

Modeling the Intellectual Behavior of a Team of Robots Based on the Multi-Agent Simulation Model

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Abstract. As a result of the information analysis of various approaches to the types of interaction of robots in a group, the following tasks are solved: an environment model and the algorithm for mobile robot autopilot in the conditions of information uncertainty and a multi-agent simulation model and algorithm for focus group behavior of a team of robots in the framework of inter-agent communication were implemented. Based on the proposed simulation model the software has been developed that allows studying the effectiveness of group robots behavior algorithms.

Keywords: Group robots · Simulation model.

1 Introduction

Currently, the following tasks are relevant for the interaction of a team of robots in conditions of incomplete information about the external environment - modeling the rational behavior of an individual robot, making a decision by a robot based on a collective task, and evaluating by the robot the results of the task. Many publications in these areas are mainly theoretical: [1], pp. 60-71, [2], pp. 1019-1033, [3], pp. 574-614, [4], pp. 174-179, there are practically no works where the authors describe the problem in a complex: from setting to implementing and evaluating the results, the available examples of online robot development systems are focused on the software or hardware manufacturer.

The proposed modeling system allows you to vary different types of robots and their collective behavior, while receiving adequate estimates of the fulfillment of the collective task. A multi-agent simulation model is the basis for a system for modeling focus group behavior of a team of robots.

2 Formulation of the problem

The object of research is the mobile robots models that can work as a part of a team. The key point is the interaction between the group members of the group,

which creates a system of constant feedback, and the objective function is the direction of behavior not of the individual, but of the entire group of robots within the general task.

The multi-agent simulation model includes a model of the environment, intelligent robots, a team interaction model, and a central control module (CCM).

An intelligent robot must have an internal model of the external environment that allows it to operate in conditions of uncertainty. The model of the environment of the robot includes a digital terrain map, algorithms for processing data from various sources of information (sensors, video cameras, GPS, etc.) in order to clarify the structure of the location in the coverage area of other robots and obstacles to movement. Information obtained from the model of the external environment is initial for the intelligent navigation system of the robot.

The structure of an intelligent robot conforms to the following scheme: an intelligent robot - i sensor subsystem of perception (obtaining information about the external environment) + intelligent navigation system + motion subsystem.

The model of the external environment is built on the basis of the knowledge base and data received from the sensor subsystem. The robot's memory should contain information about typical reactions to information signals from (sensors, control devices), information about the status of actuating devices, available resources (other robots, available time, etc.), algorithms for processing input information into control signals of actuating devices, patterns that allow to highlight information that is relevant to the robot.

The robot receives and integrates information from three sources:

- from a human user in the form of target designations;
- from sensory transducers;
- from its own knowledge database.

The operating conditions of the robot may be unknown in advance or may change in an unexpected way during its operation. For an intelligent robot, objects of the external environment and their individual parameters (soil characteristics, air temperature, wind speed and direction, etc.) may be unknown.

In order to ensure rational target behavior of the robot under conditions of uncertainty, the lack of a priori information should be compensated by the operational processing of current information received from sensors and other sources.

There are two principals behind the building of a flexible control system of an intelligent robot that can operate in different modes: "primary" navigation, which is associated with ensuring the movement of the robot to the target on the basis of instructions given by a person, and "refined" navigation is based on current environmental data received from the sensor system.

As a result, a hierarchical two-loop control system is formed, where the usual classical control scheme is supplemented by a fuzzy control subsystem. This approach involves the transition from accurate information to uncertain and vice versa.

As part of a multi-agent simulation model, a group of robots operates under the control of a central control module, which stores a general database, an exter-

nal environment model, and a knowledge base of a group of robots. The general database includes performance characteristics (PC) and the number of robots, electronic terrain map (ETM), the size of the site for the functioning of a group of robots. The knowledge base of a group of robots includes travel routes and algorithms for their construction, decision-making algorithms for the presence of an obstacle, obstacle avoidance, algorithms for solving problems of crossing routes (robots meetings), decision-making algorithm for movement (choice of speed, direction, period of time for movement), algorithms for controlling of executive devices, algorithms for assessing the executive devices state and decision-making algorithms to reach the end point of the route (goal achievement).

