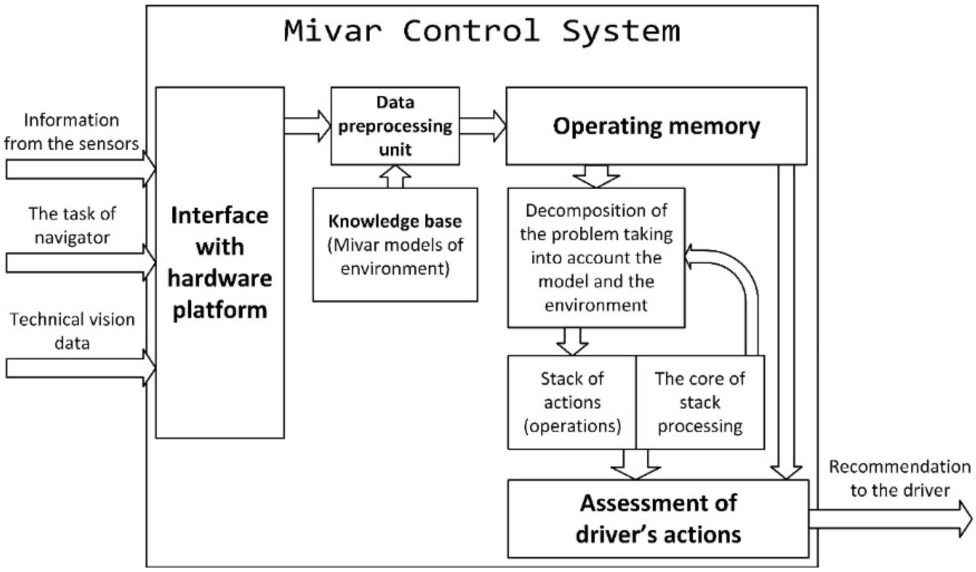

Figure 1. The structure of the MCS.

According to the scheme, the input of the system receives data recognized by vision systems, sensors of the car and the task of the navigator. The data of the external environment is converted into the object format of Mivar model environment. Formalized parameters are stored in the working memory – the memory area, which contains a lot of facts describing the current state of the subject domain, i.e. the traffic situation. According to the obtained factors with the help of Mivar model of the subject domain the algorithm of maneuver is constructed, each step of which is put onto the stack of actions. The resulting set of steps is compared with the actions of the driver and the conclusion is drawn about their consistency with traffic regulations. Let us describe the structure of the MCS in terms of Mivar computing.

M – Mivar multidimensional space. It represents a set of axes, points of space and their values. We select in this space a set of axes $X = \{x_n\}, n = 1..N$, where N is the dimension of M. Let $Q_n$be the set of elements $x_n$axis, that:

$$\forall x_n \exists Q_n = \{q_{n_{i_n}}\}, n = 1..N, i_n = 1..I_n, \tag{1}$$

where $q_{n_{i_n}}$ – the element of axis x_n, I_n – the dimension axis x_n.

The set Q_n forms a multidimensional space: $M = Q_1 \times Q_2 \times ... \times Q_n$. In space M, we denote point$m_{i_1,i_2,...,i_N} \in M$ with coordinates $(i_1, i_2, ..., i_N)$. Let $c_{i_1,i_2,...,i_N}$ be point value $m_{i_1,i_2,...,i_N}$. Then $C_M = \{c_{i_1,i_2,...,i_N}\}$ - the set of values of points in the multidimensional space M. Thus, $C_M$is a representation of a set of facts known about the subject domain in a multidimensional space M.

To transfer from multidimensional space of points in the space of values of points we define the ratio

$$\mu: C_y = \mu(M_y), \tag{2}$$

where $M_y \subseteq M, M_y = Q_{1y} \times Q_{2y} \times ... \times Q_{Ny}$ and $Ny \leq N$.

From the point of view of the multidimensional space M, the traffic situation can be represented as follows. A set of axes $A \subset X$ is the mapping of a subject domain to multidimensional space. For example,A_1– traffic light,A_2– prohibiting signs and A_3– interference on the left.The composition of objects A, which is monitored, is determined on the basis of the amount of data required to make a decision on driving, agreed with traffic regulations. Elements of multidimensional space axes will be a set ofQ_A, which consists of variable attributes of objects A.For A_1axis, the attributes can be: traffic light performance (on/off), signals of the main and additional sections. The $C_M$set in this case will display the current state of the road situation.

