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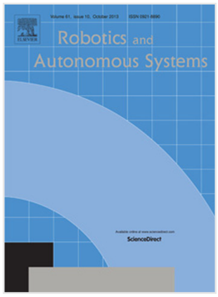

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Data transferring model determination in robotic group

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ABSTRACT

This paper describes the basic idea of data transferring in the group of robots while they move in an area with a high density of obstacles with the goal of increasing their movement speed by creating and synchronizing an area map that is made by each robot separately. This paper provides a brief review of existing robotic swarm projects and definition of the problems in robot teamwork, shows pathfinding methods and their analysis, justifies our technical vision system choice and describes its method of obstacle detecting that is based on dynamic triangulation. According to some behavioristic models, using fuzzy logic, the method of leader changing was used. This knowledge helps with the choice of appropriate models of data transferring, makes their simulation and creates a proper network between the robots to avoid data loss.

1. Introduction

The progress in different classes of mobile robot design and manufacturing and the results of their successful use in various fields brings the problem of effective management of robotic group (RG) movement in the collective operations that cannot be performed effectively by individual robots. These can include such operations as taking water samples in the waters of major ports, search and detection of any objects on land and sea areas, operation in specified areas with toxic chemicals, and others.

One of such problems is the robots group movement controlling in the conditions of strong destruction (obstruction) after the earthquakes. Such hazardous terrain can cause a signal loss during the robots communication no matter which type of network for data transferring is used (Wi-Fi, 3g, EDGE, etc.).

For analysis of data exchange network structures and justification of their choice we did introducing a series of laboratory constraints and environmental conditions in which the experiment will conduct.

Assuming that we have a limited space with dimension m x n where a group of five robots need to explore as quickly as possible an unknown territory to collect data

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about the environment, where space has a low (or no) lighting and obstruction. While others are using cameras, we will build our solution basing on the use of a technical vision system (TVS) [3] that helps immediately get the Cartesian coordinates of objects in the zone of interest, whenever possible – immediately scaled to robots own coordinate system (and its size). Systems with similar construction are described in [37, 38]. Upon receiving data about obstacle apparition from TVS (**Fig. 1**), the robot must send information about this obstacle with its coordinates to the server for synchronizing terrain data with other robots. Thus, the knowledge of general terrain maps by all robots will prevent unnecessary movement in impassable routes and increase the rate of recognition of unknown terrain.

Most of the researchers in the area of robotic group movement are limited by the experiments with simple, smooth and cyclical/closed trajectories [1, 2] and the use of «follow the leader» methodology, while we consider the problem approximate to the real situation. The results of our pathfinding methods modeling will allow to determine the desired trajectory as close as possible to smooth on real terrain, adjusting to the conditions that were detected by the TVS, in a strictly defined geometric pattern and coordinate the actions of the robots group.

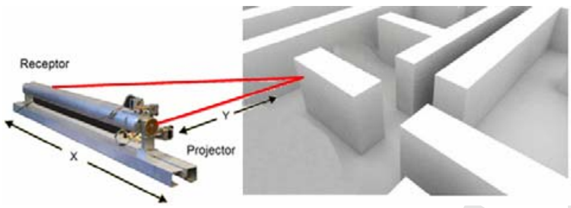


Fig. 1. Use of TVS in case of obstruction

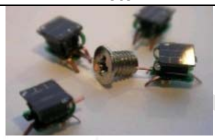
As mentioned before in hazard terrain there is a probability of signal failure between the robot and server. This particularly leads to the need of network structure to be changed. The data obtained by individual TVS of each robot must be properly processed on the server and synchronize all of the robots. The organization of interactions in our robotic group is based on the static swarm model [27]. It is characterized by the absence of a given control center and is a variation of a fixed network – a set of agents. Our "changing the leader" method based on [27, 31, 32] allows solving this problem of network structure reorganization by selecting the most appropriate communication point (robot) for sending requests to the server. Furthermore, this method can be used in other areas of task distribution.

This paper is organized as follows. Section 1.1 provides a brief review of the existing robotic swarm projects and a definition of problems in robots teamwork which solution is the main goal of this paper. The choice of maps storage method and algorithms to work with them (the calculation of routes, etc.) represented in Section 2, while selection, justification and TVS operation description (to determine passable and impassable places) is briefly explained in Section 3. Group of robots behavior determination is represented in Section 4. Knowing the method of solving the above problems the model of a data exchange system (Section 5) can be developed. In Section 6 the conclusions are made.

1.1. Definition of problems in robots teamwork

There are many examples of systems that implement collective behavior and can be used for tasks similar to ours. Some of the examples are represented in **tab. 1**.

Table 1.
List of existing robotic swarm projects.

Project name	Photo	Description
I-SWARM [4]		Developed in Germany (University of Karlsruhe) micro-robots with "collective thinking". Robots are only able to recognize each other and stick to its community.
Multi Robot Systems [5]		Developed in University of Alberta in Edmonton, USA studies robots collective behavior. This institution has several robots systems (Multi Robot Systems (MRS)) in development. The project is devoted to problems of collective decision-making.
Project SwarmBot [6]		The US company iRobot engaged in the development of small robots that can work together to carry out certain actions. It is expected that the SwarmBot robots can join a group of up to ten thousand and perform tasks such as search for mines, research of unknown territory (including ~~on~~ other planets), detection of harmful substances, and etc.

