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CENTRAL INSTITUTE FOR CONSERVATION, BELGRADE
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AND PROMOTION OF NEW TECHNOLOGIES

DESIGN AND CONTROL OF EDUCATIONAL MOBILE ROBOT FOR MATERIAL TRANSPORT IN INTELLIGENT MANUFACTURING SYSTEM

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Abstract: *This paper presents an approach to design and control an intelligent mobile robot for material transport in manufacturing system. Two DC motors are used in order to configure differential drive mobile robot. Furthermore, mobile robot is designed using Arduino microcontrollers, which are compatible with MATLAB and Simulink. Steering controls for translation and rotation of mobile robot are obtained using artificial neural networks (ANNs), which are trained in MATLAB neural network toolbox and implemented in Simulink model. Simulink model is also used for modeling of the transportation route which mobile robot follows as well as acquiring data from sensors. Experimental results show that mobile robot, using the described methodology, is able to complete the transportation task with satisfactory accuracy.*
Key words*: intelligent mobile robot, artificial neural networks, material transport, MATLAB, Simulink.*

INTRODUCTION

A robot is a machine, especially one programmable by a computer, capable of carrying out a complex series of actions automatically [1]. Robots can be guided by an external control device or the control may be embedded within the robot itself. Robots may be constructed to take on human form but most robots are machines designed to perform a task with no regard to how they look [1].
In this paper, focus is to design a mobile robot capable of carrying out a mission to transport a specific object to its destination. Control of the robot must be autonomous. For that to be possible, robot must be able to acquire data from its surroundings via suitable sensors, in this case ultrasonic sensors.
This paper is organized as follows. Designing a mobile robot and using the necessary components correctly in that manner is described in chapter 2.
When robot acquires data from its surroundings, it is important to convert that data to units that can be used for controlling the robot. Data used in this case are: distance and rotation. Distance and rotation are converted to control units using ANNs. Units are used to define how much a DC motor shaft should rotate. Shaft rotation is measured by Hall sensor located on DC motors. Detailed explanation and function diagrams of ANNs used for controlling the robot are described in chapter 3. Simulink model is used to process acquired data and give instructions to a robot by using previously mentioned ANNs and triggered subsystems. Instructions are given in a form of a vector that contains everything that is necessary for a robot to complete his assignment. Detailed explanation is given in chapter 4. Experimental results are shown in chapter 5.

MOBILE ROBOT DESIGN

When designing a robot, it is recommended to build a control unit in a way that it can be mounted on numerous different robot configurations. Control unit in this case consists of three floors. Going from top to bottom, batteries are mounted on the third floor, voltage regulators are on the second, microcontrollers and H-bridge are on the first floor. DC motors, servo motors and ultrasonic sensor are mounted on main platform of the robot. Complete design is shown on figure 1. Main platform can be configured differently and control unit would still be compatible.

Arduino microcontrollers are used to control the robot. All components are connected with jump wires. One prototype board is made to so that connections between components are easier to establish. Prototype board consists of soldered 2.54 mm pins. It serves as place to plug in Arduino Nano too. Arduino Uno, Arduino Mega and H-bridge are placed next to the prototype board. Prototype board is displayed on figure 2.

