Modelling and Visualization of Robot Coalition Interaction through Smart Space and Blockchain

Alexander Smirnov and Nikolay Teslya[a]
SPIIRAS, 39 14th Line, St. Petersburg, Russia

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Abstract: Nowadays the study of interaction models of intelligent agents is one of the main directions in the field of joint task solving. It includes studies of coalition formation principles, tasks decomposition and distribution, winnings sharing, and implementation of proposed techniques and models. This work focuses on ensuring the interaction of coalition members through distributed ledger technology and smart contracts using Hyperledger Fabric platform, as well as modeling and visualizing the interaction of intelligent robots using open software Gazebo and Robotic Operation System. The ontology of context used to adjust robot actions is presented. It combines environmental characteristics with robots and tasks descriptions to provide full situation context. The paper presents a modelling approach architecture with an example of modelling and visualization based on obstacle overcoming scenario.

1 INTRODUCTION

One of the main directions in the field of collective work of robots is the study of interaction models of intelligent agents (Bayram & Bozma, 2015; Vig & Adams, 2005). Interaction of agents is most often required when solving a problem that cannot be solved by the efforts of one agent due to the lack of its capabilities. In this case, the task is divided into several independent subtasks. Each of them is then assigned to a separate agent (Bayram & Bozma, 2015; Cui, Guo, & Gao, 2013). The importance and relevance of these studies is due to the development of robotic systems in which each individual robot can be considered as an independent intelligent agent. A robot can make decisions to achieve its own goals and a common goal. This interaction model is also called a coalition. A wide range of tasks in the development of coalition interaction models lies in the field of models that provide the most optimal choice of participants in a collective solution to the problem and ensure the interaction of coalition members (Dukeman & Adams, 2017; Klusch & Gerber, 2002).

The formation of a coalition and the joint solution of tasks by robots can be demonstrated in most detail within the following subject areas: precision agriculture, remote planet exploration, emergency medicine. In all these areas, many high specialized robots have been developed. They effectively solve a limited set of tasks within the framework of the conditions for which they were developed. For example, to solve the problem of precision agriculture, there are robots that can conduct soil quality exploration, automated seeders, cultivators, tractors, etc.

However, to solve a complex problem that goes beyond the conditions of each robot, it is required to provide platform for their joint work. To ensure the full cycle of growing crops, it is necessary to successively solve the problems of field exploration, selection of crops grown, sowing, watering and harvesting. To do this, it is required to form a coalition of robots in such a way as to solve a complex common problem with the maximum overall effectiveness of the coalition. Efficiency calculating for different subject areas depends on the gain that can be obtained when solving the problem: the maximum harvest for precision agriculture, the number of people rescued for disaster medicine, and the total amount and time spent on obtaining, processing and transmitting information about the state of the monitored objects of interest for remote sensing tasks.

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[a] https://orcid.org/0000-0003-0619-8620

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The solution of the coalition formation problem with the mathematical theory of fuzzy cooperative games was presented in a previous work by the authors (Smirnov, Sheremetov, & Teslya, 2019). This work focuses on the secure interaction of coalition members through distributed ledger technology and smart contracts using Hyperledger Fabric platform, as well as modeling and visualizing the interaction of intelligent robots with open software Gazebo and Robotic Operation System.

The paper is structured as follows. Section 2 discusses the existing forms of coalitions and methods for modeling and visualizing their interaction. Section 3 presents a coalition interaction model based on the concept of smart spaces, including a description of the ontology-based context model used to form the coalition. Section 4 presents the architecture for the coalition members interaction through a distributed ledger. Section 5 shows the architecture and an example of visualizing the interaction of coalition members using robots' models and simulating the physical world in the Gazebo environment. Section 6 concludes the article and provides directions of future work.

2 RELATED WORK

Currently, the main research directions of solving the problem of coalition work of intelligent robots are the following: organization of a coalition, information exchange between coalition members, distribution of tasks and resources between coalition members.

