Autonomous Searching Robot with Object Recognition Based on Neural Networks

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***Abstract*—The presented paper describes the design and implementation process of a six-wheeled autonomous robotic platform. The device is equipped with advanced object recognition algorithms based on neural networks. It is low cost and easy to build a device capable of roving in varied terrain. It is ideal for scouting missions, or mapping visited areas. Following a brief introduction into the explored topic, a design process of a considered robot. Mechanical, electronic and onboard sensory systems are found in the next part of the article. The following section consists of a description of the control and navigation approach used in our system. Then, YOLO object recognition algorithm is explained, followed by a proposed experiment to validate its abilities. Set of tasks were given to the robot, that had to complete them autonomously. Results are highly satisfying. The YOLO algorithm proved useful in object recognition providing crucial data required during autonomous drive mode.**

***Index Terms*—mobile robots, autonomous robots, object recognition**

I. Introduction

The goal of the project was to make a robot that would work during search and reconnaissance operations in difficult terrain, without human intervention. The robot equipment has been selected to provide as much input as possible, so that decision systems will be able to better respond to changes in the environment and more accurately fulfill their tasks. The robot should have wireless communication and its own power source, which guarantees the possibility of operations in all conditions and without the participation of other devices or the power supply network. The robot should also have a GPS-based navigation system and an IMU unit that will allow it to navigate autonomously as intended and to avoid dangerous positions that could cause capsizing. Person search has been based on machine learning, which is now the leading way to recognize and identify unique objects. The entire performance should be tested under nominal operating conditions. The possible appearance of the robot is shown in Fig. 1.

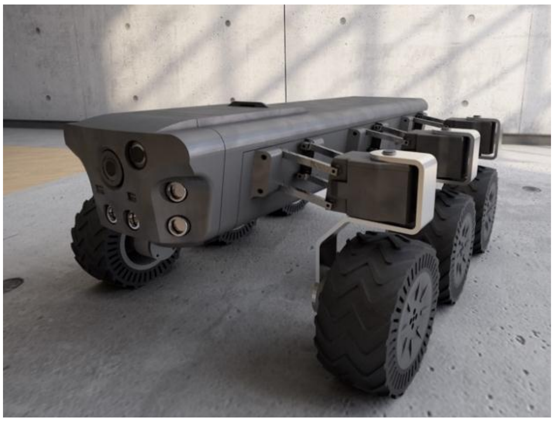

Figure 1. Visualization of the robot project.

II. Project

A. Construction

The robot is built on the basis of a modular structure that provides the possibility of easy disassembly and assembly of another type of suspension, starting with fewer wheels to caterpillars. In the basic configuration, 6 wheels are mounted, each wheel is a swivel wheel and can move independently. This type of suspension together with high ground clearance guarantees good conditions for traveling on challenging terrain. In addition, the swivel wheels allow much more accurate operation and autonomous navigation of the robot.

A multi-link independent suspension with shock absorbers ensures stability and durability.

Most of the body and parts of the robot were made using 3D printing technology [1], arms, servo and wheel holders, and other key elements were cut from an aluminum block or bent from sheet metal.

Each wheel has an independent motor that provides drive and servomotor that sets its position relative to the body. Due to the fact that each wheel can be turned separately, the robot can rotate in place and overcome challenging terrain. The low robot height allows getting to hard to reach places. At the same time, wide viewing angles minimize the risk of overlooking the object. The whole structure is shown in Fig. 2.

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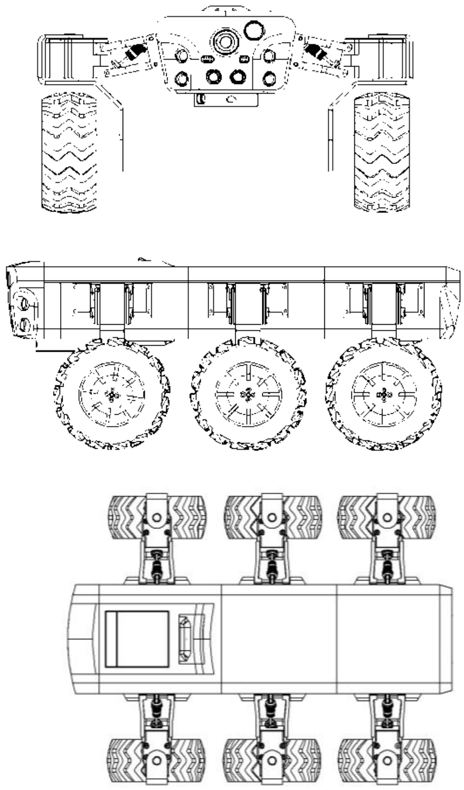

Figure 2. Orthogonal views of robot construction.