Project Centibots [7]		There are small robots that can work as a single organism, and alone. Their goal is to study enclosed space, make its plan and perform some tasks. Robots do not have a centralized management system. The algorithm is based on the principles of robots "independence and initiative," they occasionally interact with each other and depending on the circumstances, automatically reallocate roles.
Project Swarmanoid [8]		The main objective of the project is to study the behavior of inhomogeneous groups of robots. The considered task was in which a team of wheeled robots, a flying robotic spy and the handling robot jointly found the object (book), and manipulated it.
Evolving robots [9]		The Swiss Laboratory of Intelligent Systems (Polytechnic School, Lausanne) studies "evolution" of robots. Robot evolved gene that determines behavior. A group of 10 robots competed for food. The challenge was to find robots "food source", which is a luminous ring on one end of the arena. Robots can "communicate" with each other by m light signals. The evolution of robots in experiments sometimes leads that even the robots were taught to deceive opponents, letting the "wrong" light, being near the trough.
Robots scouts Scout [10]		Developed in the distribution centers of robotics, University of Minnesota, USA. Designed for intelligence, the robot is a very high quality from a technical point of view device. The robot can work in a team. Its design allows you to "shoot" using a device resembling automatic grenade launcher. The robot is designed to help the police and rescue services in carrying out dangerous operations. There is a central control unit, which receives information obtained by robots, and which controls the robot, the basic mode of operation is to control the robot operator.

According to the reviews of different robotic swarm projects in [4-9], a number of specific problems that occur in robots teamwork can be allocated. Among them are:

– Unpredictable dynamics of the environment;

– Incomplete and contradictory knowledge of robots (agents) on the state of the environment and the other participants;

– Variety of options to achieve the goal, the team structures, roles, etc.;

– Distributed and dynamic nature of the team action planning;

– Problems related to the fact that the swarm is a set of physical objects existing in a real complex environment (communication problems, the territorial distribution of swarm and so on.).

– Communication problems or data exchange (network architecture, protocols, etc.).

Therefore, a qualitative solvation of communication problems will make our purpose twofold. By scaling objectives, affecting on data exchange in a group of robots that were described above, we can distinguish two tasks:

1) Make a solution of the problem of a RG movement by monitoring of their local coordinates and search of presumed rotes;

2) Solve the task of roles distribution.

The description of our task solution of data transferring model selection in robotic group is following. Firstly, it is based on the existing original technical vision system with dynamic triangulation, which allows obtaining the Cartesian coordinates of visible objects in a more simplified form than the data from the cameras. It helps to solve the first task of robots position monitoring, and search the routes. Secondly, we implemented the voting system based on fuzzy logic [34-36] for the communication network formation between robots in group. This make possible to choose the better node (robot) to transfer received data from TVS between robot and server and for task distribution in robotic group. These two approaches allows dynamically select the data transferring model for further robots actions coordinating and accelerating the process of movement in hazard terrain.

2. Methods of robot swarm territory mapping and routing

For determining the method of territory map storing, we should be based on routing methods. That is why let us review some algorithms that are suitable for our task.

There are many different methods to search for the shortest routes:

1. Classic [11-12] (Dijkstra's, Floyd-Warshell's, Prim's, Kruskal's, algorithms, etc.).

2. Heuristic [13-14] (A* algorithm, ant algorithm, genetic algorithm, etc.).

2.1 Analysis of classic algorithms

Based on data from [11-12] we made the research for Dijkstra's, Bellman-Frod's and Floyd-Warshell's algorithms by generating the nine oriented graphs with 100, 200, 300, 400, 500, 1000, 1500, 2000 and 2500 nodes.

Based on capabilities of algorithms, analysis is divided into two parts: the search for routes from one node to all and from all to all nodes. In the first case analyzed only

Dijkstra's and Bellman-Ford's algorithms, as Floyd-Warshell's algorithm is used only for the search of all to all, and in the second all three algorithms.

The analysis results are presented in the form of tables (**Tab. 2-3**) and graphics (**Fig. 2,3**) (analysis was carried out in the case of "one to all" and "all to all" search) where tables represent the amount of time (in nanoseconds) needed to find a shortest path in case of 100 to 2500 nodes for each of the algorythms.