To describe a model of a subject domain in Mivar space, it is necessary to select three axes:

- V – the axis of the elements (objects);

- S – property axis;
- O – the axis of relations.

The elements of the sets V, S and O are independent and form the space VSO. Then space M is represented by a tuple of the form:

$$< V, S, O >. \tag{3}$$

In the multidimensional space VSO in automatic mode Mivar bipartite network in formalism $< P, R >$ (parameters and rules) can be built, in which

- the space objects will correspond to the network settings;
- the relations of space will comply with the rules of networking;
- the properties of the space will correspond to the restrictions of the rules of networking.

The data representation form $< P, R >$ is called Mivar network, in which, on the basis of a logical inference with linear computational complexity, algorithms of "correct" actions of the driver (or DSS of the unmanned vehicle) with enforcing traffic regulations will be automatically built. Then the traffic control system will compare the algorithms with the "performed" actions of the driver. In case of driver errors detection, Mivar control system will give hints to the driver. And in case of a fully unmanned vehicle, Mivar control system will act as a DSS system and drive the car instead of a person.

Having an example of crossing an uncontrolled intersection, we will get acquainted with the work of Mivar network, which evaluates the actions of the driver. Let car A equipped with a control system of enforcing traffic regulations plan to make a left turn (see Figure 2).

When you turn left oncoming cars and cars traveling to the intersection on the right will be obstacles which you need to give way. Also, when crossing the pedestrian crossing, pedestrians must be allowed in first. Under these conditions, the driver of car A is allowed to perform the maneuver.

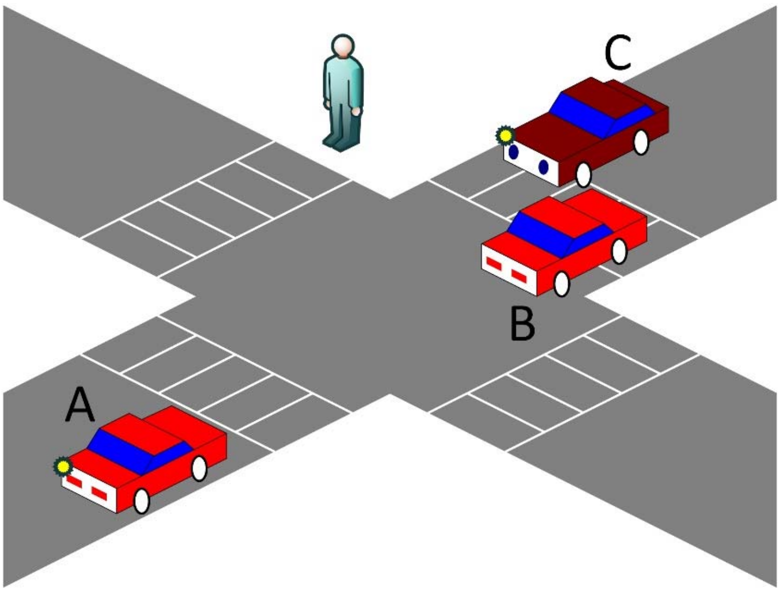

Figure 2. The subject domain "Uncontrolled intersection".

In order for Mivar system to assess the traffic situation, it is necessary to obtain the following data from the sensors of the car:

- P_1 –the task of the navigator (in this case, "turn left");
- P_2 –the status of the roads (current and target road);
- P_3 – obstacles (vehicles at the intersection);
- P_4 –information about pedestrians.

$$P_1, P_2, \dots, P_4 \in V \tag{4}$$

An example of the parameters describing the set P_4 is shown in Table 1.

Table 1. The parameters describing the set P4.

Name	Description	Valid value
Current road	Pedestrians are at a pedestrian crossing in front of the intersection	Yes/No
Target road	Pedestrians are on the pedestrian crossing after the intersection	Yes/No

To link the collected parameters, the algorithm uses R_1, R_2, and R_3 relationship groups and TP_1 intermediate indicators (a list of objects to observe) and TP_2 (obstacles on the target path).

$$TP_1, TP_2 \in V \text{ and } R_1, R_2, R_3 \in S \qquad (5)$$

For the desired parameter in the conditions of a given subject domain, we take the parameter RES (a set of recommended actions) and RES ∈ V.

The resulting Mivar network for assessing the actions of the driver of a vehicle A will look as it is shown in Figure 3.

