Emergency Autonomous Robot Design with Fuzzy Logic Control Approach

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ABSTRACT- In this study, the application of an autonomous fire extinguishing robot with a fuzzy controller approach was carried out. For this purpose, an autonomous robot which can provide motion is designed and reaching the target and controlling the position were aimed. The embedded system (Atmega2560) was used on the designed autonomous robot. Flame Sensor, Li-po battery, L298 Motor drive, DC motor, servo motor, digital compass sensor are used on this system. Robot is processing the position and route information through a fuzzy controller. As a result of the data obtained, flames created in the environment are detected by robot through the patrol and then the robot extinguishes the flames with its impeller and continues its patrol. As a result, the autonomous robot detects the flames considered as target point during the patrol task and the fuzzy controller is used to determine the distance to be taken and the direction with the digital compass.

KEYWORDS Fuzzy Controller, Autonomous Fire Extinguisher Robot, Emergency Situation Position Control

1. Introduction

Autonomous robots are the robots that act according to the information they perceive around them and perform the given tasks by using the sensors on it. An autonomous control system should be safe, stable, changeable according to the reactions and synthesize the results of the system and inform the user in an easy and understandable way.

Specifically, the technical characteristics of the robot to be designed must meet the desired control method and fulfill its duties in the cycle. It is also desirable to change system parameters over time to ensure proper and effective control. Therefore, the fuzzy logic controller, which is a control method that can exemplify human thinking ability and knowledge in the control system, can be considered as a good solution. Autonomous robots need at least two different information in order to locate the targeted position. These are the distance to be passed and the angle between the robot and the location to go. If the robots already have map data, they can reach their destination with the help of sensors they use. If the robot does not have the information if the environment, then the processes are carried out in accordance with the data obtained from the user.

One of the most important elements for the fulfillment of the tasks assigned to autonomous robots is to know their position and to map their environment [1]. Path identification and target route structures were investigated, and a graph was created on the chosen structure so that known path finding algorithms were applied on the graph [2]. The performance of fuzzy logic on electronic systems has achieved a higher success when compared with PID control applications. For example, in the studies carried out within the climate control area, it was envisaged that analog systems and air conditioners would reach certain values. Recent developments in climate control have transformed such analog systems into digital systems which can lead to the comfort level [3]. The fuzzy logic algorithms in robotic systems have been successfully applied on mobile robots (non-holonomy) with limited operating capabilities [4]. Studies were carried out in accordance with the characteristics defined by classification within the systems that use probability calculation in robotic field. In the studies carried out on the data sets, the results of the tests, which are incorrectly and accurately defined in the system, have occurred as a percentage [6].

By using the algorithm developed with sensors placed in the system, it realizes the autonomous movement by detecting the location of the fire source and perceiving the objects around it [7]. The operation carried out with a closed system has the capability of transferring video and sound to the robot, which is developed with the ability to withstand more temperatures [8]. Robots developed to be used in emergency cases instead of rescue teams to control remote environment and to analyze the environment [9]. By using the algorithm developed on the robots, robot can move its position thanks to sensors in a simultaneous location system [10]. A system has been developed to detect and extinguish fires by means of sensors present on robots which are developed in systems with a fire extinguishing area [11].

The robot, which has been developed as a multi-sensor fire detection system, has been provided with a fire detection system through its sensors [12]. By conducting simulation on the robots, the extinguishing of a fire caused in a house was carried out successfully [13]. The common detection sensors used for autonomous robot navigation carry out their work in real time, reducing the risk of errors and having rapid and successful results [14]. Path planning algorithms aim to find the most appropriate path between the location of robots and the target location by wasting less amount of energy. For this purpose, road planning algorithms are very important for mobile robots to operate in closed navigation environments [15]. Designing such systems becomes a model to improve and verify control performance. Initial model developed on mobile robots is the position control of the Segway type robot. When examining this type of systems, first thing to do is to create a dynamic model of the robot and to perform the analysis on the model created [16]. Then, the system analyzed will be designed on fuzzy logic [16].