The elements of the robot made with the use of 3D printing technology were made in 72h with one amateur 3D printer. The table size is only 250x250mm. The body is divided into 3 main modules, each of which was printed separately. Motor housings were made on one assembly.

Other aluminium elements were cut out using water-jet machine or bent from flat bars.The tires should also be printed using 3D printing technology from a flexible filament, however, in the case of the presented robot's design, finished wheels for the RC model were purchased, which have a similar size and width, and a sufficiently aggressive tread to overcome obstacles on the ground. Each of the engines located near the wheel has a casing also printed in 3D printing technology.

The engines have been selected from commercially available models so that the robot is able to overcome the force of gravity when climbing a 40 degree incline.

The design is characterised by its small size and the ability to adapt to the different needs of the individual modules, e.g. wheels can be replaced by crawlers without changing the body. On the robot's front there is space for a manipulator or other tool to expand its capabilities.

B. Electronics

Overall devices scheme is shown on Fig. 3.

The robot's low-level controller is the STM32 microcontroller with a board with outputs and inputs. The communication of the control unit with the microcontroller runs through UART, its own control frame controls each motor and the steering wheel separately.

It also manages data from ultrasonic sensors to avoid collisions with large obstacles. It also controls the light source for the camera. Servos are controlled using PWM. Scheme can be seen on Fig. 4.

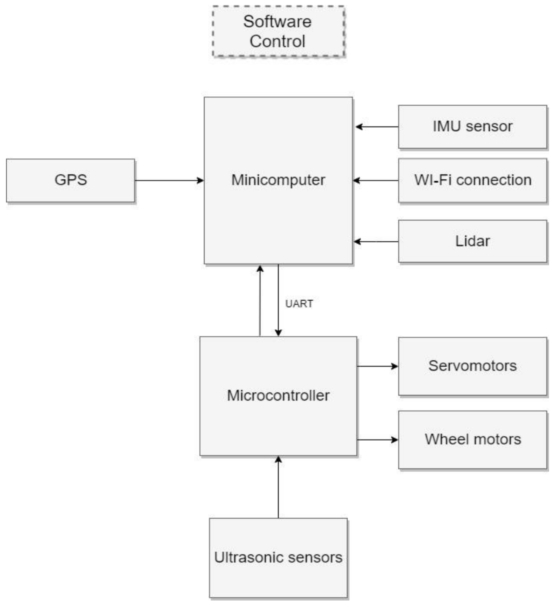

Figure 3. Overall devices scheme.

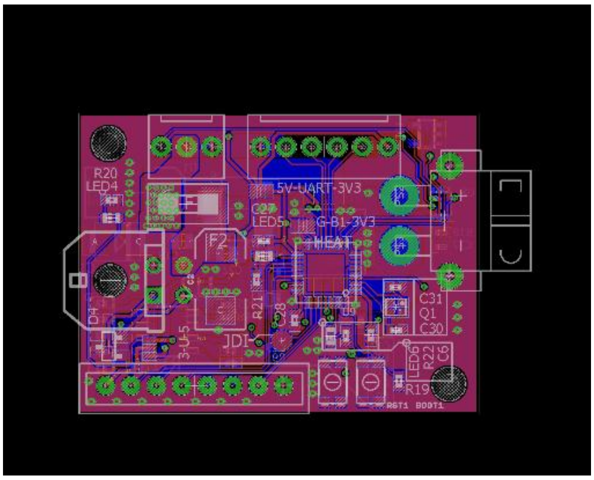

Figure 4. Schematics of self-developed wheel motor driver pcb.

Wheel motor driver is based on STM32 microcontroller. The board uses PWM for steering wheel, but can also uses CAN interface for communication. It is equipped with an integrated H-bridge system, with current capacity up to 6A, overcurrent, overvoltage, short-circuit and overheating protection of the H-bridge. The board supports SPI absolute and incremental encoders, which makes it possible to use angular position data for better wheel control. The controller includes a Full duplex UART to Half Duplex UART converter, which allows the control of digital Dynamixel servos. It is particularly slim and compact, allowing the board to be placed directly on the manipulator, e.g. in the vicinity of a motor, which limits the number of wires on the arm, as there is only one CAN cable and power supply. Selected electronic schematics are shown on Fig. 5.

