

O.I. Bizhanova, **O.S. Salykova**, **Kh. Moldamurat**, **I.V. Ivanova**
A.Baitursynov Kostanay Regional University, Kostanay, Kazakhstan
E-mail: bizhanolga@mail.ru

METHODS OF PLANNING THE TRAJECTORY OF A MOBILE ROBOT IN CONDITIONS OF UNCERTAINTY

Abstract. This article discusses methods of planning and controlling the movement of a mobile robot in an uncertain environment with fixed and moving obstacles, including those with random changes in the velocity vectors of moving obstacles. The purpose of the article is to analyze the available methods in the field of problem solving for planning the movement of a mobile robot in conditions of uncertainty. The authors have proposed a solution in which the operation of a mobile robot using simulation modeling in conditions of uncertainty will be successful.

Keywords. Mobile robots, planning methods, uncertainty conditions, simulation modeling.

Introduction.

Robots have been successfully implemented in various fields: mechanical engineering, automobile production and in a number of other areas. Currently, robots are being used in even greater numbers in agriculture, mining and the service sector. These robots have significant mobility and the ability to independently make decisions on their behavior. Therefore, to ensure the safety of such mobile robots and their successful functioning, algorithms for planning actions and movements are necessary. A mobile robot must be able to extract information from the environment and use it to move safely in a targeted manner. To do this, robots can use various types of sensors or receive the necessary information from external information systems. The tasks of planning safe trajectories of robot movement have been considered by many researchers [1-7] and these works continue, since the conditions in which robots' function are very diverse.

Mobile robots operating under conditions of uncertainty face various challenges associated with limited information about the environment, dynamic changes in the environment and limited resources.

The following strategies and methods can be used to successfully navigate and complete tasks in such conditions:

1) Sensory perception. Mobile robots are usually equipped with various sensors, such as lidars, cameras, ultrasonic sensors, etc. Sensors provide information about the environment and objects in it. Sensor data processing and filtering algorithms help to account for noise and uncertainty in measurements.

2) Tracking objects. To work in dynamic environments, robots can use object tracking algorithms to detect and track moving objects such as people, cars, and other robots. This helps to avoid collisions and plan safe trajectories.

3) Simulation modeling. Creating virtual models of the environment and the robot allows the robot to carry out preliminary planning and testing of virtual scenarios without the risk of damage or loss of resources.

4) Trajectory planning. As mentioned earlier, robots can use various algorithms for trajectory planning, such as RRT (Rapidly-Exploring Random Trees) or A* algorithms to find the optimal path under uncertain conditions.

5) Adaptation to changes. Robots must be able to adapt to changes in the environment and plan new trajectories when obstacles occur or the objectives of the task change. This may include real-time path rescheduling.

6) Using probabilistic methods. Probabilistic methods, such as Kalman filters and Monte Carlo methods, allow us to take into account the uncertainty in the robot's movement and its sensors.

7) Feedback. Feedback systems allow robots to adjust their behavior based on real data about the performance of the task. This helps to improve the accuracy and reliability of navigation.

8) Machine learning. Machine learning techniques can be used to create models that allow robots to learn from experience and improve their navigation skills.

9) Integration with the cloud and other resources. Cloud computing and data exchange with other robots or systems can be used to improve navigation and control of robots.

It is important to understand that navigation of mobile robots in conditions of uncertainty requires an integrated approach and integration of various methods and technologies to ensure the reliability and efficiency of the robot.

Materials and methods.

This article discusses the most common methods of planning the trajectory of the robot.

Planning the trajectory of a mobile robot in conditions of uncertainty is an important task in robotics and autonomous navigation. Let's analyze the known algorithms that can be used for this purpose.

Dijkstra's Algorithm is a classical algorithm that is used to find the shortest path in a graph with weights. In the context of planning the movement of a mobile robot, the graph is a grid map, and the weights on the edges can reflect the cost of moving between neighboring cells. Dijkstra allows you to find the optimal path, but does not take into account dynamic changes in the environment.

