BULGARIAN ACADEMY OF SCIENCES
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MULTIFUNCTIONAL LEARNING MOBILE ROBOT PLATFORM

A V T O R E F E R A T

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Title: ***MULTIFUNCTIONAL LEARNING MOBILE ROBOT PLATFORM***

General characteristics of the dissertation work

Learned Robotics enables students of various ages to become familiar with and deepen their knowledge of robotics and programming while learning other cognitive skills. Robotics is a growing field that allows students to learn and improve working with robots and how they can use them in various fields. Working with educational robots helps students learn how to program and build robots. By learning about robotics, students are able to learn new technologies more quickly. Robotics education can help students learn about problem solving such as programming and mechanics, etc. Educational robotics has many benefits in education. As robotics becomes more popular, schools are scrambling to find ways to integrate it into the curriculum. There are many ways to do this, but one popular approach is to use robots in math and science classes. Some fundamental problems of educational robotics such as navigation, localization are touched upon in this dissertation. programming, compiling algorithms. The state and development of scientific research and problems in the field of educational robotics are analyzed. Methods for improving localization and navigation of educational mobile robots, such as algorithms for real-time operation, correction of systematic and non-systematic errors, and improvement of motor control, have been investigated;

The mobile robotics course covers the study of the principles, methods and technologies associated with the design, programming and control of mobile robots. This subject provides students with the knowledge and skills that underpin the study of robotics, computer vision, navigation, remote control and programming.

O the core topics and skills that could be included in the mobile robotics curriculum are the following:

- **Fundamentals of Robotics:** Understanding the basic principles and terms in the field of robotics, including the hardware and software components of mobile robots.
- **Mobile Robotics Hardware:** Study of sensors, motors, and other hardware components that are built into mobile robots.
- **Programming of mobile robots:** Development of programs to control movement, interact with the environment and solve tasks using programming languages such as Arduino , C++, etc.
- **Control and Navigation Systems:** Study of algorithms and techniques for traffic control, obstacle avoidance and route optimization.
- **Robot Communication and Learning:** Examining methods of communication between robots and between robots and humans, as well as possibilities for machine learning.
- **Application design and development:** Students can be engaged in real-world projects that include designing, building and programming their own mobile robots.

Educational mobile robotics can be part of educational programs in universities, technical schools or specialized courses and trainings. This subject aims to prepare students for work in fields such as robotics, automation, artificial intelligence and software development.

The aim of the dissertation work is to research, develop and create algorithms and systems for controlling learning robots. Learning robots must be able to move autonomously or be tele-controlled, overcome obstacles, find a way out of a maze, follow a line, operate a smart camera, be able to be controlled remotely or perform other tasks, and be affordable price.

Achieving the goal of a dissertation encompasses a set of tasks. The solution of these tasks must lead to results that satisfy the set goal. Innovative approaches must be proposed for the implementation of these tasks. The formulated tasks are the following:

- To propose the structure of the control system of educational mobile robots.
- To propose innovative approaches for the development of algorithms for a learning mobile robot Nitrobot working in autonomous and manual mode to perform the following tasks:
    - Line tracking

    - Avoid obstacles
    - Finding a way out of a maze
    - Finding a way out of a confined space
    - Manual control mode
    - Machine vision
- To carry out a comparative analysis of the algorithms of learning mobile robots in the performance of certain tasks
- To conduct experiments based on the developed algorithms.
- The results of all tasks to be analyzed.

List of dissertation publications

At international conferences abroad:

Chivarov, N., Yovkov, S., Chivarov, S., Tosheva, I., Pleva, M., Hladek, D.. NITRO Educational Mobile Robot Platform for Maze Solving and Obstacle Avoidance. IEEE, accepted for print: 2021

Yovkov S., Chivarov N., Chivarov, S., Staikova, M.. Educational Mobile Robot Equipped with Intelligent Camera Huskylens. Conference Proceedings, 9th International Conference on Control, Decision and Information Technologies, CoDIT 2023, IEEE, 2023, ISBN:979-835031140-2, DOI:10.1109/CoDIT58514.2023.10284418, 2269-2274

Chivarov, N., Yovkov, S., Chivarov, S., Stoev, P., Chikurtev, D.. Teleoperation and Autonomous Mode of Transport Mobile Robot with Mecanum Wheels. 26th International Conference on Circuits, Systems, Communications and Computers CSCC 2022, IEEE, 2022, ISBN:978-1-6654-8186-1, DOI:10.1109/CSCC55931.2022.00060, 310-315

Yovkov S., Chivarov N., Chivarov S., Stoev P.. Comparative Analysis of Algorithms for Mobile Robots in Performing Certain Tasks. IEEE Xplore, 2022, DOI:doi : 10.1109/ICETA57911.2022.9974741

NITRO Educational Mobile Robot Platform for Maze Solving and Obstacle Avoidance

Chivarov, N., Yovkov, S., Chivarov, S., ...Pleva, M., Hladek, D. ICETA 2021- 19th IEEE International Conference on Emerging eLearning Technologies and Applications, Proceedings 2021.

At international conferences in our country:

Yovkov, S., Chivarov, N., Chivarov, S.. A COST-EFFECTIVE LEARNING MOBILE ROBO-PLATFORM. ADP 2021, Sofia University Publishing House, 2021, ISSN:ISSN: 2682-9584

Yovkov, S., METHODS FOR REMOTE CONTROL OF AN EDUCATIONAL MOBILE ROBOT . ADP 2022, Sofia University Publishing House, 202 2 , ISSN:ISSN: 2682-9584

Dissertation content

This dissertation consists of an introduction, four chapters, a conclusion and a list of cited literature. The main content is contained in 107 pages, and the exposition is accompanied by figures and tables. The list of cited literature includes 75 titles.

CHAPTER 1. Literature review

A historical analysis is made in the development of robotics. The types of robots are analyzed according to their purpose. The benefits of educational robotics in education are discussed . A study of the potential of educational robotics was made . The role and advantages of the STEM program in educational robotics are examined . The state of the market for educational robots is analyzed

1.1. 1 . Classification of mobile robots according to their purpose .

Industrial robots

The purpose of industrial robots is to replace the monotonous and labor-intensive activity of man, increasing the productivity of the process by achieving a high speed of the operation. Industrial robots are inextricably linked to robotic transport lines that move along pre-marked transport paths, delivering the necessary parts for work [39] .

Mining robots

The nature of the mining activity requires the use of autonomous, semi-autonomous or tele-controlled robots. These devices are used both in underground mines and for digging railway and road tunnels. To this end, many companies produce drilling machines, loading equipment, and trucks that load material, transport it, and unload it without human intervention [40].

Intelligence robots

These robots are designed to perform tasks that directly threaten human life. They work in dangerous environments and carry out missions such as detecting explosives , working underwater, detecting toxic waste or measuring radiation levels.

Space robots

In recent years, robotic systems have been widely used in space. Humanoid robots and robotic arms have been developed to assist astronauts [41] .

Personal robots

The first personal assistant robots perform simple tasks such as dusting or mowing the lawn. Using lidar technology, they map the surrounding terrain and successfully navigate around obstacles.

There are also entertaining home robots designed to keep company or play with people. Sony's Aibo robot dog is a typical example of such a robot. Aro is a robot seal that cares for patients in their homes. Wakamaru is a humanoid robot helping the elderly and disabled[42].

Medical robots

In recent years, Medical robots have increasingly entered medicine, in areas such as surgery, diagnostics and medical care.

Specialized service robots are used for medical care. These robots replace the medical person by providing assistance to the bedridden patient 24 hours a day[43].

Military robots

Military robots or whatever. Military drones are autonomous combat vehicles used for military, reconnaissance and combat purposes. They move independently by air, land, water and underwater.