The most fundamental study of how to act on the mechanic systems on mobile robotic systems is kinematics [17]. Mobile robots should be able to determine their location in the environment they work and calculate the positions they can take over the destination [17]. Mobile robots define possible paths and trajectories in the study area through kinematic analysis [17]. A mobile robot in an unknown environment has losses in movement and location which might occur when it senses and moves around [18]. Fuzzy logic research on the system that causes a barrier using its sensors offers an autonomous control architecture for mobile robots [19].

Fuzzy logic control on the autonomous robot is the most important aspect of this study due to its high adaptiveness and success in non-linear systems. An autonomous robot was formed to operate this controller on autonomous robots.

2. Hardware

The body of the robot is composed of two layers of Plexiglas on the base of the circle. Arduino Mega 2560 card is used as the central processor and the sensor and communication module as input and output devices are used in conjunction with the power supply. On the designed robot, there are sensors to detect the surrounding heat and the location, and DC motor and ball casters that will enable the movement of the mobile robot. As a power supply, the lipo battery with 3S 11.1V 1350mAh is the voltage required to operate the system.

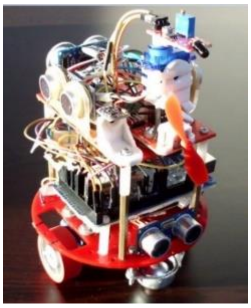

Fig. 1. Autonomous robot

The mobile robot created is shown on figure 1. The electronic components used on the designed autonomous robot are shown in Figure 2. The digital compass HMC5983L shown on Figure 2- (a) is a 3-axis compass sensor. The fan motor driver located on Figure 2- (b) is L9110 and its propeller dimensions are 75mm. The ultrasonic sensor shown on Figure 2- (c) is HC-SR04 and can be measured in a range of 4 meters. The bluetooth module shown in Figure 2- (d) is HC05 and used for the wireless serial communication protocol. The temperature sensor of the robot shown in Figure 2- (e) is a sensor board used for detecting fire with a wavelength between 760nm - 1100nm. There is one IR receiver on the flame sensor. The servo motor shown on Figure 2- (f) is used to read the flame sensor during the movement of the robot to read the values mobile. Servo motors have a working range between 0 to 180 degrees.

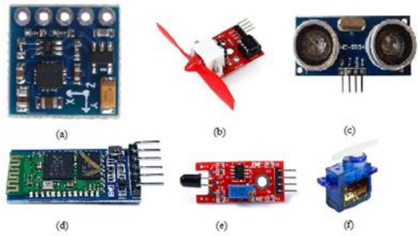

Fig. 2. Components of autonomous robot

The electronic components used on the designed robot are shown in Figure 3. The micro controller card shown in Figure 3- (a) is an Arduino card with Atmega2560 base. L298 motor driver is shown on Figure 3- (b), and two canals provide a current of 2A per motor drive channel. DC motor 12V shown on Figure 3-(c) is with 500Rpm reduction gear. The ball cater shown in Figure-3 (d) has 30 mm. metal ball. The li-po battery shown in Figure 3- (e) has 3S 11.1V 1350mAh power.

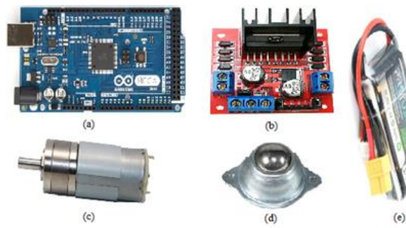

Fig. 3. Components of autonomous robot

3. Control and Software Algorithm of Robot

In the robotic algorithm, a navigation system was developed without installing any map information in the robot and the robots were moved according to the data from the ultrasonic sensor.