Table 2
Modeling results of "one to all" search

Nodes	*Dijkstra's (ms)*	*Bellman-Frod's (ms)*
100	1.7	16.2
200	5.1	68.4
300	5.7	197.6
400	7.4	454.3
500	8.7	917.6
1000	26.8	2250
1500	52.2	7800
2000	54.8	19600
2500	86.8	38500

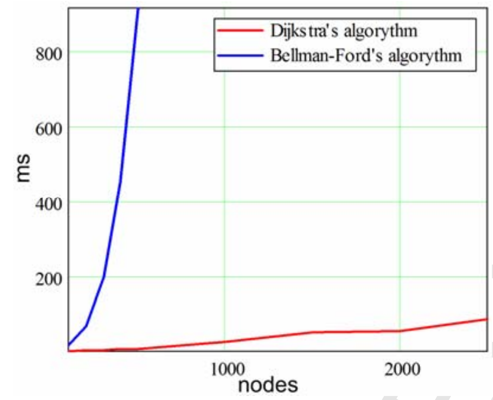


Fig. 2. "one to all search" search results

Table 3
Modeling results of "all to all" search

Nodes	*Dijkstra's (ms)*	*Bellman-Frod's (ms)*	*Floyd-Warshell's (ms)*
100	24	571	15
200	105	1040	54
300	314	2807	143
400	742	5820	304
500	1100	7802	590
1000	3510	13805	988
1500	5480		1590
2000	8040		3760
2500	15200		7320

The analysis showed that the difference in the performance of Dijkstra's and Floyd-Warshell's algorithms at "all to all" search is insignificant until we have less then 500 nodes (**Fig. 3**), but the resulting routing matrix have different parameters (length of the route is the same, but the ribs used for its passage are different). Bellman-Ford's algorithms is unacceptable for use in a task with lots of nodes becouse of its high calculation time. The use of such algorithms require a complete knowledge of the terrain (graph) and they complicate communication protocol between robots, which in this case means an increase of time of data synchronization. Thus, to find the route we will use heuristic algorithms.

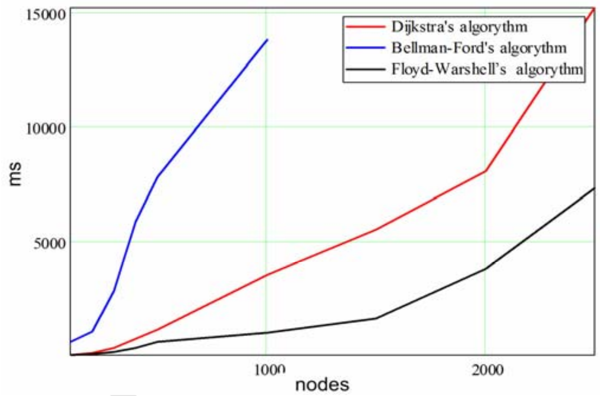


Fig. 3. "all to all search" search results

2.2 Heuristic algorithms review

Other idea of pathfinding if to use algorithms that are best for game industry, especially for real time strategies (RTS). For example it can be Lee algorithm [15] and A* search [16].

2.2.1 Lee algorithm

Lee algorithm is a wave algorithm for finding the way on the map, or tracing algorithm. Its use permits to build a path or route between any two elements in the labyrinth. From the initial element wave is distributed into four directions. The elements to which it comes form the wave front.

Elements of the first wave front (**Fig. 4 a**) are sources of secondary waves. Elements of the second wave front (**Fig. 4 b**) generating a third front, and so on. The process ends when the item reaches the final point. In the second phase we build the track.

The construction is carried out in accordance with certain rules: the construction of highway traffic passes depending on the selected priorities; the route is built by choosing the point with the wave front higher than previous until the end point.

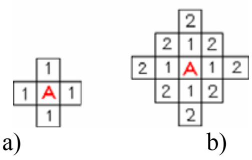


Fig. 4. a) first wave front; b) second wave front

2.2.2 A Search*

A* Search uses a distance heuristic to search routes that are closest to the ending point. The point value of each edge is the sum of G (the cost of traversing that edge) and H (the estimated cost of traveling from the neighboring vertex to the destination). Dijkstra's algorithm can be thought of as a special case of A* that does not use any heuristic for H [12]. At the start point, the algorithm considers the surrounding nodes and their point values using the G and H heuristics. Then for of each surrounding nodes it calculates the point value and uses the node with the lowest point value as its new starting point. This run recursively until the path reaches the end point; the resulting path is very efficient. A* is a more attractive algorithm for the robotics field than Dijkstra's algorithm, as paths that are directed toward the destination are explored with higher priority. A* has the same setback as Dijkstra's algorithm in that it may avoid paths that are scored poorly in the edges closer to the robot's origin, but later contains edges that are scored very highly in their balance of accuracy and efficiency.

Examples of the heuristic algorithms use are presented on **Fig. 5.**

According to the literature research the best way to store the map are matrixes. Such method of mapping is better because of next benefits:

1) Easy way to decompose the map and to synchronize it with parts that robots are explored;

2) Easy to make a layout from a previously made image (photo) by determining the passable and impassable places;

3) Easier to predict routs while having an unknown territory and faster recalculation.