Two major areas can be distinguished in the process of a coalition organizing: centralized and decentralized. The centralized organization of the coalition is characterized by the presence of a control center at which decisions are made on the composition of the coalition, the distribution of tasks, and forming a plan for solving the problem. In this case, the control center can be represented either as a separate high-powered computing device that performs only the functions of the center, and a robot that performs tasks along with the rest (Smirnov, Kashevnik, & Ponomarev, 2015). In this case, the structure of the coalition can be multilevel hierarchical, in which robots at each underlying level obey only one center of their superior level (Guerrero, Oliver, & Valero, 2017). The decentralized organization of the coalition usually implies the absence of a decision center, often focusing on bio-inspired methods of organizing collaboration, such as swarms and flocks (Koes, Nourbakhsh, & Sycara, 2005; Yu & Cai, 2009). At the same time, robots equal in hierarchy and all of them use same algorithms when making a decision.

The information exchange between coalition members is an important component of the joint problem solving by coalition, since it requires notification of coalition members about the current state of the problem solution for organizing coordinated actions, or monitoring the implementation of the plan (Verma, Desai, Preece, & Taylor, 2017). The information exchange can be organized through a common centralized repository of information on a separate device or by the distribution of information between coalition members (Shabanov & Ivanov, 2019). It also considers the combination of two approaches with the formation of so-called smart spaces - a common repository of information that provides links to resources that are coalition members, which makes information distributed among all participants (Ferrer, 2019). There are also solutions based on peer2peer networks and a distributed ledger that provide quick distribution of information between all participants, while duplicating all the information on the device of each participant (Liang & Xiao, 2010; Qian & Cheng, 2018). The distributed ledger technology can be viewed as an example of P2P networks. In addition to benefits of P2P network, the distributed ledger solutions also provide immutability of information, which can be useful when organizing a coalition with the requirement to ensure trust between the participants without a single certification center (Liang & Xiao, 2010).

The type of coalition organization also influences how tasks and resources are distributed among coalition members. Centralized hierarchical coalitions usually organize work through centralized planning when receiving a task. At higher nodes, a work plan is built taking into account the capabilities of lower nodes and coalition resources, in which the performers and the procedure for solving problems are fixed (Smirnov, Kashevnik, Teslya, Mikhailov, & Shabaev, 2015). This ensures that the stages of the plan and the entire plan are completed by a certain date with an accurate forecast of the expenditure of resources and the payment of remuneration, if this is provided for by the conditions of the task. However, this solution is not flexible, because when an emergency occurs, it leads to a deviation from the plan, with the need for its correction or complete reorganization. Decentralized coalitions are based on the adaptation of participants to current conditions, with the absence of a single plan for solving the problem (Hartanto & Eich, 2014; Tosello, Fan, Castro, & Pagello, 2017). This provides the flexibility to solve the problem under frequent changes in the composition of the coalition or available resources, but limits the ability to predict the time of solving the problem (Ivanov, 2019).

Simulation and visual modeling of the interaction of robots is also very important task. Both of them are greatly simplifies hypothesis testing by reducing development costs, and allow to visually present the results of the proposed approaches. Some researchers develop their own visualizations, displaying robots with conventional signs, since the tasks under consideration do not require detailed design of the robot (Koes et al., 2005). For detailed visualization, the Gazebo visualization package is most often used in combination with the control code of the robot operating system (Robot operation system, ROS) for controlling a virtual robot (Barbosa, Duberg, Jensfelt, & Tumova, 2019; Suárez-Figueroa, 2012; Xue, Tang, Su, & Li, 2019).

In summary it can be noted that nowadays the main attention is paid to the creation of decentralized coalitions of robots to solve complex common problems. The distribution of tasks and resources between them should be carried out based on decentralized planning to adapt to the changing context of the task, while robots take part in solving the problem considering their functionality and available resources, such as battery power or device lifetime. The interaction and exchange of information between robots should be carried out through a common repository. Taking into account the recent studies two approaches towards decentralization can be viewed: P2P model, and the use of distributed ledgers. If it is not possible to test interaction models on real robots, visualization environments should be used to model robots and their actions. The most commonly used bundle is the Gazebo simulation environment, together with the robotics operating system (ROS), which implements the robots functionality.