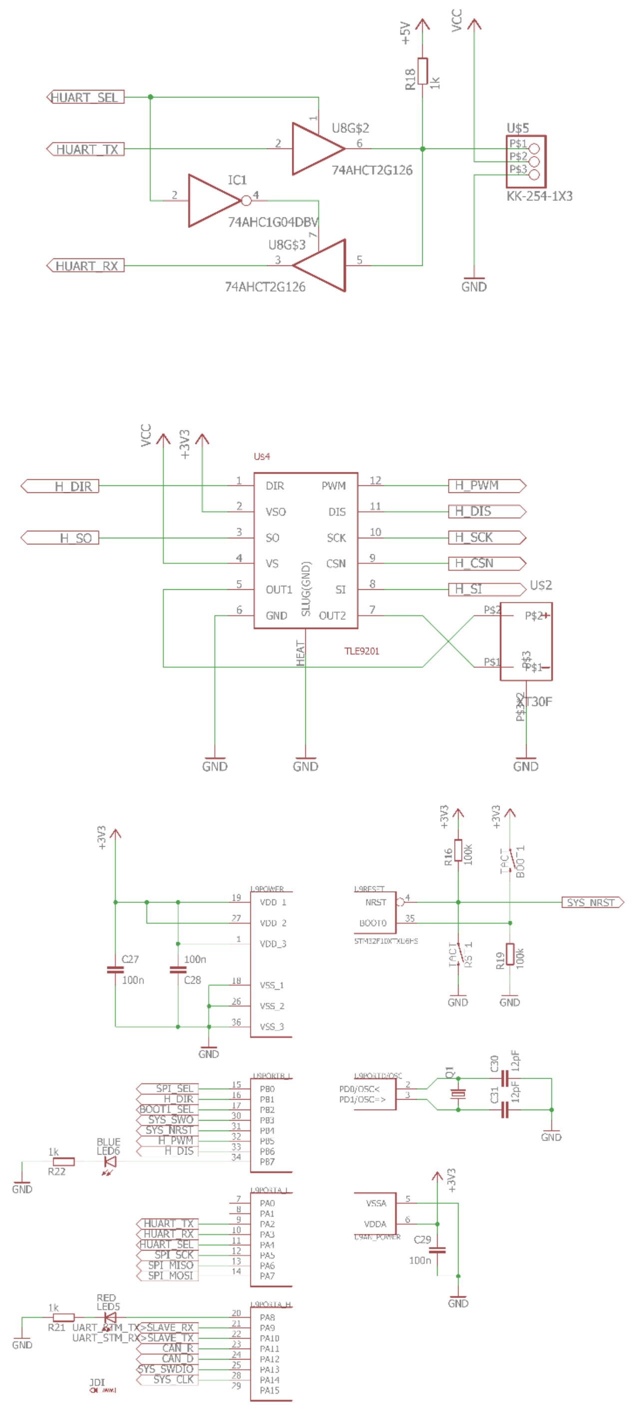

Figure 5. Electronic schematics of self-designed circuit board.

C. *Equipment*

The robot is equipped with a camera, three ultrasonic sensors, lidar. This equipment allows highly trouble-free autonomous navigation. Ultrasonic sensors detect objects located less than 1m away, which is to protect the robot from collision with a tree or other large insurmountable object. Sensors` arrangement is presented on Fig. 6.

Equipment parameters:

Lidar: max. range: 10m, view angle: 360^o, sampling frequency: 5 Hz

Ultrasonic sensors: max. detection range: 2m, min. detecion range: 30cm

Camera: resolution: 1280x1080, view angle: vertical: 30^o, horizontal: 100^o

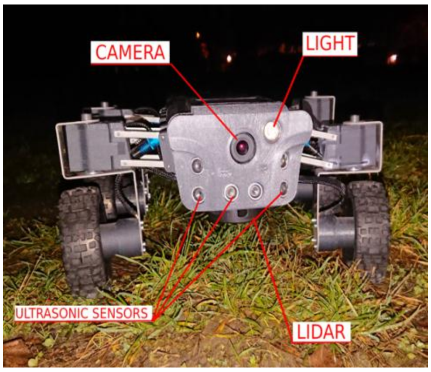

Figure 6. Arrangement of robot`s sensors.

The ultrasonic sensors are positioned to cover the widest possible field of view. The two extremes are at an angle to the front of the robot and the middle one looks straight ahead. This allows the detection of obstacles within a range of about 140 degrees.

The leader is placed under the body of the robot, due to the specifics of the device, the arms and wheels placed nearby do not affect its readings, i.e. they do not distort the received data, the readings are not taken into account at all and there are no points from the point cloud. The camera has a large matrix and is connected to the host computer via a CSI interface. The large sensor and the large size of the pixels allow for better visibility in low light conditions. In addition, the light lamp is designed to help in the absence of any external light source and ensures good visibility even in complete darkness.