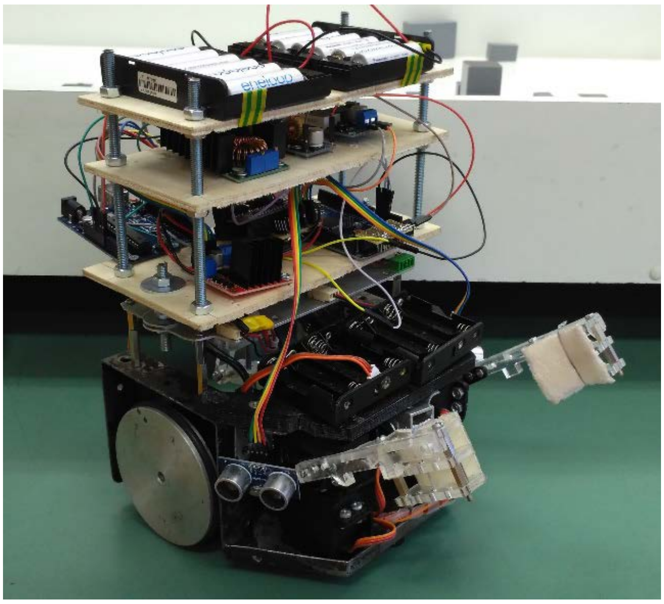

Figure 3: Design of a mobile robot

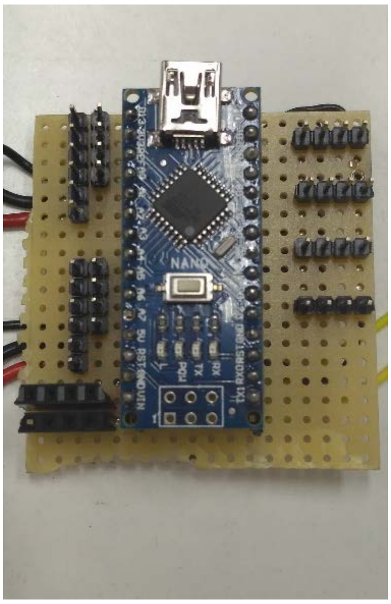

Figure 4: Prototype board

ARTIFICIAL NEURAL NETWORKS

Artificial neural network (ANN) is a paradigm[17] of artificial intelligence which is defined as a model for reasoning that is based on analogy of a human brain. It is capable to learn and generalize acquired knowledge [2]. ANNs provide significant advantage when solving a problem that requires processing data in real time and interpretation of relationships between variables in multidimensional spaces [2].
In this paper, robot is controlled with the help of a back propagation network based on Levenberg-Marquard algorithm and sigmoid activation function. ANN is trained by using measured units and acquired data from sensors which represent input and output of a neural network.
Three artificial neural networks are used:

- Neural network that defines the angle by using the relationship between the congruent sides of a triangle,
- Neural network of rotation,
- Neural network of distance.

Function diagram of the first ANN is displayed on figure 3. X axis represents the input values, while Y axis represents the output and target values in all three ANNs. Upper window is a

[17] Role model, form, an example of reputation

function diagram, while the lower window represents a maximum error which ANN can make. Input values represent the relationship between the congruent sides of a triangle, while the output value represents the angle determined by that relation.

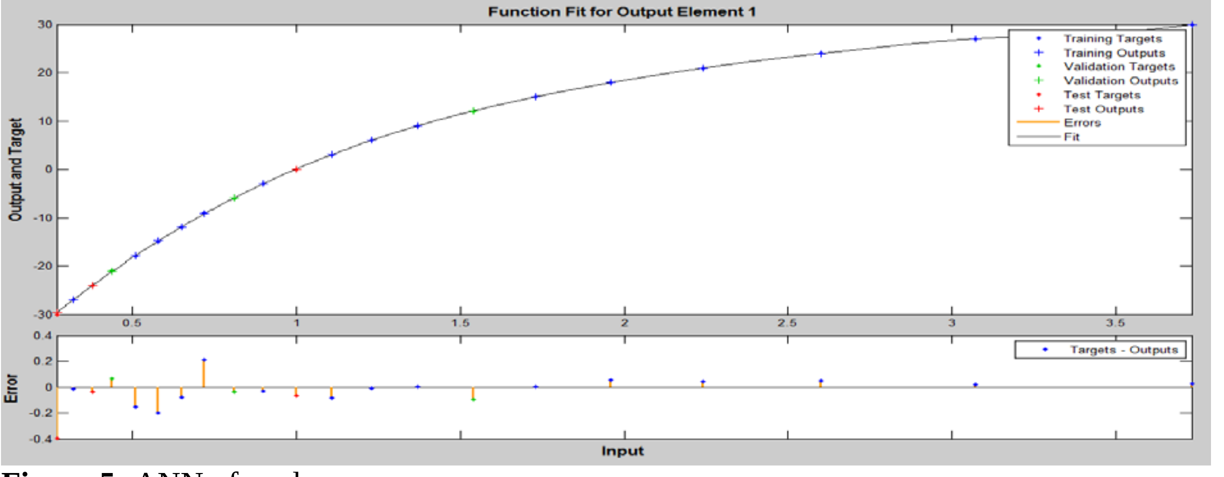

Figure 5: ANN of angle

ANN of rotation and ANN of distance are represented on figure 4 and 5. Input of the ANN of rotation is the angle (in degrees) which represents how much a robot should rotate, while control units are calculated on the output. ANN of distance is similar to the ANN of rotation. Distance, which is represented in mm, is given on the input and control units are calculated on the output to define how much the robot should go forward or backward. Control units in both cases are a number of increments which Hall sensor on DC motor uses to determine how much a motor shaft should rotate.