For the purposes of the military and police services, remote-controlled robots are being deployed to dispose of explosive devices. Their purpose is to preserve the lives of military personnel and police[44].

Educational robots and competition robots

Educational robots are systems developed with the aim of assisting pupils and students in the acquisition of knowledge, skills as well as mental and creative activity within the educational process. They are used in educational institutions, such as schools, universities and educational centers, to provide access to learning and the acquisition of knowledge.

Nanobots

Nanobots are microscopic machines or robots that have tiny dimensions, usually from 1 to 100 nanometers. Only some elements of these systems, such as bearings, sensors, synthetic molecular motors, have been produced in the world . The goal is to create robots the size of a virus or bacteria to perform tasks at the micro level. Possible areas are microsurgery (at the cellular level). In theory, nanobots could perform precise tasks at the atomic or molecular level. They may be intended to perform medical procedures[46].

Group robo - technique

Group robotics is a technological approach to coordinating multiple robots as a system that consists of a large number of mostly simple physical robots . "In a swarm of robots, the collective behavior of the robots is the result of local interactions between the robots and between the robots and the environment in which they operate." They all work in unity, and the advantage is that the loss of an individual does not disrupt the overall performance of the task, unlike by a single robot, the loss of which leads to its failure[47].

1.1. 2 . Classification of mobile robots according to navigation method.

Remote controlled robots

Wire-controlled robots are devices that an operator controls from a distance using a device such as a cable, wireless joystick, 2.4G 4CH radio RC transmitter or Android device using

Bluetooth or WiFi connection. These robots can be used in various fields and applications where it is necessary to perform actions at a distance from the operator[48].

A robot with autonomous control

An autonomous robot is a machine or device that is capable of performing tasks and functions without constant human intervention. They can react to different situations, choose the most appropriate actions and perform tasks according to predetermined goals.

Autonomous robots have no information about their location and how to reach a target or target point. These types of robots have sensors and perception systems that allow them to gather information from their environment, then use built-in algorithms and programs to analyze that information and make decisions.

1.1. 3 . Definition of Educational Robotics .

Educational robotics is a discipline designed to introduce students to robotics and programming from a very early age **.** . It is a discipline that uses learning robots to stimulate students' interest and motivation in science and technology learning. Educational robotics focuses on developing skills such as problem solving, logical thinking, programming and engineering skills through the construction, programming and control of robots. .

1.2. Forecasts for the development of educational robotics in recent years.

1.2.1 Educational Robots Market Share. Forecast of global industry trends.

The educational robots market is expected to register a CAGR of 16% during the forecast period (2020-2025). The use of learning robots is becoming more common in workplaces, homes and educational institutions. Many schools have started testing learning robots to impart knowledge to their students. These robots can help deliver lessons on STEM (Science, Technology, Engineering and Mathematics) concepts that are essential in the curriculum [51]
.

1.2.2. Exploring the Educational Potential of Educational Robotics

The benefits of learning robotics in education

Robotics is a growing field that allows students to learn and improve working with robots and how they can use them in various fields. Working with educational robots helps students learn how to program and build robots. Develops computer skills: Students learn fundamentals of programming, which is becoming increasingly important in today's world.

1. Stimulates creativity: Working with robots allows students to express their creativity through programming, design and construction.
2. Prepares for future challenges: Robotics provides an opportunity to develop innovations and solutions to real problems.
3. Develop teamwork skills as students work together to program and operate a robot.
4. Increased engagement: Robotics learning can engage students more than traditional learning methods. This is because robots are interactive and allow for hands-on learning.

5. Quality learning: Robotics training improved students' ability to learn new information. The use of robotics allows for more direct engagement with the material, resulting in better learning and understanding of the learning material.
6. Reduced costs: Robotics training can be more affordable than traditional training methods. This is because robots do not require very expensive equipment and can be reused many times.
7. Reduced time: Robotics training can save teachers time by reducing the amount of prior preparation required. This is because robots do most of the work, allowing teachers to focus on teaching rather than manual labor.
8. Improved quality: Robotics education promotes better learning by engaging students in hands-on activities and encouraging creativity

Advantages of learning robots

Learning robots have numerous advantages that can benefit the education system. They have the following advantages:

1. Individualized learning: Learning robots can be programmed according to the individual needs and learning pace of each student. This allows for personalized learning that helps fast-learners progress quickly, or extra support for those students who need extra instruction.
2. Interactivity: Robots can be used to create interactive lessons and assignments that engage students and make them interact with the material in a more interesting and exciting way.
3. Support for teachers and education professionals: Robots can be instrumental in helping teachers and education professionals assess students, identify difficulties and provide advice on optimal teaching methods.
4. Learning through play: To support learning, learning robots are being created that can create educational games and simulations to help children learn through play and experimentation.
5. Preparing for future professional roles: Working with learning robots can help students develop important skills such as problem solving for complex tasks, programming and engineering that are useful for their future careers.
6. Improving social skills: Learning robots can be used to develop social skills such as communication, collaboration and sharing. Students can learn how to interact with robots and also learn to interact more effectively with other people.
7. Motivation and self-discipline: Learning robots can help students develop better self-discipline and organization by giving them tasks and deadlines.
8. Innovation in Education: Learning robots provide the opportunity to implement innovative learning methods that may be difficult or impossible to implement by human educators.

Role trends and benefits of the STEM program in educational robotics

The STEM program plays an extremely important role in educational robotics. This combination of educational directions - science, technology, engineering and mathematics is essential for the development of students in the modern world. STEM is an extremely effective tool for acquiring knowledge and skills in the following aspects [53] :

1. Science : Students study basic scientific principles and concepts, such as mechanics, electronics, sensors, mechatronics , and more. This allows them to understand how robots and their components work.
2. Technology : STEM sciences and technology are essential to creating and programming robots. Students learn how to use computers, sensors, motors and other technologies to create functional robots.
3. Engineering: The engineering aspects of STEM focus on the design, assembly and optimization of robots. Students study engineering principles such as design, mechanics, electronics, and construction to create functional and efficient robots.
4. Mathematics: Mathematics plays a key role in robot programming algorithms. Students use mathematical concepts of calculus, geometry, and analysis to create accurate and predictable robot movements.

The STEM (Science, Technology, Engineering, and Mathematics) program in educational robotics plays a key role in the development of students by providing them with the opportunity to acquire knowledge and skills in several important areas. It aims to integrate knowledge and skills from different disciplines. , to support the development of analytical thinking, problem solving and creativity through hands-on exercises with robots and technology.

1.3. Types of mobile robots according to their drive

1.3. 1 . Robots with differential wheel drive

A differential drive robot consists of one or two passive and two coaxial wheels. The passive wheels provide stability, while the coaxial pair steers the robot by carefully modulating their speeds. Straight line motion is achieved by equal speeds on both wheels, while left and right motion occurs if the right wheel is faster than the left and the left wheel is faster than the right respectively. Spin is noticed when both wheels turn equally fast but in opposite directions. Zero turning radius is a major advantage with this drive configuration.

1.3. 2 . Steering Robots (Vehicle WMRs)

These wheeled mobile robots have a car-like kinematic structure. The main characteristic features of car-like robots are usually a limited control range of the steering wheels. The consequence of such a decision is the impossibility of rotating the robot in place. Due to this fact, such solutions are mostly used outdoors. Like cars, in mobile robots the differential mechanism is sometimes used to drive the wheels [57] .

1.3. 3 . Holonomic mobile robots with M ecanum and Omnidirectional wheels

Robot with M ecanum wheels

The Mecanum wheel is a multi-directional design of the wheel for a land vehicle that can move in any direction.