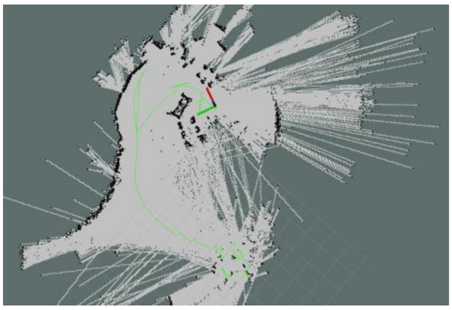

Figure 7. Lidar data-based map.

D. *Control*

Manual robot control was carried out via Wi-Fi connection. There was a minicomputer with an access point set up on board, so any computer with Wi-Fi connection and control program can manage the robot. In addition, robots can work together, with the control center being on one of them as well as an external device. The control scripts were written in C ++ [2] (using low-level network socket functions with C at the same time), and the communication itself is based on the TCP protocol - it's important to know that the control frames will not be distorted, so the robot will behave in a predictable way. Also via a network socket the control unit received orders from the imaging unit.

In addition to manual control, it is also possible to switch to autonomous [3] mode. Once there, the robot automatically generates a route based on the camera's video zone, a given search area and GPS data. Path is executed by travelling directly from point to point depending on both compass and GPS data. You can also dynamically customize the route to difficult terrain based on readings from lidar, gyro and camera. To orientate the robot, it maps it with Lidar [4] readings (results shown on Fig. 7) and saves the collected data to a file for later use [5].

E. *Autonomous Navigation Algorithm*

For the autonomous movement of the robot, data from the GPS and IMU modules were used, which included an accelerometer and a magnetometer. The resulting data collected from electronic components were processed by the control unit to determine the specific value of the angle sent to the servomotors and the rotational speed of the motors, so that you can autonomously move according to the planned route. The GPS module, by downloading the coordinates of the latitude and longitude, allowed the robot to be positioned on a previously prepared map and corrected displacement so as to follow a fixed route. The IMU module, in particular the magnetometer, allowed to determine the direction in which the front of the robot is facing, so that the correct angle setting could be made.

F. *Summary*

According to the above information, the robot is fully completed and can be made not only using 3D printing, but also from milled elements or SLS technology. This would increase the endurance. The single, largest part of the robot does not exceed the dimensions of 20x20cm, which allows it to be made on most machines available on the market.

III. Object Detection

Computer Vision [6] is one of the pillars of autonomous movement and performance of tasks by mobile robots. In the presented project it was considered that the most optimal algorithm will be YOLO - You only look once in its 3rd version, which has been optimized compared to the previous ones and ensures the fastest and most accurate object recognition [7]. Due to the high performance it is possible to use a small model trained for specific application, which is characterized by fast processing time of a single frame, which allows you to increase the speed of movement in order to detect the searched object faster. Another advantage of YOLO is placing the bouning box on the detected object which allows for more accurate location and navigation based on camera data. On the Fig. 8. there is the structure of YOLO`s neural network.

YOLO is also one of the most precise algorithms for detecting objects in the image.

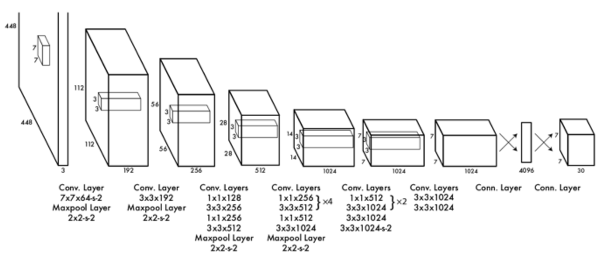

Figure 8. YOLO neural network structure [8].

The project used a pretrained model [9], which was then trained using its own dataset, which included photos of the unconscious and injured as per the assumptions. If you want to search for other objects, you should create your own model that would allow detection of a specific object as desired by the creators. Due to the use of a pre-trained model, our dataset had about 500 photos of people with the above-mentioned characteristics.

For better results and to train networks, a larger dataset should be used to recognize more complex objects, taking into account most of the possible environment during recognition.

After validation and satisfactory results have been obtained, networks were used to detect the objects sought. Another approach to this subject could be to use an algorithm and image processing methods, this is effective for simple objects or surfaces with a uniform colour, in the case presented in the article it would be very difficult and certainly less cost-effective than using machine learning as presented in the article. It would be worth considering combining both ways and creating a hybrid object recognition.