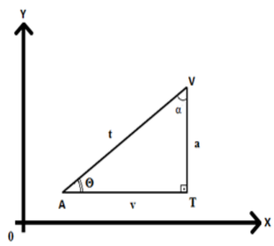

Fig. 4. Distance calculation diagram

The distance calculation diagram of the designed system is given in Figure 4. Symbol A on the diagram represents the starting position of the robot, symbol V represents the detected target point and the symbol T represents the intersection of A and V points at the X axis. Symbol "t" represents the distance between the starting position of the robot and the target point, symbol "a" represents the height of the target point on the X-axis, and the symbol "v" represents the distance from the starting point to the point of intersection. Symbol Θ is the angle variable used for the robot to reach the target point from the starting position, and symbol α is stated by 90 - Θ.

The angular diagram on Figure 5 gives the relationship between the position of the robot and the axis it sees the flame from. "x1" indicates its relation with X axis, "y1" indicates its relation with Y axis and "A" indicates the angle it has with the flame.

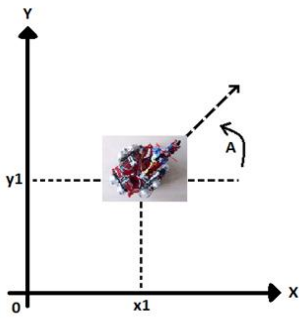

Fig. 5. Angular diagram of autonomous robot

3.1. Fuzzy Controller

Fuzzy logic is a control algorithm which has been commonly used in recent years. Application of conventional control methods does not provide the required precision in complex systems. Fuzzy control, which allows more flexible calculation, is preferred. Therefore, fuzzy control method was used in this study. The fuzzy control block diagram of the system design is given in Figure 6.

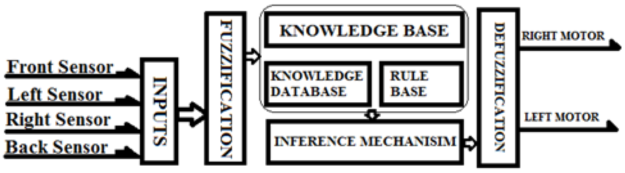

Fig. 6. Fuzzy control block diagram

The robot detects the current position with the help of ultrasonic sensors. The calculated position data is processed by fuzzy logic and calculates the distance to be traveled. The distance calculation diagram given in Figure 4 was used to calculate the distance. During operation, the flame angle is determined by the UV Flame Sensor connected to the servo motor. The angle of the robot is rotated and the direction of the angle is determined and the fuzzy logic algorithm is advanced by the calculated distance value and the distance required for extinguishing the flame.

Fuzzifier

In the fuzzing process, the digital input and output variables are converted to symbolic values. This section is divided into subsets of Right Motor and Left Motor, which are defined as input variables, which are Front Sensor, Left sensor, Right sensor, Voltage sensor and output variable. There are three sub-sets of Right Engine and Left Engine, which are the input variables of the input variables, namely the front sensor, the left sensor, the right sensor, back sensor, the three-sub-set and the output variable.

Membership Functions

Fuzzy subsets for both input and output variables of the mobile robot are defined as triangular and trapezoid type membership functions. The ranges of the Front sensor, Left sensor, Right sensor and Back sensor vary between 0 cm and 20 cm.

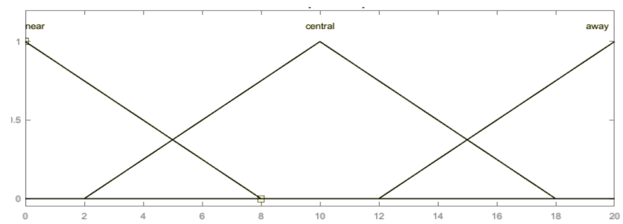

Fig. 7. Front sensor membership functions

Figure 8 shows the left sensor membership functions graph.