3 Implementation

To study the focus group behavior of a team of robots within the framework of a multi-agent simulation model, the following scenario is proposed: X number of research robots placed on a site, are controlled by CCM, located on a board of a ground-based or air-based main robot. Research robots act in the interests of the main robot, which needs to get its route through a certain territory. The land area is set on the ETM in the form of a rectangle or square; the algorithms for constructing routes based on information from the model of the external environment (MEE) distribute the research robots into areas of responsibility and set trajectories for them to study the territory (Fig. 1).

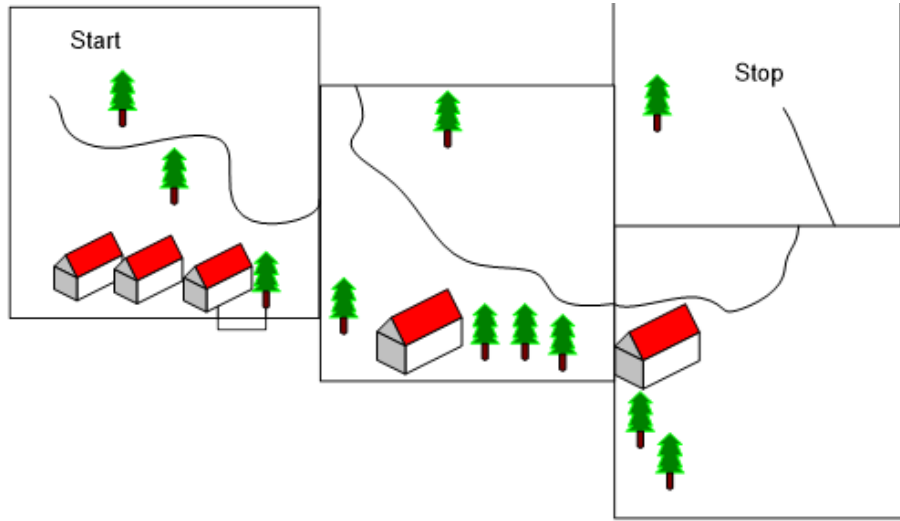


Fig. 1. Distribution of the research robots into areas of responsibility to study the territory.

The final result of the preliminary stage is an updated map of the terrain for calculating the route of the main robot. In the process, each robot sends the CCM a codogram of the following form.

A control system based on algorithms from the knowledge database controls the location and condition of all robots in the group, the presence of obstacles, and the achievement of the goal by each robot.

The on-board computer of each robot generates a codogram shown in Table 1, based on information from its sensors. A route is a set of connected segments, each segment is defined by a start and end point. The CCM calculates the speed, direction and time of movement of the robot, which will allow to reach the end point of the working segment (the one that has activity at the given moment) and gives the corresponding codogram to each robot in the group (Table 2).

Table 1. The codogram from the on-board computer of a robot.

Robot number	Coordinates	Sign of obstacles	Battery reserve	Fault-free
N	X.Y	0-1	1-100	0-1

Table 2. The codogram from CCM.

Robot ID	Sspeed	Ddirection, deg.	Time, msec
1-N	1-3	0-359	1-100

Having received a codogram, the robot, with the help of its low-level commands, drives the executive devices for movement and rotation for the time interval specified in the codogram. After receiving the response code from the robot, the CCM compares its current coordinates with the end point of the working segment and makes a decision, either issue a command for additional movement (in case of an inaccurate hit at a given point), or go to the next working segment. The decision on the end of movement along the route is made by the CCM if the robot reaches the end point of the last segment.

The scheme of the interaction of robots, the external environment and the CCM is shown in the figure 2.

The CCM performs the following algorithms in the preliminary preparation:

- the construction of a matrix of terrain areas allowed for movement of the robot, taking into account its PC and cartographic data on the terrain (angle of slope and rise), vegetation, soil and water surface
- the construction of primary routes for examination (without intersecting the motion trajectory with the trajectories of other robots)
- the algorithm for laying the route and following the route: issuing control commands and monitoring the movement of each robot (direction and speed), monitoring its status (operating time margin)