IV. Experiments

An area of 1 ha was used, with hills and valleys, wooded and with different subsoil. The tests took place in the autumn, in the evening, during mild rain. The robot was adapted to stay in a damp environment and even during the rain, which was an additional factor checking the structure - whether it will withstand the rain and not be damaged. Three sought-after objects were located in this area, each in a different environment. They were placed in random positions. The neural network recognizing images had never seen the objects in question before, which allowed the model to be verified in a sufficient way. During tests, the robot recognized objects in real time with framerate of about 10fps, which was enough to find hidden objects.

The robot was initially positioned in a randomly selected place within the search area. It determined the route and followed it throughout the entire search, properly controlling the position using the IMU. In case of an angular deviation from a given route, the robot performed a rotation manoeuvre using the swivel wheels set in the appropriate position.

A map with satellite images of the search area was provided for illustration purposes. The vehicle took into account the viewing angles of the camera, which resulted in overlapping of the viewed field, as shown in Fig. 10 in translucent red. This allows to use the time spent on searching in an effective way, as the robot does not look at the same area several times.

Figure 9. Robot during a search.

The search area was square, so the map shows where the robot turns back to stay in the designated area. In case of leaving the zone, the robot could easily return to it using the GPS module, which was also used for navigation.

If there is no GPS module or if the GPS module is lost, it is possible to implement SLAM for the robot's location, but this is limited by the search area, where there must be characteristic objects that can be a reference for the SLAM algorithm.

Figure 10. The terrain map with generated path and camera covered area.

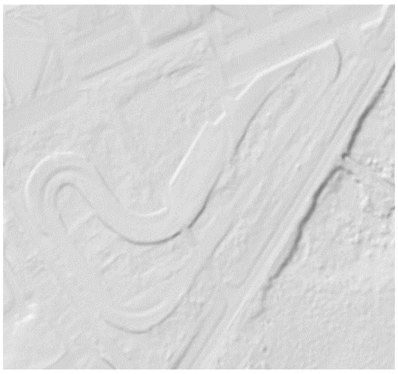

Figure 11. Numeric map of the terrain.

V. Results

The robot during the journey (shown on Fig. 9.), covered the entire route autonomously using on-board navigation [10], using data from GPS and a magnetometer, accelerometer and gyroscope to determine the position in space [11]. The terrain shown in Fig. 11 did not cause problems to the robot, the suspension worked perfectly and the vehicle steadily covered the entire route. The wide track, aggressive tire tread combined with high ground clearance ensure good traction and balance.

It was difficult for the wheels to slide on a wet surface if it was heavily covered with leaves.

Another problem was lighting, which did not work in night conditions, the anticipated field of view did not coincide with the real one, use stronger lighting to better identify objects.

The identification itself was successful (Fig. 12.) and all objects located in the robot's transit area were detected. The probability sensitivity threshold was set to 50% and each detection was signaled, then after removing the object the robot continued to search. It is important to use a small network model, trained for a specific task, so that recognition takes place in real time. A smaller image processing unit can compete with the small size model.

The whole structure was designed with a view to splash resistance, which was confirmed by the first tests, but further and more thorough tests should be performed. Also, shock absorber and swing arm mounts should be improved due to the break during testing of shock absorber and swing arm mounts, which proves the low strength of elements made in 3D printing technology for high shear loads.

Figure 12. First object detection.

VI. Further Development

In the future, it is possible to extend the described project to a robot cluster as presented in the article. Robots working together in an IoT connection could sweep the area faster and with a larger area. This would speed up the search and avoid involving people in these tasks, which would allow searching without interruptions and in all weather conditions.

It is also planned to switch from ROS to ROS2, which will allow, among other things, the introduction of a distributed system of multiple robots without a control center. This will solve the communication problem, as each of the robots will be independent. This could also be used to locate robots independently based on their transmitter signal. A large group of robots would also make it possible to replace the work of inoperative robots

- immobilized, e.g. stuck in a passageway or after a fall, by those waiting in reserve.

In the future, the design of a compact manipulator with interchangeable effects is planned. The addition of a robotic arm will allow for more operations on the victim, e.g. better position signalling, basic first aid, provision of medical supplies to victims of accidents.

In addition to the manipulator, a container for tools or other objects useful for conscious victims can also be attached.

It is possible to attach a mast equipped with a light or sound signal to allow for easier location of the robot by the search team or to send messages to the injured party.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

The main idea of this projects originates from Jakub Czygier`s field of interests. Algorithms development was a work of Przemysław Dąbrowski and Mr. Czygier. Implementations of those has been conducted by Mr. Dąbrowski. Electronical and mechanical part of this project has been accomplished by Robert Grabowy. Mr. Czygier and Mr. Dąbrowski performed experiments and provided data. Analysis of them and this paper are also their work. Dr Dzierżek and Mr. Rećko provided scientific advisory of this paper.

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