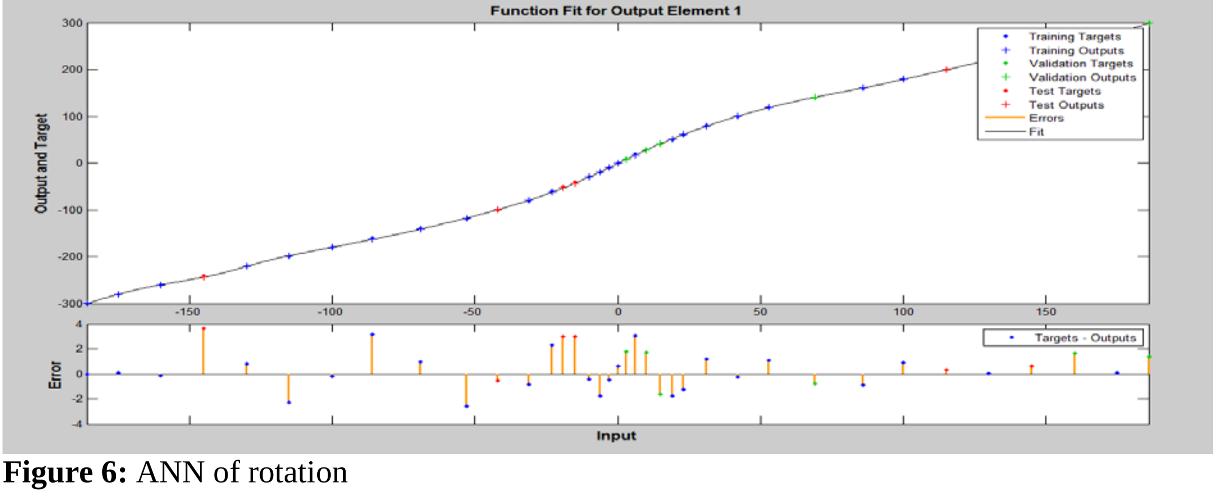

Figure 6: ANN of rotation

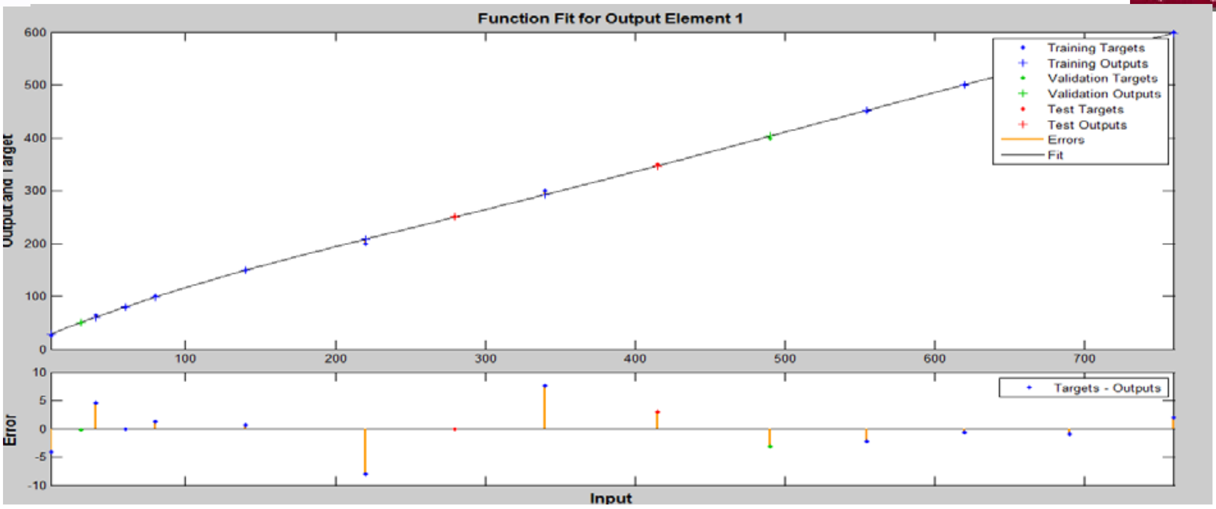

Figure 7: ANN of distance

SIMULINK

Simulink is a simulation and model-based design environment for dynamic and embedded systems, integrated with MATLAB. Simulink, also developed by MathWorks, is a data flow graphical programming language tool for modelling, simulating and analyzing multi-domain dynamic systems. It is basically a graphical block diagramming tool with customizable set of block libraries [3]. Main Simulink model is represented on figure 6. It consists of 4 subsystems: subsystem of motion, subsystem of decision making, subsystem of ultrasound and subsystem of correction.

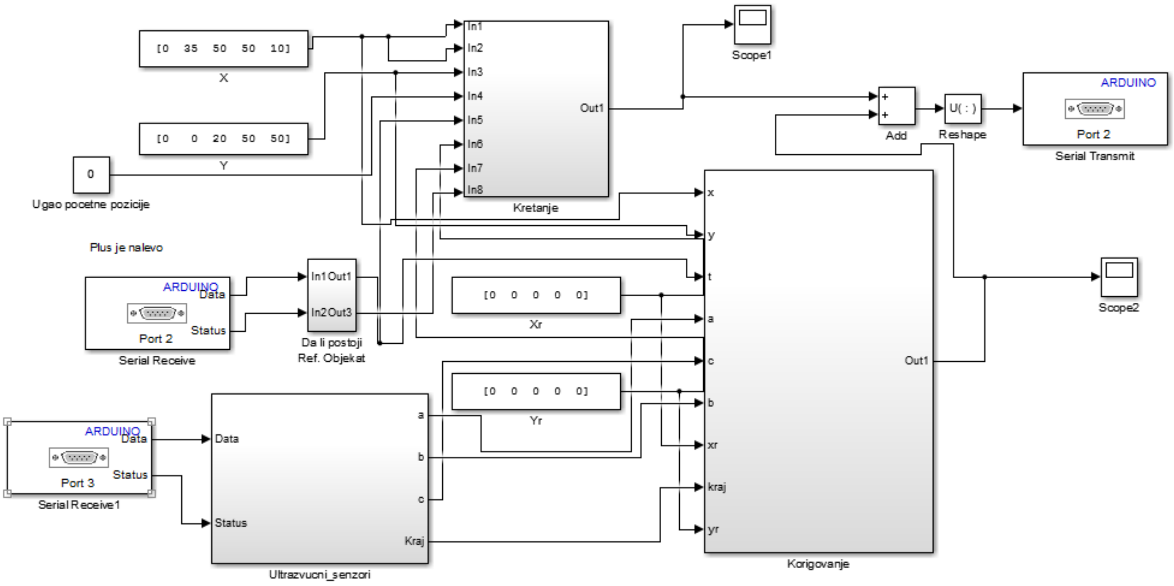

Figure 8: Main Simulink model

Subsystem of motion requires coordinates x, y and angle θ. X and y represent positions, while θ represents starting orientation. Subsystem of motion then forms a matrix. Matrix is sent to a microcontroller, which purpose is to move a robot to a desired pose. After a robot finishes its motion, microcontroller sends confirmation about it. Confirmation is received by subsystem of decision. His purpose is to decide whether to check if there is a feature of interest which robot can use to correct his pose or to move on. Subsystem of ultrasound gathers the data from ultrasonic sensors. Then subsystem of correction compares that data with the correct data defined by coordinates x_r and y_r which represent the position of a feature. If the data differs, then subsystem sends a vector of correction to the microcontroller which begins to move the robot to a correct pose. After the motion is finished, microcontroller sends a confirmation to the subsystem of decision again that robot has finished moving. Then subsystem of decision sends a positive value to the subsystem of motion so that process of motion can be continued Then the procedure repeats for the next position defined by x and y.