3 INTERACTION OF COALITION PARTICIPANTS

Robots interact through the cyberphysical framework described previously in work (Smirnov et al., 2019). The framework is based on the smart cyberphysical space (based on the “blackboard”) and blockchain. It provides the ability to organize basic interaction of robots in the physical and cyber (virtual) spaces. The interaction includes solo and joint manipulations with physical objects, information exchange about the current state of robots and objects for planning further joint actions during the coalition formation.

Coalition members can be robots of different manufacturers with different equipment, environmental sensors, and software modules. For their interaction, it is important to ensure semantic interoperability. This allows to specify a description of the properties of the coalition members and context in a format that is understandable to everyone, from machines to the system’s operators, as well as automate the search for coalition members in accordance with the requirements for the task. An ontology is used to ensure semantic interoperability. The model of the context, the coalition participant and tasks is described using the ontological modeling apparatus, which allows context-driven dynamic formation of the coalition and the distribution (redistribution) of tasks, roles and system resources taking into account not only competencies, but also the current situation in the coalition.

To build an ontological model of the context, the main scenarios of robots interaction, robot designs, and typical tasks that each type of robot solves for disaster medicine, precision farming, and remote sensing of the Earth had been analyzed. As a result, the basic concepts that should be present in the ontology were identified, among which three groups stand out: i) concepts for the current situation; ii) concepts for the design and functions of the robot; iii) concepts for the requirements and conditions for solving specific problems posed to a given group of robots.

The ontology graph for context is presented on Figure 1. For the current situation, the concepts describe the physical parameters of the environment (for example, temperature, wind speed and direction, humidity, current time, atmospheric pressure for precision farming and disaster medicine, for remote sensing - the tactical and technical characteristics of onboard target and supporting equipment, potential areas of interaction with objects observation and ground-based points for receiving Earth remote sensing data, light level, solar activity, radiation level, quality indicators of function observation of spacecraft, etc.), the position of all the coalition robots, the position and properties of objects in the field of action of the coalition.

Ontology concepts for describing the design and functions of the robot provide characteristics of the hardware and software components of the robot (number, types, measuring ranges and current sensor readings, number, types, current position of motors, state and current battery charge, fuel level (if there is a fuel tank) computing power (CPU frequency, the

