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PATH PLANNING ALGORITHMS IN MULTI ROBOT ENVIRONMENT

Key words

Robot, multi-agent system, path selection, warehouse.

Abstract

In recent years, an increasing trend in application of autonomous mobile robots in multi-agent systems worldwide has highlighted the importance of robot path planning. In this context, one of the main problems includes optimal route determination and collision avoidance development for multi-robot systems. In many situations, using multi-robot systems in the same environment is a good strategy in managing tasks, and an example of which can be the logistic environment. This paper presents robot control algorithms used for transport managing in virtual warehouses. The problem of multi-robot path planning in this paper refers to establishing an optimized path and avoiding obstacles. The algorithm proposed by the authors assumes control over the work of a single robot, in cooperation with other robots, in the same environment. The robot performs the task, which is the transport of resources from distribution points to points of storage, while the routing algorithm is used to evaluate the

effectiveness of the algorithms. Simulation results show that the proposed method can effectively improve the performance of the planned path.

Introduction

Multi-agent systems are a subject of research of a relatively young field of science, intensively developing in recent years. In information science, they are referred to as new tools and technologies, constantly supporting the analysis and design of complex computer systems. A multi-agent system is in fact a computerized system, consisting of various agents interacting with each other – communicating, cooperating, and coordinating - in order to fulfil common goals. It is relatively difficult to define what an agent is. Different definitions of this term can be found in the literature [9], and it may refer to an object, an environment, or a computer program. The difficulty of defining the concept of an agent and multi-agent system associated with it stems mainly from the fact that the agent can be used in a vast range of applications. The robots discussed in this article are chiefly used in logistic operations management. The specificity of the actions performed within these groups is to optimize them in respect to the planning and management of the routers of robots. It can be said that the automatisation of particular tasks, implemented within an informatics systems, is a widely understood computer aided system based on the methods and mechanisms of artificial intelligence [8]. When performing specific tasks, multi-agent systems solve complex problems whose main participant is very often a person. The attempts to imitate and simulate human reactions with multi-agent systems resemble a development of artificial intelligence. Intelligent agents enable a hierarchical and flexible search of regularities in a relatively short time. In addition, the intelligent agents demonstrated the ability to make autonomous decisions concerning the path leading to the destination point. Path planning [1, 3] is an activity influencing effectiveness, especially in the storage technologies, which is the subject of this article. The selected path can be possibly realize between the start location and goal location. The analysis of the available literature [4, 7] indicates the importance of the use a video technology and image processing in robot motion planning and the observation of their position. The application of the video technology provides an access to robot actual location [6]. The test conducted as part of this studies confirmed the efficiency of the test video system, which fulfils its role, enabling the robot position adjustment. The application of optical techniques is another way of improving the robots current location analysis. Thanks to the optical control method of robot motion, we gain certainty of the maintenance of the entire process at the level of high efficiency [5]. The storage technology is a particularly useful branch in the field of industrial automation. Undoubtedly, this requires constant control during every phase of performed activities. Monitoring and controlling of the whole process is very often difficult to achieve in view of the high number of performed operations. This problem is solved by the communications of agents. The interaction between the agents is carried mainly by means of communication. A communications module enables the interaction between the robot and the operator or between the robots. Depending on the chosen form, this module may enable a wired or wireless communication [10]. The analysis of the available literature indicates the effectiveness of the wireless module, which uses the radio waves. This method is ideal for long-range communication, providing that there are no external factors and noise. Separation of these functions and the control of the robots movements seem to be important [2].

The main purpose of the authors was to develop and compare routing algorithms for robots used for transport in storehouses to perform the task in the storehouse. The evaluation of algorithm depended on the following criteria: the number of clients severed in the specified time, the average service time devoted to a single customer, the average energy consumed by the robot in the specified time, and the cost of energy to serve a customer.

1. Environment description

A unique simulation tool was created in order to perform research on coordination algorithms used in mobile robots. It simulates a virtual storehouse (Fig. 1), consisting of rows of shelves with paths between them and resource distribution points. The operating principle is as follows: Clients come to distribution points; every client can deliver one or more resources and/or pick up one or more resources; and, each resource has a specific storage location in the warehouse.