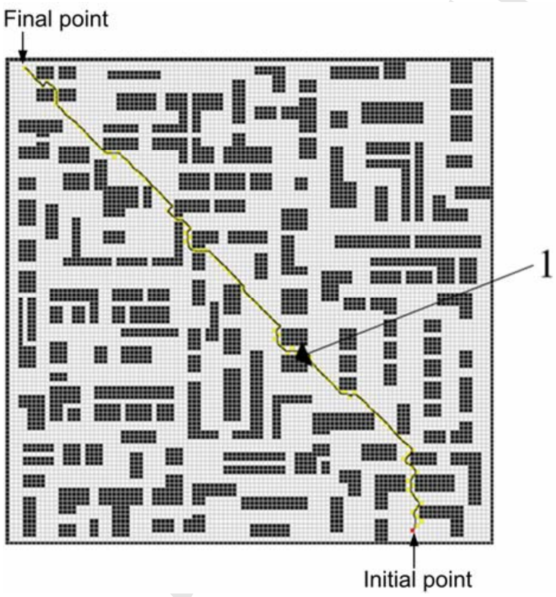


Fig. 5. Map with founded rout:1 – founded rout

Combination of this algorithm with our TVS will help to RG predict the route and estimate the passing possibility between obstacles in narrow space, by getting the real size of the corridor for further motion. As our TVS returns Cartesian coordinates, not like other technical vision systems based on cameras returns an image that need post processing, this also decrease the time of data synchronization between robots.

3. Technical vision system

Using the methodology represented in [3], where one of the purposes was to build a smooth trajectory on minimum amount of points, the size of a matrixes cell can be calculated by taking into consideration the robot size specification, safe margins and the sensors distance for the detection of obstacles. That is why we need to choose a most appropriate technical vision system.

The most common vision systems are based on using cameras. For example, in [17], to build 3D objects the time-of-flight cameras are used, in [18] the present a single camera methodology and authors of [19] use drones with cameras for mapping and 3D maps creating. Most of them are good for object recognition and etc. but in our case where we must move in complex conditions (low light, a sharp change in the landscape, so on) the vision system must satisfy such circumstances.

The TVS we are talking about has been presented before in [20-23]. Let's explain the most important aspects of the TVS.

It is based on a method called dynamic triangulation (**Fig. 6**). The main components of the TVS are the positioning laser (PL) and the scanning aperture (SA). The PL contains the next elements: a laser that emits its beam toward a fixed 45^o mirror; this mirror redirects the beam orthogonally into a rotating 45^o mirror which rotation is driven by a stepper motor. PL is driven by a stepper motor to control the laser direction. SA receive the reflected laser rays, this indicates that an obstacle has been detected.

Dynamic triangulation [24] consists of detection of laser instantly highlighted point coordinates based on two detected angles B_{ij} and C_{ij} (here *ij* means the number of horizontal and vertical scanning steps consequently) and fixed distance *a* between a projector and a receptor. Such triangle's lifetime is about 0.039×0.5/2000≈0.00000975s (where 0.039 s is minimal time of semi-sphere scanning at 7-13 rev/s motor speed; 0.5 cm is averaged laser spot size on experimental striking distance, and 2000 cm is the selected frame width). In such triangle (**Fig. 6**) if 3 parameters are known, it makes possible to calculate all others. Angle B_{ij} is calculated as simple ratio of two counters codes: number of clock pulses between two home pulses and in interval 'home pulse – spot pulse' (Eq. 1).

$$B_{ij} = \frac{2\pi N_A}{N_{2\pi}} , \tag{1}$$

where N_A is the number of reference pulses when laser rays are detected by the stop sensor and $N_{2\pi}$ is the number of reference pulses when the 45^o mirror completes a 360^o turn detected by the zero sensor.

To calculate x, y and z coordinates the next equations are used (Eq. 2-5):

$$x_{ij} = a \frac{\sin B_{ij} \cdot \sin C_{ij} \cdot \cos \sum_{j=1}^{j} \beta_j}{\sin[180^o - (B_{ij} + C_{ij})]}, \quad (2)$$

$$y_{ij} = a\left(\frac{1}{2} - \frac{\sin B_{ij} \cdot \sin C_{ij}}{\sin[180^o - (B_{ij} + C_{ij})]}\right) \text{ at } B_{ij} \le 90^o, \quad (3)$$

$$y_{ij} = -a\left(\frac{1}{2} + \frac{\sin B_{ij} \cdot \sin C_{ij}}{\sin[180^o - (B_{ij} + C_{ij})]}\right) \text{ at } B_{ij} \ge 90^o, \quad (4)$$

$$z_{ij} = a \frac{\sin B_{ij} \cdot \sin C_{ij} \cdot \cos \sum_{j=1}^{j} \beta_j}{\sin[180^o - (B_{ij} + C_{ij})]}, \quad (5)$$

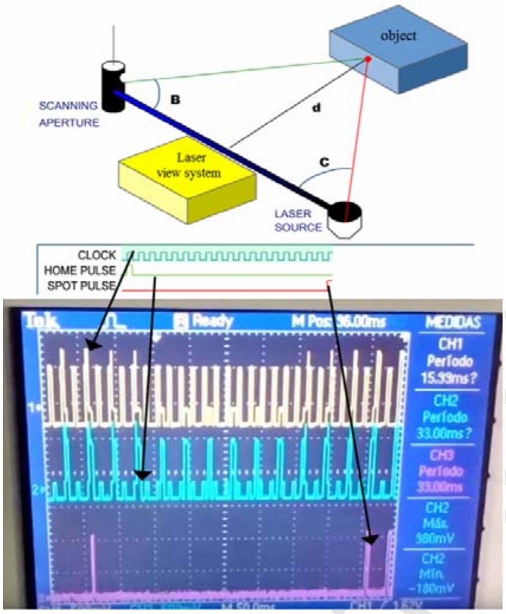


Fig. 6. Dynamic triangulation Principle of laser scanning TVS

This system in comparison to others has wide opening field of view angle (up to 160^o), due to image quality and post processing time the camera using systems are still at a disadvantage, and perfectly matches for operation in completely dark environment, which is completely impossible for camera systems.

