NAVIGATION OF REAL MOBILE ROBOT BY USING FUZZY LOGIC TECHNIQUE

A Thesis submitted in partial fulfillment of the Requirements for the degree of

Master of Technology

In

Mechanical Engineering

Specialization: Machine Design and Analysis

By

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Rourkela, Odisha, 769008, India

May 2015

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Dedicated to…
My parents and my sisters

DEPT. OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

ROURKELA – 769008, ODISHA, INDIA

CERTIFICATE

This is to certify that the work in the thesis entitled **navigation of real mobile robot by using fuzzy logic technique** By **adireddi satheesh** is a record of an original research work carried out by him during 2014 - 2015 under my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Master of Technology in Mechanical Engineering (Machine Design and Analysis), National Institute of Technology, Rourkela. Neither this thesis nor any part of it, to the best of my knowledge, has been submitted for any degree or diploma elsewhere.

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DECLARATION

I certify that

a) The work contained in the thesis is original and has been done by myself under the general supervision of my supervisor.

b) The work has not been submitted to any other Institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the thesis.

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Adireddi satheesh

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Adireddi satheesh

Abstract

Now a day's robots play an important role many applications like medical, industrial, military, transportation etc. navigation of mobile robot is the primary issue in now a days. Navigation is the process of detection and avoiding the obstacles in the path and to reach the destination by taking the surrounding information from the sensors. The successful navigation of mobile robot means reaching the destination in short distance in short period by avoiding the obstacles in the path. For this, we are using fuzzy logic technique for the navigation of mobile robot. In this project, we build up the four-wheel mobile robot and simulation and experimental results are carried out in the lab. Comparison between the simulation and experimental results are done and are found to be in good.

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INTRODUCTION

1.1 DEFINITION OF ROBOT

The robot can be defined as an electro mechanical machine that can resemble human action. It will do series of actions automatically with the help of program written in the computer.

According to application the robots are categorized into two types

1. Legged robot
2. Wheeled robot

Legged robot is made by combination of different point contacts from robot and the ground. The main advantages of legged robot are maneuverability and adaptability in rough terrain. Legged robot resemble of human body.

Wheeled robot is made by combination of different wheels contact from robot body to the ground. Wheeled robots are resembled of normal vehicles like car, bus, etc.

Locomotion mechanism of the mobile robot is to enable the robot to move in the any kind of environment. There are many possible ways to move, the selection of robot approach to locomotion (move like walk, fly, jump, swim, run, role, etc. is the important role in designing of the mobile robot.

Navigation is defined as the process of detecting and avoiding the obstacle in the path and to reach the final point with the help of different sensor information in any environment like outdoor, indoor, cluttered environment by using different soft computing techniques like fuzzy logic, genetic algorithm, neural networks, particle swarm optimization and ant colony optimization.

The main advantage of adaptation of mobile robot in the real life is it needs very less human involvement. The complete autonomous mobile robot should capable of do the things without human involvement. In the simple way, it should be capable of act in the real environment. The autonomous mobile should capable of do thing like capable of bring surrounding information with no difficulty, without human involvement the robot should move from one point to another, it should avoid the obstacles in the path and act according to the situation if necessary.

1.2 DIFFERENT TYPES NAVIGATIONS

Navigation in the any environment can be categorized into two types

I. Controlling the speed
II. Controlling the heading

Controlling the speed has two features

a) Avoiding obstacles
b) Avoiding the overturning

Controlling the Heading has 4 features

a) If obstacle comes front it can avoid
b) If obstacle comes right it can avoid
c) If obstacle comes left it can avoid
d) Goal reaching.

The above all features uses the information from the sensors and gain is goals. Feature like avoiding the obstacle use the different sensors to find out distance from obstacle to near to the robot. The feature like goal seeking uses the digital compass and it will measure the direction of the target. The feature like avoidance of overturning uses the speedometer; it gives the reading of the mobile robot speed.

Now the focus is on how to develop a navigation technique for mobile robot. For developing a navigational techniques many students, researchers are get attracted and become the main trend in the navigational mobile robots.

This trend is favorably causing the present small gap between the available technology and the new user application demands. The major problems in the industrial robots are lack of autonomy, flexibility, frequent breakdown. These robots are generally performs only pre-programmed sequence of operations in constrained environments and these robots cannot perform the operations in the new environment if faces any unexpected situations occurs. At present market, there will be a heavy competition for a complete autonomous mobile robot. For the navigation mobile robot, there are many soft computing techniques available such as genetic algorithm, neural networks, fuzzy logic, particle swarm optimization, ant colony optimization and combination of any of these two. By using these techniques, we can express the subjective uncertainties of human mind.

1.3 DIFFERENT TYPES OF SENSORS

There are two types of sensors are used for the navigation of the robot

1. Ultrasonic sensors
2. Infrared sensors

1.3.1 ULTRASONIC SENSOR

The ultrasonic sensor has two main parts one is emitter another one is receiver. The emitter will send the high frequency sound wave, that sound wave will travel in the air some time and if any that sound wave hits any obstacle then the wave will reflect, the reflected sound wave received by receiver. According to the duration of the sound wave travelled in the air automatically converts into distance between obstacle and robot.

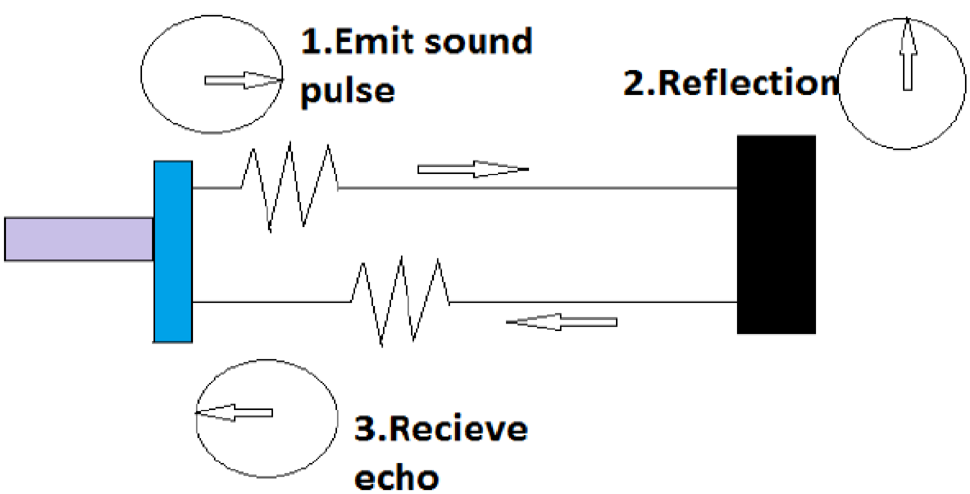


Fig.1.1: Working principle of ultrasonic sensor

APPLICATIONS OF U.S SENSORS:

- Obstacle detection
- Mapping of robots
- Navigation of mobile robot
- Distance measurements
- Colored line sensing
- In medical applications
- In security uses

1.3.2 INFRARED SENSORS

Infrared sensors are nothing but proximity sensors. These are used to detect the obstacles. The infrared sensors detect the IR radiation only. The input of the infrared sensor is infrared laser and LED especially with infrared wavelengths. IR sensor consists of mainly two parts one is emitter and another one is receiver. The emitter will send the infrared radiation and the receiver will receive or detect the infrared radiation, that is reflected from obstacle. The receiver detects only infrared radiation.

APPLICATIONS OF IR SENSORS:

- Obstacle detection
- Petroleum explosion
- Medical applications
- Infrared astronomy
- Gas detection
- Testers, encoders
- In Fax machine, printers

1.4 APPLICATIONS OF ROBOT

Robots are powerful machines, they are used in almost every application especially in industrial applications, these keep safe us from dangers while doing different tasks that are related to harmful to our health. The robot can do many functions as human being cannot do manually.

They can walk, fly, run, jump, swim, sense their surroundings and respond to the according to the environmental conditions. Computer is the brain of the robot.

These are some applications of robot

- In manufacturing industries, the robots are actively used where any repetitive work attains.
- In welding department, welding is the most dangerous thing for human. For reducing the dangers, the robots are commonly used.
- In automobile industries, for assembling the parts of the automobile is difficult for human being so that robots ply a key role in this industry.
- In military applications, the robots are frequently used. For detecting and disposal of bombs, monitoring the vehicles.
- For painting the car, good surface finish will obtain by using robot only.
- For circuit assembly for the motherboard of computer an attachment of different electronic components to the motherboard.
- In micro and nano applications, robots are widely used for accurate result.
- For inspecting and fault detections of the parts in all industries.
- Examining the different parts.
- For nuclear industries the robots are strictly used, because the gases emitted in the industry is very dangerous and hazardous to the human being.
- In space technology, space exploration, remote inspections of space stations.
- In transportation purpose
- In forests for cleaning, cutting of trees, preventing of fire etc.
- In agricultural, for Fruit and vegetable picking, fertilization, planting.
- Automatic cleaning of various place like air ports, supermarkets, industrial sites.

1.5 ADVANTAGES OF ROBOTS

- Robots give the information that human being cannot get.
- The robots can do work faster than human
- The robots give the accurate results while inspection of the pars.

- By using robots, we can far palaces like different planets.
- Most of the works can do automatically without human interaction.
- In remote areas, the robots are widely used.
- By using the robots, we can go to the far depth to the see that human being cannot.
- Robot can capture the image with in fraction of second’s time gap.

1.6 DISADVANTAGES OF ROBOT

- I we interface the robots in the factories people lose the jobs.
- Robot needs more power supply
- Maintenance of the robot is expensive.

2

LITERATURE REVIEW

Now a day's fuzzy logic is the one of the most computational method for navigation mobile robot compares to other soft computing methods like ant colony optimization (ACO), particle swarm optimization, genetic algorithm [1], this is because of efficiency and simplicity of fuzzy system. In this fuzzy system used the linguistic terms similar to those that of the human being think.

Design of 4-wheeled omnidirectional mobile robot with variable wheel arrangement mechanism by Kyung et al. [2] proposed a special mechanism called variable wheel arrangement mechanism is proposed to increase the range of velocity ratio for the continuously variable transmission (CVT) from the wheel velocity to robot velocity, which may increase the performance of the mobile robot. In addition to that, they compare the variable wheel arrangement mechanism (VWAM) with variable footprint mechanism (VFM) [3].

Modelling and Fuzzy Control of a Four-Wheeled Mobile Robot by Istvan et al. [4] in this, paper they compare the results of PID controller and fuzzy controllers. For this, they have been upgraded the simplified kinematic bicycle model of a four-wheeled robot car [5]. From these results, the fuzzy controller shows good results in terms of speed, and it is because its behaviour is closer to reality, although fuzzy controller required more calculations than PID controller.

Adaptive Dynamic Motion Controller Design for a Four-Wheeled Omnidirectional Mobile Robot by Ching-Chih Tsai et al. [6] developed a dynamic model and a dynamic motion controller for stabilization and trajectory tracking of an omnidirectional mobile robot with four independent driving omnidirectional wheels equally spaced at 90 degrees from one to another.

Fuzzy control to drive car-like vehicles by Fraichard et al. [7] provided the motion control architecture technique for a car, or that may any kind of a four-wheel vehicle that is particularly intended to work in an unknown and particularly in dynamic environments. In this, they used the fuzzy control technique, which compose of a set of fuzzy rules encoding the reactive behaviour of a vehicle. They successfully navigated car like vehicle by using fuzzy logic control method.

Navigation of multiple mobile robots in an unknown environment by Parhi [8] has explained the development of control method for a mobile robot to navigate in an unknown environment and that should be capable of avoiding any obstacle in the path, the path may be unstructured or structured, in an unpredictable and busy changing in environment conditions.