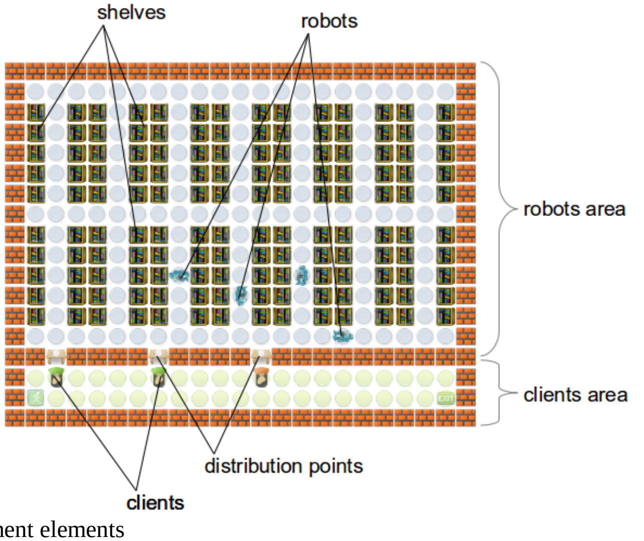

Fig. 1. Environment elements

The robots transporting resources are assumed to work in the created environment. A single robot can transport at most one item at a time. The direction transport may be as follows:

- From the shelf to the distribution point, if client wants to pick up the resource; or,
- Form the distribution point on the shelf, if client wants to deliver the resource.

A single transport operation from point A to point B is called a task. The tasks are distributed to robots by a coordinator via Task Distribution Algorithm. Robots have full knowledge about the environment, as well as an ability to communicate with each other.

The idea of the created environment implies its division into the fields. Each field can contain a shelf, a distribution point, or a space where a robot can move. On single field, at one time, there can be only one robot. The simulation process is divided into steps. At every step, every robot using the algorithm can perform a single operation. These activities include moving forward one square, making a 90-degree turn to get a resource from the shelf / distribution point, putting a resource on the shelf / distribution point, and waiting. Each operation except waiting consumes one energy unit.

Two sizes of warehouse were used in the research:

- Medium – 2 rows of 7 columns of shelves; and,
- Large – 3 rows of 10 columns of shelves.

Research concerning different numbers of robots and distribution points were performed for each size. After the initiation of the simulation, the client approaches the distribution points. Once a client leaves a distribution point, the next one approaches. There are no situations where the distribution point is not occupied by the client. In contrast, the client's needs are random. Every test had 10,000 steps and was repeated several times. The final result is the arithmetic mean of the repetitions (Figs. 2a and 2b).

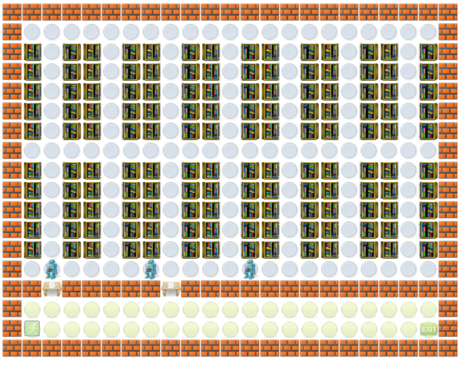

Fig. 2a. Medium size environment

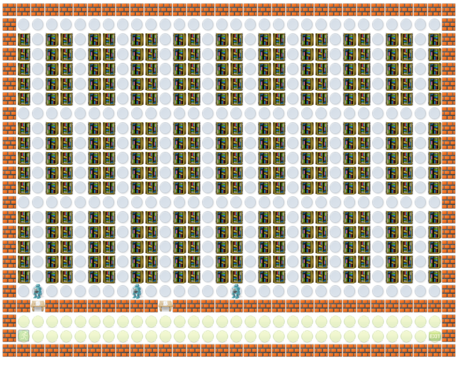

Fig. 2b. Large size environment

2. Task distribution algorithm

Task distribution algorithm is executed by the coordinator. In one simulation process, there is one instance of this algorithm. It works as follows: An order or a delivery of a specific resource by a client generates a task; the task is to transport the resource from the distribution point onto the shelf or vice versa; then, the task goes to the FIFO queue. In a later stage, if the robot is in an idle state or completes the task and reports to the coordinator for the next task. If the coordinator does not have another task to perform to assign to the robot, it is removed from the queue.