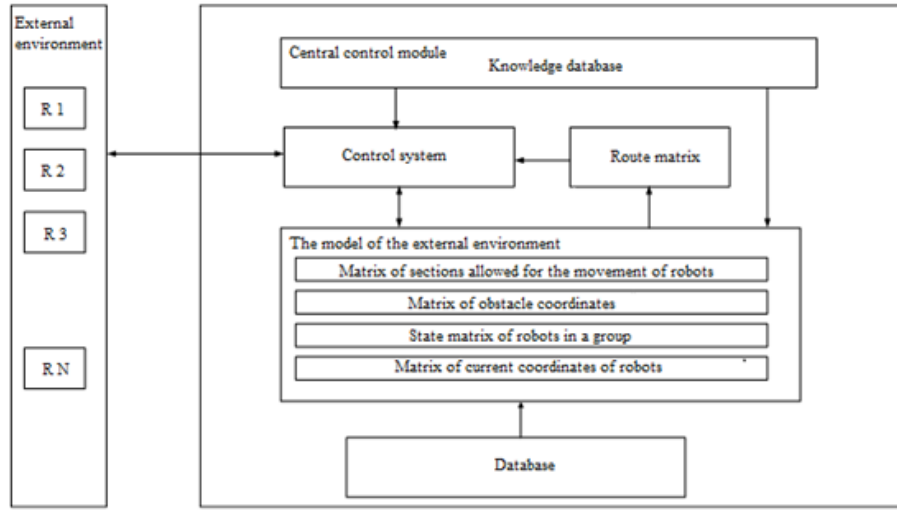


Fig. 2. Scheme of the interaction of robots (R1-RN), the external environment and the CCM in the framework of multi-agent simulation model.

- the assessment of the proximity to the end point of the route and the decision-making on its achievement by each robot
- the decision-making on the presence of an obstacle on the robot's route to bypass it and return to the route
- the collecting of information about the location of individual robots
- the determination of the presence of a communication channel with robots (in case of the absence of codograms from one of them, remember its last location)
- the algorithm for updating the matrix of obstacles and applying them to the map

In the operation mode according to the target scenario, in addition to items 2-7 of the preliminary preparation mode, the algorithm do: the construction of a robot route within the framework of the target scenario (taking into account the intersection of the motion trajectory with the trajectories of other robots), the decision-making on the interaction of robots in the case of intersection of their trajectories, the actions to achieve scenario goals.

The model of the external environment (MEE) includes a matrix of sections coordinates allowed for the movement of robots, an obstacle matrix, a matrix of current coordinates about the location of robots of the group, a state matrix of (technical) robots; the algorithms for obtaining and calculating data for these matrices are stored in the knowledge database. The output of the MEE is the route matrix of robots.

The matrix of sections coordinates allowed for the movement of robots is built on the basis of the terrain data analysis from the ETM, restricting the zones

available for movement based on the permissible steepness of the surface, the presence of vegetation or water surface, and soil properties. The obstacle matrix is compiled on the basis of information from the research robots in preliminary preparation mode. The matrix of current coordinates about the location of robots of the group is updated with a certain time interval from the CCM. The state matrix of robots of the group is updated with a certain time interval and includes information on their serviceability, power reserve, direction and speed.

Based on this model, the robot must be equipped with the following sources of information about the external environment:

- GPS sensor for global positioning based on digital maps;
- two ultrasonic distance sensors for detection and recognition of obstacles;
- a compass as a rotation sensor to determine the orientation of the robot;
- an angle sensor relative to the horizon;
- a movement detection system to determine situations of the forced stop of the robot (a decision may be made at the CCM).

For the developed simulation model, the following technique is proposed for simulating focus group behavior of a team of robots:

- The arrangement of robot agents on a simulation field (map of the area)
- The arrangement of local goals
- The application of target loads to robot agents
- The application of delivery locations target loads for robot agents
- Quality assessment of the completed group task by time (the number of simulation cycles)
- Quality assessment of the completed group task by resources (the number of robots per local target)

Figure 3 a) shows the deterministic arrangement of robot agents on the simulation field and each of them is assigned a new delivery location (or a new location in case of the absence of the target load). Figure 3 b) shows the deterministic arrangement of robot agents and their local target loads (local targets) in the simulation field. Figure 3 c) shows the routes of robot agents while delivering local target loads to delivery locations.

The combination of a group of robot agents, an array of local target loads, an array of delivery locations is called a simulation situation.

4 Experimental data

We have two cases of testing. In the first one the number of robots is fixed and we select the positions of the robots on the territory, which satisfy us by the completion time of the group task. In the second case we fix the time as a constant and try to fit in this time continuously increasing the number of robots without changing their location.

