

NAVIGATION OF MOBILE ROBOT IN CLUTTERED ENVIRONMENT

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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National Institute of Technology Rourkela

Rourkela, Odisha, 769 008, India

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Under the Guidance of

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Dedicated to...

My Dear Friends

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 Mobile Robot in Cluttered Environment** by **Mahesh Shahaji Pol** is a record of an original research work carried out by him during 2013 - 2014 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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Place:

Date:



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ROURKELA – 769008, ODISHA, INDIA

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.
- d) Whenever I have used materials (data, theoretical analysis, and text) from other sources, I have given due credit to them by citing them in the text of the thesis and giving their details in the references.
- e) Whenever I have quoted written materials from other sources, I have put them under quotation marks and given due credit to the sources by citing them and giving required details in the references.

Mahesh Shahaji Pol

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ABSTRACT

Now a day's mobile robots are widely used in many applications. Navigation of mobile robot is primary issue in robotic research field. The mobile robots to be successful, they must quickly and robustly perform useful tasks in a complex, dynamic, known and unknown surrounding. Navigation plays an important role in all mobile robots activities and tasks. Mobile robots are machines, which navigate around their environment extracting sensory information from the surrounding, and performing actions depend on the information given by the sensors. The main aim of navigation of mobile robot is to give shortest and safest path while avoiding obstacles with the help of suitable navigation technique such as Fuzzy logic. In this, we build up mobile robot then simulation and experiments 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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1

INTRODUCTION

1.1: DEFINITION OF ROBOT

“A Robot is reprogrammable, multi purposeful manipulator premeditated to be in motion material, parts, tools or specific plans through unpredictable programmed motions for the presentation of a variety of tasks.”

According to application of mobile robot, capability to navigate in the environment is essential. Navigation defined as the process of directing the movement of a vehicle from one point to another with the help of types of sensors to the different environment like indoor, outdoor and cluttered by using the various navigation techniques such as artificial intelligence. Robot navigation is nothing but the mobile robot's capability to decide its own location and then to map a path towards target location. Track planning is efficiently the addition of localization and it wants the resolving the robot present condition and a target place and together within the identical coordinates. Map building is capable of notations, which is describing the position of robot with the reference.

1.2: WHERE USED AND APPLIED?



Fig.1.1: Mobile robot with arm manipulator

Navigation of Mobile Robot in Cluttered Environment

Robots are used in almost every application related to industry where repetitive and complex task are involved and task which is very dangerous or cannot do the manually such as

- Painting the car, Welding the different specimen or machine and surface finishing in the aerospace and automobile industries
- submarine and space application
- Destructive fritter away remediation in administration labs, nuclear services and medicinal labs
- Examination of parts
- Electronic and consumer products assembly
- Inspection and dispatching parts in various industries

In industrial engineering and modern technology [35], the idea of sovereignty of mobile robots include several areas of technologies, methodologies which is deliberate for trajectory manage, avoidance of obstacle, localization of mobile robot ,path planning and many more. Almost, the sensation of a map planning, obstacle avoidance and navigation job of an autonomous mobile robot depends on the ease of use of a precise demonstration of the navigation environment.

Obstacle avoidance is the primary requirement for any autonomous robot. The major challenge in the field of Autonomous Ground Vehicles (AGVs) is navigation of the robot in environments that are closely in a mess with the obstacles. The controlling of mobile robot becomes more complex when the arrangement of obstacles not known. The mainly famous organize method for such kind of systems is depending on reactive local navigation system that compactly couples the robot dealings to the sensor that gives the necessary information. Due to all this characteristics, the fuzzy behavior techniques are commonly used. Safe maneuvering of Autonomous Ground Vehicles (AGVs) in amorphous intricate environments, compactly in a state with obstacles is still a most important problem in target-directing applications of robot vehicles. Navigation in the forest makes sure that the mobile robot not only reaches its target with avoiding the obstacles, but also gives the safe speeds that ensure constancy.

1.3: NAVIGATION TYPES

The navigation problem in cluttered environment divided into two parts that is:

- (1) Speed control
- (2) Heading control

The speed control uses two characteristics:

- (1) Avoid the obstacles and
- (2) Overturning avoidance.

The heading control done by four characteristics:

- (1) Avoid the obstacle on front side
- (2) Avoid the obstacle on right side
- (3) Avoid the obstacle on left side
- (4) Target seeking.

Each one of these characteristics uses the information from sensors and find out its remedies and action. The avoidance of obstacle characteristics uses vary the range of different sensors to calculate the distances to the close one obstacle; the target seeking characteristics uses the digital compass which measures the direction of the target and the overturning avoidance characteristics uses a speedometer which gives the reading to calculate the mobile robot speed. Confined avoidance of obstacle is a primary difficulty in the navigation of mobile robot. [35] Majority navigation problems of mobile robot done in the surrounding which known to robot and with the help sensors robot find a practicable free path travelling towards the target and avoiding the obstacles. On the other side when mobile robot has to travel in the environment that is totally or to some extent unknown then local navigation methodologies are exceptionally significant for the mobile robot to productively accomplish its targets.

Now, [29] many agricultural farm duties are hazardous for the human beings and it can efficiently improve by using robots. The problem of navigation in greenhouses is solving by modern technique that is deliberative and pseudo-reactive techniques. The initial one (deliberative technique) uses map and according to that makes an algorithm to developed a safe

and avoid the obstacle to circulate throughout the greenhouse. The further one technique (pseudo-reactive techniques) uses a sensor and from that make a feedback algorithm to move the robot through the greenhouse corridors. After that, these techniques used in the real environment and find out the navigation results of mobile robot.

1.4: MODERN APPLICATIONS OF ROBOT

A greenhouse is a building in which plants are grown. Today, agriculture constitutes one of the most important sectors under development in many areas of the world. Spain consists of largest concentration of greenhouse all over the world around more than 27000 Ha and this is one of the main sources of income in Spanish region. Productivity should increase together with product quality and harvest volume. Greenhouses require long hours of work, hazardous activities, and repetitive tasks, such as harvesting, spraying, and pruning. These circumstances decrease operational efficiency and could harm the operator's health so modern technology gives a vital importance in navigation.

For the successful execution of greenhouse tasks by mobile robots, the first step is to design vehicles appropriate to the structure and to the irregular soil in greenhouses. The second phase is the implementation of navigation techniques that permit the vehicle to move through the corridors between the rows of plants. The initially mobile robot navigates in the greenhouse if a map exists and which known then we use the deliberative method. On the other side, if the map is unknown then we go for the pseudo reactive technique.