3. Single robot working algorithm

Every robot has its own instance of the control algorithm. This algorithm, performing the role of an agent, makes decisions during every step of the simulation of the decision. A robot, having full knowledge about the environment, acts according to the decision made (moves forward, makes a 90-degree turn, get or put resource, wait). The simulator, when possible, performs the action taken by the Main Algorithm of Robot that uses one of the following types of Routing Algorithms:

- Simple Routing Algorithm (SRA),
- Directed Routing Algorithm (DRA), and
- Path Reservation Routing Algorithm (PRRA).

The aim of the authors was to examine and compare the effects of these algorithms.

3.1. Main Algorithm of Robot

Main Algorithm is responsible for managing the operation of the robot. First, the algorithm checks whether a tasks was assigned to a robot. If not, it demands allocating another task from a coordinator. If there are no free task to assign to the robot, Main Algorithm calls the Routing Algorithm for decision, and returns it to the simulator.

If a task was assigned to a robot, the algorithm checks whether the controlled robot is transporting resources at the moment. If it does not, the algorithm checks the robot’s localization. If robot is not presented at the place of loading, if necessary, it is designated a target for the routing algorithm. In this case, it could be a loading place. Next, the Routing Algorithm is queried for a decision. If the robot is presented at a loading place, the algorithm finishes the tasks and returns a command to get a new resource. In a situation where the robot is already transporting a resource, the algorithm works similarly, with the only target as a delivery place. Figure 3 shows the algorithm in the form of a diagram.