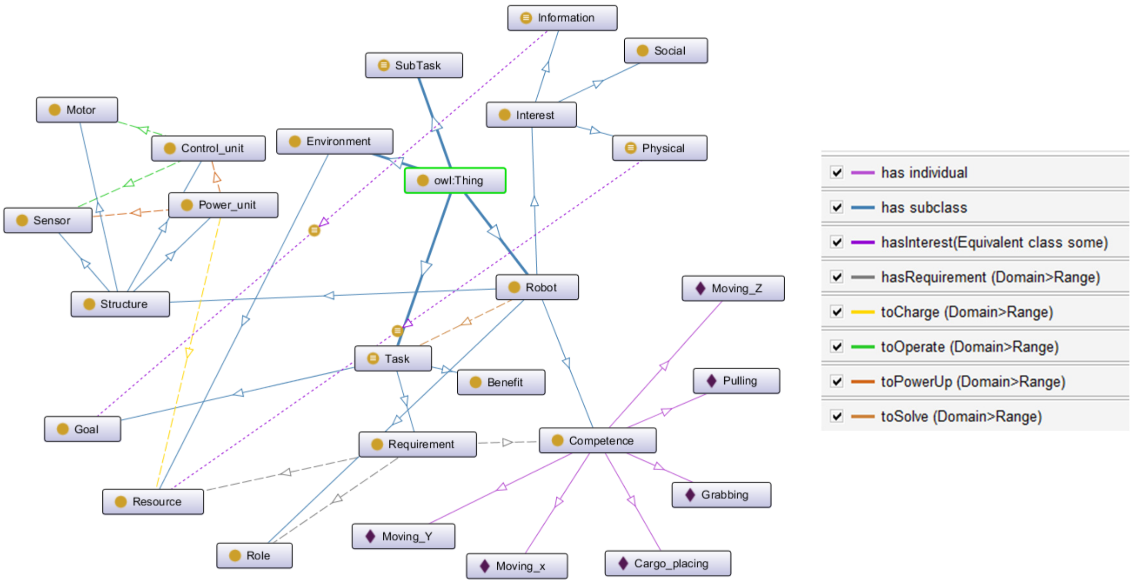

Figure 1: Context ontology.

amount of RAM, data storage, connection to data networks, information about the characteristics of the selected GNSS)) and many components (installed libraries, software modules, platforms, control code for hardware, action templates), as well as a description of the functions and possible technologies that the robot can perform using its hardware and software. The concepts of the developed ontology are synchronized with the ontology defined by the standard 1872-2015 - IEEE Standard Ontologies for Robotics and Automation (IEEE Robotics and Automation Society, 2015) to ensure interoperability while expanding the range of subject areas and the composition of coalition members.

Ontology concepts related to the task description and task requirements determine the types of tasks, the resources needed to solve them, the requirements for the functional equipment of robots, as well as the possible structures for dividing tasks solved by coalition of robots into sub-tasks.

4 COALITION MEMBERS INTERACTION THROUGH BLOCKCHAIN

Some platforms that implement blockchain technology can be extended by the use of smart contracts to provide new capabilities of ledger processing. For the purpose of coalition participant interaction, a smart contract within blockchain technology is viewed as a decentralized application available to all coalition participants.

In this work the Hyperledger Fabric platform has been chosen for blockchain network and smart contacts implementation. The choice is justified by the specifics of architecture, which makes it easy to adapt the coalition structure into the platform structure (see Fig. 2). The main elements of the architecture are nodes of three levels: “Client”, “Peer”, “Orderer”. Client level corresponds to robots whose main task is to send data from sensors, or to perform operations and report on their performance. In case of precision farming, such robots can be tools of combine harvester, scouts, and transport robots. On the higher lever, there are devices that collect information and execute the smart contracts - “Peer”. The example of peer is a control block of combine harvester. Their main task is to collect information from the lower level, process it using smart contracts and transfer it to the upper level, in which information will be disseminated and stored. The highest level is “Orderer”. Its task is to store information in the appropriate chain of blocks, to ensure the coordination and distribution of the new block between other Orderers and corresponding Peers.

All changes of coalition state are reflected in the smart space using adding/deleting relevant information according to the in the ontology. During the interaction between coalition participants through the IoT platform with the blockchain support, all smart contacts can be called either directly through the transaction initiation interface in the blockchain