Reinforcement learning with fuzzy evaluative feedback for a biped robot by C. Zhou et al. [9] in this paper, they research on how to improve the biped gait by using a particular technique known as FRL agent along with a fuzzy evaluation response.

Sonar based mobile robot localization by using fuzzy triangulation by Demirli et al. [10] described a technique that is based on fuzzy system of the sonar sensor that will get its information from the experiment and compare wetness and dryness for a particular surface. Fuzzy logic is a mathematical formulation that gives the information about the uncertainty in the unknown clustered environment [11].

Fuzzy logic technique is used for navigating the mobile robot and to reach the final point with avoiding the obstacles in the path with help of changing the direction and movement of the mobile robot. The technique used in this paper for gathering the information from the environment is image-processing technique [12].

Navigation of mobile robot in disorderly environment by predilection based fuzzy behaviors Presented by Dunlap et al. [13]. In this paper by using predilection based fuzzy system for obstacle avoidance in path planning of the mobile robot. By using multivalve network, the robot will move efficiently in any kind of environment.

Fuzzy based judgment depends on real time navigation of mobile robot in unfamiliar environments with dead ends Presented by Wang et al. [14]. In this paper, they have given developed modern grid based plan representation system. In this memory grid is the first system and other one is for behavior-based navigation. In this first system gives the environmental conditions and second system gives the avoidance of obstacle with safe way.

Intellectual Omni directed vision based on robot fuzzy system plan and accomplishment Presented by Feng et al. [15]. In this paper they have implemented the fuzzy technique to the particle swarm optimization for the navigation of the mobile robot and they also well examined in different environments for the safe navigation.

A Fuzzy logic organizer tune with particle swarm organization for two degree of freedom flight control Bingül addressed by et al. [16]. In this paper they mixed the two artificial intelligence, they are fuzzy, PSO, and gives the gives the idea regarding to the two-degree freedom of planer mobile robot and they compare these results with PID controller results.

Optimal combination of fuzzy logic regulator for mobile robot path planning by discrepancy evolution addressed by Pishkenariet al [17]. In this paper, they developed the new technique for the route taking of mobile robot by combination of discrepancy evolution addressed and genetic algorithm.

Robust path tracking control of mobile robot via dynamic petri recurrent fuzzy neural network, Rong Jong Wai, et al. [18]. In this paper, they mainly focused on the plan of the tough tracking path of robot using technique called fuzzy neural network technique. In earlier days, the wheeled mobile robots are commonly used in industries and service applications like transportation, security, cleaning etc.

Mobile robot manages with integrating fuzzy and neural network presented by Vukoslavej et al. [19]. In this paper, they have developed and implemented the navigation algorithm for the robot depends on the ultrasonic freedom scan. Self-learning neural network and crash-free path organize representation are the two path planning algorithms used in this paper.

An expert fuzzy cognitive map for reactive navigation of mobile robots by Motlagh at al. [20]. In this paper, they have used the fuzzy cognitive map (FCM) interface mechanism instead of rule base technique. The problem with rule base technique is large number of rules, and inefficient definition of contributing factors.

Robot navigation in very cluttered environments by preference-based fuzzy behaviors by Majura at al. [21]. In this paper, they present new type of fuzzy system by using multivalued logic framework known as preference based fuzzy behavior system.

A fuzzy logic based multi-agents controller by Olajubu at al. [22]. In this paper, they have developed the fuzzy logic based controller model and simulated for a (Multi-Agents System Controller (MASC).

Application of a hybrid controller to a mobile robot by Juing-Shian Chiou et al. [23]. In this paper, they have presented the applications of a hybrid controller to the optimizations of mobile robot movement. From this, they found the optimal angle and velocity of the mobile robot moving in the outdoor environment. From this hybrid controller more effective movement results determined. By using the method of generalized predictive controller, they predict the target position. By using fuzzy logic technique, they have determined the left and right wheel velocities of the mobile robot.

Simulation of fuzzy motion controlled four-wheel steered mobile robot by Gyorgy Schuster [24]. in this paper there are two parts, in first part description about simulation of physical object such as the four-wheel steered mobile robot and second part describes the control algorithms and also results relate to the simulation of software and positioning of four wheel mobile robot

3

KINEMATIC ANALYSIS OF 4-WHEEL MOBILE ROBOT

3.1 DEFINITION OF ROBOT KINEMATICS

Configuration of robot system is combination of kinematic chains with multi degrees of freedom. The links in the robot are interconnected and forming the geometry. The study of this geometry is known as robot kinematics. To develop different non-linear equations to that links of the robot. By using these non-linear equations, we will do kinematic analysis.

3.2 INTRODUCTION OF ROBOT KINEMATICS

At present, the wheeled mobile robots are used in many applications like military, industries, medical, transportation, agricultural where the human being con not do the work. For this, we should mainly concentrate on path planning of the mobile robot.

In our research, the kinematic model is four-wheel mobile robot. The all wheels are bore wheels. We should concentrate on the bore wheel mechanism. For the mobile robot kinematic analysis, we derive the expressions for the kinematic model by considering the mobility of the robot affected by different parameters. By using these expressions implementing on the mobile robot find out the steering angle.

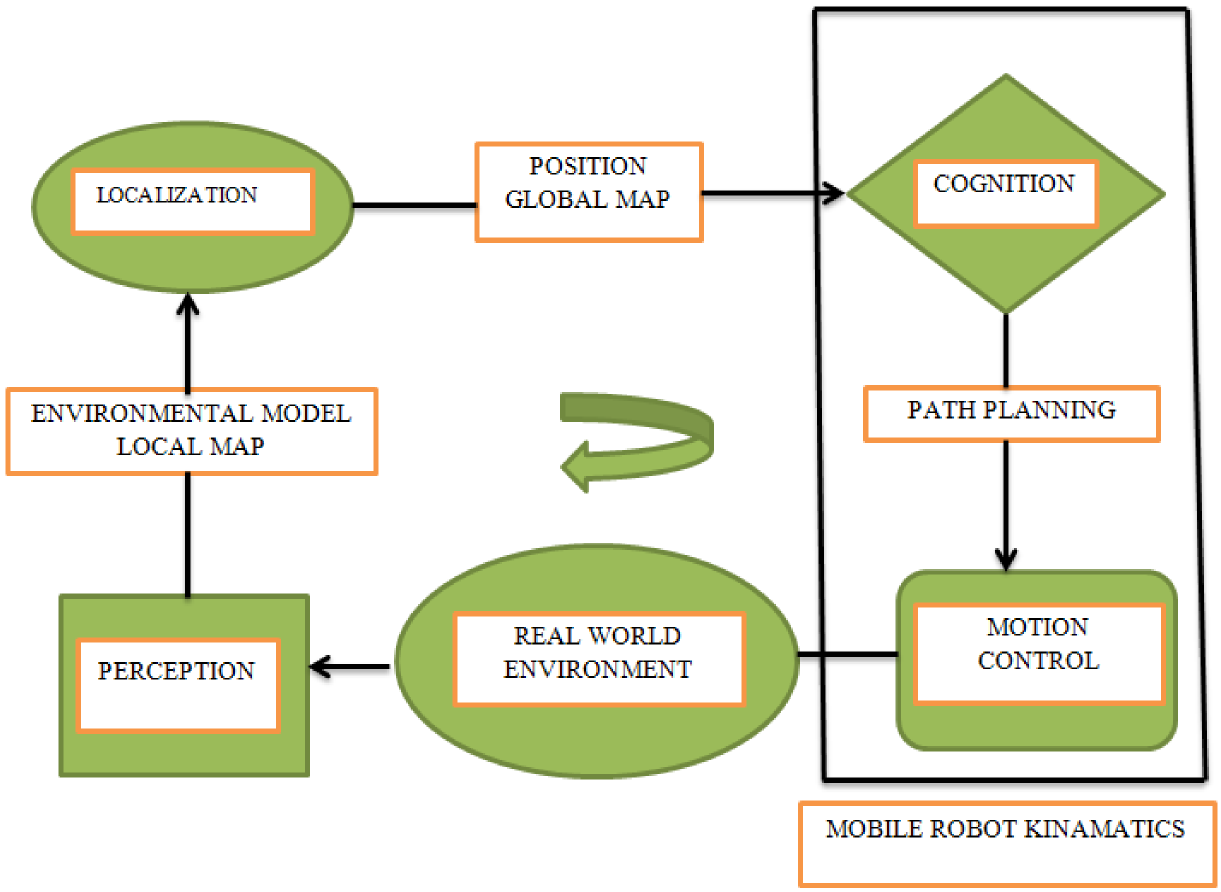


Fig.3.1: Control Mechanism for mobile robot navigation

3.3 KINEMATIC MODEL OF 4-WHEEL MOBILE ROBOT

A typical kinematic model of a four-wheeled mobile robot is shown in Fig. 3.2. The motion and orientation are achieved by independent actuators such as DC geared motors, which provide the necessary torques to the all driving wheels. This work is developed in a four-wheeled mobile robot, the robot's all wheels are attached to separate motors responsible for direction change (steer control). The kinematic Modelling of the robot in the environment is shown in Fig.3.2

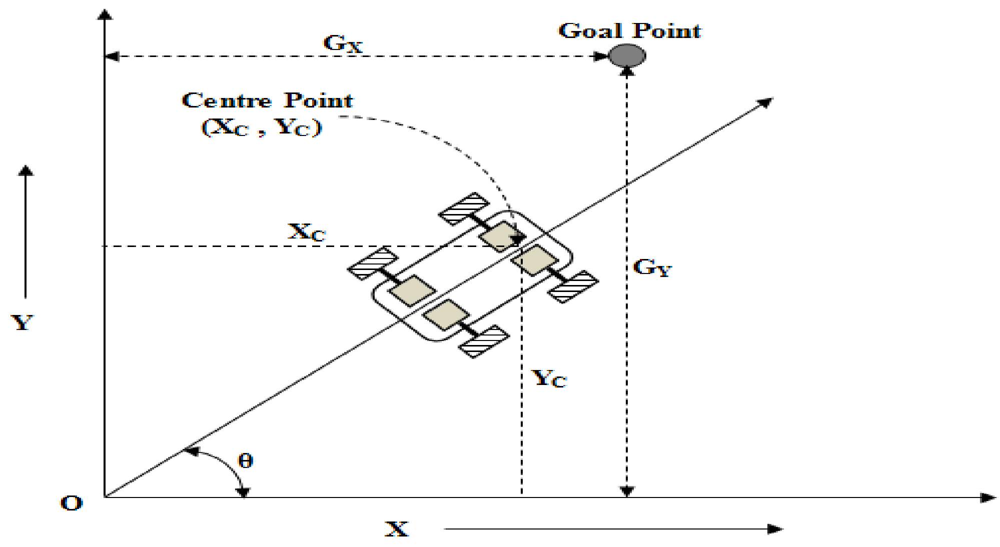


Fig.3.2: Kinematic model of four-wheel mobile robot

Where

(O, X, Y)— Field navigation environment

(X_{C}, Y_{C})— Center point from the middle of the front two wheels

(G_{X}, G_{Y}) — Goal point in X and Y-axis

θ — Steering angle relative to the (O,X)

$$X_{j+1} = X_{j} + V \times \cos\theta \quad (1)$$

$$Y_{j+1} = Y_{j} + V \times \sin\theta \quad (2)$$

$$\theta = \tan^{-1}\left[\frac{G_{Y} - Y_{j+1}}{G_{X} - X_{j+1}}\right] \quad (3)$$

Where j = 0, 1, 2, 4, 5, 6…... n.

$$V = \frac{\pi \times D \times N}{60} \text{ M/sec} \qquad (4)$$

Where

X_j — current position of mobile robot in X-axis

Y_J — current position of mobile robot in Y-axis

X_{j+1}— updated position while the robot is moving in X-axis

Y_{J+1}— updated position while the robot is moving in Y-axis

θ — steering angle (or turning angle either left, right, straight)

V — velocity of motor in m/sec. (velocity varies from 0.067 to 0.167 m/s)

N — angular velocity of motor in RPM (revolutions per minute)

D — diameter of the wheel in meters.