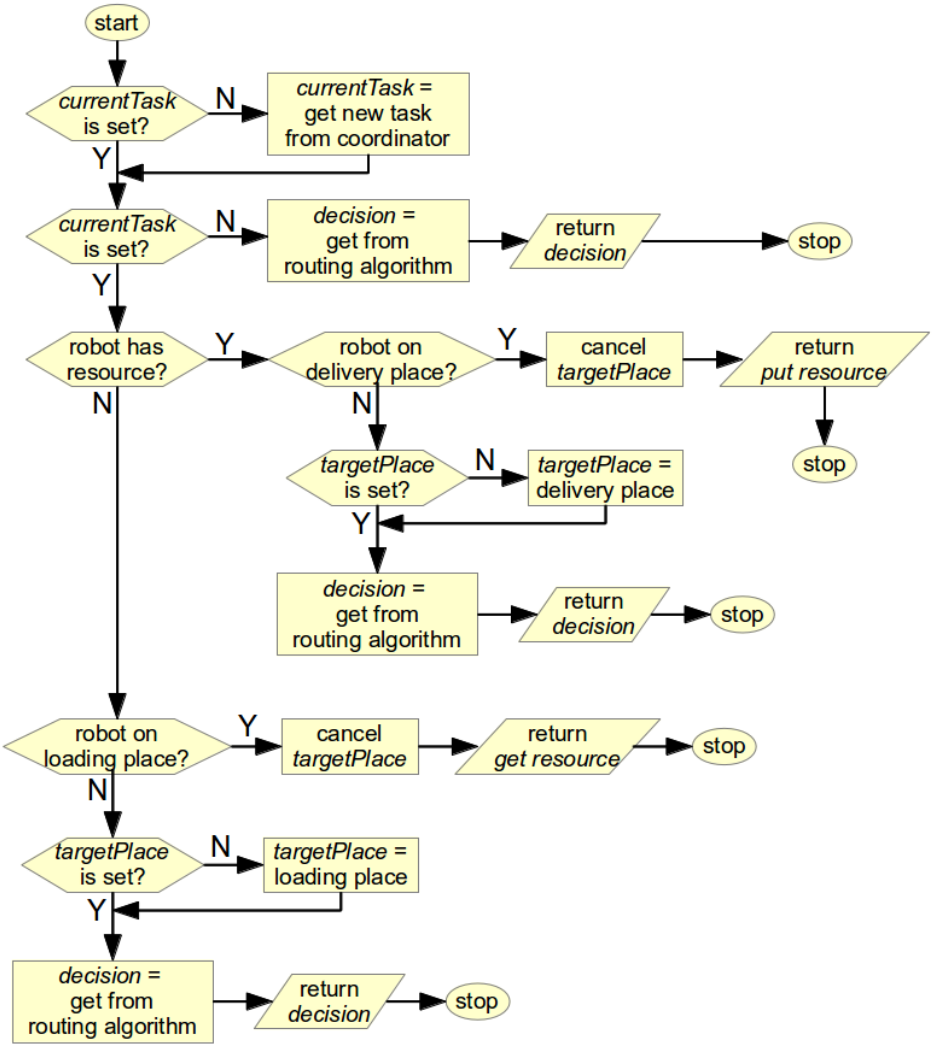

Fig. 3. Main algorithm

3.2. Simple Routing Algorithm (SRA)

SRA works as follows: If the algorithm has the target place established, the shortest path to this target is determined, taking obstacles into account. If the algorithm does not have the target established, the algorithm returns a wait decision.

In addition, to avoid deadlock, which means an inability to calculate the path to the target by the robot because of being blocked by other robots, a deadlock prevent method was developed. When the robot is not moving for some time, a random movement is performed. Figure 4 shows the algorithm in the form of a diagram.

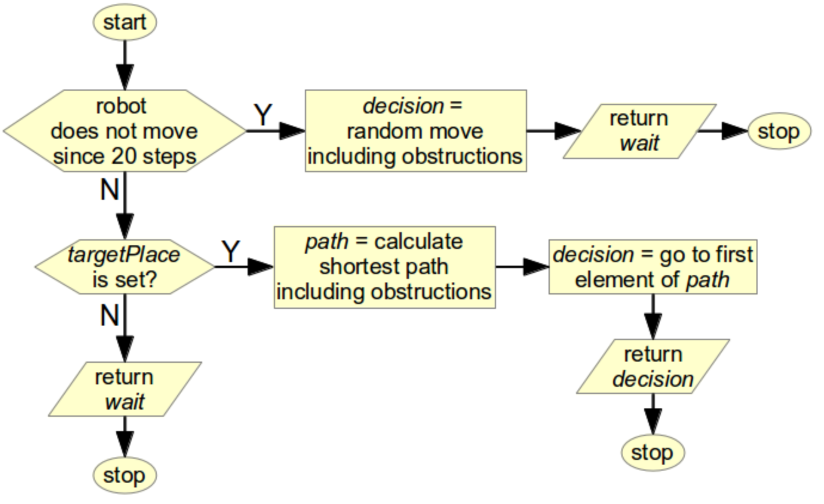

Fig. 4. Simple Routing Algorithm

3.3. Directed Routing Algorithm (DRA)

RDA is based on the need to indicate and establish a direction of movement for the corridors. Figure 5 shows the environment with designated directions of traffic in the corridors.

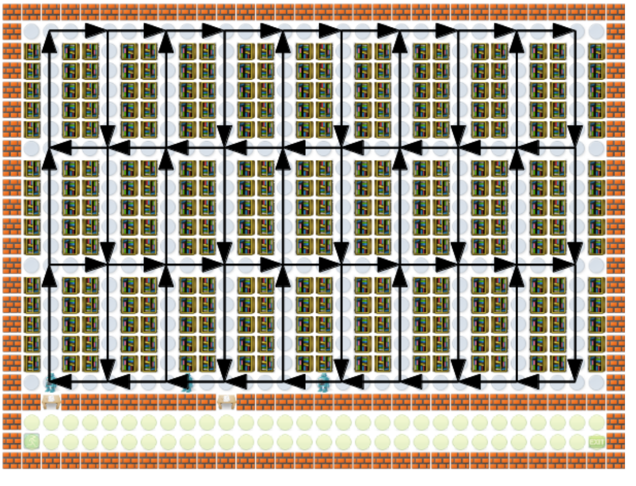

Fig. 5. Environment with directed corridors

The algorithm works as follows: If the target place is set, the algorithm determines the shortest path to this target, taking into consideration the designated directions of traffic in the corridors. If there is no target established, the robot performs a random motion, taking the established directions into account in order not to block the aisles. The result is that each robot is constantly in motion. Figure 6 shows the algorithm in the form of a diagram.