As a result of experimental studies, X number of simulation situations are randomly set in which the array of local target loads, delivery locations, and the

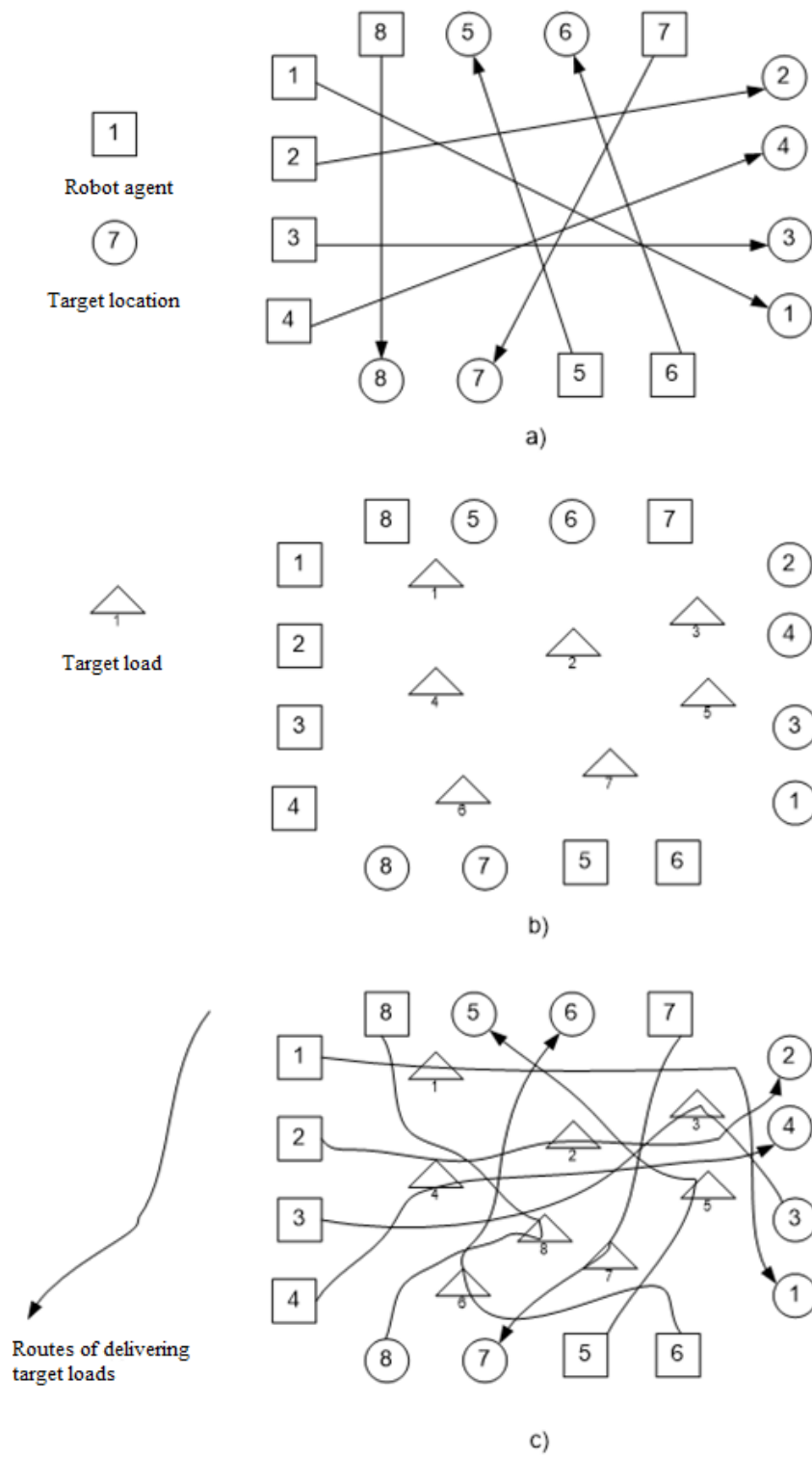


Fig. 3. Options for setting and completing the tasks of research robots in the framework of a multi-agent simulation model.

number of robots are deterministic. The placement of robots on the ground and the assignment of local target loads by them are random processes. A study of the focus group behavior of a team of robots is carried out on the basis of an estimate of the delivery time of the entire target load to the destination (the execution time of the group task) for X number of simulation situations.