4

FUZZY LOGIC

4.1 FUZZY LOGIC

Now a day's fuzzy logic is the one of the most successful technology for developing the advanced control systems. Because fuzzy logic is simple to understand and simple to develop. Fuzzy logic control system provides an excellent platform in which human perception based actions can be easily performed. By using a fuzzy logic control system the way human being thinks and makes decisions can be developed and enforced in robotics by simple IF-THEN or IF-ELSE rules and can be mix with easily understandable and natural linguistic illustrations. The present all design analyses are purely mathematical or purely logical based. For these design analyses, we required accurate equations and the output of the solution may or may not give the accurate result. But by using fuzzy logic technique, we can get approximate result of the final solution. The input requires for fuzzy logic system are only some linguistic terms and need not use complex equations.

Fuzzy logic is extensively used in the mobile robot navigation. The fuzzy logic controller used in this navigation of mobile robot should be intelligent like human being with avoiding the interrupts in the path following and to reach the destination. In path there are different types of obstacles are there. Hence, we should provide efficient mechanism to categories the obstacles and takes the action accordingly.

The flow chart showing the steps involved in the fuzzy logic controller. First step in the fuzzy logic controller is the real world environment; in tis the fuzzy controller studies the environment under which it is kept, this information is taken by using different sensors. Then the information will be conveying to the fuzzy logic control system through the information extraction system. Obstacle avoidance and path mapping are the two informations taken by the FLC. This information will send to the robot by using different circuits. Then the robot will follow the path. That the information given taken from the FLC. By using perception-based action the robot will avoid the obstacle in the path following and this this action is decided by the fuzzy logic controller. By repeating these steps, the robot will reach to the destination with avoiding the obstacles in the path by taking the decisions from the fuzzy logic controller.

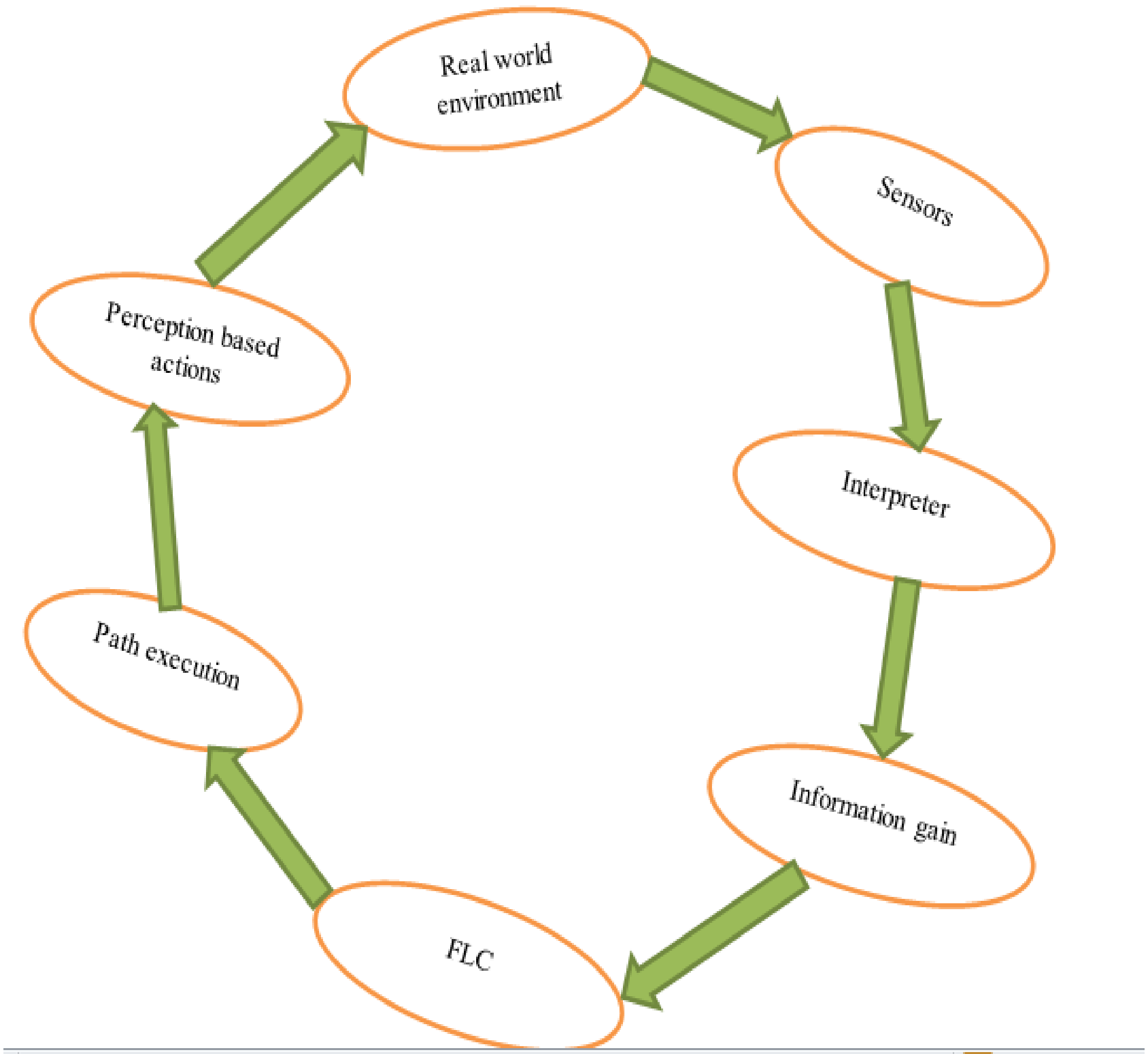


Fig.4.1: Flow chart for steps involved in the fuzzy logic controller.

4.2 FUZZY INTERFACE SYSTEM

Fuzzy interface system is the process of mapping the input to the output by using fuzzy logic. The process of FIS consists of different membership functions, rules, fuzzy logic operations. The rules of fuzzy can be applied to the fuzzy system. If the rules are suitable applied to fuzzy interface system the design of fuzzy controller is done. If the rules are not applied suitable to fuzzy interface system, we should change the rules.

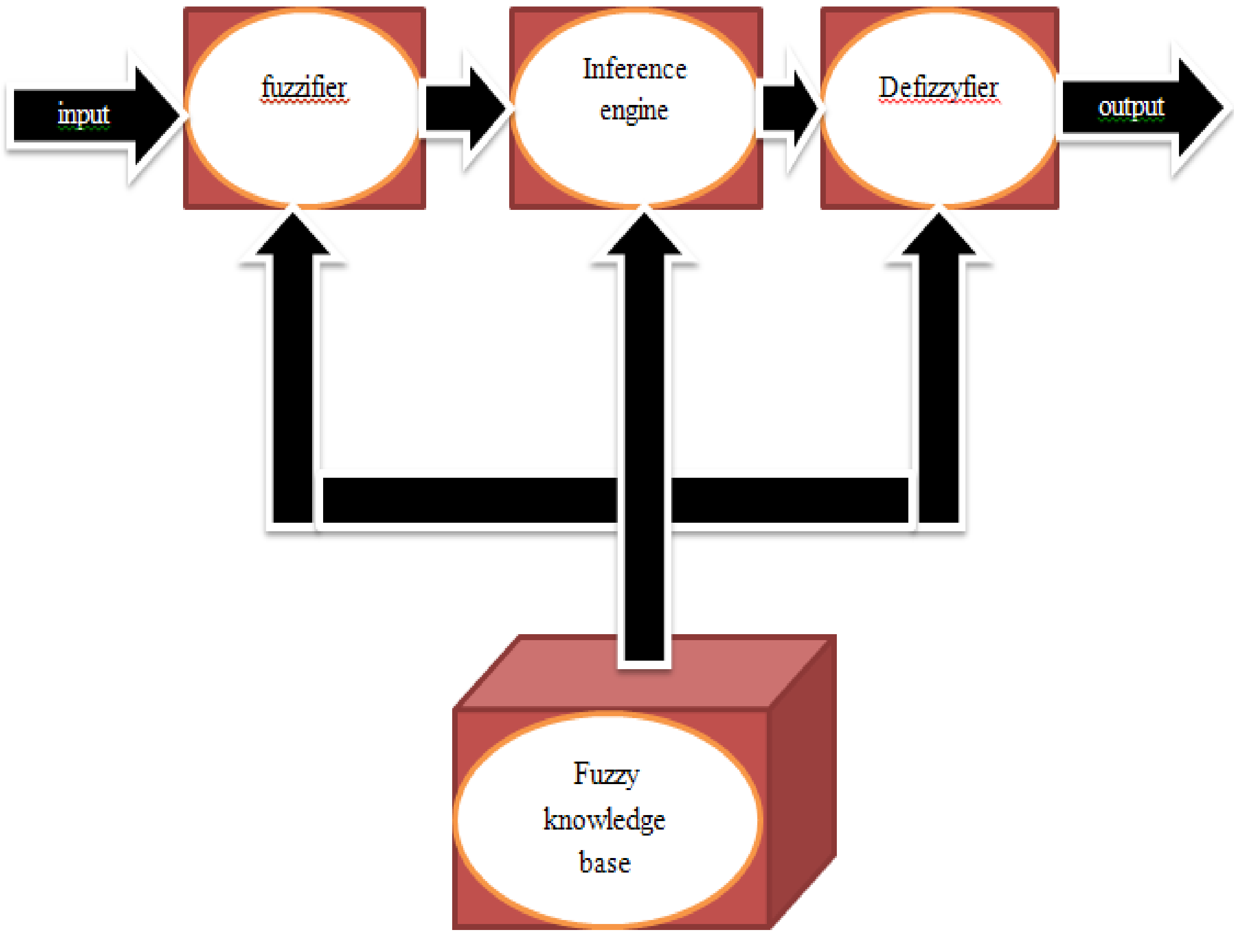


Fig.4.2: Fuzzy Interface System

The steps involved in the fuzzy interface system are

- Fuzzification
- Fuzzy inference
- Defuzzification

4.2.1 FUZZIFICATION

The membership functions are defined on the input variables are applied to their actual values or the fuzzifier converts the crisp input to the linguistic variables by using membership functions. These member ship functions are stored in the fuzzy knowledge as shown in the above fig.4.2

4.2.2 FUZZY INFERENCE OR INFERENCE ENGINE

By using, different fuzzy rules like if-then or if-else convert the fuzzy input to the fuzzy output or Truth-value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule.