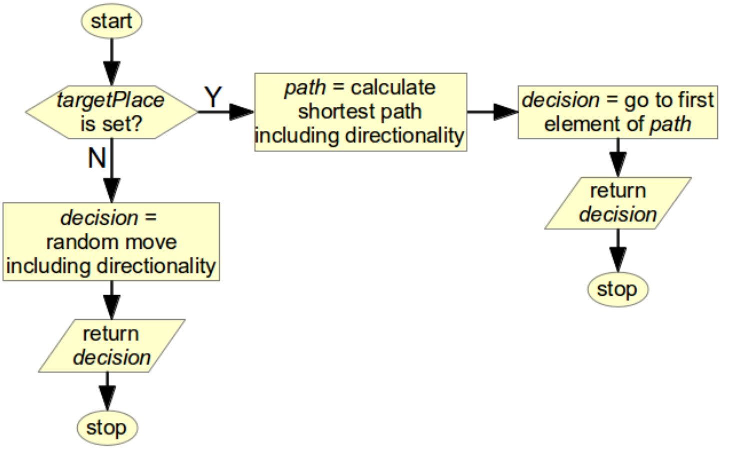

Fig. 6. Directed Routing algorithm

3.4. Path Reservation Routing Algorithm (PRRA)

The general principle of the algorithm is based on the reservation of the entire path leading to an established target for one robot only. Thanks to this action, other robots are not allowed to move along the reserved path or to reserve parts of it. Figure 7 shows an example of the operation performed by the algorithm.

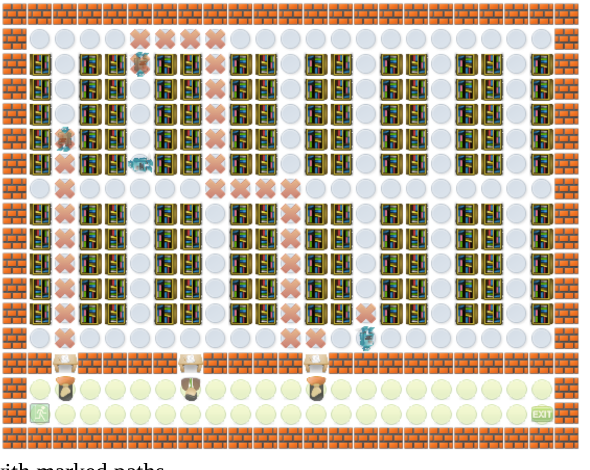

Fig. 7. Environment with marked paths

If the algorithm has an established target place, it tries to reserve the shortest path to the target, including markers belonging to other robots. If reservation is possible, the algorithm can put markers on the whole path.

In the next step, the algorithm checks whether the robot has a path reserved. If it has, it returns the decision of going along this path. Additionally, if the robot is on its own marker, it removes this marker, thus making this part of the path free for other robots. In a situation where the robot does not have a path reservation, the algorithm returns a wait decision. In addition, similarly to the case of the SRA algorithm, a deadlock prevent mechanism is used. Figure 8 shows an example of the algorithm.