The Mecanum wheel is a form of omnidirectional wheel, with a series of rubberized outer rollers obliquely attached to the entire circumference of its rim. These rollers usually have an axis of rotation at 45° to the plane of the wheel and at 45° to the axis line. Such construction provides additional kinematic advantages for Mecanum wheels compared to conventional wheels. Thus, a full holonomic approach is used to describe the dynamics of a Mecanum four-wheeled mobile robot. Each Mecanum wheel is an independent non-steerable drive wheel with its own drive transmission and, when rotated, generates a drive force perpendicular to the roll axis that can be vectored into a longitudinal and transverse component relative to the vehicle.

The dynamics of a four-wheeled robot with Mecanum wheels located on two parallel axes is investigated The robot moves so that all its wheels have constant contact with the plane. The body of the robot has mass m 0, its center of mass is located along the longitudinal axis of symmetry of the body. The distance from the center of mass C of the robot to each of its wheel axes is ρ , the distance between the wheel centers is 2 l . The coordinates of the center of mass in a fixed coordinate system XOY are xc , yc , the angle formed by the longitudinal axis of symmetry of the body with the axis OX is ψ , each wheel has a mass of m 1. The angles of rotation of the wheels relative to the axes that are perpendicular on the planes of the respective wheels and pass through their centers are φi , and the torques applied to the wheels are Mi (i 1...4).

Robot with Omnidirectional wheels

Omni wheels or poly wheels, similar to Mecanum wheels, are wheels with small discs (called rollers) located around the circumference of the main wheel, which are perpendicular to the direction of rotation. The effect is that the wheel can be driven at full power, but will also slide sideways with great ease. These wheels are often used in holonomic drive systems[59].

A platform using three omni wheels in a triangular configuration is commonly called a Kiwi Drive. The Killough platform is similar; named after Stephen Killough's work with omnidirectional platforms at Oak Ridge National Laboratory. Killough's 1994 design used pairs of wheels mounted in cages at right angles to each other and thus achieved holonomic motion without using true omni directional wheels.

Omniwheels combined with conventional wheels provide unique performance characteristics, such as a six-wheeled vehicle using two conventional wheels on a center axle and four omniwheels on the front and rear axles.

1.3.4. Multifunctional hybrid robots

Hybrid robots are widely used in civilian tasks and military missions, such as field and space exploration, disaster rescue, reconnaissance and surveillance. They are usually required to enter an unstructured, harsh and hostile environment equipped with various devices. In these scenarios, mobility and maneuverability in rough terrain is a critical criterion for the design of mobile robots [60].

Compared to conventional robots, hybrid robots can change their structures and configuration to better adapt to a different, complex and completely unstructured environment.

Typically, crawler mobile robots have excellent terrain adaptability, full mobility, and ability to overcome obstacles. Wheeled hybrid robots usually have 4 or 6 motor-driven wheels. Changing the geometry of the suspension of the wheels ensures contact with the ground surface of each wheel.

1.4. Examples of robots used in the classroom

There are already many examples of robots being used in the classroom, with some pretty impressive results. Among them are:

1. Makeblock mBot [61]
2. Robo Wunderkind [62]
3. OWI 535 [63]
4. LEGO [64]
5. NAO [65]
6. NitroBot

1.5. Types of wheeled mobile robots

Most wheeled robots are differentially steered, which use separately driven wheels to propel the robot. They can change direction by turning each wheel at a different speed. There may be extra wheels that are not powered by a motor, these extra wheels help keep the robot balanced.

2-wheeled mobile robots

Two-wheeled robots are more difficult to balance than other types because they have to move to stay upright. The center of gravity of the robot body is kept below the axis, usually achieved by mounting the batteries below the body. Those equipped with wheels that are parallel to each other. These vehicles are called bicycles, and when one wheel is in front of the other, they are robots with tandem wheels. Two-wheeled robots need to keep moving to stay upright, and they can do this by moving in the direction the robot is falling. To balance, the base of the robot must remain below the center of gravity. For a robot that has left and right wheels, it needs at least two sensors. A tilt sensor (accelerometer and gyroscope) that is used to determine the tilt angle and wheel encoders that track the position of the robot platform.

3-wheeled mobile robots

3-wheel robots can be of two types: differential steering (2 driven wheels with an additional free-spinning wheel to keep the body in balance) or 2 wheels powered by a single source and powered steering for the third wheel. In the case of differentially driven wheels, the direction of the robot can be changed by changing the relative rotational speed of the two separately driven wheels. If both wheels are driven in the same direction and speed, the robot will go straight. Otherwise, depending on the speed of rotation and its direction, the center of rotation may fall anywhere on the line connecting the two wheels.

The center of gravity of this type of robot must lie inside the triangle formed by the wheels. If too heavy a mass is mounted on the side of the free-spinning wheel, the robot will tip over.

Omni Wheels Robots

Omni robots are multifunctional systems that can move in all directions with great maneuverability. The operating principle of Omni robots is based on specific technical characteristics that allow them to move and perform tasks in an intelligent and efficient way. The principle of operation is based on the combination of diverse technologies and systems, which allows them to adapt and perform different tasks in different environments. [54]

Omni-robots are equipped with special wheels that allow them to move forward, backward, sideways and diagonally without having to rotate. This movement design allows them to avoid obstacles more efficiently and move more flexibly in confined spaces.

The omni wheel is made up of one large wheel and several smaller ones, the smaller ones having an axis perpendicular to the axis of the main wheel. This allows the wheels to move in two directions and the ability to move holonomically, meaning it can instantly move in any direction. Unlike the robot, which moves nonholnomically and must be in motion to change direction. Robots with many wheels can move at any angle in any direction without turning beforehand. Some omni-wheeled robots use a triangular platform, with the three wheels positioned at a 60-degree angle. The advantages of using 3 wheels rather than 4 are that it is cheaper and the 3 points are guaranteed to be on the same plane so each wheel in contact with the ground but only one wheel will turn in the direction of travel.

Mecanum Wheels Robots

The Mecanuim wheel has a series of rubberized outer rollers obliquely attached to the entire circumference of its rim. These rollers usually have an axis of rotation at 45° to the plane of the wheel and at 45° to the axis line. Each Mecanum wheel is an independent non-steerable drive wheel with its own drive train and, when rotated, generates a drive force perpendicular to the roll axis that can be vectored into a longitudinal and transverse component relative to the vehicle.

The typical Mecanum design Robot is the four-wheeled configuration, as demonstrated by one of the omnidirectional mobile robots URANUS (pictured) or a wheelchair with Mecanum wheels (similar to those in the picture), with alternating left- and right-hand casters whose axes at the top of the wheel are parallel to the diagonal of the vehicle frame (and therefore perpendicular to the diagonal when the bottom of the wheel is in contact with the ground). In this way, each wheel will generate a thrust approximately parallel to the corresponding diagonal of the frame. By changing the speed and direction of rotation of each wheel, the summation of the force vectors from each of the wheels will create both linear motions and or rotations of the vehicle, allowing it to maneuver with minimal space requirements.

4-wheeled mobile robots

Robots with 2 driven and free-rotating wheels

These robots are the same as the differential control robots discussed above, but with 2 free-spinning wheels for added balance.

Robots with 2 driven and free-wheeling wheels are more stable than the 3-wheel version of robots because the center of gravity must stay inside the rectangle formed by the four wheels instead of a triangle. This leaves more usable space. However, it is recommended to keep the center of gravity in the middle of the rectangle, as this is the most stable configuration, especially when the robot makes sharp turns or moves on an uneven surface.

Robots with 2 X 2 powered wheels for tank-like movement

This kind of robot uses 2 pairs of driven wheels. Each pair (connected by a line) rotates in the same direction. The tricky part with this kind of drive is getting all the wheels to turn at the same speed. If the wheels in a pair are not moving at the same speed, the slower one will slide (inefficiently). If the pairs do not move at the same speed, the robot will not be able to move in a straight line.