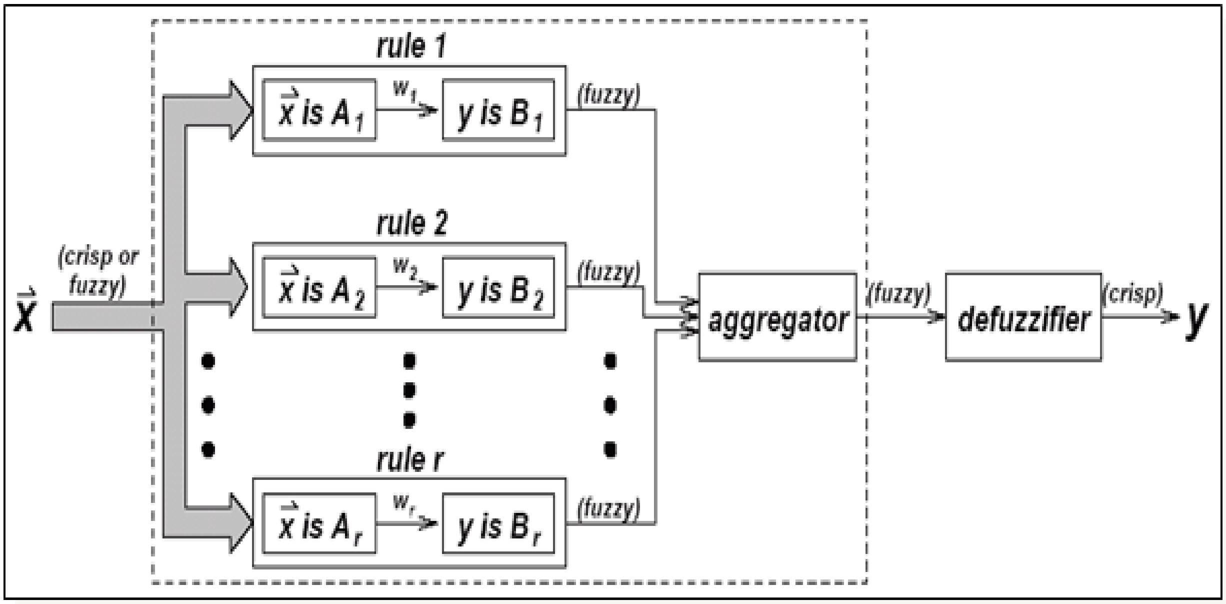


Fig.4.3: Inference Engine

4.2.3 DEFUZZIFICATION

The output obtained from the fuzzy inference engine will converts to the crisp value by using output membership functions.

- Methods for defuzzification
- Centre of gravity method
- Centroid area method
- Weighted average method
- Mean of maximum method
- Smallest of maximum method

4.3 MAMDANI FUZZY SYSTEM

In mamdani fuzzy system, there are six steps for compute the output of fuzzy inference system given the input as follows.

1. Computing the fuzzy rule set.
2. By using membership functions fuzzifying the input.
3. Form the rule strength by mixing the fuzzy inputs according to fuzzy rules.
4. By mixing the rule strength and output membership functions, we can find the outcome of the rule. This is called implication.
5. For getting of output distribution, we should combine the consequences. This is called aggregation.
6. The output distribution should defuzzify. This is called defuzzification.

The below figure shows the how the final result or overall output **Z** obtained. This is two rule mamdani fuzzy inference system and this fuzzy system has two crisp inputs **X** and **Y.**

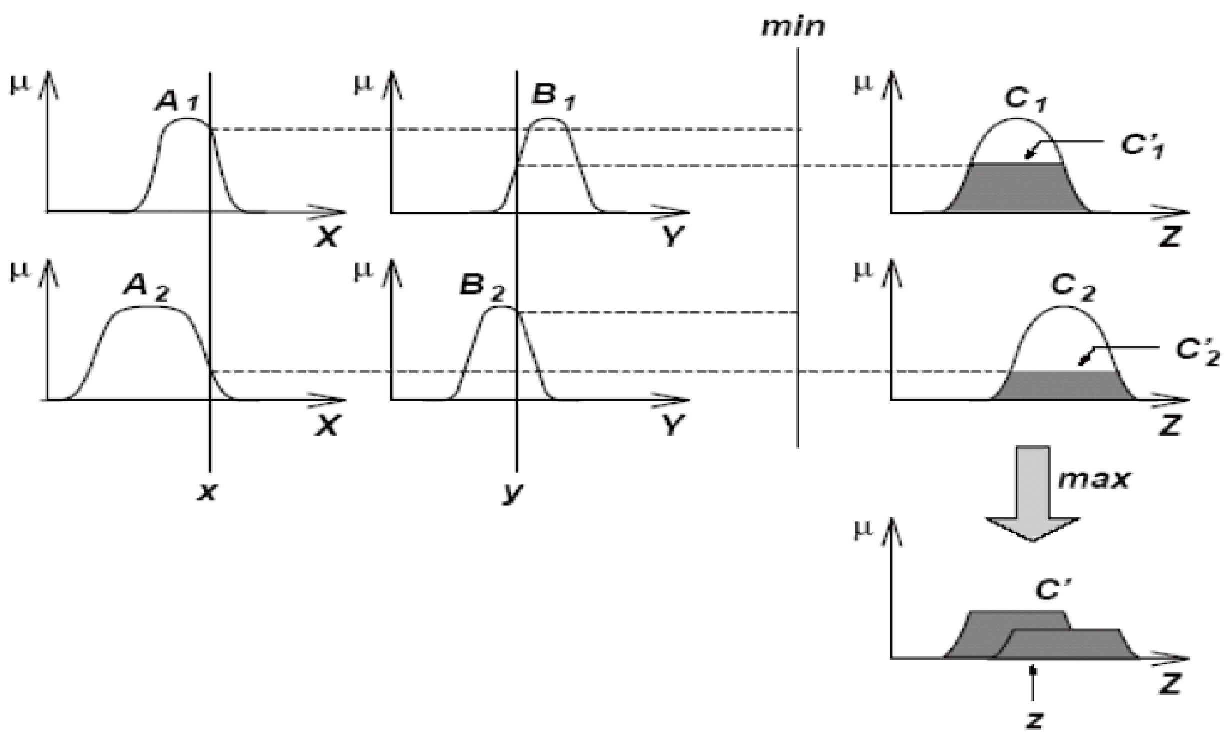


Fig.4.4: Mamdani Fuzzy System

4.4 DESIGN OF MAMDANI FUZZY CONTROL MODEL FOR FOUR-WHEEL MOBILE ROBOT

Input variables: Different obstacle distances. They are

FOD-front obstacle distance

ROD-right obstacle distance

LOD-left obstacle distance

Different obstacle distances are obtained by using sensors. The distances are obtained in centimeters (cm).

Output variables: Motor pulse width modulation (velocity of motor). They are

FRMPWM-front right motor pulse width modulation (motor velocity)

FLMPWM-front left motor pulse width modulation (motor velocity)

BRMPWM-back right motor pulse width modulation (motor velocity)

BLMPWM-back left motor pulse width modulation (motor velocity)

The right (front and rear) and left (front and rear) motor velocity controlled by Pulse Width Modulation (PWM) signal ranging between 0-255 means low to high voltage of the motors speed and its corresponding fuzzy values are low and high.

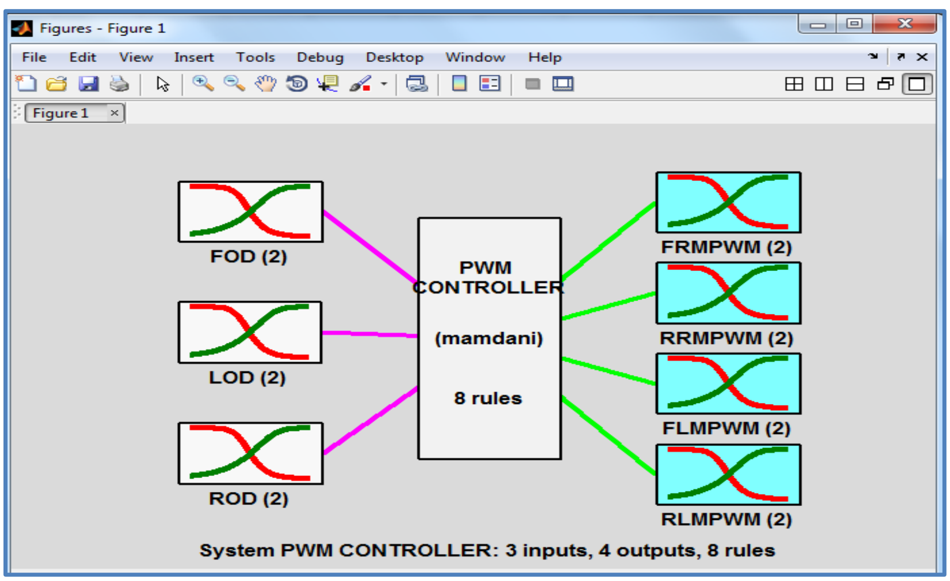


Fig.4.5: Fuzzy logic controller architecture.

Input membership functions: generalizes bell shaped (g-bell).

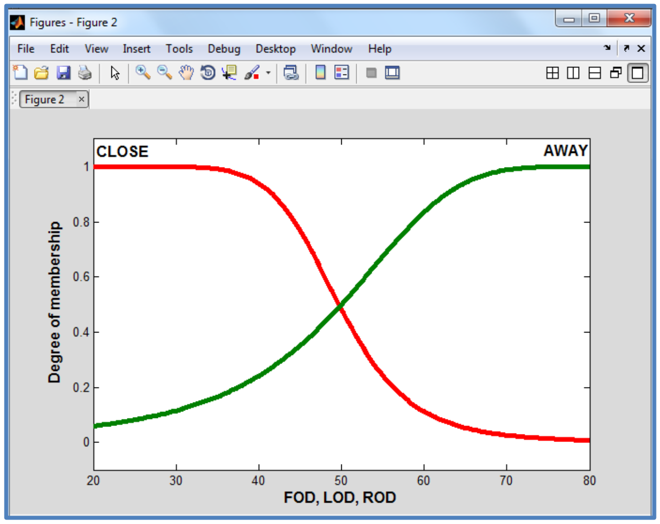


Fig.4.6: Input variables.

TABLE 4.1. MEMBERSHIP FUNCTION VALUES FOR INPUTS

Order No.	Linguistic Values	Membership Function	Corresponding Fuzzy Values
1	Close	Generalized Bell-Shaped (gbell)	[30, 3.5, 20]
2	Away	Generalized Bell-Shaped (gbell)	[30, 2, 80]

Output membership functions: generalizes bell shaped (g-bell).

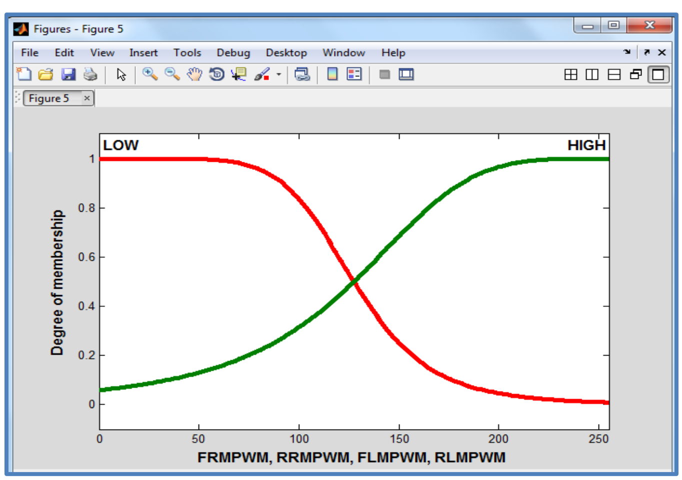


Fig.4.7: Output variables.

TABLE 4.2. MEMBERSHIP FUNCTION VALUES FOR OUTPUTS

Order No.	Linguistic Values	Membership Function	Corresponding Fuzzy Values
1	Low	Generalized Bell-Shaped (gbell)	[127.5, 3.4, 0]
2	High	Generalized Bell-Shaped (gbell)	[127.5, 2, 255]

Input linguistic terms are: close(C), away (A).

Output linguistic terms are: low (L), high (H).

There are eight rules in the rule table, as shown in Table 4.3.