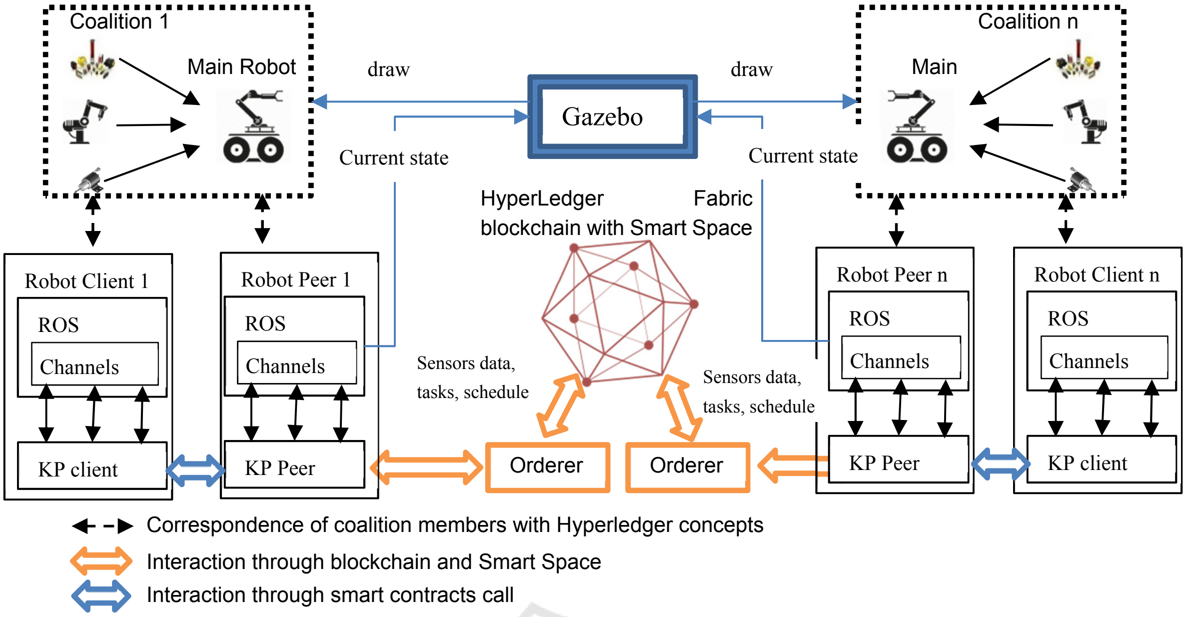

Figure 2: Coalition members' interaction through HyperLedger Fabric with Smart Space support.

or using other smart contacts methods. To simplify the use of custom protocols in blockchain, the method of any contract placed in the contract chains should be called using the basic smart contract.

For this purpose, a basic smart contract was developed, which provides the following functions of interaction between coalition participants:

1. Coalition schedule upload using XML format. It provides receiving and parsing the plan; generating entries in the blockchain from the extracted items of robots, tasks associated with robots, the order of the task execution, and the timing of each task; sending notification to the blackboard through blockchain knowledge processor to start the plan execution.

2. Start the task execution. Accept a message from the robot about the start of the task execution, store the moment of the real start of execution in the blockchain, verify with the planned one, and store the fact in case of a strong deviation.

3. Completion of the task. Same as with the start the contract provides function to get notification, check correctness of execution and store this fact to the ledger. In case of a strong deviation from the plan, this fact is stored to the blockchain and notification about the failure of the plan is sent to other coalition members through the smart space.

The basic smart contract is available through the REST API so each robot can access the schedule without direct connection to the blockchain just using HTTP protocol. In addition, a simple web page is available for a human operator to check the coalition state and follow the process of joint task solving.

5 VISUALIZATION ARCHITECTURE AND COALITION INTERACTION EXAMPLE

For the experiments, a scenario of coalitional interaction of robots was implemented to jointly overcome obstacles in a Gazebo modeling environment (Agüero et al., 2015; Koenig & Howard, 2004) with ROS Melodic framework (Stanford Artificial Intelligence Laboratory et.al., 2018) (see Figure 3). The use of the above software is currently widespread in the field of robotic modeling and includes a diverse library of elements and off-the-shelf devices, which can significantly reduce model development time. Due to the possibility of connecting third-party models, it is also possible to quickly create a three-dimensional physical world that simulates the real world with automatic object collision calculation, environmental physical parameters. This feature allows to faithfully display the physical world and take into account a large number of parameters during modeling.