Robots controlled with a steering system, like a car

Another type of navigation involves the form of car driving. This method allows the robot to turn in the same way a car would. This is a much more difficult method to build and makes dead reckoning much more difficult. This system really has an advantage over previous methods where the robot is driven by an internal combustion engine

Robots with 5 or more wheels

Used on larger robots. It's not always very practical. Especially when more powerful wheels are used, the design becomes much more complex as each of the wheels must rotate at the same speed when the robot needs to move forward. Differences in speed between the left and right wheels in differentially steered robots cause the robot to turn instead of moving in a straight line. The difference in speed between wheels on the same side causes the slowest wheel to slip.

CHAPTER 2. Algorithms for performing tasks in autonomous mode of operation of an educational mobile platform .

2.1. Algorithms for exiting a maze and avoiding obstacles

2.1.1. Main goals and objectives

The goal is to conduct research and create methods and algorithms of a learning robot designed to avoid obstacles and exit a maze. Conducting these studies should contribute to the development of learning robots by improving and expanding their capabilities to perform the assigned tasks. In performing these tasks, the learning robot must move autonomously, recognize objects representing obstacles, make decisions in certain situations and be affordable. Research covers the following problem areas in learning robots: navigation, sensor systems and control systems.

To fulfill the set goals, the following tasks must be completed:

1. Researching obstacle avoidance methods.
2. Researching methods for exiting an unfamiliar maze.
3. Development of a low-budget learning robot to perform the assigned tasks.
4. Development of algorithms to perform these tasks.
5. Conducting real experiments and analyzing the results of conducted research and experiments.
6. Presentation of conclusions from the conducted experiments.

2.1.2. Algorithms

In robotics, obstacle avoidance is the task of moving an object without crossing or colliding with obstacles. What is crucial to the concept of obstacle avoidance is the growing need to use unmanned mobile and aerial vehicles in urban areas, especially for military applications.

In order for the robot to avoid obstacles, a detection and navigation algorithm is required. One of the popular obstacle avoidance algorithms is the potential fields algorithm. This algorithm uses the idea of creating a potential field around the obstacles and the target point, which causes the robot to avoid the obstacles by moving in the direction of decreasing potential.

The main steps of the flow field algorithm are:

1. Obstacle detection: The robot must have sensors that allow it to detect obstacles in the environment. This may include the use of sensors such as ultrasonic sensors, laser scanners (LIDAR) or video cameras.
2. Creating the potential field: For each obstacle, a potential field is created that reflects the negative effect it has on the robot. By using a mathematical model, the obstacles are transformed into vector fields of potential.
3. Creating a target field of potential: The robot must have an idea of the desired target point to move towards. This target point also becomes a field of potential, but in this case the field of potential reflects the positive effect of movement towards the desired point.
4. Combining the potential fields: The potential fields from the obstacles and the target point are combined into a single potential field by summing the vector values. This creates the final potential field that tells the robot in which direction to move.
5. Robot navigation: The robot follows the direction set by the potential field, continuously updating its position and moving in the direction of the lowest potential. This process is repeated until the robot reaches the desired target point.

The flow field algorithm is just one of many solutions for obstacle avoidance. There are other algorithms, such as the wall following algorithm and algorithms based on machine learning. Each algorithm has its advantages and disadvantages, and the choice of the most suitable one depends on the specific task and the characteristics of the robot.

Three ultrasonic sensors (HC-SR04) were used to perform this task. These sensors scan for obstacles, frontally, to the left and to the right. The idea of the algorithm is as follows. After starting, the robot starts moving in a straight direction. The speed of the electric motors is the same ($V_L = V_{R,}, V_L > 0$). The robot continuously scans for an obstacle in front of it via the frontal sensor. The distance threshold from the robot to the obstacle is preset in the software. The block diagram fig(…) illustrates an obstacle avoidance algorithm.

When an obstacle is detected, the robot executes a motion stop command ($V_L = V_{R,} = 0$)and both side sensors scan for obstacles on the left and right respectively. Depending on which side the obstacle is closer to the robot, it executes a 90 degree turn ($V_L = -V_{R,} = turnRight,\ V_R = -V_{L,} = turnLeft,$)in the opposite direction of the obstacle and continues its movement in the straight direction. When a new obstacle is detected, the cycle repeats. In case the obstacles on the left and right are out of range of the sensors, the robot turns in a direction preset by the software.

This is the basic learning objective algorithm for obstacle avoidance. This algorithm does not aim to move the robot from the start point to the target point, but only to avoid collision with obstacles by moving in a closed workspace.

Algorithms for exiting a maze

A labyrinth is a structure or path that is complex and tightly woven, with many paths and turns. This is usually a path that leads to a central point or exit. Mazes can be physical structures made of walls, hedges, or abstract designs drawn on the floor or rendered on paper.

It is important to note that mazes differ from much simpler structures called mazes, which also contain multiple paths but have a solution or exit that can be found by simply following the correct paths. In mazes, on the other hand, there is no single correct solution and finding the exit can be challenging.

The right or left hand rule

The principle of solving a maze using the left or right hand method is as follows. If the maze is simply connected, i.e. all its walls are connected together or to the outer boundary of the maze, then by keeping one hand in contact with one wall of the maze, the solver will not get lost and will reach an exit if there is one. Otherwise, the solver will return to the entrance after traversing each corridor to that connected section of walls at least once. This method was used to perform the present experiment.

During the execution of the task, maze cells visited once and cells visited twice can be marked. Thus, it can retrace the solution by following those cells visited once. This method does not necessarily find the shortest solution and does not work at all when the goal is in the center of the maze and has a closed circuit around it, as the maze solver will go around the center and end up back at the beginning.

Trémaux's algorithm

This method of solving the maze is designed to be usable by a person inside the maze. It is similar to the recursive backtracking method and will find a solution to all mazes as the solver walks along a passage, drawing a line behind him to mark his path. When it reaches a dead end, the solver turns around and goes back the way it came. When it encounters an intersection it has not visited before, the solver chooses a new passage at random. If he follows a new passage and comes across an intersection he hasn't visited before, it will treat it as a dead end and he must go back the way he came. (This last step is the key that keeps the solver from going around in circles or missing passages in convoluted mazes.) If the solver walks a passage he has visited before (ie marked once) and encounters an intersection, he must take a new one passage if one is available, otherwise it takes an old passage (ie marked once). In case all the passages are empty it means that they have not been visited yet. If the passage is marked once, it means that it was entered exactly once. If it is marked twice, it means that the solver entered it and was forced to go back in the opposite direction. When the solution is finally reached, paths marked exactly once will show a direct path back to the beginning. If the maze has no solution, the solver will end up back at the beginning with all passages marked twice.

A recursive backtracking algorithm

The decision principle is as follows. If the solver is on a wall (or an area he has already drawn) he reports a failure, otherwise if he is on the finish line he reports a success. In other cases, the solver tries to move recursively in all four directions. When the solver tries a move in a new direction, it draws a line and erases a line when it detects an error. A solution will be marked when the solver succeeds. When returning, it is best to mark the space with a special value so that it is not revisited from another direction. From a computer science perspective, this is basically depth-first search. This method will always find a solution if one exists, but it is not necessarily the shortest solution.

A random mouse

This is the simplest and one of the most ineffective methods of solving a maze, which basically consists of moving randomly, i.e. moving in one direction and following that passage through any bends until you reach the next intersection. No 180 degree turns are made unless necessary. This simulates a person randomly wandering around the maze with no memory of where they have been. It's slow and not guaranteed to ever end or solve the maze, and once the end is reached it'll be just as hard to retrace your steps, but it's definitely simple and doesn't require any extra memory to implement.