According to fact that for area maps formation heuristic search methods was chosen that require the use of matrixes and TVS based on dynamic triangulation – is necessary to determine the physical dimensions of the matrix cells.

Based on the modeling results in [3] for planning of the robot movement let us determine the size of the sector, on which we will move it as the size of robot plus 50% safe margin for it be able to turn and have a smooth path – this sector will be presented in the form of a matrix where the physical size of its element will be equal to the size of the maximum possible obstacles to overcome.

4. Behavioral models for robotic group

As mentioned before, our robotic group will cooperate using the specific behaviorism according to the task. This model has been partially presented before in [25, 26]; the explanation will take into consideration only the basics aspects of different cooperation rules and models.

Collective behavior of robots can be divided into the following areas:

1. "Rigorous" mathematical solution – is a research in the systems theory field and the creation of formal models and mechanisms of collective behavior.
2. Technologies of multi-agent systems (TMS).
3. Simulation modeling – implementation models of interacting agents (robots).
4. Swarms, bee and ant algorithms. Such methods and algorithms based on swarm intelligence.
5. Evolutionary methods. The main task is an implementation of the evolutionary mechanisms by inner swarm interaction.
6. Distributed artificial intelligence (AI) – the results obtained in the theory of distributed systems, decision theory, and even the theory of TMS are the basics.
7. Robotics group – approach to the coordination of robotic swarms. Basis of RG – is the effect of the behavior emergence that observed in social insects.

The most appropriate behavioral model is RG with dynamic leadership system implementation. Leader in our case will have a role of a hot spot for data transferring.

4.1. Leadership

Leadership is one of the principal features of swarm robotics is the local nature of the interaction of robots with each other, as well as the robot with the environment [28]. This interaction is called implicit communication [29]. The idea is that each robot in group interacts directly only with its neighbors, in a restricted area of visibility. In such system, the robots make their own decisions on how to proceed, based on some simple rules for local interaction.

In the "follow the leader" method is considered that the group has a priori defined leader, who sets this movement. Terms of local interaction can be very different: from a purely formal [30] to very exotic. For example, rules of schooling movement based on the model of the springs and shock absorbers. "Spring" component model defines the attraction of individuals to the leader (and not to each other), and "Shock absorbers" – pushing away from the leader. In [31], on the other hand, described an option which allows determine the leader to solve the problem of coordinated motion.

4.2 Changing the leader

Solution of the problem has been presented in [31]. The problem is formulated by the following way. Let there be a set of agents with limited communication capabilities. This means that agents are only able to a direct local interaction between neighbors. The challenge is to choose agents leader by voting.

Each agent is described by the quartet

$$A = (\alpha, L, C, W)\,, \tag{6}$$

where α – agent's identification, L – list of neighbor agents from whom he can receive information, C – identification of the "candidate" to vote for, W – weight of the candidate C (amount of voices that have to be given for a candidate).

The essence of the voting procedure is that each agent determines for whom his neighbors will vote. At the same time, depending on the weight of the candidate for whom the neighbor voted, an agent can change their minds and vote for the same candidate.

The probability that agent *i* change his mind under the influence of opinion agent *j* (opponent) may be defined as follows:

$$p_{ij} = \frac{W_i}{W_i + W_j} \tag{7}$$

Propensity to change his opinion naturally depends on the degree of conviction (or weight) of the candidate.

The distribution of votes and their weights in the initial moment of time is carried out in the following way: each agent votes for himself (declares himself a candidate), and the weight of this decision is the number of agent's neighbors.

Example of choosing "candidate" can be represented according to an algorithm on **Fig. 7**. At the beginning, we choice possible "candidates" to vote, then for each of them goes analysis and estimation of the selected criteria.

To justify the selection of "candidate" let us use fuzzy logic.

Let us use linguistic variable e = "evaluation of candidate", the value of which can be set using the five levels scale of M = {«very low", "low", "medium", "high", "very high"}.

From this we get many alternatives to E in the following form:

$$E = \{e_1, e_2, ..., e_n\}, \tag{8}$$

where e_i – alternative "candidate", at $i = 1..n$.

The next step is to determine the input parameters (characteristics) for the calculation of the "candidate" mark. We offer the following characteristics:

1) territorial:
- c_1 = "the distance to the end point of movement";
- c_2 = "the possibility of further movement";
- c_3 = "possibility of choosing an alternative route";

2) effectiveness:
- c_4 = "the number of detected new obstacles";
- c_5 = "effective distance traveled";
- c_6 = "total distance traveled";

3) surroundings:
- c_7 = "the number of close agents (robots)";

4) status:
- c_9 = "the physical state of the agent (robot)";
- c_{10} = "battery level".