TABLE 4.3. MAMDANI TYPE MINIMUM RULE BASED FUZZY LOGIC CONTROLLER FOR FOUR WHEELED MOBILE ROBOT NAVIGATION WITH OBSTACLES IN CLUTTERED ENVIRONMENT

Fuzzy Rule No.	Front Obstacle Distance	Left Obstacle Distance	Right Obstacle Distance	Front Right Motor PWM	Rear Right Motor PWM	Front Left Motor PWM	Rear Left Motor PWM
1	Away	Away	Away	High	High	Low	Low
2	Close	Close	Close	Low	Low	High	High
3	Away	Close	Away	Low	Low	High	High
4	Away	Away	Close	High	High	Low	Low
5	Close	Away	Away	Low	Low	High	High
6	Close	Close	Away	Low	Low	High	High
7	Close	Away	Close	High	High	Low	Low
8	Away	Close	Close	Low	Low	High	High

The Mamdani-type fuzzy model with eight typical if–then fuzzy rules are expressed as-

Rule 1: If ***FOD*** *is* ***Away****,* ***LOD*** *is* ***Away****, and* ***ROD is Away*** *then* ***FRMPWM*** *is* ***High, RRMPWM*** *is* ***High, FLMPWM*** *is* ***Low,*** *and* ***RLMPWM*** *is* ***Low.*** *And so on.*

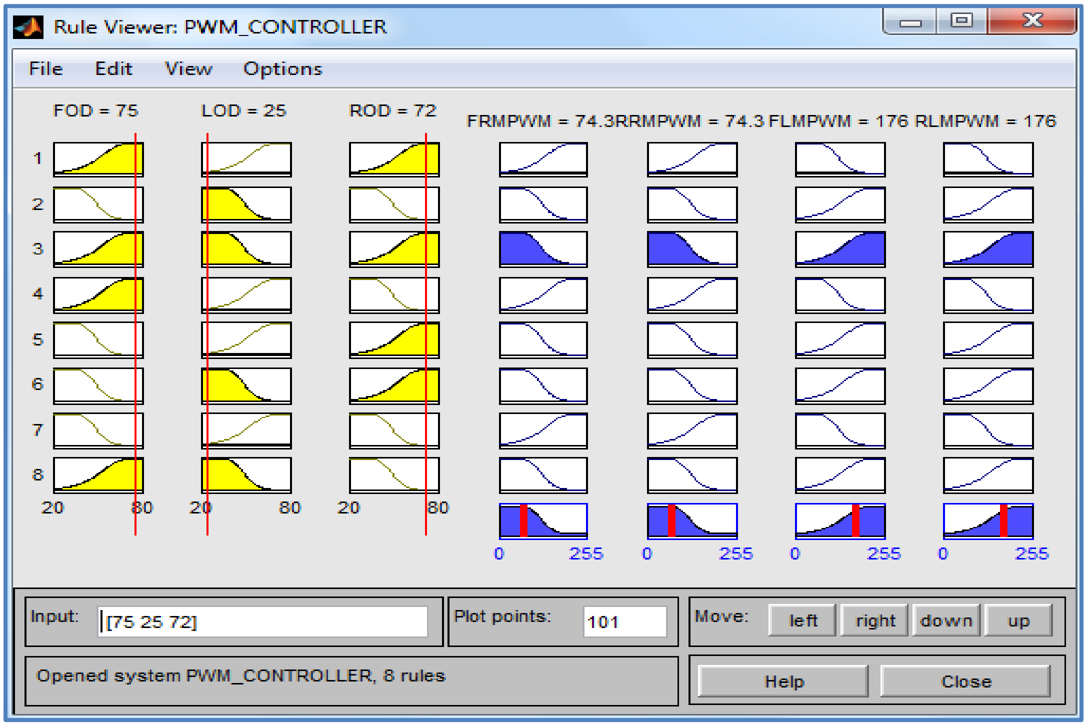


Fig.4.8: Rule viewer of the fuzzy model

We used the method of Centre of Gravity Defuzzification to calculate the velocity of all motors of the 4-WMR:

$$\text{Front Right Motor PWM}=\frac{\sum_{i=1}^{8}\mu_i\left(\text{Front Right Motor PWM}_i\right)\times\text{Front Right Motor PWM}_i}{\sum_{i=1}^{8}\mu_i\left(\text{Front Right Motor PWM}_i\right)} \quad (1)$$

$$\text{Rear Right Motor PWM}=\frac{\sum_{i=1}^{8}\mu_i\left(\text{Rear Right Motor PWM}_i\right)\times\text{Rear Right Motor PWM}_i}{\sum_{i=1}^{8}\mu_i\left(\text{Rear Right Motor PWM}_i\right)} \quad (2)$$

$$\text{Front Left Motor PWM}=\frac{\sum_{i=1}^{8}\mu_i\left(\text{Front Left Motor PWM}_i\right)\times\text{Front Left Motor PWM}_i}{\sum_{i=1}^{8}\mu_i\left(\text{Front Left Motor PWM}_i\right)} \quad (3)$$

$$\text{Rear Left Motor PWM}=\frac{\sum_{i=1}^{8}\mu_i\left(\text{Rear Left Motor PWM}_i\right)\times\text{Rear Left Motor PWM}_i}{\sum_{i=1}^{8}\mu_i\left(\text{Rear Left Motor PWM}_i\right)} \quad (4)$$

5

EXPERIMENTAL SETUP

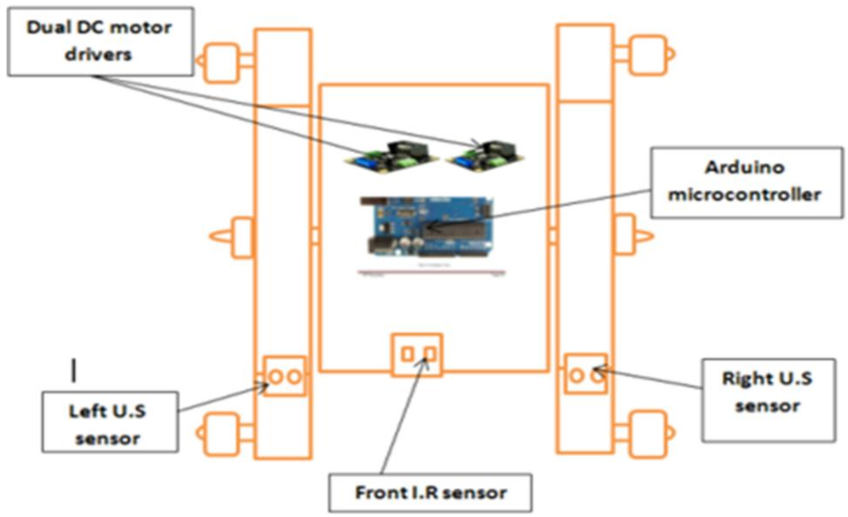


Fig.5.1: Line diagram of four-wheel mobile robot

TABLE 5.1: SPECIFICATIONS OF FOUR WHEEL MOBILE ROBOT

Micro Controller	Arduino Mega ATmega 2560
Motors	Four 12V DC motors
Motor controller	L298 48Volts, 2A dual DC motor controller.
Ultrasonic sensor	HC SR-04: Distance measuring range 20cm to 400cm.
Infrared sensor	GP2Y0A02YK0F: distance Measuring Range 20cm to 150cm.
Input voltage (recommended)	7 to 12Volts
Input voltage (limits)	6 to 20Volts
Speed	Max:30RPM Min:12RPM
Communication	USB connection serial port
Size	62cm*49cm*30cm
Weight	4.93kg
Power	Rechargeable Lithium Polymer 3 Cell, 11.1V, 2000mAh, 20C Battery
Digital I/O pins	54(of which 15 can be used as PWM outputs)
Analogue input pins	16
Flash memory	256 KB of which 8 KB used by boot loader
SEAM	8KB
Payload	500gram approx.

5.1 ARDUINO MEGA 2560

The microcontroller used to communication between all the devises in the mobile robot. They are DC motor drivers, sensors etc. In setup this, the microcontroller is Arduino Mega 2560. It is based on ATmega2560 datasheets. The microcontroller has fifty four digital input/output pins, sixteen analog inputs, four hardware serial ports, a sixteen MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. Arduino mega 2560 contains everything needed to support the micro controller and it is easily connected to the computer by using USB cable.

Kit contains:

- One-USB cable
- One-Arduino Mega 2560

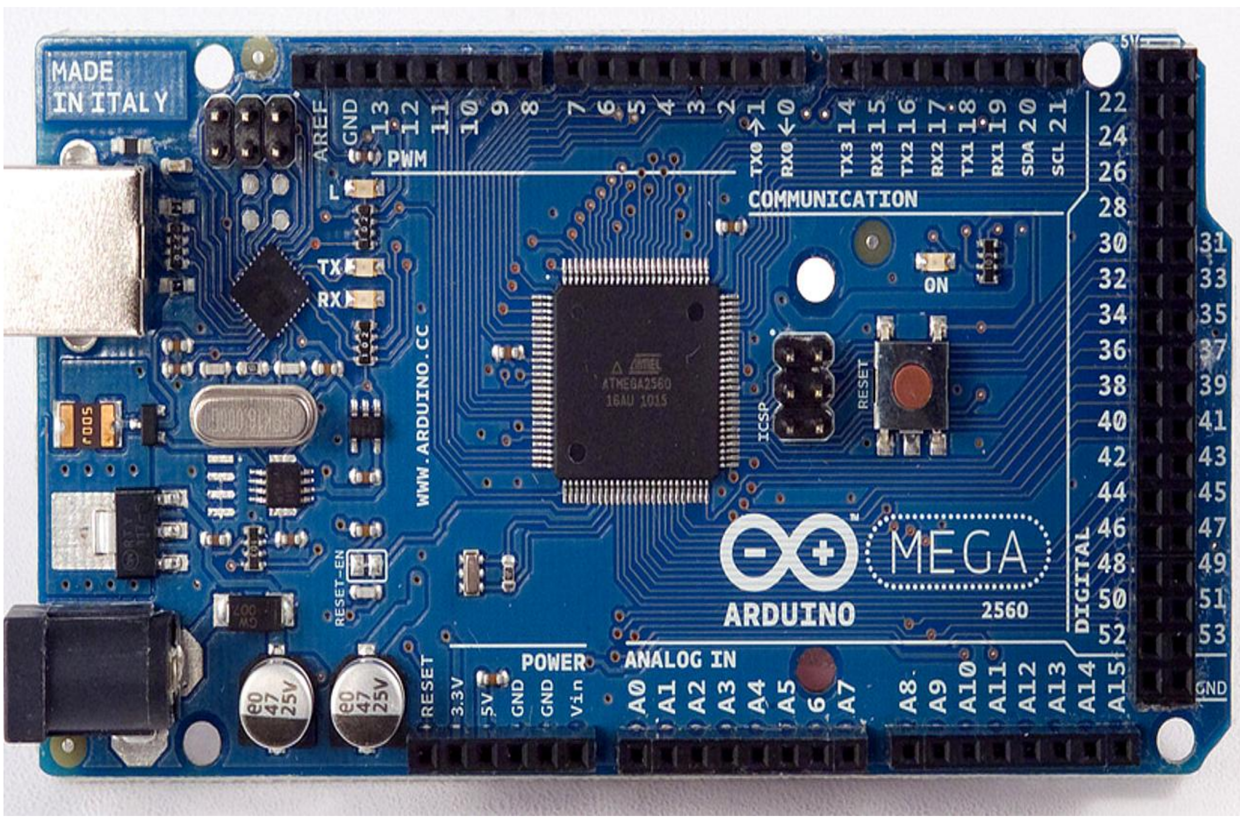


Fig.5.2: Arduino Mega 2560

TABLE 5.2: SPECIFICATIONS OF ARDUINO MEGA 2560

Operating voltage	5 volts
Flash memory	256 kilo bites
Input voltage (limits)	6-20 volts
Input voltage (recommended)	7-12 volts
Digital input pins	54
Analog input pins	16
DC current pre input/output pins	40 milliamp
DC current for 3.3 volt pin	50 milliamp

5.2 DUAL DC MOTOR DRIVER

The DC motor driver controller used in the mobile robot to communicate between the motors and microcontroller. The DC motor controller used in this mobile robot is L298 48Volts, 2A dual DC motor controller. It will drive the two DC motors at the same time. Each L298 has two H-Bridges.