Ultrasonic sensor gives the simple way and efficient methodology for the distance measurement. With the help of this, we can find out the distance of obstacles from the mobile robot. Generally, range of Ultrasonic sensor is 1 Inch to 10 Feet and operating temperature range is $+32$ to $+158^{\circ}$ Faraday (0 to 170° Celsius). Infrared sensor used to detect the obstacle and three laws Planks Radiation Law, Stephan Boltzmann Law, Wien Displacement Law, govern it. Digital Compass used to detect the heading of mobile robots. UVTRON Flame Sensor is well suited for use in flame detector and fire alarm.

Robots are mostly concerned with the performing a particular motion of the robot manipulator and at the same time different sensors to execute specific functions according to

Navigation of Mobile Robot in Cluttered Environment

application where it is used. The manipulator and attached tooling possibly will execute the operational themselves (such as welding and surface finishing) or take parts to further devices and these devices perform the operations. Modern technologies are concerned with autonomous robot communications with parts such as interaction forces and torques that can be restricted and with the help of these technologies will permit more the robot applications in assembly.

2

LITERATURE REVIEW

2.1: FUZZY LOGIC

Fuzzy controller technique with image processing technique using Open Source Computer Vision presented by Gonzales [1]. Fuzzy logic used for managing the navigation of robot directing towards the destination with obstacles avoidance with the help of changing the direction and movement of the mobile robot. Image processing technique is used to gathering the information of the environment.

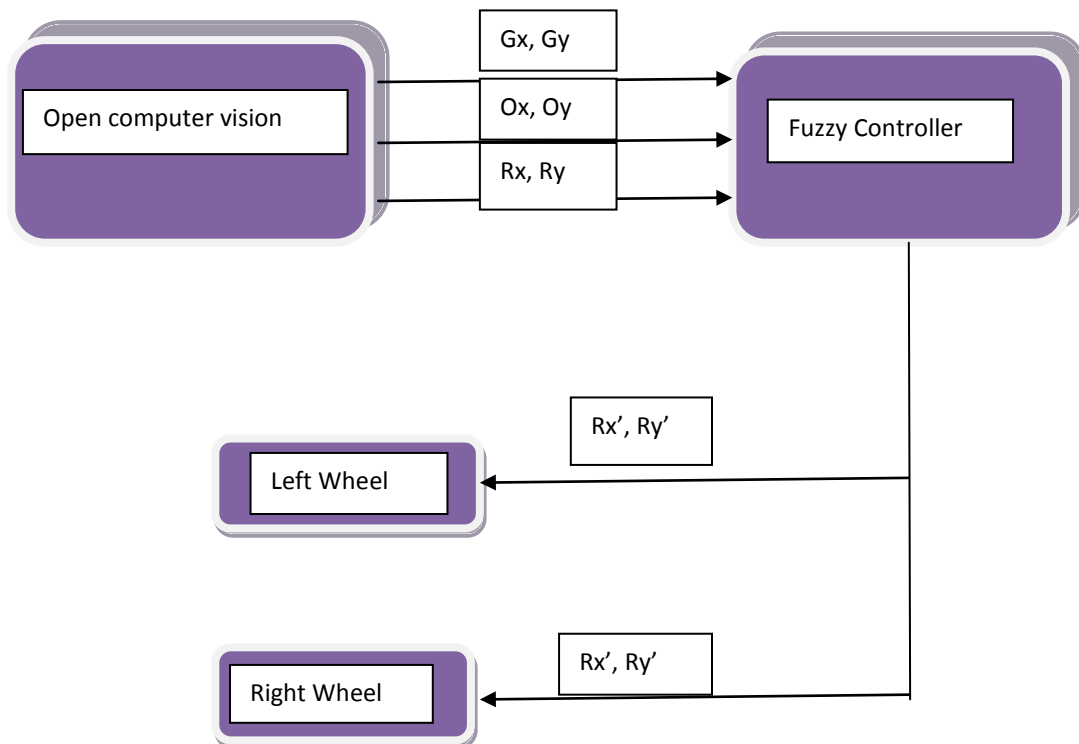


Fig.2.1: Open source Computer vision using Fuzzy controller

Where,

Gx, Gy -	Position of Robot
Ox, Oy -	Obstacles
Rx, Ry -	Destination

Navigation of Mobile Robot in Cluttered Environment

Navigation of mobile robot in disorderly environment by predilection based fuzzy behaviors Presented by Dunlap et al. [2]. In this, they solve the problem of navigation of autonomous ground vehicle. Dunlap gives clear idea regarding intend of predilection based fuzzy behavior system for the obstacle avoidance path planning direct of mobile robot vehicles applications with the help of multivalve judgment network so robot travel efficiently even though in a very disorderly environment.

Fuzzy based judgment depends on real time navigation of mobile robot in unfamiliar environments with dead ends Presented by Wang et al. [3]. They give idea regarding developed and modern grid-based plan representation, in which first system defined as “memory grid”, and other one that is depend on behavior-based navigation method, which defined as “smallest risk method”. In these first one-system proceedings, the information about environment and the other one gives the mobile robot is capable to decide the safest section that can avoided the collision with the obstacles.

Fuzzy logic technique for path planning of several autonomous mobile robots addressed by Parhi et al. [4]. In this Fuzzy logic controller’s uses four kinds of input characteristics, two kinds of output characteristics using diverse membership functions which are developed and the developed function is used for the navigation of mobile robots. In this they gives the information from sensor that is ultrasonic sensors used for calculating the distances of the obstacles around mobile robot and infrared sensor used for detecting the behavior of the destination.

Intellectual Omni directed vision based on robot fuzzy system plan and accomplishment Presented by Feng et al. [5]. In this, the developed particle swarm optimization (PSO) is implemented to repeatedly produce the fuzzy rule-based system .They also characterize the performance of autonomous mobile robot in the well-known path and tracking environment and navigation is done.

A Fuzzy logic organizer tune with particle swarm organization for two degree of freedom flight control Bingül addressed by et al. [6]. They gives a idea regarding two degree of freedom planar mobile robot proscribed by the Fuzzy judgment regulator which is mixed up with a another AI technique that is particle swarm optimization. The specified route, the members of Mamdani-type-Fuzzy judgment director is optimizing by the particle swarm optimization with

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the help of three dissimilar cost functions. For comparison, PID controller tuned with particle swarm optimization.