Using the ROS operating system also has several advantages. The first is that this operating system supports the basic functions of real-life robots related

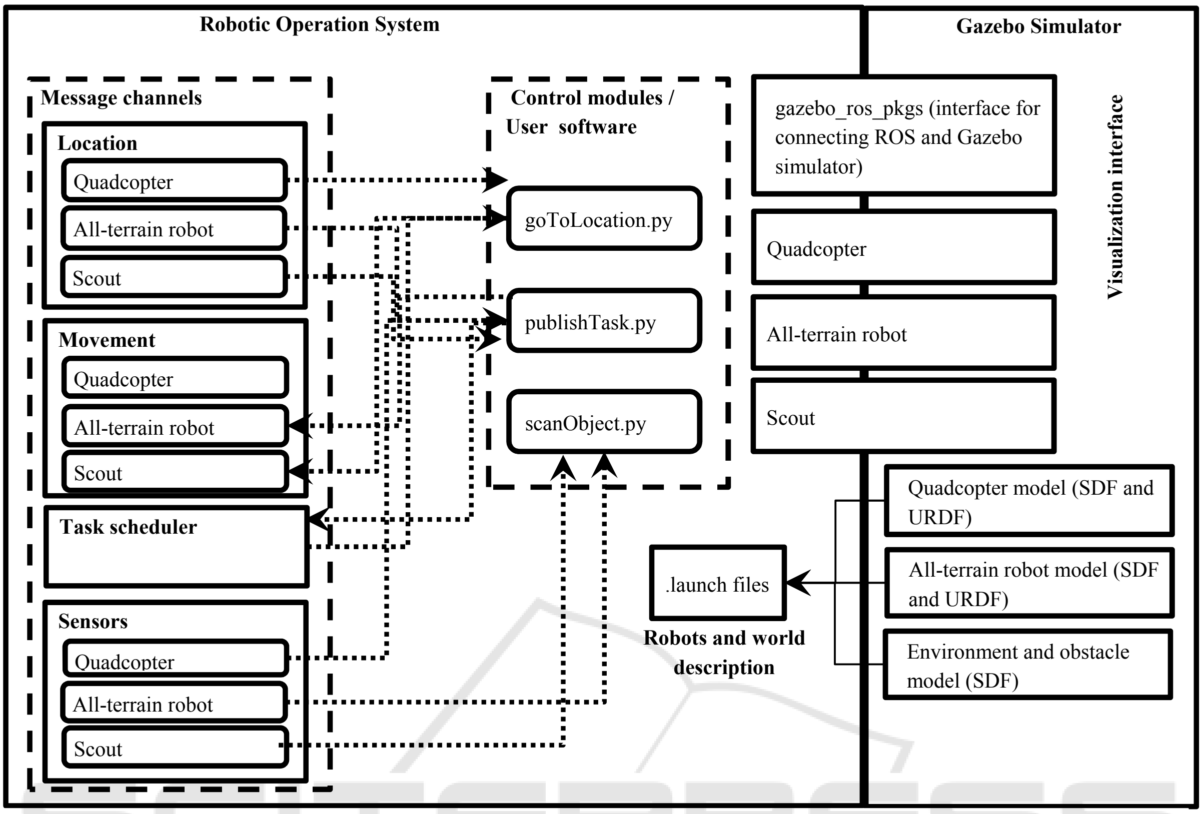

Figure 3: Software architecture for robot interaction visualization.

to controlling servo drives, receiving data from sensors and exchanging data with the external environment through an accessible communication channel. Interaction between robots is carried out through specially organized channels in the operating system, to which a program can be subscribed and receive sensor readings from them or send control commands. In the presented architecture, the robot knowledge processor (KP) subscribes to channels and transmits messages from the robot to the smart space and blockchain using the ontology, as well as receives back the task that needs to be completed, and the schedule and controls the actions of the robot.

The second important advantage is the ability to integrate ROS both in existing robots and in robot models created in the Gazebo simulation environment. This allows to develop a model of robots interaction in the virtual world and then, with minimal changes, transfer it to physical robots, and due to high-quality simulation of the physical world conditions, many features of the physical environment will be taken into account during virtual implementation and estimation.

The following robot models were developed to implement the scenario (see Figure 4): all-terrain robot, quadcopter, and scout.

All-terrain robot has the following characteristics: six wheels, three independent parts (front, center and back). The front and back parts have lift mechanisms that allows to rise or down parts of robots to overcome obstacles. On the front and back parts of the robot there are laser distance sensors to measure the distance to objects, directed in parallel to the surface on which the robot moves. The robot is equipped with a coordinate sensor (GPS/GLONASS in real robot) for tracking location.