Algorithm A (A-Star)* combines the characteristics of a breadth-first search and a heuristic search. It can also be used to find the optimal trajectory on the grid. A* takes into account heuristics to predict the distance to the target and thus can be effective for mobile robots.

RRT (Rapidly-Exploring Random Trees) algorithms are probabilistic algorithms that create a tree of random points in the robot's state space. They can be used to plan movement in uncertain and dynamically changing environments.

Monte Carlo Methods uses random samples to estimate probabilities and find the optimal trajectory. The Monte Carlo method is especially useful in situations where the environment is highly undefined.

Simulation planning allows you to create virtual models of the environment and the robot to test different trajectories before they are applied in a real environment. This allows you to take into account uncertainties and avoid dangerous situations.

An important aspect of trajectory planning in conditions of uncertainty is the use of data from sensors (such as lidars, cameras, inertial sensors and others) to update the motion plan in real time and adapt it to a changing environment.

Hybrid methods are relevant when several methods are combined for a more effective solution. For example, you can use the A* algorithm for global planning and the RRT method for local path adaptation.

The choice of method and algorithm depends on the specific task, environment and requirements for the robot. It is also important to take into account the computational limitations and the possibilities of integration with the robot's hardware.

One of the more effective methods for controlling the movement of a mobile robot is the use of the simulation method. This method represents the process of developing and optimizing control algorithms for a robot in a virtual environment. This method allows you to test and improve algorithms before using them on a real robot. For the successful operation of a mobile robot using simulation, a general algorithm of operation is used, which consists of several stages:

- Choosing a simulation environment: Choose the simulation software or platform that suits your needs. Popular simulation environments for mobile robots are Gazebo, V-REP, Unity3D and robot simulators provided by some robotics frameworks.

- Creating a robot model: Create a virtual 3D model of your mobile robot in the selected simulation environment. This model should include the physical characteristics of the robot, such as size, shape, weight and wheelbase.

- Sensor Simulation: Add sensors to your robot model, such as laser scanners, cameras, gyroscopes and accelerometers. These sensors will be used to sense the environment and provide feedback to control algorithms.

- Development of a control algorithm: Write a control algorithm for your robot. This algorithm determines how the robot should move and react to the environment. You can use classical control algorithms or machine learning methods.

- Configuring Scripts: Create scenarios or tasks in which you want to test the control algorithm. These can be tasks of navigation, obstacle avoidance, route planning, and others.

- Start the simulation: Run a simulation simulation with your robot model and control algorithm. In this environment, you will be able to observe how the robot interacts with the environment and performs tasks.

- Analysis and debugging: Analyze the simulation results and debug the control algorithm if necessary. Change the parameters and control strategies to improve the performance and behavior of the robot.

- Optimization: Experiment with different versions of the algorithm and robot settings to achieve optimal results.

- Validation on a real robot: After successful simulation and debugging of the algorithm, you can transfer it to a real mobile robot and additionally configure it to work in real conditions.

Simulation modeling allows you to save time and resources, as well as reduce risks when developing and testing control algorithms for mobile robots in conditions of uncertainty.

Simulation modeling for mobile robots is an innovative technique that allows you to simulate the operation of a mobile robot in a virtual environment in order to develop, test and optimize control and navigation algorithms without the need to use real hardware. This approach has several key advantages:

- Resource savings: Simulations are much cheaper and safer than working with real robots. You can conduct many experiments without the cost of materials, electricity and maintenance of real equipment.

- Speed of development: Simulation modeling allows you to quickly create and change scenarios and conditions, which speeds up the process of developing and testing control algorithms.

- Safety: The virtual environment does not pose a danger to the robot and surrounding objects, which allows you to conduct tests in a variety of scenarios without the risk of damage to the equipment.

- Behavior study: Simulations allow you to study the robot's behavior in more detail in different conditions, as well as analyze sensor data and behavior in real time.

Simulation modeling for mobile robots and robotic systems in general is actively being researched and developed by many scientists and research groups around the world. This is an interdisciplinary field in which scientists from the fields of robotics, computer science,

engineering, artificial intelligence and many others work. Here are some well-known researchers and scientists whose work is related to simulation modeling for mobile robots:

- Sebastian Thrun: Professor of Computer Science and Robotics, one of the pioneers of autonomous cars and the creator of a course on machine learning for self-driving systems in online education. He actively worked on the application of simulation modeling for autonomous cars.