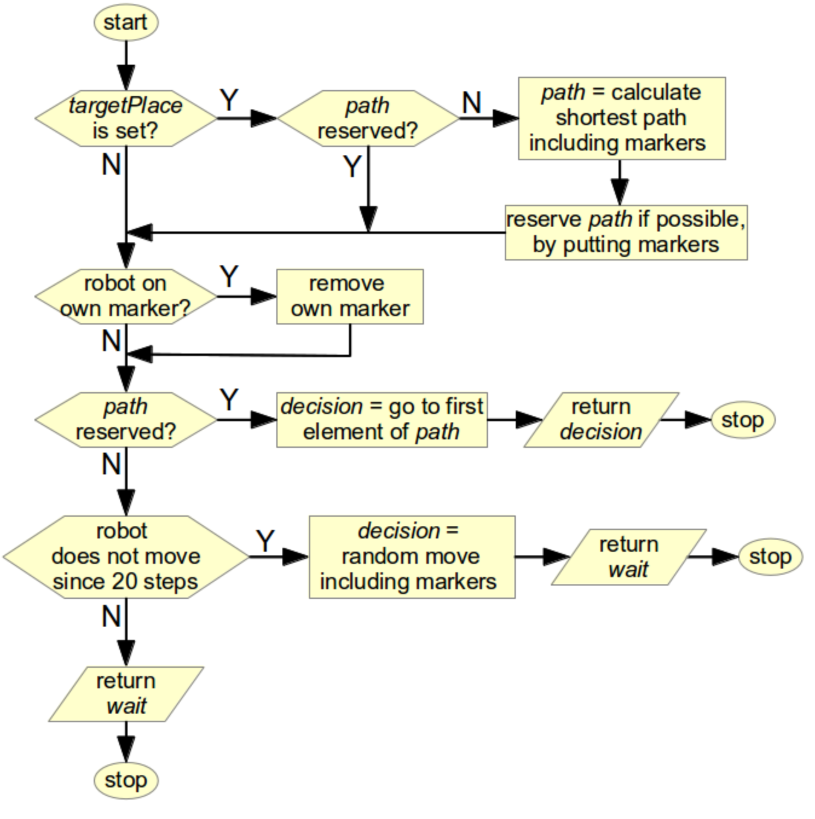

Fig. 8. Path reservation routing algorithm

4. Results

Figure 9 shows the results of the examination of the proposed algorithms in terms of the number of serviced clients as a function of the number of robots. The included charts clearly show that, for a small number of working robots, the

SRA algorithm is better, but for more robots and clients, it is better to use the DRA algorithm. For SRA and PRRA algorithms, there exists an optimal number of robots for a given environment size and the number of distribution points. In contrast, for the DRA algorithm, the increase in the number of robots increases efficiency.

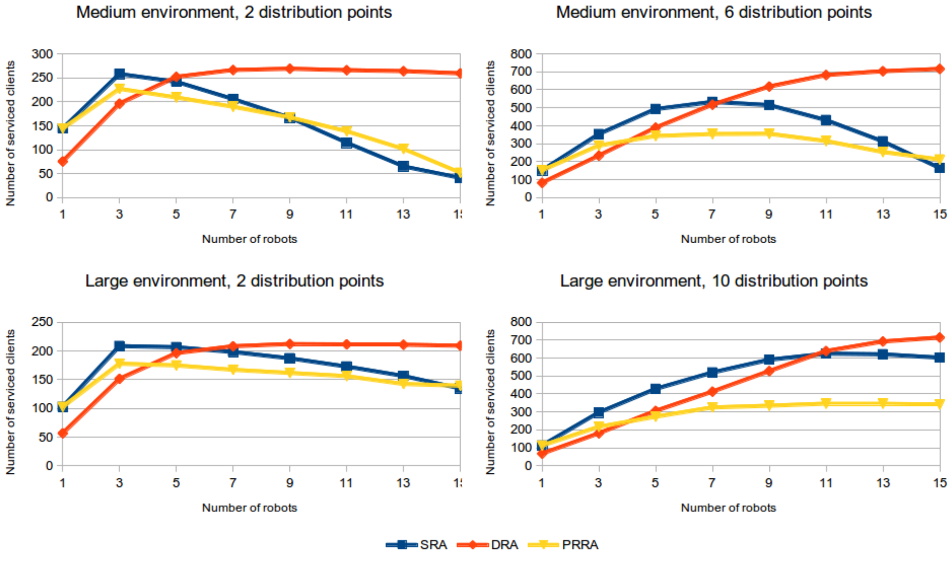

Fig. 9. The results of the examination of the proposed algorithms in terms of the number of serviced clients as a function of the number of robots

Figure 10 presents the results of the examination of the proposed algorithms in terms of average client service time as a function of the number of robots. In some parts of the characteristics, the client service time is similar, independently of the algorithm used. Increasing the number of robots increases the customer service time for SRA and PRRA algorithms.

Figure 11 presents the results of the examination of the proposed algorithms in terms of average robot energy consumption as a function of the number of robots. It can be seen that, during the examination, the most energy was consumed by the robots using the DRA algorithm. Increasing the number of robots in a simulated environment did not practically affect the amount of energy used by one robot. It is caused by the fact that, when using the DRA algorithm, all the robots are constantly in motion. The situation is different for SRA and PRRA algorithms, where robots move only when necessary.

