Creation of autonomous groups of combine harvesters and tractors for agriculture based on the Mivar decision-making systems "ROBO!RAZUM"

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\textbf{Abstract.} The Mivar decision-making system (MDMS) "ROBO!RAZUM" can be used to control autonomous combine harvesters and tractors, which can additionally perform a variety of actions in the process of moving through the field: working in group interaction mode, performing tasks in different weather conditions and even with a faulty or disabled technical vision using the internal map of the area and information from internal inertial sensors or from the GLONASS system. The theoretical basis for the application of MDMS "ROBO!RAZUM" is the result of the practical implementation of MIPRA program, which dramatically reduced the requirements for equipment and time to solve the problems of STRIPS-planning robot actions.

1. Introduction

In the area of artificial intelligence, there is currently a critical mass of technologies enabling the creation of a decision-making system (DMS) for autonomous groups of combine harvesters and tractors for agriculture and other complex applications, from homeland security to mining. It is important to note that autonomous robots require logical intelligence, and the intelligence module of the DMS can be implemented with a Mivar Constructor of Expert Systems Wi!Mi "Razumator" [1-2]. This system allows constructing algorithms for planning the actions of individual robots and even heterogenous multi-level robotic systems [3]. The theoretical basis of mivar-based DMS was described in many works, for example, for autonomous vehicles [4-5], special superfast summers [6], automatic control systems [7], traffic accident analysis [8], and decision support systems for medicine [9]. It is noteworthy that the DMS for agriculture are hybrid intelligent information systems from the standpoint of system architecture [10]. These systems, aside from mivar technology-based modules, may include solutions based on meta graphs [11-12], cognitive computer graphics [13-14], neural network-based algorithms [15], and intelligent analysis methods [16].

At the conference IASF-2018, the architecture of a mivar system for enforcing traffic regulations, as well as other mivar-based products for transport [5, 8], was presented in [17]. In [18], the possibility of using mivar expert systems for planning the actions of robotic system [18] was conducted. In 2019, the results of successfully solving this problem were published in the form of a software system MIPRA [19]. We note that MIPRA was developed to solve conventional STRIPS-planning problems in a modified conventional domain called “Blocks World” [20].
Based on mivar DMS, a software framework "ROBO!RAZUM" was developed for the area of robotics. This framework can be used for controlling autonomous combine harvesters and tractors, which can perform various actions in the process of moving on the field. They also can work in group interaction mode [21]. They can operate in different weather conditions and even with a faulty or switched off machine vision system using only the internal map of the area and the information from the onboard inertial sensors or the GLONASS system. In 2016, the mivar decision-making system (MDMS) "ROBO!RAZUM" [22] was the first in the world to control a group of autonomous robots. In January 2017, we conducted field tests of the automobile control system by creating special knowledge bases and integrating "ROBO!RAZUM" in the control loop of the automobile in collaboration with the research team of Shadrin S. S. [4].

2. Analysis of the specifics of operating autonomous groups of combined harvesters and tractors

It is crucial to determine the scope and tasks for the DMS for automobile groups of combine harvesters and tractors based on the information from various customers and the analysis of the subject domain. Robotic systems based on them are often used for solving tasks of damage control and recovery after accidents and natural disasters. Such situations impose greater requirements on the diversity of situations and the autonomy of the robotic system without a communication channel with an operator. From the standpoint of mivar technologies and the decision-making speed of more than 5 million rules/sec, such toughening of requirement is not detrimental. Based on our estimates, the number of production rules in the driving regulations for driverless vehicles will not be greater than 10000. Thus, the capabilities of the MDMS "ROBO!RAZUM" guarantees the solutions of the most complex problems for automobiles and the extension of these problems for combined harvesters for work in different conditions, including accident damage control and recovery.

Thus, the specifics of the subject domain of a "tractor" include the following:

1) Tractors (robotic systems) have to negotiate complex terrain, where possible routes ("roads"), as well as obstacles and the profile of the terrain, may change dynamically.

2) Robotic systems are complex multi-level systems, where a part of the robotic system or an individual mini-robotic system can perform some tasks autonomously. For example, a UAV can take off the robotic system to observe the territory for creating maps and searching possible "roads" on it. Another example of this would be special sensors determining the soil composition for "ROBO!RAZUM" to give instructions to a combined harvester to dynamically change the fertilizer composition and control the movement of the robotic system at the same time.

3) The machine vision system [23] can be external subsystems of the robotic system, which in some cases will have to move on the "field" in poor visibility conditions or with the onboard machine vision system faulty. In this case, the robot can procure the information for the DMS from external systems or using a map previously loaded in the DMS (the map is dynamically updating based on the data from the external machine vision systems) and the data from the onboard inertial sensors about the robot's movement on this "virtual map".

Besides, "combines and tractors" can work together and help each other solve complex tasks, i.e., group control of the robotic system is possible. For example, two tractors move together across rough terrain. If the first tractor gets in a "mire" and starts drowning, the second tractor can pull it out, and they continue performing their task. Such capabilities of the MDMS give birth to new requirements to robotic systems ("tractors"), which should be capable of physical and information interaction.

We note that if there are no radio communication channels, the robotic systems can exchange information via another physical channel, for example, via the optical channel. For example, one robotic system displays signals with special devices (similar to marine semaphores of the pre-radio era: flags and projectors). Besides, robotic systems can approach each other and exchange information via a special "cable." If a robotic system goes out of order, the other robotic system can approach to out of order robot, connect to it via the cable, diagnose the faulty robot and, potentially, repair it. Other options for interaction are possible.
3. Interaction between a robotic system and various obstacles

It is evident that MDMS "ROBO!RAZUM" can be given the tasks on the level of full-fledged "Mars rovers," when only the autonomous control of the group of robotic systems is possible. We note that in general case, the knowledge bases in the DMS can be complemented from the new experience of the robotic systems, similar to the way animals and even humans learn. Such an "experience-based" self-training system can be implemented as a separate module or a subsystem because mivar technologies generally allow the robots to make new rules and logical relations. After that, new rules can be added to the common knowledge base and disseminated among other robots of the groups via a special procedure.