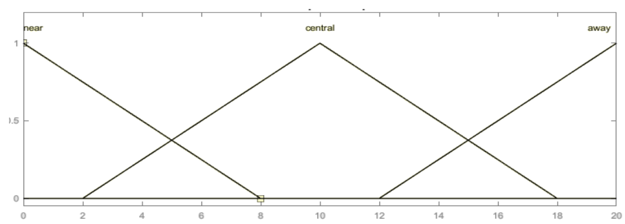

Fig. 8. Left sensor membership functions

Figure 9 shows the right sensor membership functions graph.

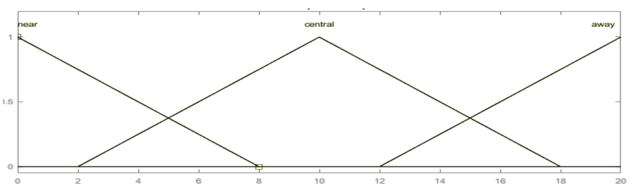

Fig. 9. Right sensor membership functions

Figure 10 shows the back sensor membership functions graph.

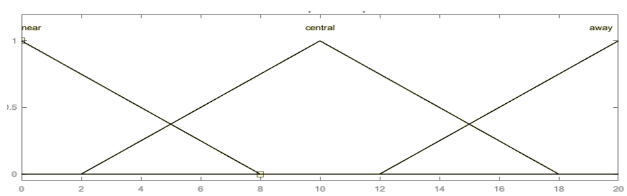

Fig. 10. Back sensor membership functions

The ranges of Right Engine and Left Engine mobility variables are determined as between -255 and +255. Figure

11 shows the right motor mobility membership functions graph.

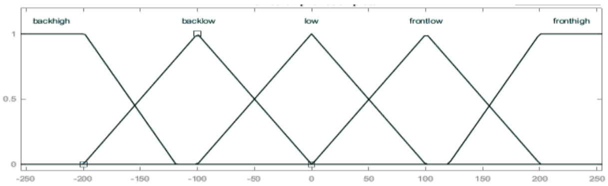

Fig. 11. Right motor mobility membership functions

Figure 12 shows the left motor mobility membership functions graph.

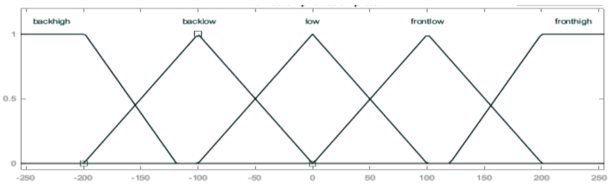

Fig. 12. Left motor mobility membership functions

Fuzzy Inference

Fuzzy rules are the most important part of the fuzzy logic controller unit. The reason behind this is the formation of knowledge base and decision-making ability of the mobile robot in this unit. There are many techniques to create fuzzy reasoning. For any input, each rule is used with a certain degree of weight. MAX-MIN (Mamdani) fuzzy reasoning method was chosen on the mobile robot to perform the work. In this method, the fuzzy cluster in the output appears as a result of the clusters in the input are subjected to logical transaction. The output numerical value is determined by the weight average method.

Determination of Fuzzy Rules

In this study, 81 fuzzy rules were determined which show the relationship between the verbal expression and fuzzy expression of the Front Sensor, Left Sensor, Right Sensor, Back Sensor, Right Motor and Left Motor. The list of rules generated for the Motor direction data, and the output clusters which correspond to input clusters is given below.