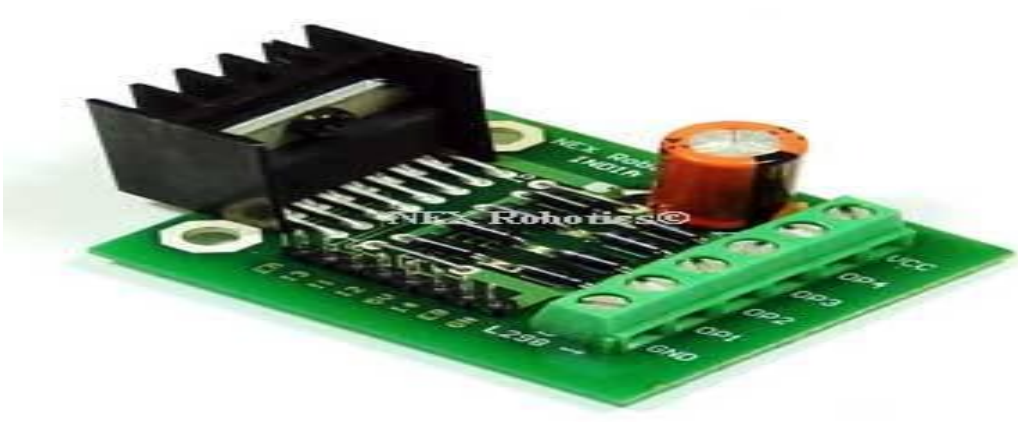


Fig.5.3: Dual DC motor driver

TABLE 5.3: SPECIFICATIONS OF DUAL DC MOTOR CONTROLLER

Operating voltage	8Volts to 46Volts
Output current	2Amp per H-Bridge
To Drive	Two DC motors at a time.
LED's	Two LED's per H-Bridge

5.2.1 APPLICATIONS

- Numerically controlled machines
- Industrial automated robotics
- Dc motor drive
- Computer printers and plotters

5.3 ULTRASONIC SENSOR

Ultra sonic sensors are used in the navigation of mobile robot for obstacle detection. The US sensor used in the mobile robot is HC SR-04. It measures the distance ranging from 2cm to 400cm with accuracy of 3mm.

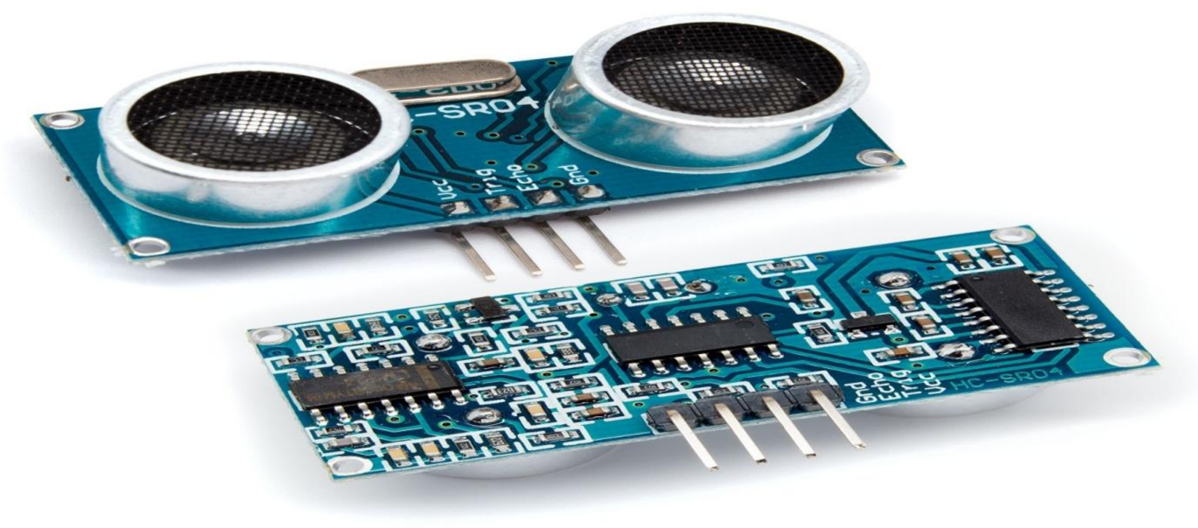


Fig.5.4: Ultrasonic sensor

TABLE 5.4: SPECIFICATIONS OF US SENSOR

Range	2cm to 400cm
Dimensions	20*45*15mm
Power supply	5volt DC supply
Operating temperature range	0 to 70 degree centigrade
Communication	+TTL pulse

5.4 INFRARED SENSOR

GP2Y0A02YK0F is the one of the type of IR sensor used in the navigation of mobile robot. Purpose of using IR sensor in the navigation of mobile robot to detect the obstacle. It can detect the obstacle in the range from 20 to 150 cm.

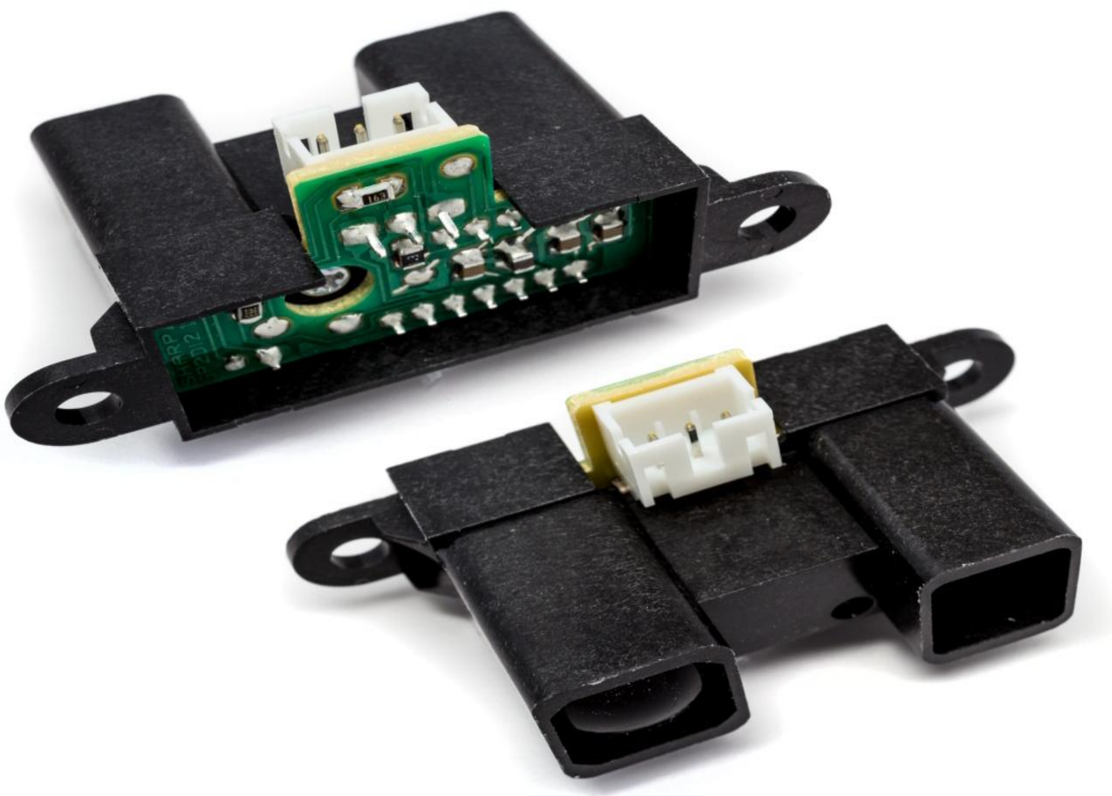


Fig.5.5: IR sensor

TABLE 5.5: SPECIFICATIONS OF IR SENSOR

Range	20 to 150cm
Supply voltage	4.5 to 5.5 volts
Dimensions	29.5*13*21.6 mm
Output type	Analogue
Average current consumption	33mA
Weight	5grams

5.5 BORE WHEEL

This is the wheel compatible for motors having 8mm shaft diameter. This type of wheels made up of rubber gripped with plastic wheel. Here we are using four wheels operated by DC motors.

Fig.5.6: Bore wheel

TABLE 5.6: SPECIFICATIONS OF BORE WHEEL

Wheel diameter	106mm
Wheel thickness	44mm
Hole diameter	8mm
Wheel weight	124grams

5.6 MOTOR

In the navigation of four-wheel mobile robot, we are using four 12Volt DC motors to operate the four wheels. Four motors are attached to the four wheels.

Fig.5.7: DC motor

TABLE 5.7 SPECIFICATIONS OF DC MOTOR

DC power supply	4 to 12volts
RPM	30RPM
Shaft diameter	8mm

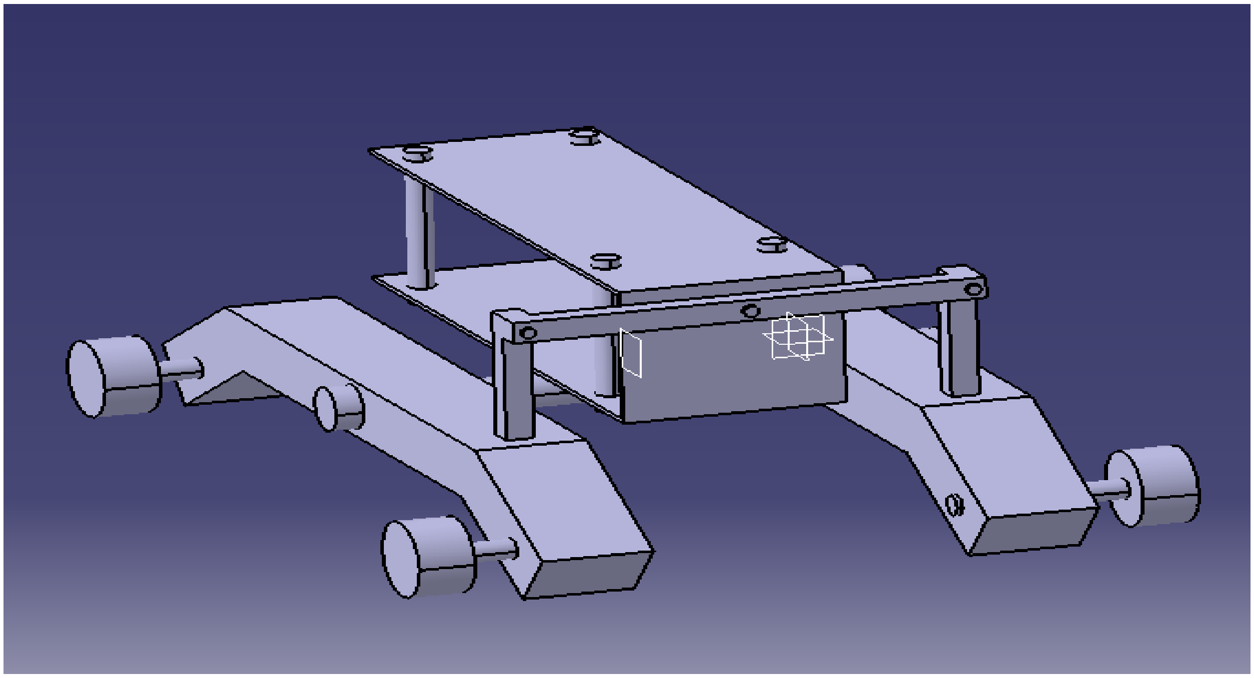


Fig.5.8: Four Wheel Mobile Robot

6

RESULTS AND DISCUSSIONS

In our research, experimental prototype is a four-wheel mobile robot shown in Fig. 6. The DC motors gives the motion and orientation of 4-WMR. The motion and orientation of 4-WMR are obtained by independent actuators such as DC motors, and the motors give the necessary torque to all wheels. The mobile robot movement is controlled by the PWM signal of four wheels. Four 12Volt DC motors are attached to four wheels separately, the two pair of DC motors are attached to two dual DC motor drivers L298 and drivers pins are connected to an Arduino microcontroller to drive all four wheels to obtain forward and backward, left and right movements, the voltage of the motors are controlled by the PWM (pulse width modulation) signal ranging between 0-255, that means low to high polarity of the wheels. Microcontroller takes commands from the fuzzy controller with training fuzzy rules, which is connected to the dual DC motor driver for generating the correct PWM signal of each motor of the four-wheel mobile robot.