EXPERIMENTAL RESULTS

When robot configuration and programming of microcontrollers are complete, robot needs to be tested in specified area. Testing area is shown on figure 7 and represents laboratory model of manufacturing environment.

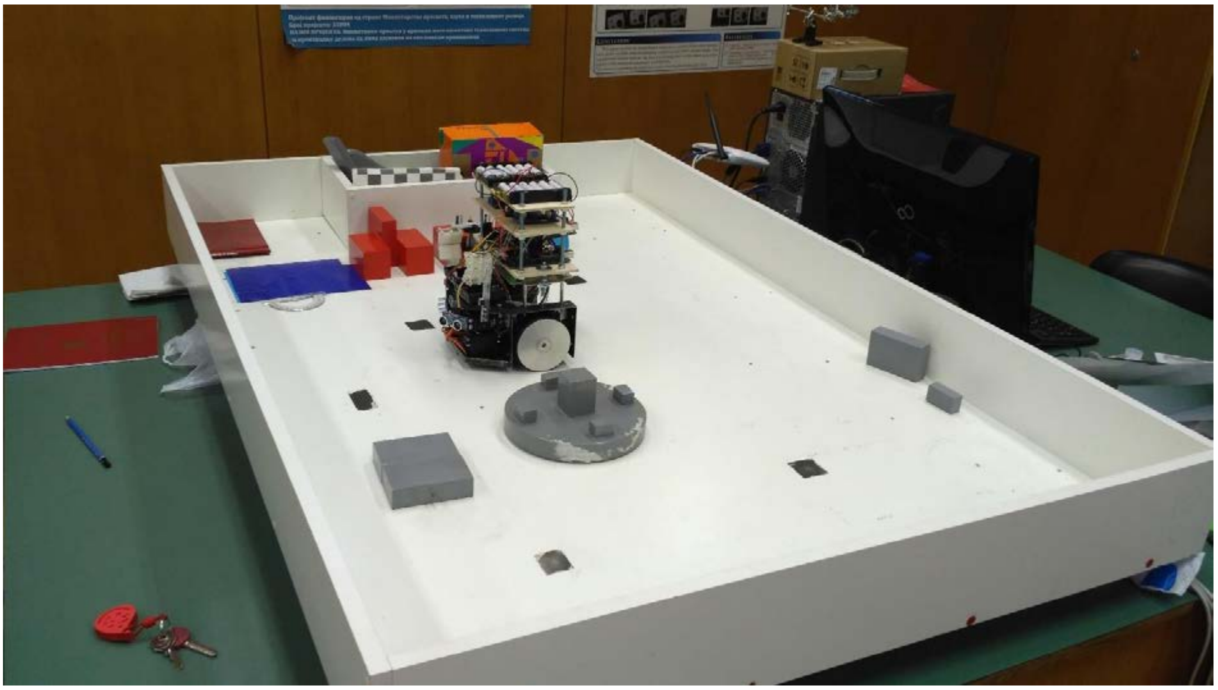

Figure 9: Testing area

Defined positions and starting orientation of the mobile robot are given by next vectors:
$x = [0\ 35\ 50\ 50\ 10]$
$y = [0\ 0\ 20\ 50\ 50]$
$\theta = 0°$
Goal of this experiment is to determine the accuracy of robot positioning.
Defined path that robot needs to traverse is displayed on figure 8. „Start“ represents the first pose, while „Cilj“ represents the final pose that robot needs to get to.