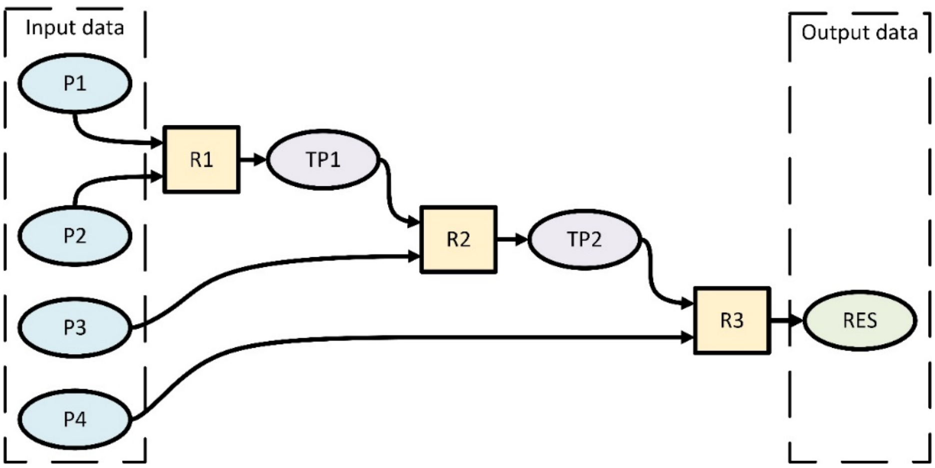

Figure 3. Algorithm graph.

The regulations and parameters of road traffic developed in advance are entered into Mivar knowledge base (another name: Mivar database and rules). According to the acquired knowledge base, recommendations for driving in the current traffic situation are formed depending on the signals transmitted to Mivar traffic control system from the vision system and other data collection systems. It is important to emphasize that for teaching Mivar knowledge bases it is necessary to create formal descriptions of subject domains in the formalism of bipartite oriented Mivar networks, but these issues are investigated in other works. It is important to remind [5] that three software products have been developed for: Expert systems – Wi!Mi Razumator [29]; Understanding the meaning of texts - Tel!Mi; the Decision Support System for autonomous robots – Robo!Razum. WiMi! Technology is used in Tel!Mi to understand the meaning. Product Tel!Mi using texts of instructions allows automatically teaching Wi!Mi Razumator and Robo!Razum. Together, these products can be used for the Internet of Things (IoT) and other cyber-physical systems, as Mivar products Wi!Mi, Tel!Mi, Robo!Razum can work on one common computational module “processor-memory” [5].

Thus, all the prerequisites have been done to create Mivar control systems of enforcing traffic regulations on the basis of Razumator and expert systems that can be used both for Driver Assistance systems and Decision Support systems of unmanned vehicles.

5. Conclusion

One of the most important components of saving lives on the roads is to improve road traffic safety by means of enforcing traffic regulations by drivers. Mivar technologies of the development of expert systems based on logical inference machine Razumator are capable of processing in real time the information received from the system of technical vision about the road situation and build algorithms of the driver's actions that are fully consistent with traffic regulations. Thus, currently, there are all necessary modules to create Mivar control systems of enforcing traffic regulations on the basis of Razumator and expert systems that can be used for driver assistance systems. Such systems will prompt the driver the maneuvers allowed by traffic regulations, and in case of violation of traffic regulations will inform about the violation. In case of legislative authorization Mivar control systems of enforcing traffic regulations will inform state body about the violation and fine a driver similar way to the existing complexes of fixation of violations of traffic regulations. Mivar control system of traffic regulations will be installed in cars to help drivers and evaluate their actions through the whole volume of traffic regulations, in contrast to existing systems which are able to capture only the “simple” violations of the regulations (one rule “If-Then”).

Mivar approach has a high potential for the evolutionary development of software and hardware systems. Therefore, experience and knowledge gained during the development of driver assistance systems (MCS of enforcing traffic regulations) will be further used in the creation of completely autonomous unmanned cars. It is important to note that the powerful tools of Mivar Wi!Mi Razumator, Tel!Mi, Robo!Razum, Mivar scalability models of knowledge and small hardware requirements allow you to get a low cost of MCS TR as well as easily and quickly adapt the product to the legislation of the countries in which you plan to operate the car.

The proposed concept of constructing Mivar control systems of enforcing traffic regulations meets the requirement of economic accessibility of the product for a wide range of buyers. MCS TR can be embedded in new cars in factories or can be installed as additional equipment in the cars which are already in use. Due to the high computational power of Mivar Razumators, there are big opportunities for implementation of high-speed driver assistance systems and decision support systems for unmanned vehicles; this is especially important for real fast-changing road conditions.

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