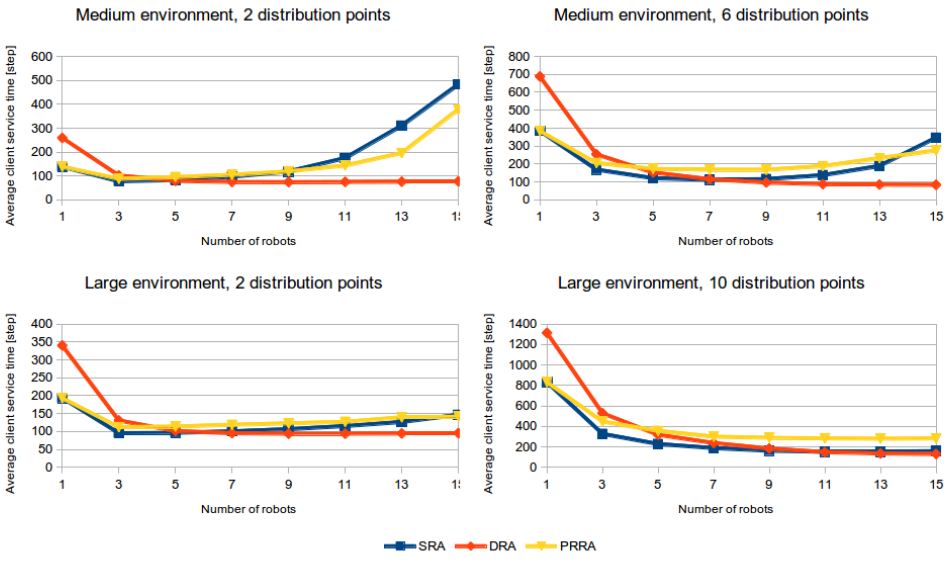

Fig. 10. The results of the examination of the proposed algorithms in terms of average client service time as a function of the number of robots

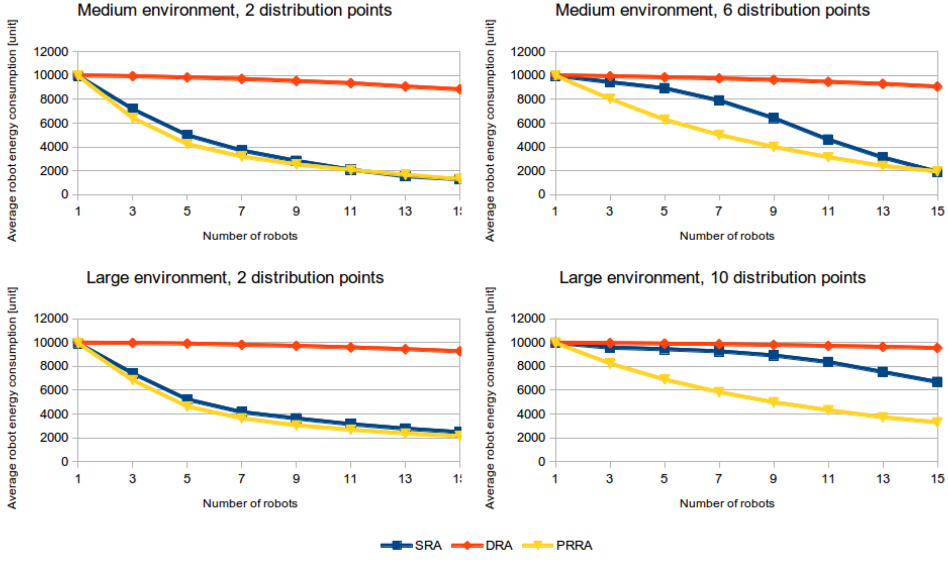

Fig. 11. The results of the examination of the proposed algorithm in terms of average robot energy consumption as a function of the number of robots

Figure 12 presents the results of examination of the proposed algorithms in terms of robot energy consumption per serviced client as a function of the number of robots. The data indicates that, in case of presence of more distribution points, regardless of the number of robots and the type of the algorithm, the amount of energy required to service a single client has similar values.