The table shown below summarizes the characteristics of the above algorithms for solving the maze. Algorithms for solving mazes can be classified and evaluated according to these criteria. The following are column descriptions:

1. Solutions: This describes the solutions the algorithm finds and what the algorithm does when there is more than one. The algorithm can choose one solution or leave several solutions.
2. Guarantee: This is whether the algorithm is guaranteed to find at least one solution. Example: Random mouse is "no" because it is not guaranteed to succeed, and the left or right hand rule algorithm is "no" because no solutions will be found if the target is within an island. Dead end and shortest path search are yes because successful exit is guaranteed.Focus: There are two main types of maze solving

algorithms: Focus on the "Solver" or focus on the "Maze". When the focus is on the "Decider" then the maze is unknown. When the focus is on the "Labyrinth" it can be viewed from above as a whole and useless and useful passages can be rendered meaningless.

3. Human Feasible: Refers to whether a human can easily use the algorithm to solve the maze while in a life-size version or while looking at a map from above. Some focusing algorithms can be implemented by a human inside (or above) the maze, while some focusing mazes can be implemented by a human, but only above. Other algorithms are complex or sophisticated enough that they can only be reliably done by a computer.
4. No Memory: Whether no additional memory or stack is needed to implement the algorithm. Efficient algorithms require and consider only the raster image of the maze and do not need to add markers to the maze during the solving process.
5. Fast: This is whether the resolution process is considered fast. The most efficient algorithms only need to look at each cell in the maze once, or they may skip sections entirely. The running time should be proportional to the size of the maze, or in computer science terms O(n^2), where n is the number of cells on a side. The Random Mouse algorithm is slow because it is not guaranteed to finish, while the Tremaux algorithm potentially solves the maze from every intersection.

An algorithm	**Solutions**	**Warranty**	**Focus**	**Humanly feasible**	**No Memory**	**Fast**
Rule of the arm	1	no	Conclusive	Inside/Above	Yes	Yes
Bet Algorithm	1	no	Conclusive	Inside/Above	Yes	Yes
Chain algorithm	1	Yes	Decisive+	no	Yes	Yes
Tremaux algorithm	1	Yes	Conclusive	Inside/Above	no	Yes
Recursive Backtracker	1	Yes	Conclusive	no	no	Yes
Dead end filler	All +	Yes	Labyrinth	Above	no	Yes
Dead end filler	All	Yes	Labyrinth	no	no	Yes
Search for the shortest paths	All the shortest	Yes	Decisive+	no	Yes	Yes
Shortest path finder	1 Shortest	Yes	Decisive+	no	Yes	Yes
A random mouse	1	no	Conclusive	Inside/Above	Yes	no

2. 2. Line tracking algorithms

2.2.1 Main goals and objectives

Line tracking is the process of automatically detecting and tracking a line on a surface such as a road, line marker or similar

Here are some of the methods used to track a line:

1. Optical sensors: This is one of the most commonly used methods of line tracking. Optical sensors use photodiodes to detect the light reflected from the line. They can be placed above or below the surface and track the position of the line relative to them.
2. Infrared sensors: In this method, sensors use infrared rays to detect the line. Typically, pairs of infrared emitters and receivers are used, which are placed on the robot or vehicle.
3. Ultrasonic Sensors: The ultrasonic sensor method uses sound waves to detect objects and surfaces.
4. Magnetic sensors: These sensors use magnetic fields to track the line.
5. Computer Vision: Using cameras and image processing algorithms, computer vision can be used to detect and follow the line.

The purpose of this experiment is to create algorithms for a learning robot designed to follow a line.

Achieving a goal encompasses a set of tasks. Solving these tasks will lead to results that satisfy the set goal. The formulated tasks are the following:

1. A study of line tracking methods.
2. Development of a low-budget learning robot to perform the assigned tasks.
3. Development of algorithms to perform these tasks.
4. Conducting real experiments and analyzing the results of the conducted experiments.
5. Presentation of conclusions from the conducted experiments.

2.2.2. Algorithms

Line-following algorithms are widely used in robotics and autonomous systems that must follow predefined lines or paths.

Here are some of the most popular line tracking algorithms:

1. Center of Gravity Tracking algorithm - This algorithm calculates the center of gravity of the line by finding the center of gravity of the pixels in the image frame. The robot follows this point to stay on the line.
2. Line Width Tracking algorithm - This algorithm uses the information about the thickness of the line on which the robot is moving. The robot follows the center of the line, striving to maintain uniform line thickness within the image frame.
3. Proportional controller (Proportional Controller) - This is a control algorithm that uses the difference between the current position of the robot and the target line to generate a control signal. The difference is multiplied by a proportional factor that determines the strength of the correction. The robot is guided to the target line using this control signal.

4. Histogram Projection - This algorithm uses a histogram of the image to find the vertical positions of the line. A histogram represents the number of pixels in each vertical bar of the image. The robot tracks the pixels with the highest number in the histogram, which indicates that the line passes through that vertical position.

The task of the robotic platform is to move along the track following the outlined line without leaving it, in the first case the robot moves in a closed circle and the experiment is carried out in both clockwise directions, and in the second case the robot passes the entire track and stops at a stop sign.

The principle of operation of the robot following the line is related to the light. Here we use the behavior of light on the black and white surface. The white color reflects all the light that falls on it, while the black color absorbs the light.

CYTRON MAKER-LINE is an electronic chip that has an integrated IR transmitter (LED) and receiver (photodiode). They are used to send and receive light. When IR rays fall on a white surface, they are reflected to the IR receiver, generating some voltage changes

When infrared rays fall on a black surface, it is absorbed by the black surface and no rays are reflected; thus the IR receiver does not receive any rays.

With proper calibration of the CYTRON MAKER-LINE module, when its sensor senses a white surface, the Arduino Mega will receive 0 (LOW) as an input, and when it senses a black line, the Arduino will receive a 1 (HIGH) as an input.

Based on these input signals, the program must provide the correct output signal to the motors to control the movement of the robot. For this purpose, a diagram was developed of all possible combinations of the readings of the module's sensors and what action the robot should take to follow the line.

2.3. Educational Mobile Platform NITRObot

2.3.1. Main goals and objectives

The aim of this research in the dissertation is to create methods and algorithms of a learning robot NITRObot, which must perform the following tasks:

1. obstacle avoidance
2. searching for a way out of a maze
3. searching for a way out of closed

Conducting these studies should contribute to the development of learning robots by improving and expanding their capabilities to perform the assigned tasks. In performing these tasks, the learning robot must move autonomously and make decisions in certain situations. Research covers the following problem areas in learning robots: navigation, sensor systems and control systems.

Achieving a goal encompasses a set of tasks. Solving these tasks will lead to results that satisfy the set goal. The formulated goals are the following:

1. Development of a low-budget learning robot to perform the assigned tasks.
2. Development of algorithms to perform these tasks.

3. Conducting real experiments and presenting the results of the conducted experiments.
4. Presentation of conclusions from the conducted experiments.

The design of the robot meets four main requirements, which are listed below:

1. Low cost: It should be affordable for students and schools interested in robotics, while meeting the requirements for a fully functional system. This requirement dictates costs that should not exceed 100 euros and will in no way limit the level of functionality offered in the presented mobile robo-platform.
2. Design: It should stimulate the imagination and enthusiasm of students and is of key importance for this project. This requirement allows the use of recycled or second-hand materials in the manufacture of the main components - chassis, etc.
3. Simplicity: The concept of simplicity is limited to 3 requirements: installation, operation and maintenance. The time to assemble the robot should not exceed 2 hours. Once the platform is assembled, working with the robot should be easy for robotics beginners.
4. Open source: Open source is the best distribution model for this initiative. It is clear that the robotic kit should be easily accessible to all stakeholders, including teachers, educators and students.