Optimal combination of fuzzy logic regulator for mobile robot path planning by discrepancy evolution addressed by Pishkenari et al [7]. In this paper, the Differential Evolution (DE) and the Genetic Algorithms (GA) approach beneath the grouping of evolutionary optimization techniques and these evolutionary methods developed to carry out the optimal plan of a fuzzy regulator for the mobile robot route tracking.

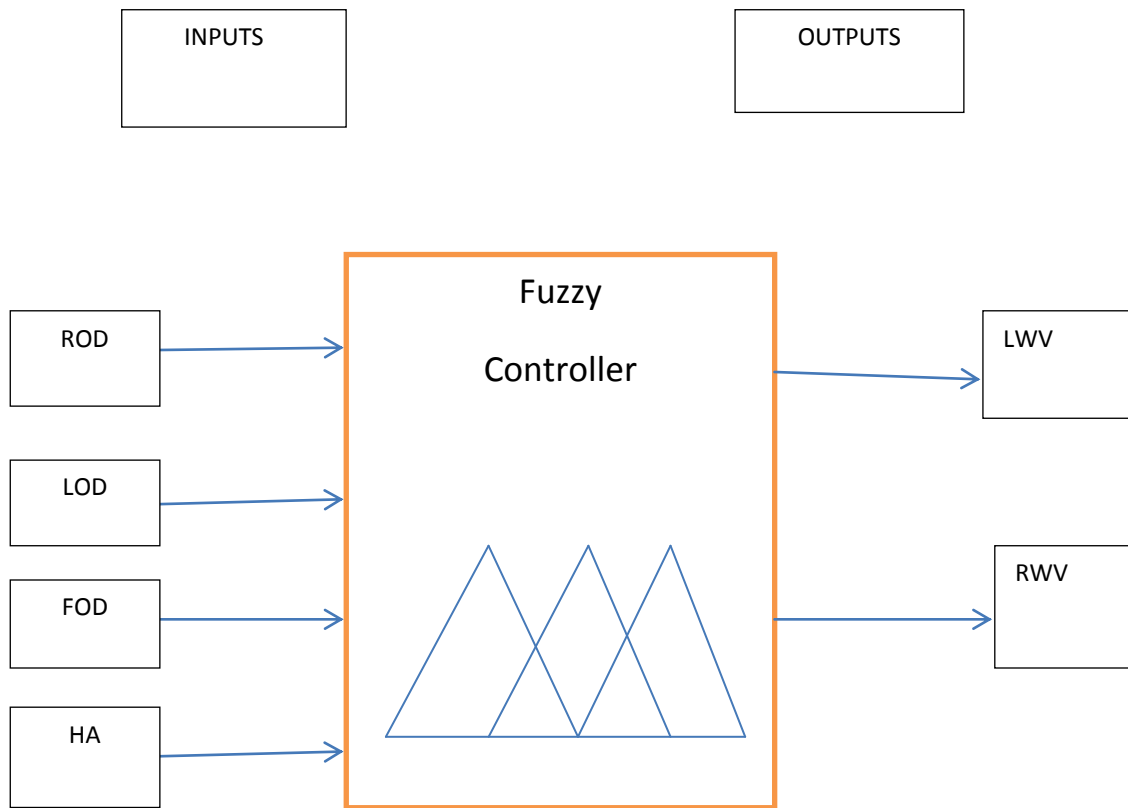


Fig 2.2: Fuzzy Logic

Where,

ROD- Avoiding the Right Obstacle

LOD- Avoiding the Left Obstacle

FOD- Avoiding the Front Obstacle

GS- Goal Seeking

LW- Left Wheel

RW- Right wheel

2.2: NEURAL NETWORK:

A performance organizer depends on spiking neural network for mobile robots Presented by Wang et al. [8]. In this, they use the ultrasonic sensor gives the information to robot and it avoids the obstacles. The ultrasonic sensor gives the information and this information programmed into frequency coding for the sensory neurons. In this integrated-and-firing model implemented and the Hebbian, learning algorithm trains the SNN.

Self-governing mobile robot navigation using a twofold simulated neural network Presented by Wahab[9]. They give idea on intellectual to be in charge of a self-governing mobile robot that can be travel efficiently in a known or unknown environment to find a destination. In this, they explain the motion-planning quandary in mobile robot power using synthetic neural networks method. They prepared algorithm that is depend on two neural networks. In this early one neural network worn to resolve the free gap needed to avoid the obstacles. The other one neural network is resolve the navigate robot into destination.

Path optimization of autonomous mobile robot with the help of an synthetic neural network regulator Presented by Parhi et al. [10]. In this paper they design an intellectual organizer for mobile robot with the help of a combination of different layer feed ahead neural network, which allows robot to travel in a realistic environment. In this paper, the output of neural network is steering angle.

Dempster Shafer Neural Network presentation for ground vehicle travelling application Presented by Aggarwal et al.[11]. They focus on organizing GPS (global positioning system) and INS (Inertial navigation system) statistics for ground vehicle direction finding application and recommended the effective Dempster Shafer Neural Network (DSNN) presentation with the help of combining this theory and the artificial neural network so that reduce the positional incorrectness throughout the nix GPS outage and the GPS outage situation for the small cost inertial sensors.

Navigation of Mobile Robot in Cluttered Environment

Independent mobile robot localization depend on RSSI measurements using an radio frequency identification (RFID) sensor and neural network back propagation artificial neural network (BPANN) Presented by Sabto et al. [12]. In this paper using an radio frequency identification (RFID) system with a partly random tag distribution, each of the section in the environment is individually recognized, and the mobile robot can be concentrate itself successfully without the requirement of a prior location knowledge base for the tags. In this, a controlled form of feed frontward backside propagation artificial neural network (BPANN) used for categorizing the tag signals based on their received strength signal indicator (RSSI).