There are two kinds of sensors are used in the mobile robot such as one sharp infrared range GP2Y0A02YK0F sensor and ultrasonic range finder HC SR-04. The purpose of sensors used in the mobile robot is to prevent collision with surrounding obstacles. One infrared sensor attached at the front side and it will sense the obstacle and two ultrasonic sensors are attached at left and right side of the robot such that they range from an angle of -80° to 80° approximately with respect to center line of robot. The HC SR-04 two ultrasonic sensors are attached to the left, and right sides of the robot are connected to the digital input port of the Arduino microcontroller. The GP2Y0A02YK0F sharp infrared sensor mounted on the front side of the robot is connected to the analog port of the Arduino microcontroller.

The following possibilities are taken from the sensor data interpretation for the safe navigation of real mobile robot:-

(1) If the obstacle nearer to the left side of the mobile robot the fast cascade fuzzy controller will send a control command to the dual DC motor drivers through microcontroller for generating the high PWM signal for left side of motors and low PWM signal for right side of motors to protect the robot against collision from left obstacle and reaches the goal successfully.
(2) If the obstacle nearer to the right side of the mobile robot the fast cascade fuzzy controller will send a control command to the DC motor drivers through microcontroller for generating the low PWM signal for left side of motors and high PWM signal for right

side of motors to protect the robot against collision from right obstacle and reaches the goal successfully.

(3) If the obstacles nearer to the front side of the mobile robot the fast cascade fuzzy controller will send a control command to the DC motor drivers through microcontroller for generating the either high PWM signal for right side of the motors and low PWM signal for left side of the motors or low PWM signal for right side of the motors and high PWM signal for left side of the motors to protect the robot against collision from front obstacle and reaches the goal successfully.

(4) If the obstacles nearer to the left and front side of the robot the fast cascade fuzzy controller will send a control command to the DC motor driver through microcontroller for generating the high PWM signal for left side of motors and low PWM signal for right side of motors to protect the robot against collision from left obstacle and reaches the goal successfully.

(5) If the obstacles nearer to the right and front side of the mobile robot the fast cascade fuzzy controller will send a control command to the DC motor drivers through microcontroller for generating the low PWM signal for left side of motors and high PWM signal for right side of motors to protect the robot against collision from right obstacle and reaches the goal successfully.

(6) If there are, no obstacles nearer to the robot all the wheels velocity PWM are moving at the same speed.

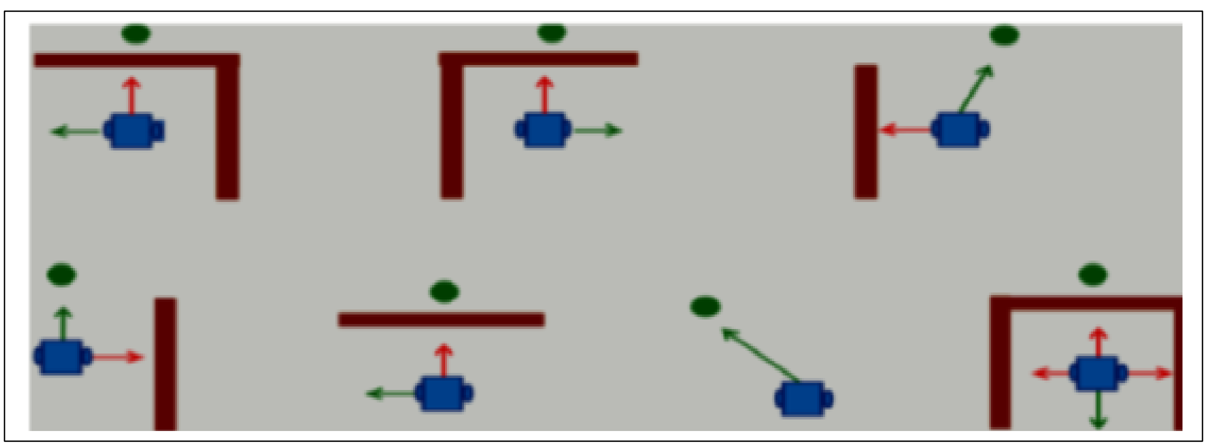


Fig.6.1: Various positions of obstacles

6.1 SIMULATION NAVIGATION RESULTS

In the first case if no obstacle present in the path with the help of simulation using mamdani fuzzy logic in MATLAB the mobile robot takes 13.65 seconds to reach the final point and experimentally the mobile robot takes 14.68 seconds to reach the final point. The error between experimental and simulation result is 7.54%

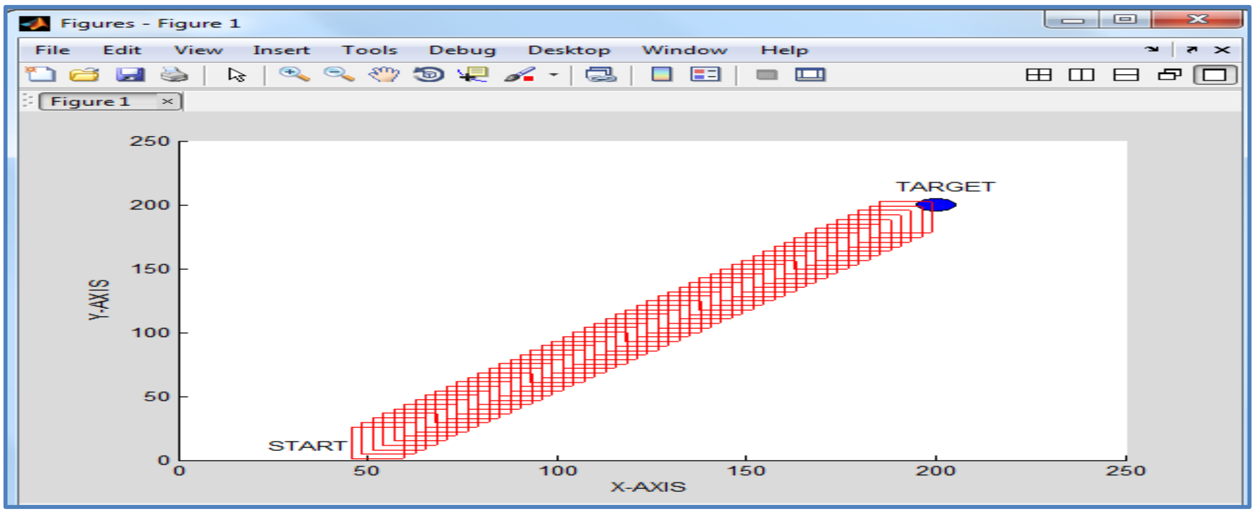


Fig.6.2: simulation of mobile robot navigation with No obstacle in the path

In the first case if no obstacle present in the path with the help of simulation using mamdani fuzzy logic in MATLAB the mobile robot takes 15.74 seconds to reach the final point and experimentally the mobile robot takes 17.10 seconds to reach the final point. The error between experimental and simulation result is 8.64%

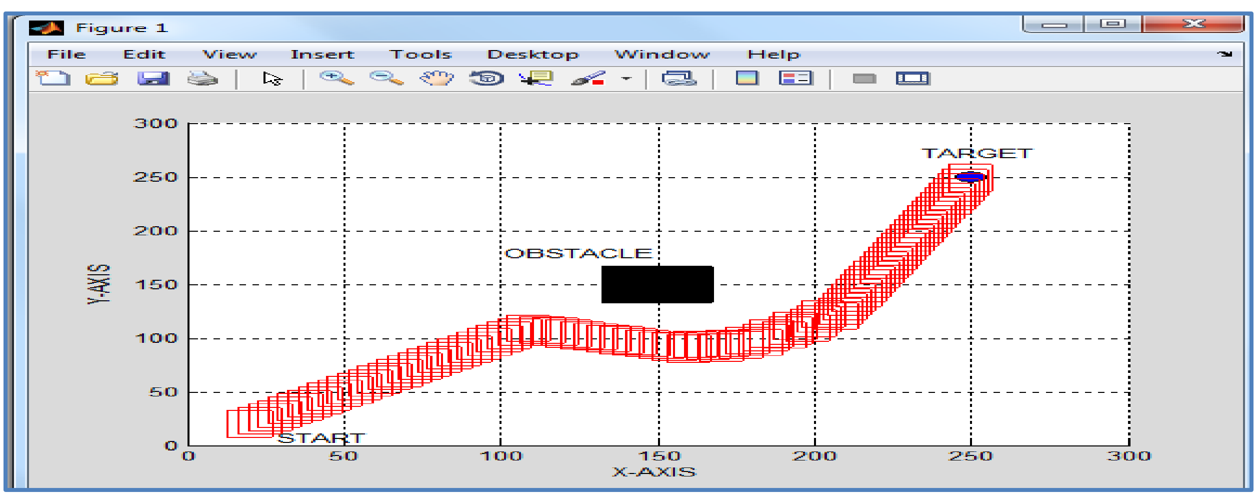


Fig.6.3: simulation of mobile robot navigation with Single obstacle in the path

In the first case if no obstacle present in the path with the help of simulation using mamdani fuzzy logic in MATLAB the mobile robot takes 19.84 seconds to reach the final point and experimentally the mobile robot takes 21.57 seconds to reach the final point. The error between experimental and simulation result is 8.71%

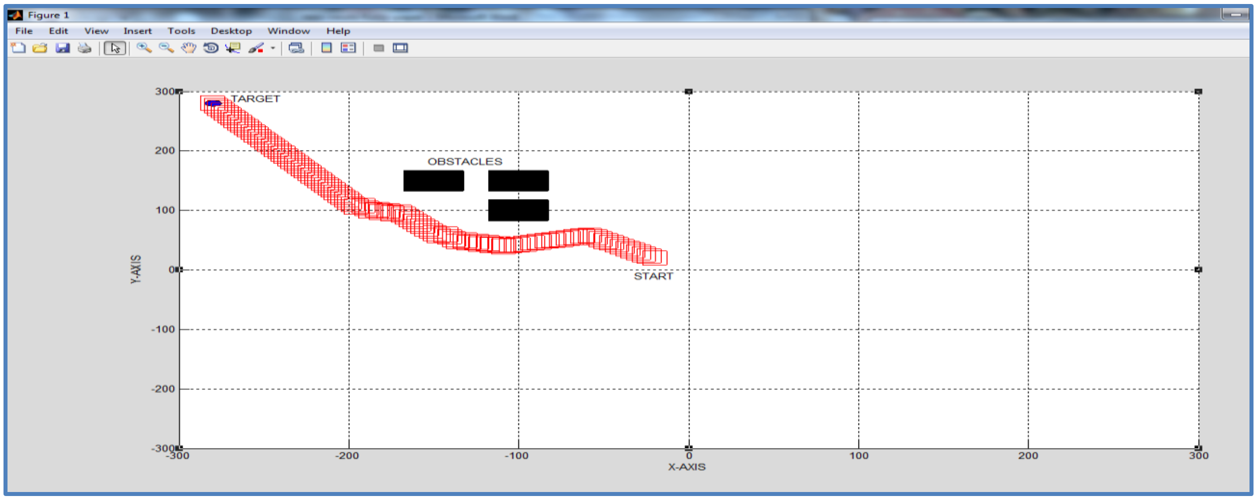


Fig.6.4: simulation of mobile robot navigation with three obstacles in the path

In the first case if no obstacle present in the path with the help of simulation using mamdani fuzzy logic in MATLAB the mobile robot takes 25.75 seconds to reach the final point and experimentally the mobile robot takes 27.82 seconds to reach the final point. The error between experimental and simulation result is 8.03%