Each of these characteristics is estimated by the extent of its availability for the i-th candidate and determined by an expert (robot):

$$C_i = \{c_{i1}, c_{i2}, ..., c_{ik}\}, \tag{9}$$

where c_j – characteristic value of i-th alternate "candidate" at $j = 1..k$.

Each of the characteristics is "weighted" with the help of experts:

$$W = \{w_1, w_2, ..., w_k\}, \tag{10}$$

where w_j – the j-th characteristics weighting, $\sum w_i = 1$.

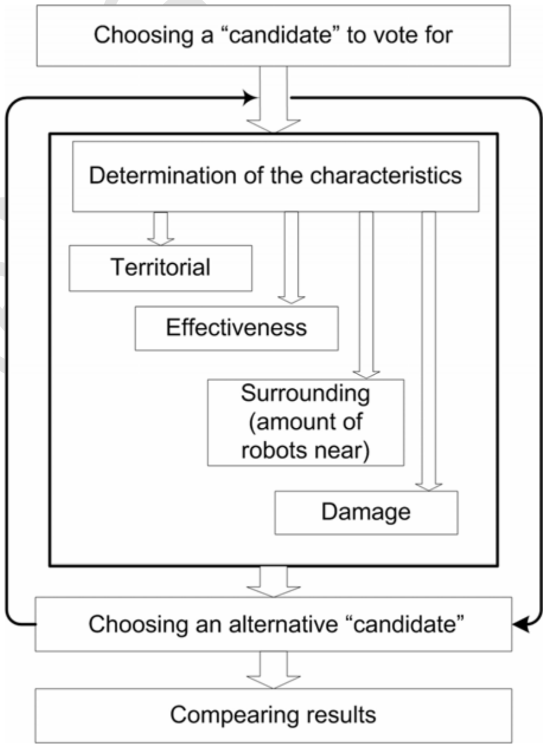


Fig. 7. Stages of agent selection to vote for

Evaluation of the i-th "candidate" takes the following form:

$$e_i = \sum_{j=1}^{k} w_j c_{ij} \tag{11}$$

To determine the value of linguistic variable we use three types of membership functions [32], where the extreme values ("very low" and "very high") will determine Z-shaped (12) and the S-shaped (13) function[f. The degree of belonging to the intermediate values will be determined bell-like membership function (14). A general view represented on **Fig. 8.**

$$f_{vl}(e_i) = \begin{Bmatrix} 1, x < vle \\ \frac{1}{2} + \frac{1}{2}\cos(\frac{e_i - vle}{vl - vle}), vle \le x \le vl \\ 0, x > vl \end{Bmatrix}, \quad (12)$$

where vle – the threshold to which the membership function is equal "1"; vl – a threshold, after which the membership function is equal "0";

$$f_{vh}(e_i) = \begin{Bmatrix} 1, e_i > vhs \\ \frac{1}{2} + \frac{1}{2}\cos(\frac{e_i - vhs}{vhs - vh}\pi), vh \le e_i \le vhs \\ 0, e_i < vh \end{Bmatrix}, \quad (13)$$

where vhe – threshold, after which the membership function is equal to "1"; vh – a threshold, after which the membership function is equal "0";

$$f_{gb}(e_i) = \frac{1}{1 + \left|\frac{e_i - c}{a}\right|^{2b}}, \quad (14)$$

where c – mid of a membership function; a – value at which $f_{gb}(c + a) = 1$ и $f_{gb}(c - a) = 1$; b – the value of function smooth regulation.

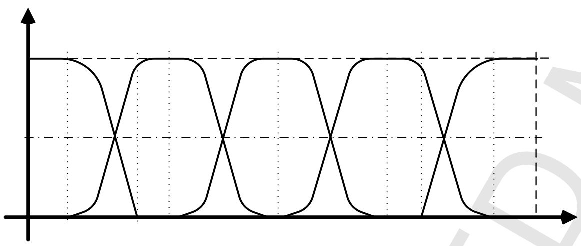


Fig. 8. Membership functions

5. Methods of data transfer

When using the strategy of centralized management of a robots group R, every robot $R_i (i = 1, 2, ..., N)$ of group transmits information about its condition, collects information about the environment in the central control device, and receives commands from the central control unit (**Fig. 9**).

In group of N Robots, where every robot transfers on central control device message with size of K_{out} and receive commands with size of K_{in}, the volume of transferred info will be:

$$I = N(K_{in} + K_{out}). \quad (15)$$

Thus, the load on the communication channel is directly proportional to the number of robots in the group.

Lest make a modeling of such system consider the case N = 5 (where n – amount of robots) in two sates – where all robots have a good connection to a server (**Fig. 10**) and when robot #1 and robot #2 has bad connection that cause a package lost (**Fig. 12**). Modeling is based on queue theory, where information about obstacle that was found by robots is sent to the server for further processing.