Rule 1. If Front Sensor is close to == and Left Sensor is close to == and Right Sensor is close to == and Back Sensor is close to == then Right Motor is less than == and Left Motor is less than ==

…

Rule 11. If Front Sensor is close to == and Left Sensor is average == and Right Sensor is close to == and Back Sensor is average == then Right Motor is backwards fast == and Left Motor is forwards fast ==

…

Rule 37. If Front Sensor is average == and Left Sensor is average == and Right Sensor is close to == and Back Sensor is close to == then Right Motor is forwards slow == and Left Motor is backwards slow ==

…

Rule 61. If Front Sensor is far from == and Left Sensor is close to == and Right Sensor is far from == and Back Sensor is close to == then Right Motor is backwards fast == and Left Motor is forwards fast ==

…

Rule 73. If Front Sensor is far from == and Left Sensor is far from == and Right Sensor is close to== and Back Sensor is close to == then Right Motor is forwards fast == and Left Motor is backwards fast ==

…

Rule 81. If Front Sensor is far from == and Left Sensor is far from == and Right Sensor is far from== and Back Sensor is far from == then Right Motor is forwards fast == and Left Motor is forward fast ==

Defuzzifier

The algorithms designed with fuzzy logic cannot give net value as an output. As absolute values are needed, fuzzy information needs clarification. The commonly used center of gravity method is used. The fuzzy inference cluster formed has the center of gravity and the value corresponding to the center is taken as the absolute value.

In Figure 13, mathematical operation graphic and formula of defuzzifier along with center of gravity method and equation (1) are provided.

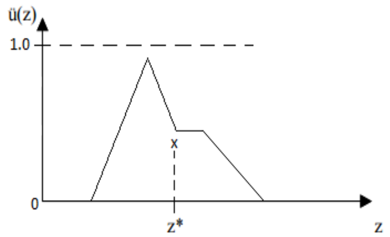

Fig. 13. Center of gravity membership defuzzification method.

$$Z = \frac{\int ü_ç(z).zdz}{\int ü_ç(z).dz} \quad (1)$$

Figure 14 shows the 3 dimensional drawing of expected output information on the robot according to the data from the input sensors.

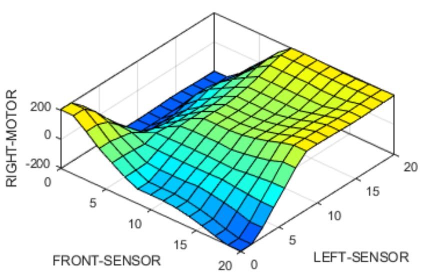

Fig. 14. 3D drawing of output data

4. Kinematic Analysis

In this study, kinematic analysis performed on the robot is modeled on a solid body with wheels running on a horizontal plane. Figure 15 shows the axis information of the robot on the ground. Table 1 and equation (2) show the geometric relationship that directs the robot.

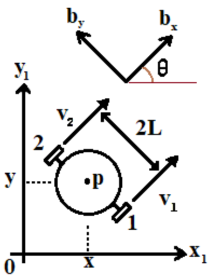

Fig. 15. Axis information of the robot on the ground

Table 1. Geometrical examination of Robot

R^b	b_x	b_y	b_z
x_1	cosθ	-sinθ	0
y_1	sinθ	cosθ	0
z_1	0	0	1

$$\varepsilon = \begin{pmatrix} x \\ y \\ \theta \end{pmatrix} = R^b \begin{pmatrix} \frac{R(\omega 1+\omega 2)}{2} \\ 0 \\ \frac{R(\omega 1-\omega 2)}{2L} \end{pmatrix} \quad (2)$$

5. Experiments

In this study, the position control of an autonomous robot in the fixed runway environment has been implemented with the fuzzy controller approach. In Figure 16, the front sensor, left sensor, right sensor and back sensor are indicated as input variables and the right motor and left motor were indicated as output variables.