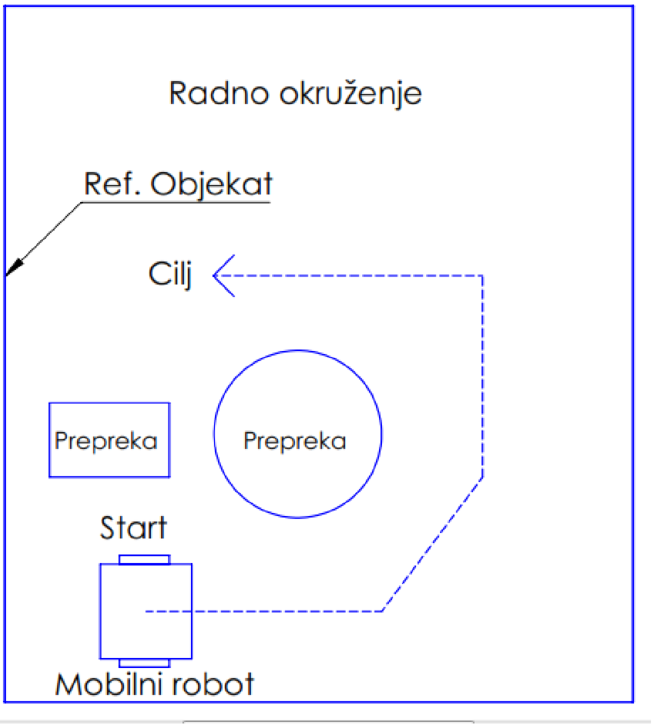

Figure 10: Testing area with the defined path

Results of measurements are shown in table 1. X and Y represent the error of robots positioning on x and y axis, while θ represents robot orientation. Desired orientation is 180°. Measured orientation is shown in table 1.

Table 1: Measured position and orientation of a robot

Number of measurement	X[mm]	Y [mm]	θ [°]
1	-4	9	150
2	-1	13	150
3	-6	10	165
4	-5	5	160
5	-3	10	150
6	-9	7	160
7	-3	11	160
8	-1	12	150
9	-3	12	150
10	-4	13	150
11	-9	4	165
12	-9	7	155

When robot gets to his final pose, it needs to check if his accuracy of positioning was satisfactory. Using the ultrasonic sensors placed in the front, robot scans the feature of interest and corrects his position. Final pose and scanning the feature of interest (in this case, the wall) is shown on figure 9.

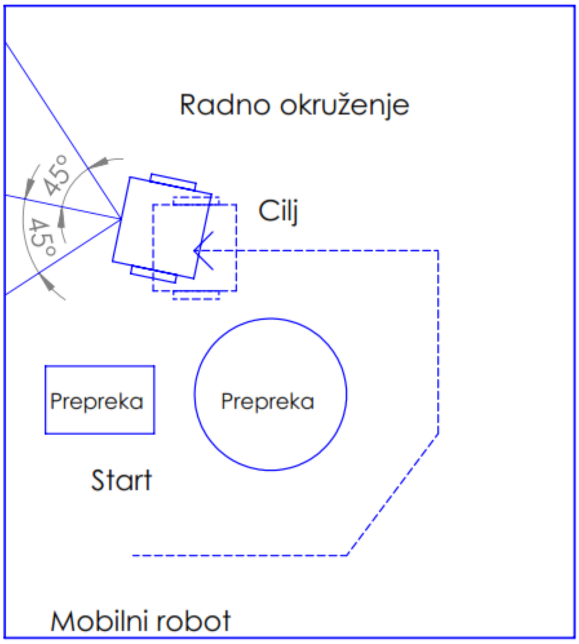

Figure 11: Desired and achieved position

After robot corrects his position and orientation, measurements are taken again. Results of measurements are shown in table 2. Parameters in table 2 are the same as in table 1.

Table 2: Measured position and orientation of a robot after correction

Number of measurement	X [mm]	Y [mm]	θ [°]
1	1	9	175
2	0	13	180
3	1	10	180
4	0	5	175
5	0	10	180
6	1	7	185
7	0	11	180
8	0	12	175
9	-1	12	180
10	0	13	180
11	0	4	175
12	0	7	180

CONCLUSION

In this paper it was presented how to design a mobile robot and program it to complete a specified assignment. Every component and its role in the configuration were described. This is not the only way to configure the robot. Only a minimal number of components were used when designing this type of a robot. It leaves much space for improvement and modifications.
Using the ANNs it was easy to convert distance and angle to control the units which robot could use to move around. By using ANN the user can avoid or simplify a mathematical solution of the problem, and therefore solve it with satisfactory accuracy.

Simulink model was used to process the data and it provided the user with clear overview to what was happening during the test. Model can also be easily modified to suit other configurations. Model can be expanded further to please other configurations and use other components.
Experimental results have shown that robot could do its assignment with satisfactory accuracy. It is also worth mentioning that any feature with flat sides can be used by ultrasonic sensors to correct the position and orientation of the robot.

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