Modeling in Matlab was made in period of 500 seconds for all cases and gave us the next results represented on the next figures: **Fig. 10** shows us the total amount of sent requests for processing and processed requests from all five devises, there difference explained as some of the requests are duplicated; **Fig. 11** represents a timeout in request processing (amount of time needed for the next request to be processed by server)(*Timeout for robot #1*, *Timeout for robot #2* and etc.); **Fig. 12** represents a modeling for the second case, where the bad signal to server cause the loss of requests (difference between sent requests for processing and received requests).

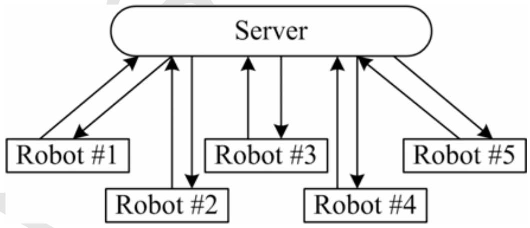


Fig. 9. Information exchange with centralized management

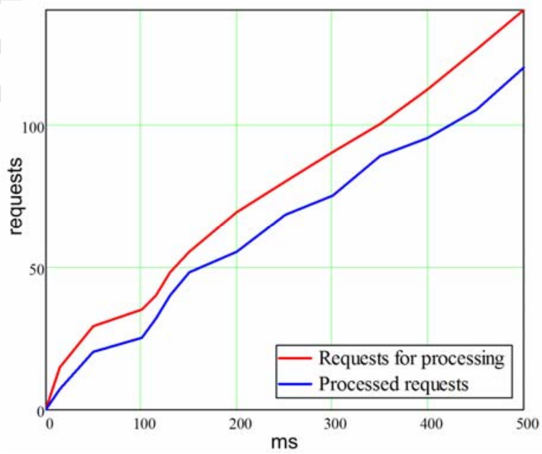


Fig. 10. Total amount of sent and processed requests

Such data loss causes troubles in movement of robots and increases the time of task implementation. That is why the network structure must be changed.

When using a hierarchical strategy of centralized management central control device is subject to several top-level hierarchy of the robots, each of them are subject to several robots lower level of the hierarchy (**Fig. 13** represents hierarchy for our case).

Such complex control schemes require very high performance of communications, because all the robots, except the lowest level of the hierarchy, are interacting with robots of lower and upper levels of the hierarchy. Displacement information through the transceivers of the robot, may be estimated as:

«Very low» «Low» «Mid» «High» «Very high»

1

$$I = n(k_{in} + k_{out}) + K_{in} + K_{out}, \quad (16)$$

where n – the number of robots in the lower level of hierarchy; k_{in} – the amount of information in incoming messages from the lower level robot of hierarchy; k_{out} – the amount of information in outcoming messages to the lower level robot of hierarchy.

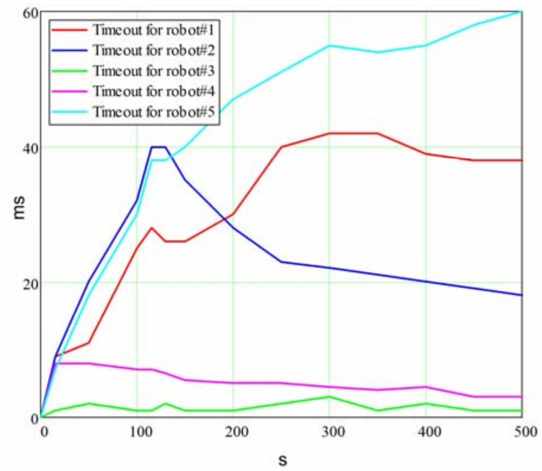


Fig. 11. Timeout in request processing

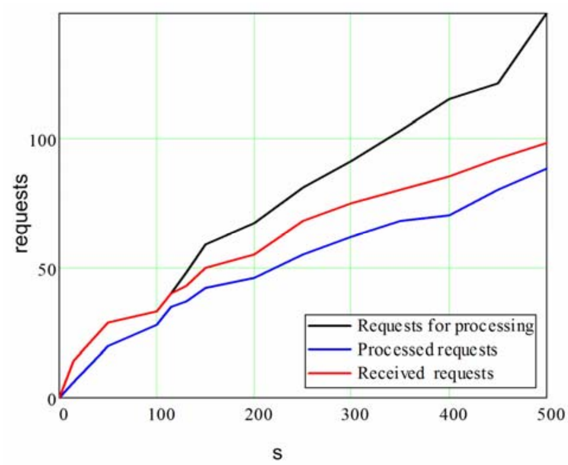


Fig. 12. Total amount of sent, received and processed requests with signal loss

Strategies of centralized hierarchical control modeling principles are the same as in previous scheme. **Fig. 14** shows that during the loss of connection to server all the unsent request were compensated by sending them through the neighbour. However, this also increased the timeout in request processing for robots #3 and #5 (**Fig. 15**).