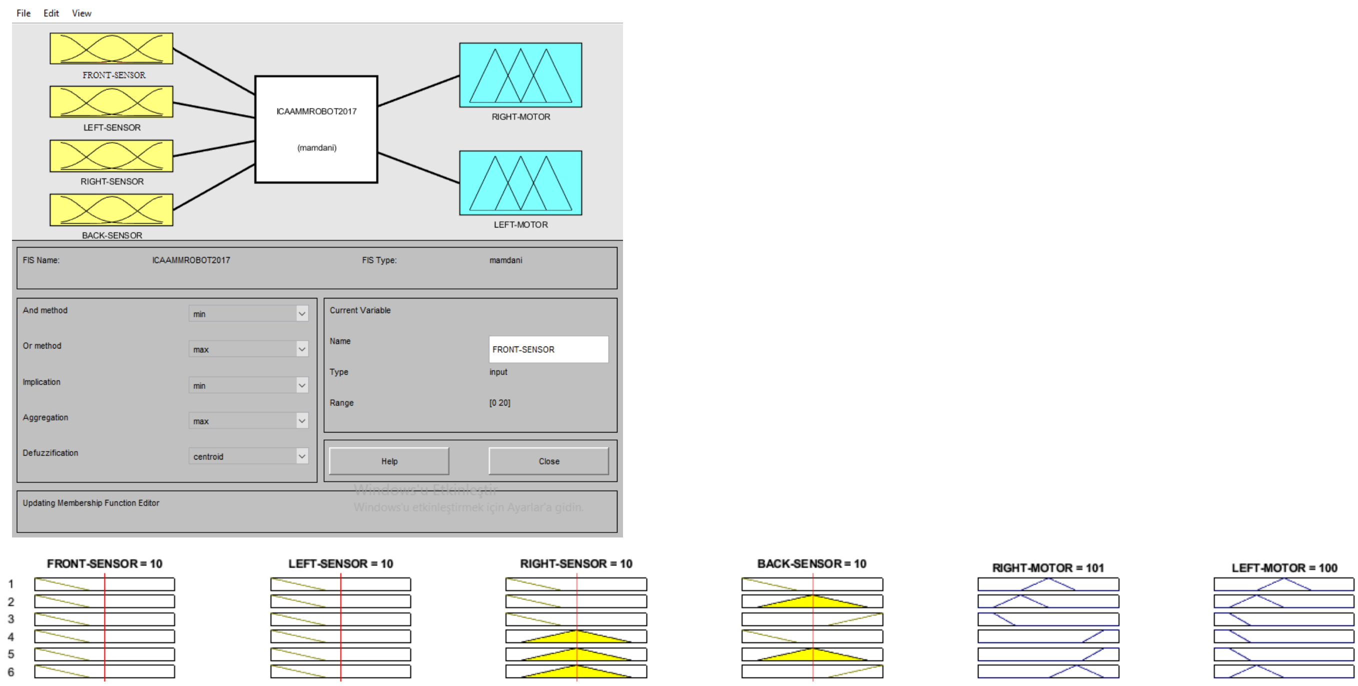

Fig. 16. Input and output variables

With the fuzzy controller approach, it has been seen that the robot moves easily on different floors and goes to the desired targets. Tests were repeated by changing ground and target distances. In Figure 17, images are provided from the operation moments of the robot on different test floors.

Fig. 17. Images from operation moments

Figure 18 shows the results of the table of rules which is created in fuzzy algorithm with the calculated results.

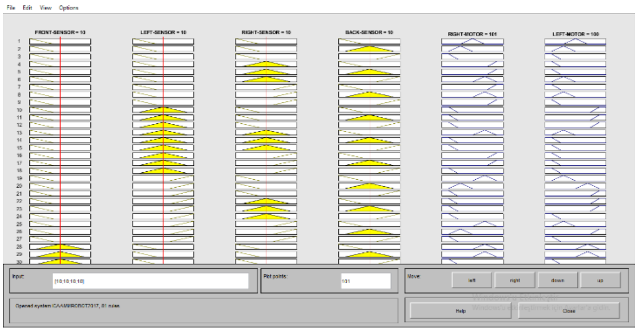

Fig. 18. Sample output of fuzzy table of rules

In these experiments, the runway used was designed to be portable. In this way, the fuzzy control software of the robot was tested on different floors. Between Figures 19 and 26, the results of the experiments on the software were examined.