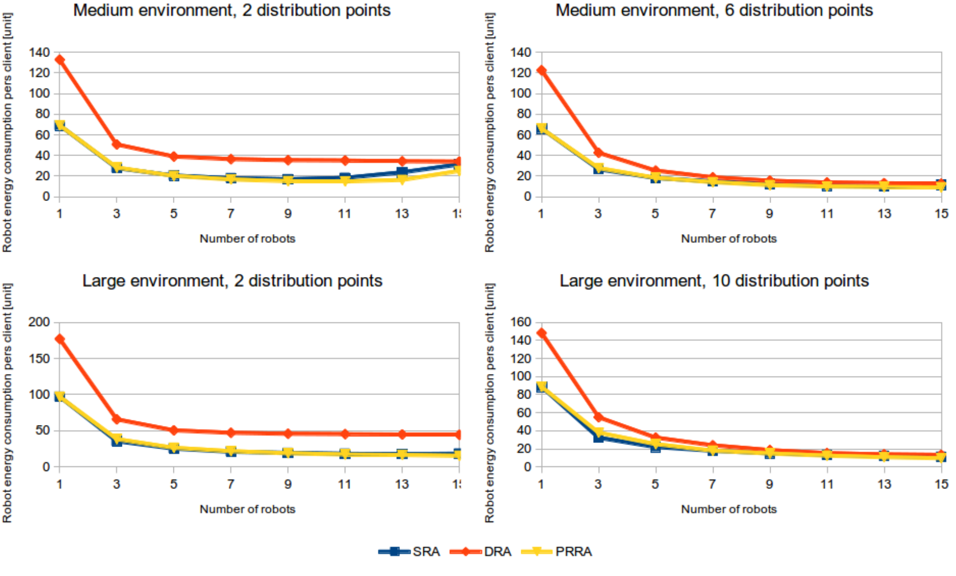

Fig. 12. The results of the examination of the proposed algorithms in terms of robot energy consumption per serviced client as a function of the number of robots

5. Conclusions & Future plans

Performed simulations clearly show that the use of the DRA algorithm provides the best results for a large number of robots. On this basis, a conclusion was drawn that it is important to test these algorithms in a situation where one of the robots breaks down. Further analysis of the DRA algorithm shows that its use increases the energy consumption for a single robot. This is due to the specific nature of this algorithm, based on the continuous movement of all robots. This makes its efficiency lower in a situation in which there is a low frequency of incoming clients. It would be also interesting to test the DRA algorithm in other layouts of the movement directions in the corridors. The amount of energy needed to service a single client is similar for all algorithms. The exception is the DRA algorithm, for which the small number of distributions increases the quantity of energy consumed for single client service. It is advised to use the SRA algorithm in environments with a small number of robots.

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Algorytmy planowania tras robotów w środowisku wieloagentowym

Słowa kluczowe

Robot, systemy wieloagentowe, wybór ścieżki, magazyn.

Streszczenie

W ostatnich latach tendencja wzrostowa stosowania autonomicznych robotów mobilnych w systemach wieloagentowych spowodowała wzrost znaczenia planowania ścieżek robotów. W tym kontekście jednym z głównych problemów stało się wyznaczenie optymalnej trasy ruchu robota oraz unikania kolizji. W wielu sytuacjach zastosowanie systemów wieloagentowych jest dobrą strategią do zarządzania przepływem zadań w określonym środowisku, przykładem może tutaj posłużyć środowisko logistyczne. Niniejszy artykuł przedstawia algorytm sterowania ruchem robotów w zarządzaniu transportem w wirtualnych magazynach. Problem planowania ruchem robotów w ramach niniejszego artykułu odnosi się do znalezienia optymalnej ścieżki poruszania się między miejscem początkowym a docelowym w taki sposób, aby uniknąć przeszkód. Proponowane przez autorów algorytmy zakładają kontrolę pracy jednego robota, we współpracy z innymi robotami, w tym samym środowisku. Każdy robot wykonuje zadanie poprzez transport zasobu z punktów dystrybucji do punktów składowania. Proponowane algorytmy wyznaczania tras są ocenianie pod względem czasu realizacji zadań oraz wydajności energetycznej. Wyniki symulacji wskazują, że proponowana przez autorów metoda może skutecznie zwiększyć wydajność planowania ścieżek ruchu robotów.