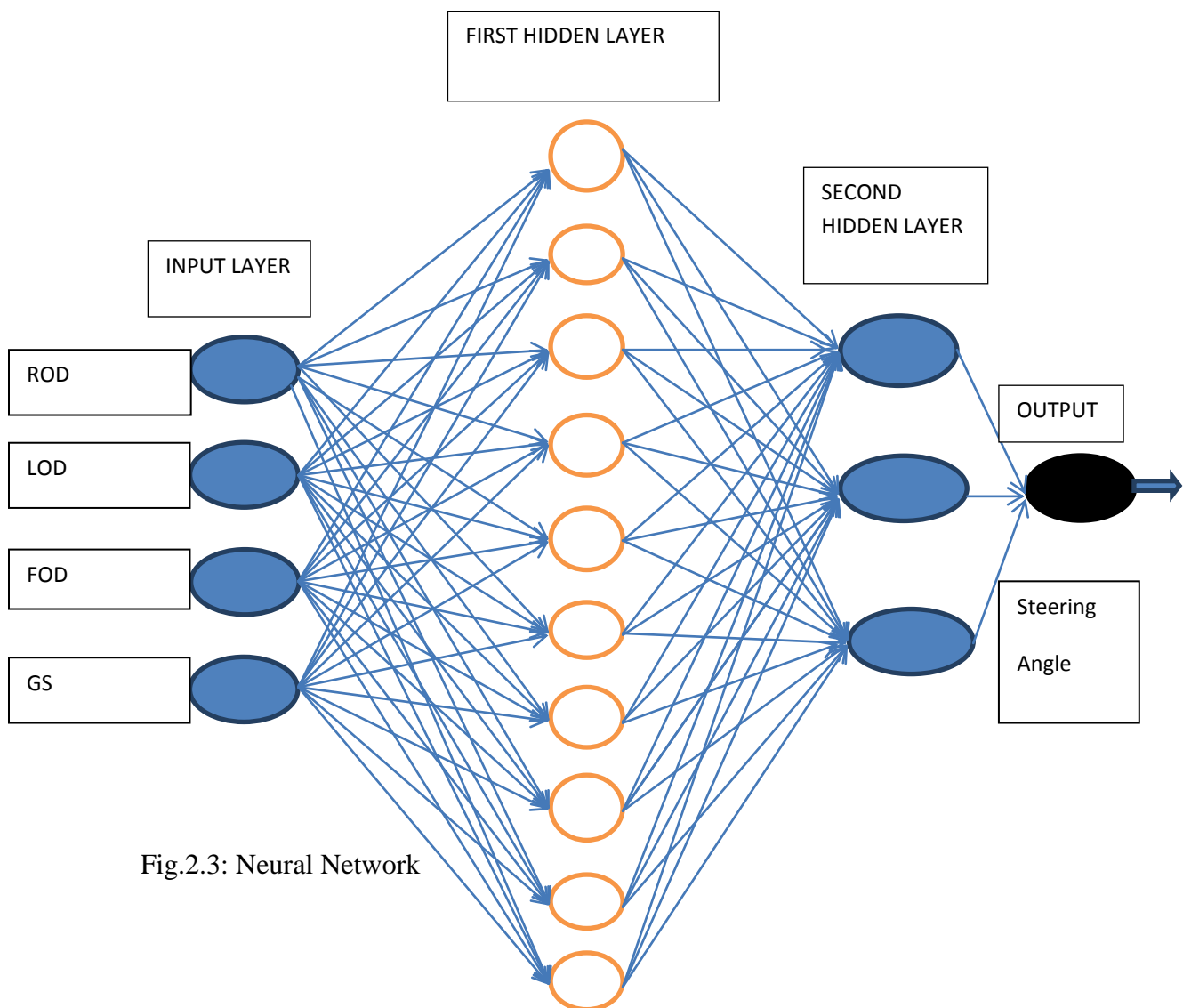


Fig.2.3: Neural Network

Mobile robot avoids the obstacle with the help of Neural Network Presented by Chi et al. [13]. They give an idea of Neural Network power system which is capable to lead the mobile robots negotiate from first to last with uninformed obstacles. In this, the model taught by using Mat lab toolbox and Aria library for activity direct. In these two hundred fifty six precise patterns is distinct to assist robot to put in order in the different circumstances.

2.3: GENETIC ALGORITHM:

Passageway scheduling of mobile robot depend on Chaos Genetic Algorithm Presented by Gao et al. [14]. They give an idea regarding practical symbols, algorithm and the fitness function are implemented in the chaos genetic algorithm, and this operation is supplementary to the genetic algorithm, the junction pace of the genetic algorithm is enhanced, and the restricted optimization is stopped with the help of chaos genetic algorithm. After doing this, result is obtained by the chaos genetic algorithm not only assure the shortest track but also gives the path which is effective to avoid the collision with the obstacle.

Path planning of mobile robot depend on Hybrid Genetic Algorithm in unfamiliar surrounding presented by Zhang et al. [15]. In this; robot operational surrounding represented by grid replica. They also focused on, track preparation which is depend on genetic algorithm, also digital potential meadow technique is introduced, and diverse fitness functions of practicable path and impracticable path are also adopted, these pick up the pace and meeting of algorithm and advances the precision of process.

Mobile robot track planning depend on Uneven situate Genetic Algorithm Presented by Shijie et al. [16]. In this paper the compensation of uneven situate and genetic algorithm is integrated for efficient track planning momentum and improve the meticulousness. The preliminary inhabitants of Genetic Algorithm is simplified by the uneven situate method to remove the minimum assessment creation rules and this is utilized to guide a sequence of reasonable path, then genetic algorithm is used to explain the most excellent pathway.

Efficient plan for PID constraint of robot depend on Genetic Algorithm Presented by Mingyou et al. [17]. In this, presentation key for the instance basic of unlimited fault assessment accepted as smallest thing to select the constraints and worldwide penetrating ability of genetic

algorithm implemented to give optimum result and after that decrease complexity in regulation of PID constraints preceding information circumstances. In this, recreation solution shows the efficient design for the PID constraints and improves the manage exactness and sturdiness of the method.

Superior genetic algorithm with co-evolutionary approach for the comprehensive pathway preparation of various mobile robots Presented by Hong [18]. In this uses a co-evolution methodology combined with advanced genetic algorithm (GA). They also focused on the surrounding in which the mobile robots are travelling and information regarding the surrounding is well known. In this enhanced genetic algorithm gives an efficient and precise fitness function that improves heritable operators of conservative genetic algorithms and gives a new genetic alteration operator.

Track planning methodology for navigation of mobile robot with the help of Petri-GA optimization Presented by Parhi et al. [19]. They gives a basic knowledge which is depend on genetic algorithm for track navigation of several robots for several targets looking for behavior in occurrence of obstacles is projected. In this genetic algorithm method is integrated on the Petri-Net model to make it included navigational organizer. Petri-Genetic algorithm model also control inters robot crash efficiently than the only genetic algorithm alone.