The above requirements are sufficient for a completely ready, functioning system.

2. 3.2. Algorithms

The RUS-04 ultrasonic sensor and servo motor are used in this algorithm. Initially, the robot moves forward, continuously scanning for an obstacle in front of it. In this case, the servo motor is positioned at 90 degrees and the ultrasonic sensor scans in a straight direction. In the presence of an obstacle, the robot executes a motion stop command. The servo motor is positioned at an angle of 0 degrees and the ultrasonic sensor scans for an obstacle to the right of the robot, then the same operation is repeated at an angle of 180 degrees and scans for an obstacle to the left. The two results are compared and depending on which obstacle is more distant, the roboplatform makes a 90 degree turn with the same direction and continues its movement in a straight direction. The cycle repeats itself. In the event that the obstacles on the left and right are outside the range of the sensor, the robot turns in a direction preset by the software.

The algorithm is based on the solution of the maze exit problem, which states that if one of the walls (in this case the right one) is followed, the robot will reach the maze exit. That is, following a wall from the right and simultaneously searching for an opening in this wall is implemented. The robot constantly scans in front of it and to its right for the presence of a wall. If no wall is detected on the right (ultrasonic sensor indicates free space), the robot makes a 90 degree turn to the right, then goes in a straight direction and continues scanning. If there is a wall on the right and there is no wall in front of the robot, it executes the command to move in the straight direction and continue scanning. If there is a wall on the right and there is a wall in front of the robot, it executes the command stop movement, then executes a 90 degree turn to the left. and continues scanning.

The algorithm for finding an exit from a closed space is similar to that for finding an exit from a maze with the main difference that in the maze the corridors are of fixed dimensions and the turns are perpendicular (which simplifies the algorithm), while in this case the roboplatform is located in a space with irregular shape (the walls of which make an unknown angle relative to each other). In this algorithm, the ultrasonic sensor and the servo motor are used, and the algorithm tries to follow the obstacle (wall) that is located to the right of the robot. In the program, a parameter is set in advance - the distance of the robot from the right wall, which is equal to one width of the robot. This is the correct position of the robot, where it must move in a straight direction and be on an imaginary "axis line". The algorithm constantly scans in both directions (to the right and in front of the robot). The robot moves continuously in a straight direction. Based on the distance read by the right sensor, if the robot is to the left of the "axis line", ie. has moved away from the wall, we make a slight turn to the right. If the robot is located to the right of the "axis line", i.e. has approached the wall, we make a small movement correction with a slight turn to the left. If the robot is on the axis line, the robot is in its correct position and moving straight ahead. If the right sensor shows a very high value (distance), i.e. empty space on the right, follows a right turn until the sensor indicates that it detects an obstacle (wall) on the right again, and then the robot continues to move forward and follow the center line again. If the front sensor shows that there is an obstacle (wall) in front of the robot , it follows a left turn until the front sensor shows that it no longer detects an obstacle in front, and the right sensor shows that the right obstacle (wall) is one robot away, t .is the robot is on the "axis line". Then the robot again continues to move straight ahead and follow the axis line.

2.4. Comparative analysis of the algorithms of learning mobile robots in the performance of certain tasks

2.4.1 Main goals and objectives

Requirements for comfortable maneuverability of vehicles have recently attracted a lot of attention. For example, vehicles or robots equipped with a classical steering system require a large turning radius for turning. Consequently, these platforms have difficulty turning or avoiding obstacles in tight interior spaces.

Achieving the goal of encompasses a set of tasks. Solving these tasks will lead to results that satisfy the set goal. The formulated tasks are the following:

They developed two robotic platforms, one with a differential drive and the other with mecanum wheels capable of performing the tasks assigned to them.

1. A study of methods for moving from a start point to an end point following a line .
2. Researching methods to overcome previously undefined obstacles.
3. Development of algorithms to perform these tasks.
4. Conducting real experiments and displaying the results of the conducted experiments.
5. Presentation of conclusions from the conducted experiments.

2.4. 2 . Algorithms

The first task is to compile algorithms to move the robots from point **A** to point **B** following a continuous line. The line along which the transport robots move between the two points has perpendicular turns.

The differential wheel drive robot follows this line using three modules with three infrared line tracking sensors each located on the front, left and right of the robot. The algorithm for performing this task is as follows. Initially, the robot moves straight ahead following the line. When the line tracking module detects that there is no line ahead, it means it is following a left or right turn. The robot does not stop, but continues its forward movement until one of the side sensors detects a line. Depending on which side module has detected the presence of a line, the transport robot will make a 90 degree turn in the direction of the turn and continue its movement in a straight line in the corresponding direction. This sequence of maneuvers continues until the frontal sensor registers a STOP marker. This means that the robot has reached its final destination

The mecanum wheeled robot follows this line using four modules with three infrared line tracking sensors each located on the front, back, left and right of the robot. The algorithm for performing this task is as follows. Initially, the robot moves forward following the line. When the line tracking module detects that there is no line ahead, it means it is following a left or right turn. The robot does not stop, but continues its movement until one of the side sensors detects a line. Depending on which of the side modules has detected the presence of a line, the mobile robot will continue its rectilinear movement in the corresponding direction. When the tracking line module again detects the absence of one, it means that it is following a turn again. In this case, the front or rear sensors read this turn and the robot continues its movement in the direction corresponding to the sensor registered the line. This sequence of movements is repeated until one of the sensors registers a STOP marker. This means that the mobile robot has reached its final destination.

The next task is to compile algorithms to move the robots from point **A** to point **B** , overcoming previously undefined obstacles.

To accomplish this task, the differential wheel drive robot is equipped with an ultrasonic sensor mounted on a servomotor located at the front of the robot. During the execution of the task, the servo motor rotates in sequence left, forward, right, thus the ultrasonic sensor scans for the presence of an obstacle in the direction in which the servo motor rotated it. While moving to the target point, the robot encounters undefined obstacles on its way. The algorithm for performing this task is as follows. Initially, the robot moves in a straight direction, scanning for an obstacle in front of it, left and right. The robot continues its movement in a straight direction until it encounters an obstacle in front of it. After reaching the first obstacle, the robot makes a 90-degree turn counterclockwise (to the left) and continues its movement in a straight direction. The scan continues with two options following. The first possibility is for the robot to detect that there is free space on the right. In this case, the robot performs a 90 degree turn maneuver in the direction of the free space and continues its movement in a straight direction until it encounters an obstacle in front of it again. Then it makes a 90-degree turn clockwise (to the right) and continues its movement in a straight direction. This sequence of zigzag turns ensures that the robot will reach its destination point. In the second possibility, after the robot has encountered an obstacle in front of it, performed the corresponding maneuver and continued its movement in the right direction, it can encounter an obstacle (side wall) again. It then makes a 180 degree turn and continues its movement until it finds an empty space in the direction of the target point. Then he makes a turn in the direction of the empty space and continues his movement in a straight direction until he again encounters a new obstacle in front of him. In this case, he again performs a 90-degree turn in the opposite direction of the previous turn and continues his movement. In this way, he again repeats the zigzag movements until reaching the final goal .

To perform this task, the robot with mecanum wheels is equipped with 3 ultrasonic sensors located in the front, left and right parts of the robot. While moving to the target point, the robot encounters undefined obstacles on its way. The algorithm for performing this task is as follows. Initially, the robot walks straight ahead. The robot continues to move until it encounters an obstacle in front of it. After reaching an obstacle, the robot starts moving in a straight line to the left. The movement of the robot continues until the ultrasonic sensor detects the absence of an obstacle. Then he continues his path straight ahead again until he encounters another obstacle. In this case, the robot changes its direction of movement from left to right rectilinear movement. This sequence of zigzag movements is repeated until the robot reaches the target point. In the event that while moving to the left or right, the robot encounters a side obstacle, it will start moving in the opposite direction until the frontal ultrasonic sensor detects the absence of an obstacle. Then the robot again continues its forward movement following its final .