As an example, we consider ways the robotic systems may interact with different obstacles. We have solved the task of separating the obstacles into two types: passable and impassable. For example, bushes and high grass are passable obstacles for a tractor, while trees, posts, and houses are impassable obstacles which have to be driven around. We stress that we will consider special tractors, which can move and raise special objects during accident damage control and recovery. This is a special case of regular tractors having special equipment to perform tasks on cleaning up the accident zone or delivering cargo through it.

We introduce the third type of obstacle, which we shall refer to as a "movable obstacle." We should note right away that, in some cases, the options of "moving the obstacle" may vary. The obstacle can be pushed "up" the road, hooked to the robot and pulled "back" or just pushed aside. In some cases, in shafts and urban debris, special equipment can be used - tractors with buckets, excavators, and loaders. In this case, another type of obstacle will emerge. This type of obstacle can be leveled to the ground. Besides, there may be an obstacle that can be lifted with a mobile crane and taken elsewhere. As we see, there is a large and "open" set of different types of obstacles. However, all these obstacles can be taken into account in the knowledge base of the MDMS, and the information about them will be taken into account in the operation of robotic systems and their multi-level and heterogeneous groups.

Mivar DMS allows "special tractors" to close in on the obstacle and try pushing it off the road. After this attempt, there are different options. The options strongly depend on the capabilities of the machine vision system. However, we assume that the information about the territory had been collected, and an electronic map of it had been created before the accident even in the worst-case scenario. This map has many "layers" containing information for different profiles. This map is loaded in the memory of the DMS of the robotic system, and it is used to determine the places where the robotic system can go. This can be done by explicit definition of "roads," while it is also possible to make a sort of "chessboard," where passable "square" and obstacles on them will be indicated. In 2016, this approach was implemented for the task of controlling mini-tractors and children's robot toys. The issues of creating such a map require further research.

Let us consider a group of robotic systems having a common map, and they perform a task on moving a certain cargo through an accident zone. The terrain of the zone had changed due to the accident, and new obstacles, which had not been shown on the map, had emerged. If it is possible, the group of robotic systems uses their resources and merges the data from the machine vision systems to update the map. This update can indicate free roads or detect various obstacles. The obstacles, for example, can belong to three types: 1) impassable, 2) passable, 3) movable. Generally, obstacles are of the third type, which can be removed by the robotic systems themselves, therefore, we may call these obstacles "removable." Based on the information collected, a mivar bipartite graph of possible moves is created. This graph explicitly stores "nodes," where robotic systems may be located, and "edges" the robotic systems can use to move from one node to another. Such a graph corresponds to a map received from the machine vision system, and it can be constantly updated upon getting new information in real time. RAZUMATOR can search for a route on this map with a speed of more than 5 million rules/sec [1]. In other words, mivar rule inference is used for finding the shortest path on the graph of possible moves of the robotic systems.

Then the group of robotic systems finds the root using the mivar DMS, identifies obstacles and performs actions to move cargo using the rules from its knowledge base if the route is free. If there are obstacles belonging to the second (passable) and third (impassable) type, the MDMS makes a plan for
overcoming these obstacles, and the robotic systems move with the cargo. At any moment of time, the plan can be altered with the speed of more than 5 million rules/sec to take into account new obstacles or capabilities of the robotic system. However, this largely depends on the capabilities of the machine vision system.

4. Robotic system operation with a faulty machine vision system
Let us consider the possibilities of operating a robotic system in conditions when the machine vision system is out of order or cannot function because of weather conditions. So, initially, each robotic system has a map of the area of operations. We assume that the robotic system has a system of inertial sensors that can accurately determine all movements of the robotic system and its position in space (slopes, turns, etc.). The easiest way to operate is based on constructing a route based on the pre-loaded map without any machine vision, and the robotic system moves along this route based on the information from the inertial sensors. This option is used by driverless vehicles for moving along a preset trajectory. If using the first robotic system uses a method of trial and error and is stopped by an obstacle on an empty road, the obstacle bypass procedure is launched. For example, the robotic system may first try to drive around the obstacle or move it off the road. For example, an automobile may give its first spot to a tractor, which can try moving the obstacle aside based on the previously loaded map and free the road for other robotic systems. Depending on the composition of the robotic system, different options for removing or overcoming such obstacles are possible. If the obstacle cannot be removed, the next stage is initiated. But, depending on the situation, a simultaneous search of different ways of overcoming the obstacle and finding the path for the group of robotic systems is possible.

Another stage is the search for the alternative route, for example, by finding the other route on the map of the area. If the alternative routes exist, robotic systems can be sent there. A simultaneous check of all or some of the routes is also possible. The check can be done using the channel of communication between robotic systems or without it when a robotic system returns to the initial point and reports where the route is passable or not. We should stress that the capabilities of mivar technologies allow implementing this with current technology right now. Research has been carried out, and the task of planning the operation of robots (MIPRA) has been solved, so now we can pass over to creating knowledge bases and training of the mivar DMS (this will be research work followed by prototyping and field testing).

5. Conclusions
Artificial intelligence has been created, and mivar decision-making systems "ROBO!RAZUM" can control autonomous combined harvesters and tractors. These devices are complex heterogeneous and multi-level robotic systems. "ROBO!RAZUM" can control them even with external machine vision systems using just an onboard map of possible moves with dynamically changing obstacles. Besides, robotic systems can be controlled to perform complex tasks on the move [24].

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