- Peter Corcoran: Professor of Robotics and Automation, known for his work on simulation and simulation of robots. He also developed the popular Robotics Toolbox library for MATLAB, which is used for simulation modeling.

- Nick Roy: A scientist in the field of autonomous systems and mobile robots who researches simulation and machine learning techniques for robot navigation.

- Andreas Mueller: Professor and specialist in the field of machine learning and artificial intelligence, working on the development of machine learning methods for controlling robots and using simulation modeling for robot training.

- John Langford: A scientist in the field of machine learning and robotics, working on the application of reinforcement learning algorithms and simulation learning to control mobile robots.

- Oliver Brock: Professor of Robotics, whose work includes the development of reinforcement learning algorithms and the use of simulation modeling to teach robots various skills.

Results.

This article discusses the method of planning the trajectory of a mobile robot based on simulation modeling under uncertainty. We will assume that the position of the target point where the robot should arrive is known and does not change.

The authors solved the set tasks taking into account the following assumptions and conditions – the coordinates of static obstacles are a priori known; dynamic obstacles have a known speed of movement; dynamic obstacles can change the direction of their movement randomly; for dynamic obstacles, the parameters of the laws of distribution of random variables are known; the coordinates and velocity vector of dynamic obstacles are "available for measurement" at discrete moments of time after a certain time interval.

These assumptions are valid under the assumption that the robot's control system (or an external system) monitors the area where the robot is moving. The practical implementation of such monitoring is possible on the basis of sensors, vision systems or lidars. During such monitoring, the current position of each obstacle and its motion parameters are evaluated, assuming that the velocity vector can be described by the normal distribution law of a random variable. It should be noted that for the robot's control system, information about obstacles is updated after a time interval that exceeds the time interval for making decisions about the robot's motion parameters. The simulation model is developed and implemented in the Matlab environment.

If there is a chance of a robot collision, then two solutions are possible. If a collision can occur with a stationary obstacle, then it is bypassed, the criterion for choosing the best option is the minimum path (time) of the bypass. If a collision is possible with a moving obstacle, then the planned speed of movement of the robot is changed and the prediction of the possibility of a collision is made again.