2.5 Machine vision

Machine vision refers to the technology and methods used to enable computers or machines to interpret and process visual information.

Machine vision systems typically consist of three main components: image acquisition, image processing, and decision making. Here's a quick overview of each component:

1. Image Acquisition: This involves capturing visual data using cameras or other imaging devices.
2. Image Processing: Once images are acquired, they go through a series of processing steps to enhance and extract relevant features.
3. Decision Making: After the image processing stage, the machine vision system analyzes the retrieved information to make decisions or perform specific tasks.
4. Activities, object tracking and person identification.

2.5.1. HuskyLens smart camera

HuskyLens is an easy-to-use AI machine vision sensor with 7 built-in functions: face recognition, object tracking, object recognition, line tracking, color recognition, label recognition, and object classification.

2. 5.2. Line Tracking, Goals and Tasks, Algorithms .

Line tracking by a robot equipped with a smart HyskyLensa camera is an innovative method that finds application in the field of robotics and automation .

Achieving a goal encompasses a set of tasks. The formulated tasks are the following:

1. Investigation of a line tracking method using a HuskyLens smart camera .
2. Development of algorithms to perform this task.
3. Conducting real experiments and analyzing these experiments.
4. Presentation of conclusions from the conducted experiments.

The task the robot has to perform is to follow a line using a HuskyLens smart camera. To do this, the camera is mounted on the front of the robot and tilted so that the camera lens is pointed at the line.

When HuskyLens detects the line it has learned, a blue arrow will show the predicted direction of the line .

. If the line the robot is on is straight and located in the middle of the screen, the arrow will be vertical and point to the top of the screen. In this case, the robot moves in a straight direction .

When a right turn is imminent, the upper end of the arrow will begin to deviate to the right along the X-axis. Since the robot is differentially driven, the left wheels will begin to move faster and the right wheels will begin to move slower, and the robot will initiate a maneuver right turn. The speed of the wheels is proportional to the deflection of the arrow on the X-axis. The sharper the turn, the greater the deflection of the arrow. It must not go beyond the display, because in this case the robot will stop moving. The robot will continue to turn until the arrow pointer returns to its original position (vertical). This means that a straight line is ahead. Then the robot continues its straight line movement .

When a left turn is imminent, the top end of the arrow begins to deviate to the left along the X-axis. The robot will begin to turn left until the arrow returns to its original position (vertically in the center of the display). Then the robot will continue its straight line movement .

2.5.3. Tracking objects, goals and tasks, algorithms.

Tracking objects with robots is an important task that is used in various fields such as home robotics, manufacturing process automation, medical robots, and others. This functionality allows the robot to follow the movement of a certain object in space and maintain visual contact with it.

In order for the robot to track the object, image processing is used using sensors such as cameras, lidars or infrared sensors. The process usually involves the following steps:

1. Object detection: The robot must detect the object it wants to track. This can be done by processing visual data from the cameras or through the sensors if the object emits certain signals (eg infrared signals).
2. Feature Extraction: Once the object is detected, the robot uses algorithms to extract features from the object that make it recognizable and unique. This may include size, shape, color or other visual characteristics.
3. Motion tracking: The robot uses the object's feature information to track its movement in real time.

In object tracking methods, ultrasonic sensors are most often used to determine the distance to an object. The goal is to develop algorithms for tracking an object using a HuskyLens smart camera, in autonomous mode of operation. To conduct experiments based on the compiled algorithms and to analyze the results of the conducted experiments

To conduct experiments based on the compiled algorithms, analyzing the results of the conducted experiments. Conducting these studies should contribute to improving the functionality of learning robots by improving and expanding their capabilities to perform certain tasks.

Achieving the set goal encompasses a set of tasks. The formulated tasks are the following:

1. Investigation of an object tracking method by a learning robot equipped with a HuskyLens intelligent camera .
2. Development of algorithms to fulfill the set goal.
3. Conducting real experiments and analyzing these experiments.
4. Presentation of conclusions from the conducted experiments.

The algorithm of this task is as follows. Initially, we select a minimum distance between the target object and the robot and enter the frame size as a constant quantity. At this distance, the robot is stationary. It cannot approach the object at a distance less than the minimum. When the object we are tracking moves away from the robot, it decreases in size relative to the camera screen. The robot tries to compensate for this shrinking of the object relative to the frame by starting a movement in the direction of the object. If the target object starts moving left or right along the X-axis relative to the camera screen, it means that the object is moving left or right relative to the robot. In this case, the robot begins to turn towards the object, compensating for this offset. The sharpness of the turn depends on the degree of displacement of the frame surrounding the target object. In this algorithm, we don't care about the Y-axis because the robot is moving in two-dimensional space. For the correct execution of the task, only the displacement of the frame relative to the X-axis and the withdrawal in depth are taken into account.

When the target object stops moving, the robot continues to move until it approaches such a distance to the object that the frame has reached its constant dimensions. In this case, the robot has approached a minimum distance from the target object and stops its movement anticipating upcoming movements of the object.

CHAPTER 3. Remote control of educational mobile platforms

3.1 Definition of Remote Control

Remote control is a method of remote control of a device using a smartphone, infrared transmitter (remote control of TV devices, remote control device of the robot kit, etc.), wireless joystick or 2.4G 4CH radio RC transmitter. This control method allows the operator to control the movement, functions and operations of the device through wireless communication and specially developed applications. Telecontrol is used frequently in a variety of fields, including robotics, industry, research, education, and the entertainment industry.

3.2. Remote control of a learning mobile platform, algorithms.

Remote controlled robots are devices that can be controlled by an operator using special devices such as a wireless joystick, a remote control device (infrared transmitter) or a 2.4G 4CH radio RC transmitter. These robots can be used in various fields and applications where it is necessary to perform actions at a distance from the operator.

The tele-controlled robot is designed to perform the following tasks:

1. remote control using an IR transmitter (remote control of a TV or other device with an infrared transmitter such as the remote control included in the kit of a standard robotic platform) and a receiver "IR Infrared Transmitter Module 38khz".
2. remote control with joystick and 2 receiver-transmission modules "NRF24L01 2.4Ghz wireless data transmission module".
3. remote control by means of a button block using "RF Receiver and Transmitter Module 433Mhz Remote controls" with which the communication between the operator and the robot takes place .
4. remote control via 2.4G 4CH radio RC transmitter.

When writing the remote control software using an infrared sensor, the IRremote.h library was used to scan the HEX code of the remote device that controls the robot . With the help of this library, the code of each button of the remote control device is scanned and the corresponding code can be converted into a command to control the robot using the software. In this way, the receiver has as many channels as there are buttons on the remote device with which transmitter-receiver communication takes place. Seven buttons are programmed to drive the robot. One button is responsible for moving the robot straight forward, another button for moving backwards, and four buttons for turning left and right in the forward and reverse directions, as well as a button to stop the movement.

Joystick remote control software and 2 NRF24L01 2.4Ghz transceivers use two software. The first software is intended for the joystick control module, and the other for the receiver responsible for the movement of the robot. The method used to communicate wirelessly with the Arduino is the nRF24L01 module. This is an inexpensive module that provides two-way communications using the 2.4 GHz band.

In telecontrol with wireless receiver-transmitter module RF Receiver and Transmitter Module 433Mhz Remote controls two software are used . The main part of this robot is the radio frequency remote control and control system. To implement RF remote control, a cheap

433mhz module is used, which is a pair of transmitter and receiver modules. Here in this project the module sends and receives data using Arduino library.