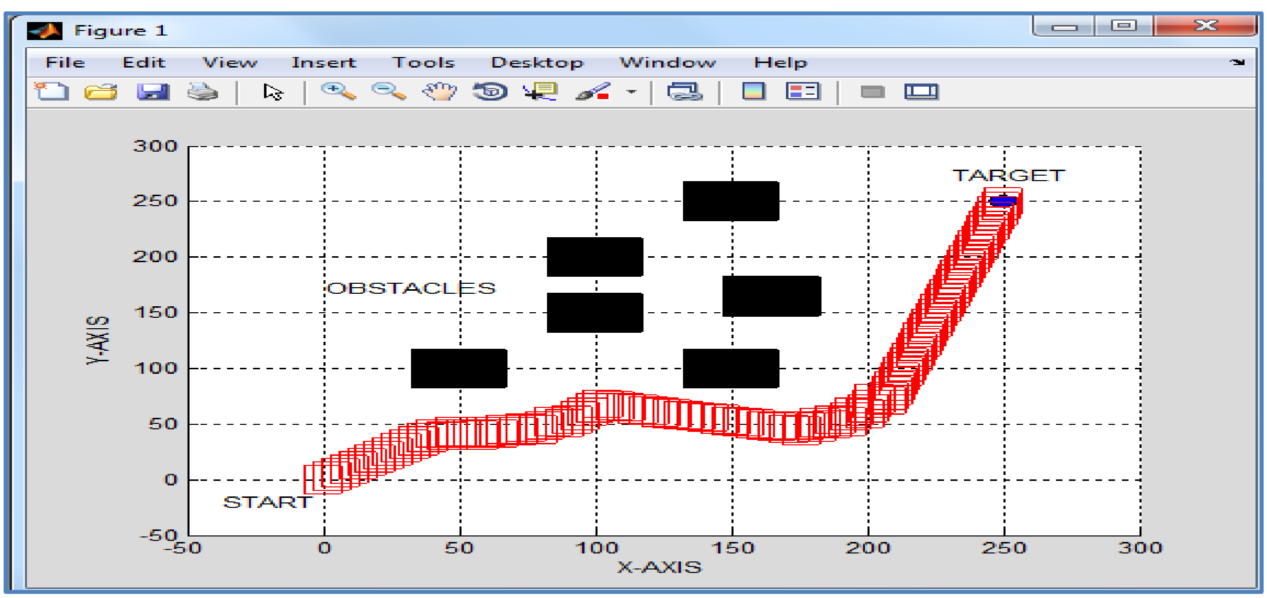


Fig.6.5: simulation of mobile robot navigation with six obstacles in the path

6.2 EXPERIMENTAL NAVIGATION RESULTS

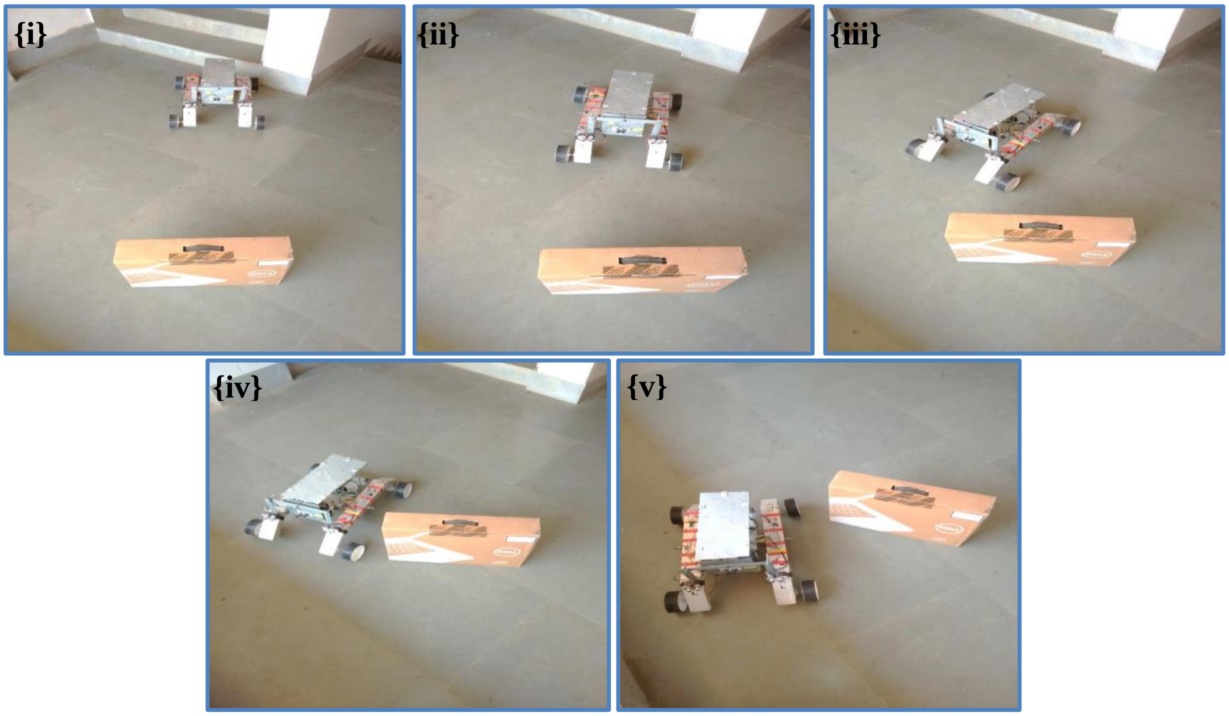


Fig.6.6: experimental navigation of mobile robot with single obstacle in the path

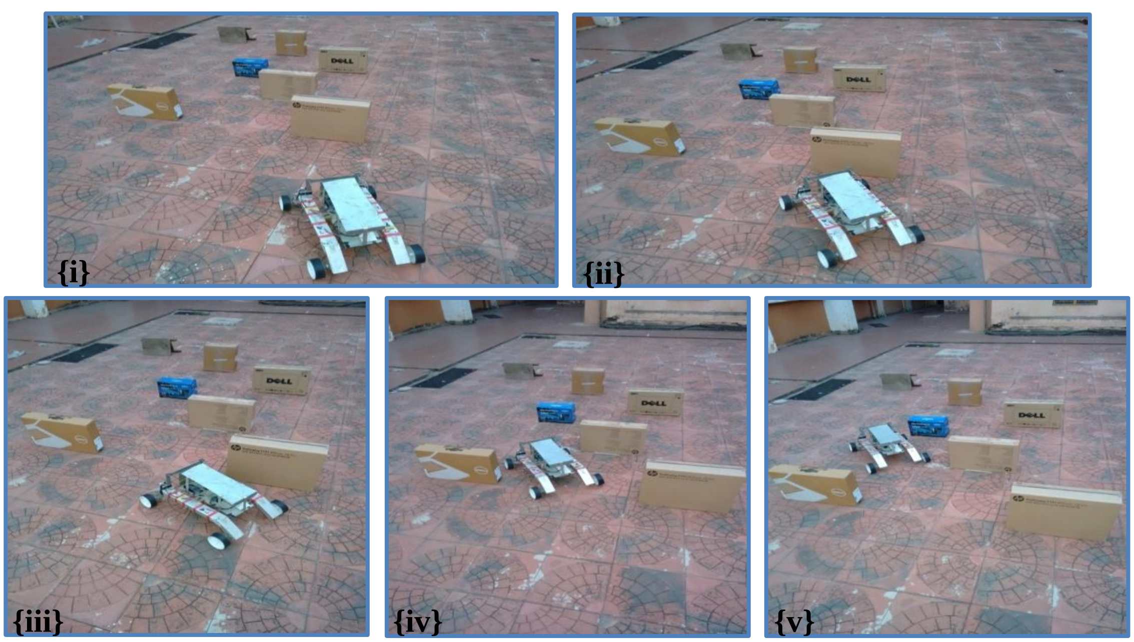


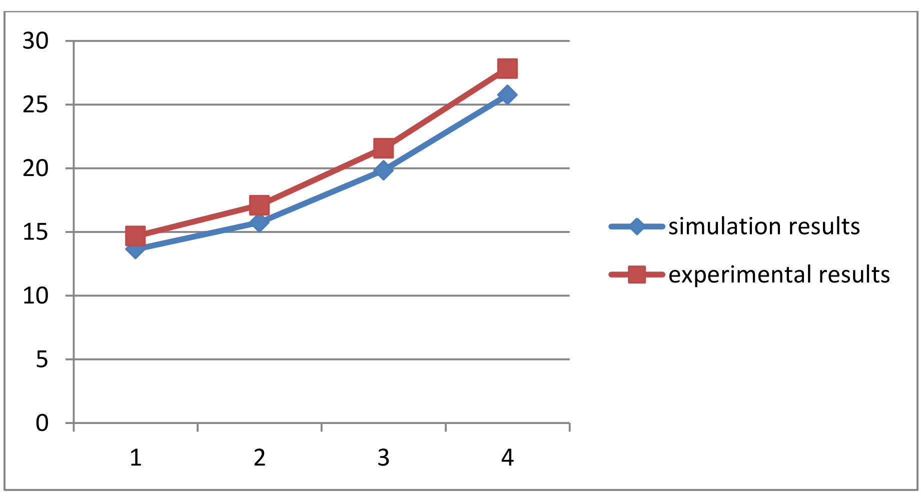
Fig.6.7: experimental navigation of mobile robot with multiple obstacles in the path

TABLE 6.1 EXPERIMENTAL AND SIMULATIONS RESULTS

Sr.no	Figure description	Navigation path length in Pixels.		Time taken to reach the final point in seconds		Error between experimental and simulation results (%)
		Simulation results	Experimental results	Simulation results	Experimental results	
1	No obstacle present in the path	315.08	345.8	13.65	14.68	7.54
2	Single obstacle present in the path	433.73	472.52	15.74	17.10	8.64
3	Three obstacle present in the path	398.83	412.5	19.84	21.57	8.71
4	Six obstacles present in the path	413	432.5	25.75	27.82	8.03

6.3 Error Graph:

Time taken to reach the destination in seconds



Reference axis

7

CONCLUSION AND FUTURE WORK

In this project, we presented the navigation of four-wheel mobile robot by using sensor based fuzzy PWM controller in an unknown environment. We have studied the structure of the kinematic model of four-wheel mobile robot. By writing the code in the MATLAB, the simulation work done with avoiding the obstacle in the path. In this, we are using fuzzy logic technique for the navigation autonomous four-wheel mobile robot in unknown environment. The simulation results showed that the mobile robot reach the destination without collision with the obstacle and experiments are carried out in the lab. The comparison between experimental and simulation results shown. The error obtained between simulation and experimental is about 8% approximately. The goal of this mobile robot is to reach the destination with avoiding the obstacles in the path.

Scope for the future work:

- In this project work, the AI techniques developed for path planning analysis of mobile robot enable the robots to avoid hitting among each other and with static obstacles. However, future development of the techniques may require for avoidance of dynamic obstacles other than static obstacles.
- Multiple mobile robots with multiple targets are considered instead of single mobile robot with single target.

8

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