Antariksha Bhaduri work on the finding out the shortest and safest crash free track and navigation for the convenient autonomous robot that is travelling in a motionless surrounding which is covered by many hardens with a acknowledged size and shape. In this, they used hybrid technique in which combination of genetic algorithm and artificial immune system (GAIN) is used which gives the optimal crash free track for the autonomous robot. The network cell structure used for this is very simple and gives a fast calculation result with the small number of the cells. After that bhaduri compared the result of the GA, GAIN, and he found that GAIN gives the promising result in case of navigation of mobile robot.

2.4: PARTICLE SWARM OPTIMIZATION (PSO):

A Geese particle swarm optimization integrated with fuzzy controller for Extended Kalman filter based answers of concurrent localization and mapping problems in robot Presented by Chatterjee et al. [20]. In this they planned a effective execution of newly planned change to Particle Swarm Optimization algorithm which is nothing but Geese Particle Swarm Optimization algorithm, to integrate the parameter of the supervisor, in use for the Extended Kalman filter method for finding out the simultaneous localization and mapping troubles of robots. This technique is mainly appropriate for the process uncertainty related with Extended Kalman filter based simultaneous localization and mapping move towards unknown or wrongly known.

Integrated fuzzy logic and genetic algorithmic method for concurrent localization and navigation of robots Presented by Begum et al.[21]. In this paper, the essential of the proposed simultaneous localization and mapping algorithm is depend on an island representation genetic algorithm that find out the most possible track that provides mobile robot with the finest localization information.

When we deal with hybrid AI (artificial intelligence) technique in which Cesar Munoz [22] recommended an adaptive behavior of mobile robot swarms with the help of neural network and genetic algorithm. When the environment in which navigation is occur and if it is unknown to mobile robot then it is considered as unsupervised learning and if the environment is known then it is considered as supervised learning stage. In this, navigation is considered in unsupervised learning stage. In this soft computing technique is used and experiment is conducted on Khepera robot simulation which depend on neural network technique to produce the behaviors of mobile robot with the help of sensory information. In this preparation of neural network is given with the help of genetic algorithm and in this every entity whose fitness function is output of the function and which is directly proportional to the area enclosed by the mobile robot. In this fitness function is given by:

$$F_i = (Z_v / Z_{Max}) \quad (2.1)$$

Where,

F_i – fitness of entity,

Z_v = visited zones,

Z_{Max} = highest amount of promising visited zones.

Application of mobile robot recently used in many applications for example; firstly, it is used in NASA Mars Rovers and now a day it is used in domestic lawn rovers. S. Veera Ragavan developed waypoint navigation system with global positioning method and global information technique. Waypoint is nothing but the set of the coordinates, which is unique identify a point and represent in the real environment. The GPS based system consisting wider path choices outfitted with communication device and throws the information where it is required. They used two optimization algorithm techniques for solving the track-planning difficulty of mobile robot navigation. In this particle swarm optimization and genetic algorithm- artificial immune system are developed and implemented on mobile robot for track optimization and find out the shortest and safest path and compare these behavior of these two algorithm. After doing too much research, S.Veera Ragvan PSO gives the better result than the GA-AIS. For the larger network GA-AIS shows the improvement and gives better result than PSO. So for shorter network use PSO and for larger network use Ga- AIS.

Hsu Chih Huang work in the field of Omni directional robot. It broadly classified into two types. First, one is Special wheels in which Omni directional platform have active tracking direction and passive moving direction. Second, one is Conventional wheels that are classified into caster wheel and steering wheel. In this, Hsu Chih Huang gives idea on intelligent motion controller design for four-wheeled Omni directional mobile robot. For this, they use genetic algorithm and particle swarm optimization AI techniques. With the help of these techniques, they give better trajectory tracking and stabilization of Omni directional mobile robot. They focused on that work because when we compare with car like robot this robot gives better result to move towards any position and attain the any desired orientation.

2.5: Fuzzy logic and Genetic algorithm:

Optimization of interval type-2 fuzzy logic controllers for a perturbed autonomous wheeled mobile robot using genetic algorithms Presented by Martinez et al[23]. Before this many researcher work on the field of mobile robot but does not give any idea of path navigation of the unicycle mobile robot. In this Martinez gives a path regulator for the vibrant replica of a uni cycle robot by the combination of a kinematic and a torque controller based on the second type fuzzy logic method and genetic algorithms i.e. hybrid AI navigation techniques. In this, they used the computer simulations for confirm the presentation of the path regulator of self-governing mobile robot and application of robot used to different navigation problems. Mobile robot possessing non-holonomic properties so many researchers attracted in the field of mobile robot and do some research regarding this. In this system Genetic algorithm used for optimization of the constant for the trajectory tracking and optimizes the parameter of the membership function that is used in fuzzy logic control. In this many research is going on and we do not have find out the best method for such kind of applications.

2.6: Fuzzy logic and Neural network:

Self-governing analogous parking of a car like mobile robot by a integration of neural and fuzzy based organizer Presented by Demirli et al. [24]. In this paper, they mainly pay attention on toughest container of analogous parking in which the parking planetary proportions cannot recognize. In this the planned representation uses the information from the 3 sonar sensors which is mount on front left place of car to choose steering angle and the 5th-order polynomial position track for generating the training information. Fuzzy representation is recognized by subtractive cluster representation and it is taught by ANFIS and simulating outputs shows that sculpt can effectively choose about the movement way at all variety time with not knowing the parking dimension room width, which is depend on direct readings which is given by sonar sensor that assist as input.

Application of neural and fuzzy organizer for Sumo Robot manages Presented by Erdem [25]. In this, mainly focus on design the robot that used for engineering student in the robotics event competition. In this coordination between output which is given by sensory signals and motor manage pulse is extremely nonlinear in sumo robot; flexible compute methodology is used

for nonlinearity relation and manage the robot in a rivalry ring. First, Fuzzy deduction System for identifying and follow the opponent in rivalry ring is developed, and it is relate with the output signal which is given by sensor to the motor organize pulses. After that, Artificial Neural network based knowledge representation used for the regulation withdrawal and modification in the FIS constraints.