The quality functional

$$E = f(X, t) \quad (1)$$

of performing the group task depends on the time t spent on achieving the goal. Then, by searching on the graph for points with minimum values along the Y axis (Figure 4), we can find combinations that correspond to the optimal (in the given constraints) time variant of the arrangement of group robots and assigning target loads to them.

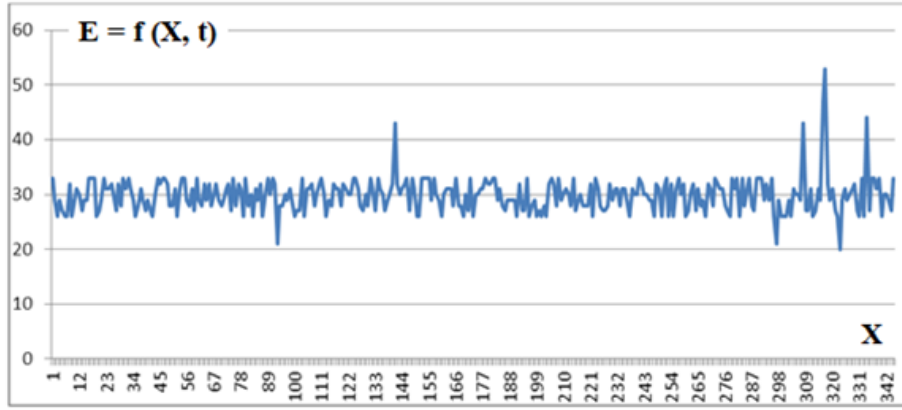


Fig. 4. Quality functional (1) of performing the group task from the time t spent on achieving the goal.

The quality assessment of the completed group task by resources (the number of robots per common target) is performed by randomly generating X number simulation situations in which the array of target loads, delivery locations, and the time spent on achieving the group task are deterministic. The quantity of robots Q , their placement on the ground, and the assignment of local target loads to them are random processes.

The quality functional

$$E = f(Q, t = \text{const}) \quad (2)$$

of performing the group task depends on Q – the minimum quantity of robots that is necessary to achieve the group goal for a given time interval $t = \text{const}$. Then, by searching on the graph for points with minimum values along the Y axis (Figure 5), we can determine the minimum required quantity of robots, with which it is possible to optimally complete the group task.

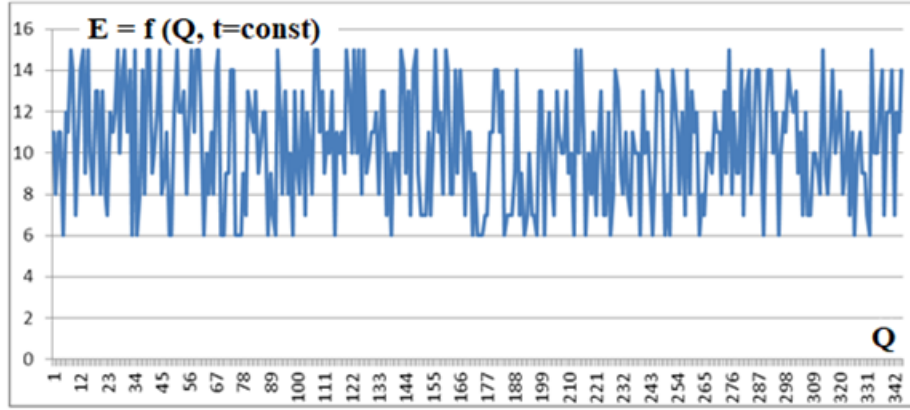


Fig. 5. Quality functional (2) of performing the group task from the Q – the minimum quantity of robots that is necessary to achieve the group goal for a given time interval $t=\text{const}$.

It should be noted that the options for fixing local loads to individual robots in the group proposed as a result of the simulation are also optimal for the constraints specified by the experimental conditions.

5 Conclusion

According to the results of experiments, it was found that an increase in the number of control points and the number of iterations to find the optimal route on the simulation field positively affects the optimization results, since the final route is getting better due to more precise adjustments to the control points. The calculation interval for decision-making of the robot on the route allows to perform operations in near real-time mode.

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