Fig. 19. Information on speed and direction calculated by using the data obtained from the sensors in the first environment where the autonomous robot operated

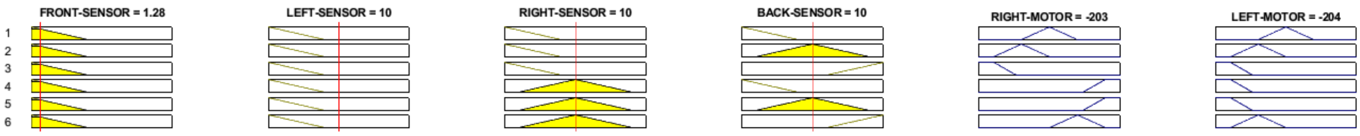

Fig. 20. Information on speed and direction calculated by using the data obtained from the sensors in the second environment where the autonomous robot operated

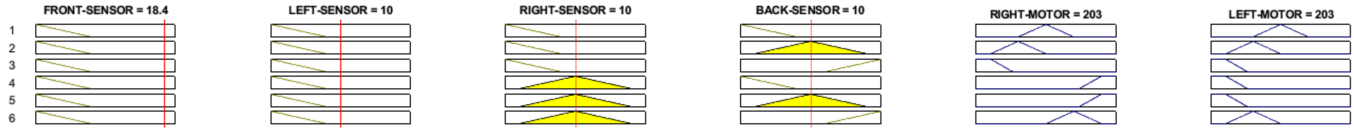

Fig. 21. Information on speed and direction calculated by using the data obtained from the sensors in the third environment where the autonomous robot operated

Fig. 22. Information on speed and direction calculated by using the data obtained from the sensors in the fourth environment where the autonomous robot operated

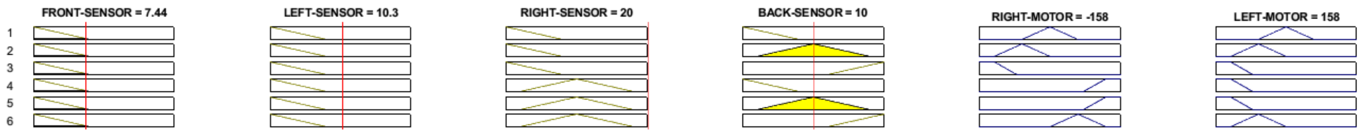

Fig. 23. Information on speed and direction calculated by using the data obtained from the sensors in the fifth environment where the autonomous robot operated

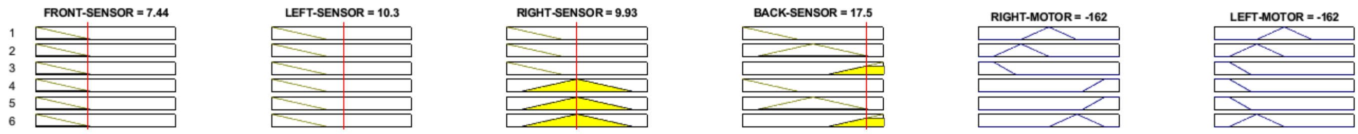

Fig. 24. Information on speed and direction calculated by using the data obtained from the sensors in the sixth environment where the autonomous robot operated

Fig. 25. Information on speed and direction calculated by using the data obtained from the sensors in the seventh environment where the autonomous robot operated

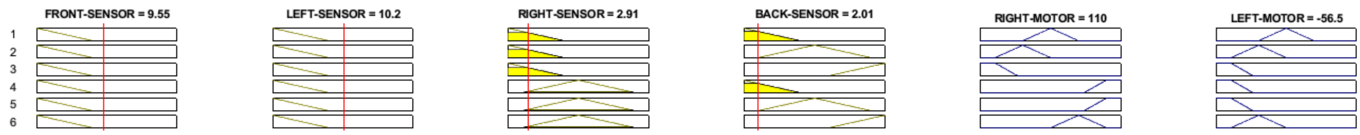

Fig. 26. Information on speed and direction calculated by using the data obtained from the sensors in the eighth environment where the autonomous robot operated