In early days wheel based mobile robot is widely used in many industrial and services applications such as room cleaning, factory automation, security, and transportation Rong Jong Wai [26] focused the plan of the tough tracking path of robot using vibrant petri recurring fuzzy neural network. It also focuses on petri net and recurrent frame incorporated to the fuzzy neural network.

Mobile robot manages with integrating fuzzy and neural network presented by Vukoslavej et al. [27] This paper uses 2 path planning algorithms: self-learning neural network which is essential to forming movement map for mobile robot, and a crash-free path organize representation which is depend on heuristic neuro-fuzzy methodology. In this, they describe robotic platform for development and implementing the navigation algorithm depend on ultrasonic freedom scan.

2.7: ANT COLONY OPTIMIZATION (ACO):

Track preparation for mobile robot navigation with ACO and fuzzy cost task evaluation Presented by Garcia et al. [28]. They gives a proposal to find out the solution of track planning for the robots which is depend on Ant Colony Optimization Meta-Heuristic. In this method for “SACOd_m”, d symbol is using for distance and m symbol for memory. In this, the judgment creation procedure is affected by present gap in the source and destination nodes furthermore the ants remembering the visiting positions.

2.8: ANT COLONY OPTIMIZATION (ACO) AND PARTICLE SWARM OPTIMIZATION (PSO):

Path planning of mobile robot in 3D surrounding depend on Ant Colony Optimization - particle swarm optimization mixture algorithm Presented by Shi [29] and in this, he first gives a simplified rule for obstacle compartmentation in 3D surrounding, and then proposed the tracks of mobile robot throughout particle swarm intelligence algorithm. In this ACO used for plan the track for mobile robot transit able territory, and PSO used for enhancing the constraints of ACO. In this PSO is used for optimize the ACO and with the help of this mixed algorithm we can calculate the navigation difficulty of self-governing mobile robot. In this navigation problem means a appropriate directing track for the autonomous mobile robot from the starting or initial start position to a designated final or reached position in an environment or workplace with the obstacles. This method can be widely used in mining applications where autonomous mobile robot not having necessary information of the global environment. The simulation result obtained by this method is very efficient and feasible in nature and in this navigation; difficulty for the autonomous robot is set up based on the Bitmap method.

3

KINEMATIC ANALYSIS OF MOBILE ROBOT

3.1: DEFINITION OF ROBOT KINEMATICS:

It is defined as the association of multi degree freedom of kinematic chains which forming the configuration of the robotic system. In this, various links are interconnected and forming the geometry and the study of such geometry considered in the robot kinematics. In these nonlinear equations used for the configuration of the mobile robot and with the help of this equation kinematic analysis is done.

3.2: INTRODUCTION OF ROBOT KINEMATICS

Now a day's wheel mobile robot is widely used in every field such as military, industrial , agricultural where human beings cannot work properly or efficiently or impossible to work. In this, they mainly focused on the path; planning so proper control mechanism is required for the mobile robot.

There are different types of mechanism. Therefore, it is necessary to study the different type of mechanism of the wheeled mobile robot such as fixed wheel mobile robot, steered wheel mobile robot, castor wheel mobile robot and so on. In kinematic analysis of mobile robot, we derive the expression of kinematic models taking into consideration of the restraint to robot mobility affected by the various kinematic parameters. After that, this equation implementing on the mobile robot and find out the steering angle and configuration of robot.

For controlling the movement of mobile robots, we require:

- Kinematic or dynamic model of robots.
- Model of interaction between wheel and the robot.
- Definition of the required motion.
- Speed and Position control.
- Control law that satisfied the requirements.

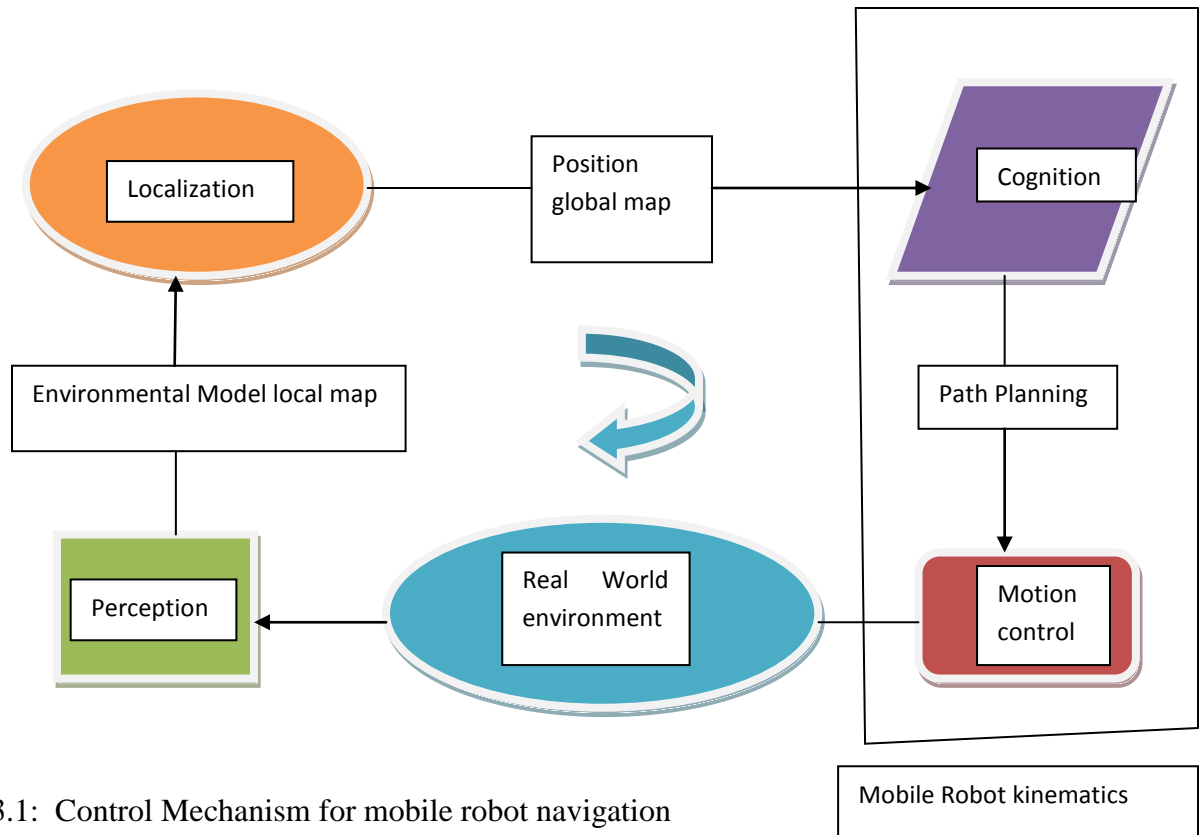


Fig. 3.1: Control Mechanism for mobile robot navigation

3.3: KINEMATIC ANALYSIS OF WHEEL MOBILE ROBOT:

3.3.1: MOBILE ROBOT POSITION

Let us consider the kinematic model for autonomous wheeled robot in level surface as shown in the fig.