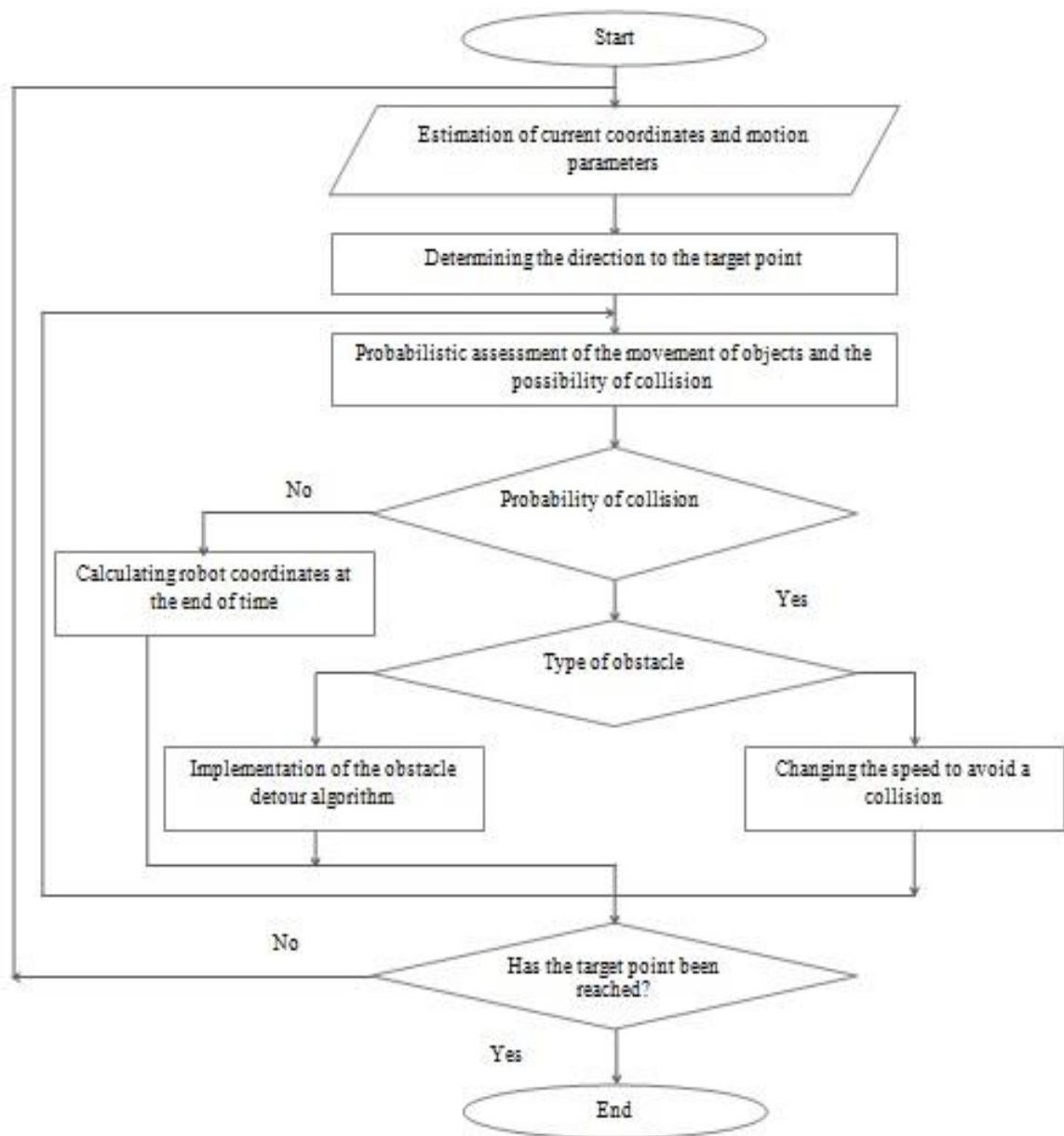


Figure 1 - General algorithm for reaching the target point

When planning the trajectory of a mobile robot based on simulation modeling under conditions of uncertainty in the presence of stationary obstacles in the working area, an intermediate point was determined at each planning interval to which the robot should move in time (determined by the event horizon).

To test the operability of the method for the case of static and dynamic obstacles, in addition to stationary obstacles, there were movable obstacles in the working area, the direction of movement of which changes randomly.

Let's assume that at some interval of motion planning, the possibility of a robot collision with a moving obstacle moving from the starting point was detected. To prevent a collision, the speed of the robot will be reduced. And once again, the prediction of the possibility of a collision was made. If there is no collision, the robot moves to a new intermediate point. After that, the trajectory of the mobile robot is planned for a new time interval that determines the event horizon.

Discussion.

The proposed method of planning and controlling the robot's movement takes into account the random nature of the movement of dynamic obstacles. For possible collision situations, several strategies have been implemented to ensure the safe movement of the robot. Depending on the current situation, various algorithms of robot behavior are implemented. The robot's behavior strategies differ for situations when it is dangerously approaching stationary and moving obstacles.

The proposed method ensures the safe movement of the robot to the target point. The method allows you to set the value of the safety zone when planning the trajectory of the robot and, if necessary, change it depending on the accepted prediction time – the event horizon.

Detour of stationary obstacles is carried out in the best way to minimize the time of movement to the target point.

Further improvements to the proposed method will include the following solutions:

- Determination of the best intermediate point for movement when bypassing static and dynamic obstacles, taking into account the forecast of changes in their location at an interval exceeding the accepted prediction time;

- Implementation of long-term forecasting of changes in the situation in the mobile robot movement zone for strategic and tactical decision-making. This will allow you to avoid situations that have no solution and plan close to the optimal trajectory of safe movement of the mobile robot.