3.3. Remote control using the MIT Application Inverter Android application

One of the methods for remote control of a transport robot with Mecanum wheels is Bluetooth communication with smartphones or tablets using the Android or iOS operating systems.

The MIT App Inventor web application was used to create the management software .

MIT App Inventor is an intuitive, visual programming environment that enables the creation of fully functional applications for smartphones and tablets running the Android or iOS operating system. This tool is block-based, and makes it easy to create complex, high-impact applications in significantly less time than traditional programming environments. It uses a graphical user interface (GUI) that allows users to drag and drop visual objects to create applications. App Inventor is a cloud-based tool that allows the creation of applications directly in the web browser.

CHAPTER 4. Experiments and obtained results

4.1. Experiments and results when performing the tasks - avoiding obstacles, exiting a maze and exiting a closed space

After researching the set tasks, tests of the described algorithms were carried out.

The motors driving the platform are not stepper or servo motors, but direct current without encoders. This requires calibration (compensating for the speed difference) through tests so that the robot can move in a straight line without deviation from the straight line.

After calibrating the engines, tests of the obstacle avoidance algorithm began. After starting, the robot approached an obstacle, the front sensor sent a stop command to the controller, but the robot, due to momentum, failed to stop and crashed into the barrier. After decreasing the speed after several consecutive trials, the optimal speed setting was reached and the robot stopped in front of the obstacle at 10 cm. Proceed to the second part of the test - avoiding an obstacle by turning left or right at a right angle. In the first attempts, the platform failed to complete the correct 90 degree turn and crashed into the wall. After adjusting the parameters, another trial followed, where the robot made very sharp turns and deviated from the wall. After several attempts and parameter tuning, an accurate result was achieved and the robot successfully performed the maneuver.

4.2. Experiments and results on the line-following task

After researching the set tasks, tests of the described algorithms were carried out.

At the beginning of the program, the maximum powers for both engines and two speed correction coefficients, respectively for the left and right engines, are set as constants. Initially, these coefficients have a value of 1.0 in which the robot will move straight ahead, but in the process of experimentation, these coefficients will change their value from 0.0 to 2.0, thus changing the current speed of the motors and the robot will make left turns or to the right.

The goal is, based on the readings of the line tracking sensor, to determine the speed coefficients of the two motors, depending on what position the robot is in relation to the line.

In the initial test, we deliberately set the coefficients at their limit values so that no matter how far the robot deviated from the line, it made a turn to the line with the speed coefficient of the inner wheel 0.0 (current speed - 0) and the outer wheel 2.0 (current speed – max). Upon starting the test, the robot began to make sharp zigzag movements around the line.

In subsequent trials, we began to gradually "soften" the turns, with the goal being that the closer the robot is to the turn line, the smoother the turn, and the further away from the turn line, the sharper the turn. A graph of the pretest, midterm, and final test results is shown.

4.3. Experiments and results on line tracking and object tracking tasks using HUSKYLENS smart camera

After researching the set tasks, tests of the described algorithms were carried out.

To perform this task, we initially set the maximum permissible low speed of the motors, tilted the camera at an arbitrary angle relative to the plane on which the line is located, and placed the robot on a straight section of the line. After starting the robot, it immediately left the line and stopped its movement. Since the angle that the camera made with the plane with the line was very small, the field of view increased and the camera covered not only the straight section on which the robot was located, but also part of a bend. The arrow moved in the direction of the turn, this fooled the robot and it started to turn even though it was on a straight line .

After camera angle adjustments and experimentation, we arrived at an optimal angle of 45 degrees. The robot successfully completed its task.

After the successful completion of the task, we set the maximum speed of the engines and conducted a new experiment. At these values, the speed of the robot was too high and it left the line when turning. We began to gradually reduce the speed of the engines until a successful result.

In the object tracking experiment, we initially selected a minimum distance between the target object and the robot and entered the object size as a constant quantity. At this distance, the robot must remain stationary. It cannot approach the object at a distance less than the minimum. When we zoomed out, the object we were tracking decreased in size relative to the camera screen. The robot attempted to compensate for this shrinking of the object relative to the camera screen by initiating movement in the direction of the object. When we started to shift the object to the left or right, the robot started turning towards the object, compensating for this shift. The sharpness of the turn performed by the robot depended on the degree of displacement of the target object. In this algorithm, we did not care about the Y-axis of the camera screen because the robot is moving in two-dimensional space. For the correct execution of the task, we took into account only the displacement of the object relative to the X-axis of the camera screen and its depth draw.

4.4. Experiments and results of the mobile robot telecontrol task using different control systems

When controlling the robot remotely using an IR transmitter-receiver, the robot passed the test successfully. The robot followed the commands exactly and moved in the directions chosen by the operator.

In the method using a Joystick controller and the nRF24L01 transceiver modules, the robo-platform did an excellent job with the task at hand. The signal was strong enough and the robot followed the operator's commands accurately with unrestricted direct line of sight.

In the next method of remote control of the robot through two-way communication using a 433MHz transceiver module and a control panel with buttons, the robot also coped with the task. It executed the commands exactly in a perimeter of about 100m, which is quite enough for the set goal.

4.5. Experiments and results in the comparative analysis of mobile robots performing certain tasks with different types of navigation.

The mobile robot with differential wheel drive moves at 0.4m per second. This means that it takes him 5 seconds to cover a section of 2m length. It takes 1 second to perform a maneuver, a 90 degree turn. It took him 23 seconds to move from point **A** to point **B.**

The mobile robot with mecanum wheels has one advantage. It is an omnidirectional robot and to perform maneuvers, it does not need to turn as it can move sideways and diagonally. But he also has a drawback. Due to the specific location of the wheel rollers at an angle of 45 degrees, they have greater friction and therefore the speed of the robot is lower by 0.36m/s.

For the experiment moving from point **A** to point **B** , overcoming previously undefined obstacles, a route with dimensions of 4500mmX3500mm was built. The route has one entrance and one exit. In the closed space there are previously undefined obstacles with dimensions of 700mmX50mm. The experiment was conducted on the basis of the compiled algorithms.

The mobile robot with mecanum wheels traveled the same distance at a speed of 036m/sec. Since it is an omnidirectional robot and does not need to turn, it only performs straight-line movements (movement in the straight direction, movement to the left and right) to overcome the course. He completed the task in 25.28 seconds.

CONCLUSION

Some of the main problems in teaching mobile robots are considered in the dissertation work. The problem areas affected are as follows: localization, navigation, remote control, computer vision driving, navigation, QR recognition codes and objects and interfaces to control learning robots.

In the process of work, research and creation of methods, algorithms and systems for controlling learning robots has been carried out. Conducting these studies contributes to the development of learning robots by improving and expanding their capabilities to perform tasks of varying complexity. This indicates that the purpose of the dissertation has been met.

Methods, techniques and algorithms have been developed to improve and realize the set tasks. After conducting experiments, the achieved results show good achievements in the considered problem areas. Improved navigation accuracy and movement speed, computer vision for line tracking and object recognition, and QR codes. Innovative methods for remote control of robots have been developed. The results of the experiments satisfy the solution of the set performance tasks.

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The main theoretical and applied contributions of the present dissertation are:

1. The state and development of scientific research and problems in the field of visual robotics are analyzed. Methods for improving localization and navigation of educational mobile robots, such as algorithms for real-time operation, correction of systematic and non-systematic errors, and improvement of motor control, have been investigated;
2. Researched methods and algorithms for a robot overcoming obstacles , searching for an exit from a maze , an exit from a closed space and following a line have also been implemented.
3. Methods and algorithms for remote control of a robot through various devices have been implemented and studied.
4. HUSKYLENS intelligent camera have been implemented and researched . .
5. A comparative analysis of robots with different types of navigation and control systems was made.

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