Quadcopter robot has the functionality of a standard quadcopter for moving in three-dimensional space. The robot is equipped with a laser distance sensor to scan for obstacles and is directed downward perpendicular to the plane of rotation of the rotors. Same as all-terrain robot the quadcopter is equipped with a coordinate sensor for tracking location. The quadcopter model, which implements the quadcopter robot functionality, was implemented based of the hector_quadrotor free model package (Meyer, Sendobry, Kohlbrecher, Klingauf, & Von Stryk, 2012, 2018).

Scout robot is a four-wheel mobile robot with the function of moving on a two-dimensional surface

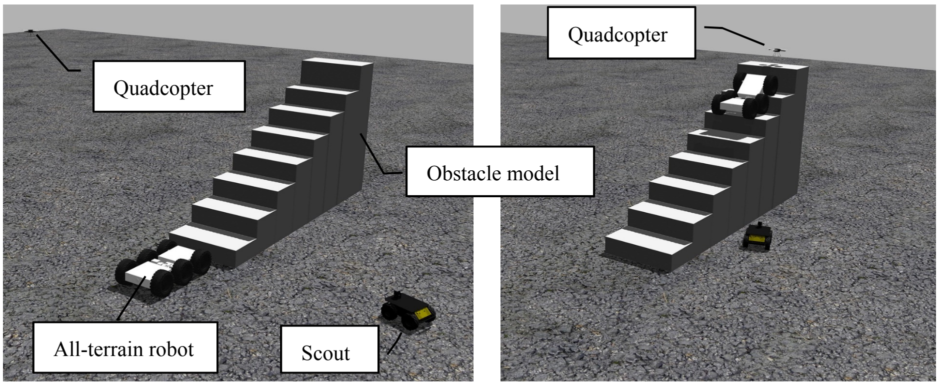

Figure 4: Visualization of robots interaction with Gazebo and ROS (left side– initial scenario stage, right side – final stage).

without huge obstacles. The robot is equipped with laser distance sensors located around the perimeter of the body to scan the space around the robot. The robot is also equipped with a coordinate sensor for tracking location. Scout robot model was implemented based on the husky_gazebo package (Gariepy, Mukherjee, Bovbel, & Ash, 2019).

The transmission of control signals to the robot and the receipt of data from the sensors is carried out through subscription to the channels in ROS associated with the equipment of the robots. For example, for the all-terrain robot, channels have been created through which data from the distance sensor and coordinates can be received and independent control actions to each of the robot servos can be sent. For each of the servos, it is also possible to obtain its status by accessing the corresponding channel.

6 CONCLUSIONS

The paper provides modelling of the scenario of joint problem solving by robots' coalition proposed early by the authors. The modelling is based on the open source packages Gazebo and ROS that are de-facto standards of virtual environments modelling in visualization in the field of robotics. The interaction between robots is implemented based on the smart space combined with the blockchain platform.

To describe the environment the ontological model of context has been developed. The ontological model provides the concretization of the parameters that can be used to describe the context of the joint problem solving in various fields, including precision agriculture, disaster medicine, and remote sensing of the Earth. The benefit of ontological context model is in easy adaptation to other areas by supplementing it with concepts that describe the current situation, specific to these areas, while maintaining the context in terms of describing the structure and functions of robots and tasks.

The visualization shows simple scenario of three robot cooperation for obstacle overcoming. Selection of tools for visualization and communication between robots shows how they can be combined for modelling scenarios of robot cooperation. This result can be further scaled to implement more complex scenario of precision agriculture that requires implementation of physical world, robot models, and providing secure interaction between them. The interaction will include secured interoperation through blockchain and cyber-physical space, coalition formation, and rescheduling of complex problem solving.

The future work will be focused in precision agriculture scenario implementation and performance estimation to prove that the proposed solution is appropriate for this kind of tasks.

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