6. Results

Table 2. Test data of system

Experiment number	Front Sensor Information	Left Sensor Information	Right Sensor Information	Back Sensor Information	Calculated Right Motor Speed Information	Calculated Left Motor Speed Information	Range of diversion from Target Point
1	10	10	10	10	101	100	2
2	1.28	10	10	10	-203	-204	3
3	18.4	10	10	10	203	203	-3.75
4	7.44	17.7	10	10	152	-146	1
5	7.44	10.3	20	10	-158	158	2
6	7.44	20.3	9.93	17.5	-162	-162	-4
7	17.2	2.48	9.93	10.2	-134	182	-1
8	9.55	10.2	2.91	2.01	110	-56.4	5

In this study, designed fuzzy control structure was tested through eight different experiments. Experiments were performed on stone ground in experiments 1, 3, 5 and 7; and on wood ground in experiments 2, 4, 6 and 8. For each experiment, the robot has located its position by using the measurements taken from the sensors.

In experiments, it was observed that there was 3-7 cm. diversion from the target point on wood ground due to the structure of rubber on roller and there has been 2-4 cm. diversion from the target point on stone ground. The reason for the diversion has been determined as the inability of robot to stop due to deformation on rollers during brake at the target point as a result of acceleration. The measured test data is given in Table 1. On Table 2, right, left, front and back sensors and the diversion distance from target points are measured as centimeters. On table 2, right and left motor speed information calculated was measured as Rpm. Rpm is considered to be the number of turn / cycles performed within 1 minute on a fixed axis. The forward movement of the motor on Table 2 is shown as positive "+" and the reverse movement as negative "-".

First experiment has the data measured with Figure 19 in section five. The robot has moved forward to the destination in the direction of positions it obtained with right, left, back and front sensor. 2 cm. diversion was measured from the target point. Second experiment has the data measured with Figure 20 in section five. The robot has moved backward to the destination in the direction of positions it obtained with right, left, back and front sensor. 3 cm. diversion was measured from the target point.

Third experiment has the data measured with Figure 21 in section five. The robot has moved forward to the destination in the direction of positions it obtained with right, left, back and front sensor. 4 cm. diversion was measured from the target point. Fourth experiment has the data measured with Figure 22 in section five. The robot has moved backward to the destination in the direction of positions it obtained with right, left, back and front sensor. 1 cm. diversion was measured from the target point.

Fifth experiment has the data measured with Figure 23 in section five. The robot has moved forward to the destination in the direction of positions it obtained with right, left, back and front sensor. 2 cm. diversion was measured from the target point. Sixth experiment has the data measured with Figure 24 in section five. The robot has moved backward to the destination in the direction of positions it obtained with right, left, back and front sensor. 6 cm. diversion was measured from the target point.

Seventh experiment has the data measured with Figure 25 in section five. The robot has moved forward to the destination in the direction of positions it obtained with right, left, back and front sensor. 1 cm. diversion was measured from the target point. Eighth experiment has the data measured with Figure 26 in section five. The robot has moved backward to the destination in the direction of positions it obtained with right, left, back and front sensor. 5 cm. diversion was measured from the target point.

7. Discussion and Recommendations

In this study, a fuzzy logic-controlled system of an autonomous robot was developed. For this purpose, an autonomous robot has been designed and experimented on different grounds.

During the experiments, 8 samples were taken at different starting positions by measuring their arrival distance to the target points. In all of these experiments, diversions from the distances to be reached were realized. 5

cm diversion in the forward direction and 4 cm diversion in the reverse direction were measured.

It was determined that the diversions occurred because the robot was not able to stop due to the deformations generated during brake while moving with varied speeds on different grounds. To correct this error, the stop resolution and the accuracy to reach the destination can be increased by changing the structure of the roller used on the DC motor.

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