7. Conclusions

In this paper, we have proposed and substantiated the choice of dynamic data exchange network for robot communication based on voting process. This robot swarm is processing and transferring the geometrical data of our original TVS´s which are enough precise and naturally represents information about swarm surrounding in the same Cartesian system. It significantly simplifies the decisions for navigation performance. The decision of dynamic data exchange is supported by average timeout in request processing that in the end of the modeling is suspended to the time of our TVS obstacle detection time (≈0.039 s in both cases of network structure (**Fig. 11**, **Fig. 15**)).

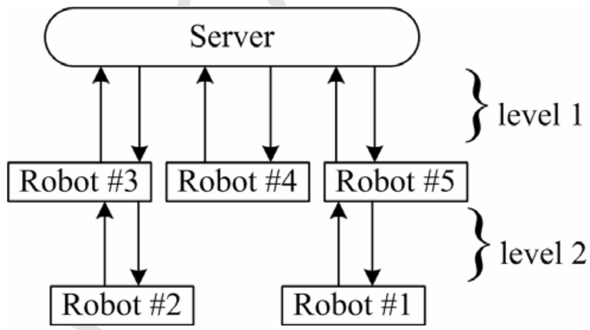


Fig. 13. Information exchange using strategies of centralized hierarchical control (shown 2 levels)

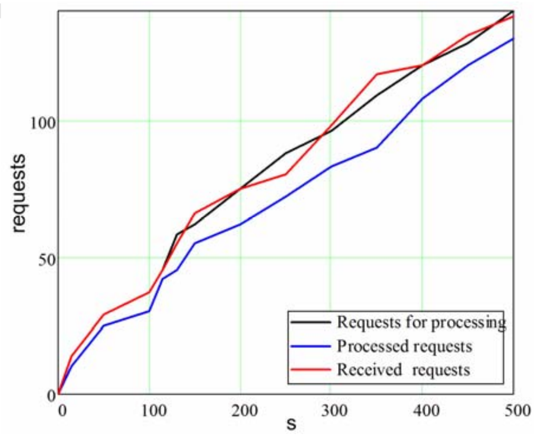


Fig. 14. Total amount of sent, received and processed requests with signal loss using centralized hierarchical control

The leader changing system that we implemented improves the process of data transferring by dynamically changing the network model from centralized management to centralized hierarchical control and backwards.

Results of our system implementation are shown on **Fig. 16** by comparing of the number of processed requests before and after leader changing system implementation.

Such approach helps to increase the movement speed of group of robots and decrease the time of their task accomplishment.

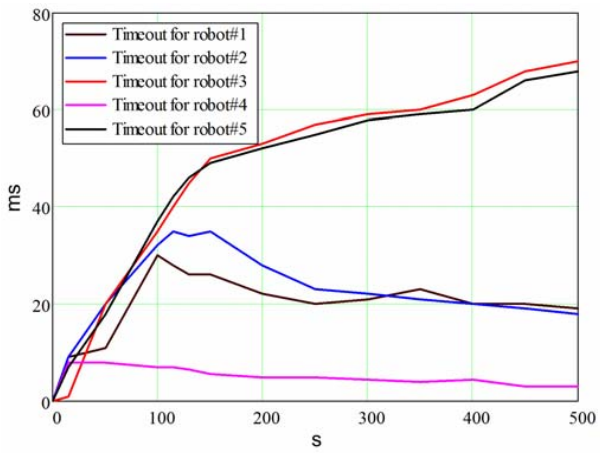


Fig. 15. Timeout in request processing using centralized hierarchical control

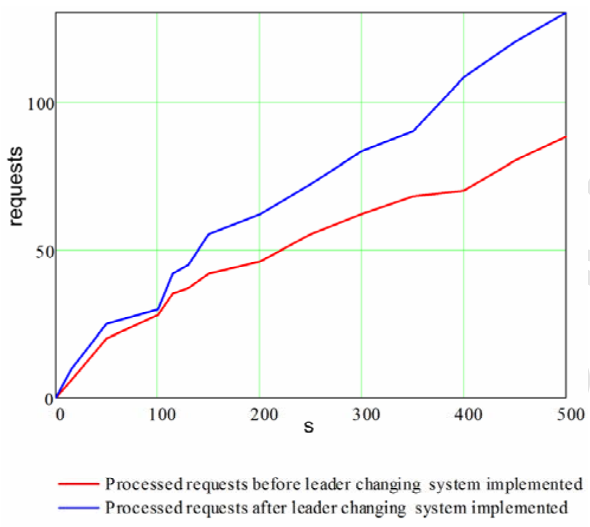


Fig. 16. Comparison of the number of processed requests before and after leader changing system implementation

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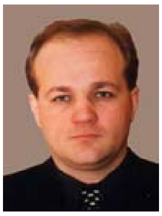
This idea of data transferring model in the group of robots is proposed.

Justified technical vision system choice.

Described technical vision system method of obstacle detecting.

The mechanism of leader changing method based on fuzzy logic was used.



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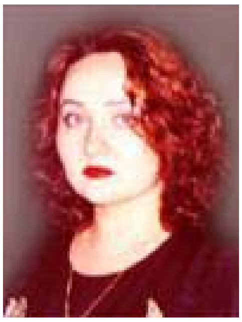

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