Conclusion.

The experiments performed with mathematical modeling of the processes of planning and controlling the movement of a mobile robot allow us to draw the following conclusions.

The method of planning the trajectory of a mobile robot in an environment with fixed and moving obstacles, including those with random changes in the velocity vectors of moving obstacles, is considered; The method takes into account possible collisions at a given time interval of the forecast horizon;

The method is able to implement several collision prevention strategies, including for detouring stationary and moving obstacles with a change in its own speed and direction of movement;

The results of the study showed the effectiveness of the method for planning trajectories and controlling the movement of the robot in conditions of stationary and moving obstacles.

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Ольга Бижанова, магистр, аға оқытушы, А.Байтұрсынова атындағы Қостанай өңірлік университеті, Қостанай, Қазақстан, bizhanolga@mail.ru

Ольга Салыкова, т.ғ.к., қауымдастырылған профессор, А.Байтұрсынова атындағы Қостанай өңірлік университеті, Қостанай, Қазақстан, solga0603@mail.ru

Хуралай Молдамурат, т.ғ.к., қауымдастырылған профессор, Л.Н.Гумилев атындағы Еуразия ұлттық университеті, Астана, Қазақстан moldamurat@yandex.ru

Ирина Иванова, п.ғ.к., қауымдастырылған профессор, А.Байтұрсынова атындағы Қостанай өңірлік университеті, Қостанай, Қазақстан, valera_irina_69@mail.ru

БЕЛГІСІЗДІК ЖАҒДАЙЫНДА МОБИЛЬДІ РОБОТТЫҢ ҚОЗҒАЛЫС ТРАЕКТОРИЯСЫН ЖОСПАРЛАУ ӘДІСТЕРІ

Аңдатпа. Бұл мақалада белгісіздік жағдайында мобильді роботтың қозғалысын жоспарлау және басқару әдістері, қозғалмайтын және қозғалмалы кедергілері бар орта, оның ішінде қозғалмалы кедергілердің жылдамдық векторларының кездейсоқ өзгеру сипаты қарастырылады. Мақаланың мақсаты - белгісіздік жағдайында мобильді роботтың қозғалысын жоспарлау үшін есептерді шешудің қол жетімді әдістерін талдау. Авторлар белгісіздік жағдайында Имитациялық модельдеуді қолдана отырып, мобильді роботтың жұмысы сәтті болатын шешімді ұсынды.

Түйінді сөздер. Мобильді Роботтар, жоспарлау әдістері, белгісіздік шарттары, Имитациялық модельдеу.

Ольга Бижанова, магистр, старший преподаватель, Костанайский региональный университет имени А.Байтурсынова, Костанай, Казахстан, bizhanolga@mail.ru

Ольга Салыкова, к.т.н., ассоциированный профессор, Костанайский региональный университет имени А.Байтурсынова, Костанай, Казахстан, solga0603@mail.ru

Хуралай Молдамурат, к.т.н., ассоциированный профессор, Евразийский национальный университет имени Л.Н.Гумилева, Астана, Казахстан, moldamurat@yandex.ru

Ирина Иванова, к.п.н., ассоциированный профессор, Костанайский региональный университет имени А.Байтурсынова, Костанай, Казахстан, valera_irina_69@mail.ru

МЕТОДЫ ПЛАНИРОВАНИЯ ТРАЕКТОРИИ ДВИЖЕНИЯ МОБИЛЬНОГО РОБОТА В УСЛОВИЯХ НЕОПРЕДЕЛЕННОСТИ

Аннотация. В данной статье рассматриваются методы планирования и управления движением мобильного робота в условиях неопределенности, среде с неподвижными и подвижными препятствиями, в том числе имеющими случайный характер изменения векторов скорости подвижных препятствий. Целью статьи является анализ имеющихся методов в области решения задач для планирования движения мобильного робота в условиях неопределенности. Авторами предложено решение, при котором работа мобильного робота с использованием имитационного моделирования в условиях неопределенности, будет успешной.

Ключевые слова. Мобильные роботы, методы планирования, условия неопределенности, имитационное моделирование.