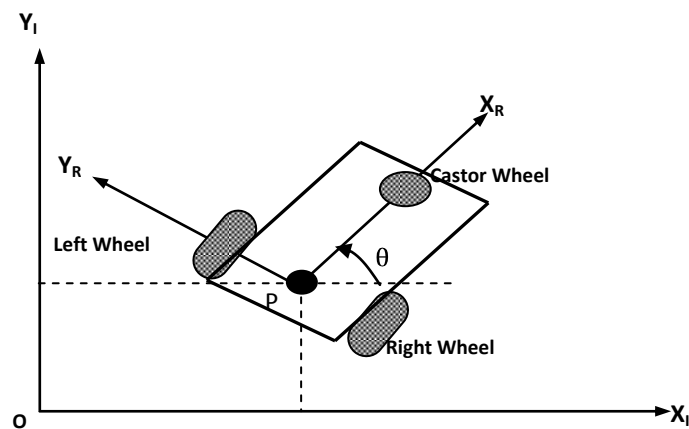


Fig. 3.2: Position of mobile robot in plane

Where,

$(OX_I Y_I)$ - Base Frame

$(OX_R Y_R)$ - Moving Frame

ω - Steering angle

In this mobile robot are having three wheels in which one wheel is castor wheel which is attached to the chassis on one side and remaining two non-deformable wheel is attached to another side and they moving in a horizontal plane. The wheel robot position ξ is defined in the world coordinates by x , y and θ . Point P is represented by (x, y) and θ is the mobile robot orientation.

$$\xi = \begin{matrix} x \\ y \\ \theta \end{matrix} \quad (3.1)$$

In order to find out the robot position requires the movement alongside the axes of world orientation structure to the movement alongside the axes of robot local orientation structure. The orthogonal rotation matrix expressing the orientation of $(OX_I Y_I)$ with respect to the robot frame $(OX_R Y_R)$ is given by

$$R_{\theta} = \begin{matrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{matrix} \quad (3.2)$$

The above matrix used to map the movement in global reference frame to action in terms of robot frame.

$$\xi_R = R(\theta)\xi_I \quad (3.3)$$

3.4: WHEEL KINEMATIC ANALYSIS

For this, we are making some assumption such as:

- Robot moves in a planer surface.
- The Guidance axis is perpendicular to the floor.
- Wheel rotates without any slippery problem.
- Mobile robot does not having any flexible parts which make system more complicated and difficult to handle.
- During small amount of time, the direction maintained constant and vehicle moves from one point to another point follows the circumferential arc.

3.4.1: FIXED STANDARD WHEEL:

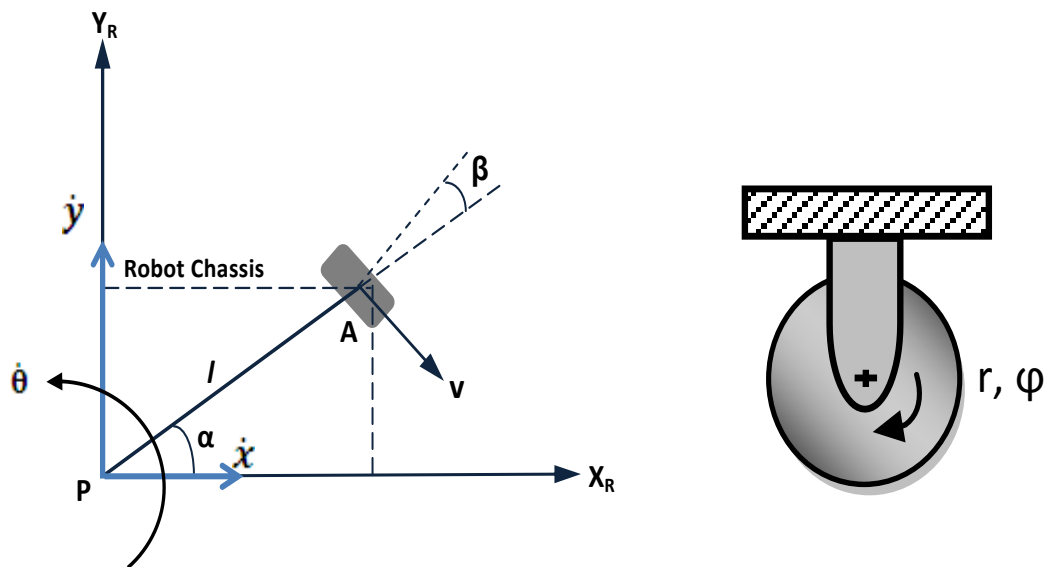


Fig 3.3: Geometric constraints of fixed standard wheel

In this figure, the point 'A' represented by the center of the fixed wheel of mobile robot and this point is fixed with the reference frame. The position of 'A' is defined with the help of polar coordinates by distance $PA=l$ and the angle α . The orientation of the plane of the wheel with respect to PA is representing by the constant angle β . The rotary motion angle of fixed wheels around its axle and it is denoted $\varphi(t)$ and radius of wheel is ' r '. Therefore, location of fixed wheel defined using four parameters α, β, l, r and its movement by time changeable angles

$\beta(t)$. When components velocity of the contact point projected on the fixed wheel plane, we can consider two following constraints:

- along the wheel plane

$$-\sin \alpha + \beta \cos \alpha + \beta l \cos \beta R \dot{\theta} \xi + r \dot{\varphi} = 0 \quad (3.4)$$

- orthogonal to the wheel plane

$$\cos \alpha + \beta \sin \alpha + \beta l \sin \beta R \dot{\theta} \xi = 0 \quad (3.5)$$

3.4.2: STEERED STANDARD WHEEL:

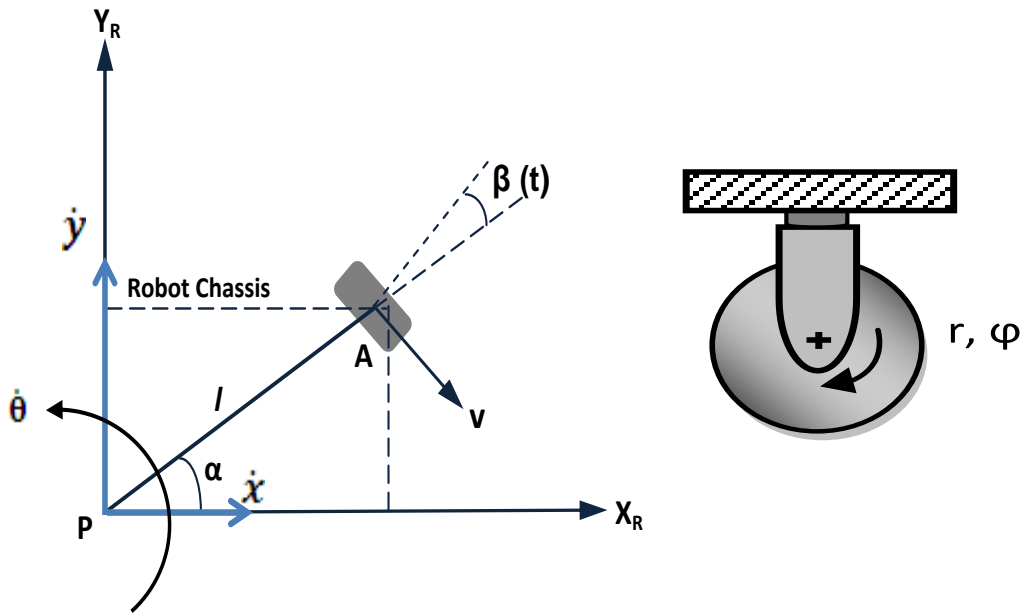


Fig.3.4: Geometric constraints of steered standard wheel

A steered standard wheel is such that the movement of wheel with respect to the frame is a revolution around vertical axis goes through the center of the wheel as shown in Fig.3.5. The expression is same as for a fixed standard wheel, only difference is that now the angle $\beta(t)$ is time varying. Therefore, position of wheel defined using three constant parameters l, α, r and its movement with respect to the frame by 2 time-varying angles $\beta(t)$ and $\varphi(t)$. We have the same expression form as above:

- along the wheel plane

$$[-\sin(\alpha + \beta) \quad \cos(\alpha + \beta) \quad l\cos\beta]R(\theta)(\xi) + r\varphi = 0 \quad (3.6)$$

- orthogonal to the wheel plane

$$[\cos(\alpha + \beta) \quad \sin(\alpha + \beta) \quad l\sin\beta]R(\theta)(\xi) = 0 \quad (3.7)$$

3.4.3: CASTOR WHEEL:

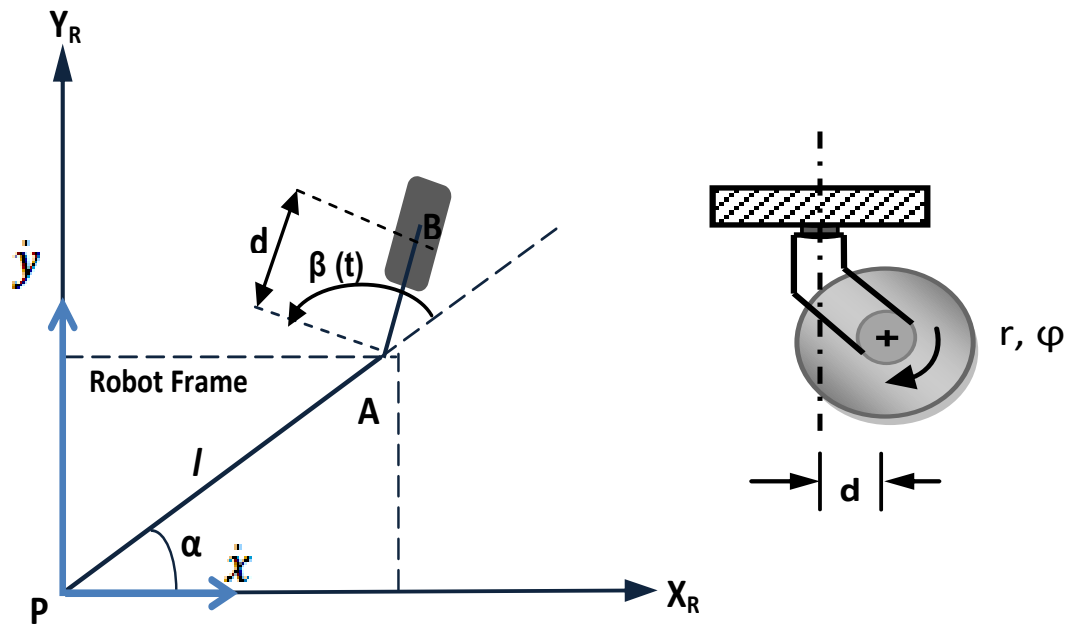


Fig.3.5: Geometric constraints of castor wheel

In this type of wheel, the rotary motion of wheel surface is around vertical axis that does not go by through center of wheel (Fig.3.4). 'B' is the center of the wheel and is connected to the frame by a rigid bar AB of length 'd' which can be rotate around a fixed vertical axis at point 'A'. The location of wheel defined using four parameters α , l , r , d and its movement using two changeable angles $\beta(t)$ and $\varphi(t)$. For this wheel constraints are in following form:

- along the wheel plane

$$[-\sin(\alpha + \beta) \quad \cos(\alpha + \beta) \quad l\cos\beta]R(\theta) \begin{pmatrix} \dot{x} \\ \dot{y} \end{pmatrix} + r\dot{\varphi} = 0 \quad (3.8)$$

- orthogonal to the wheel plane

$$\cos(\alpha + \beta) \dot{x} + \sin(\alpha + \beta) \dot{y} + l\sin\beta R(\theta) \dot{\xi} + d\dot{\beta} = 0 \quad (3.9)$$

4

AI TECHNIQUE

4.1: FUZZY INFERENCE SYSTEM:

Fuzzy inference (reasoning) is the actual process of mapping from a given input to an output using fuzzy logic. Fuzzy inference systems successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision.

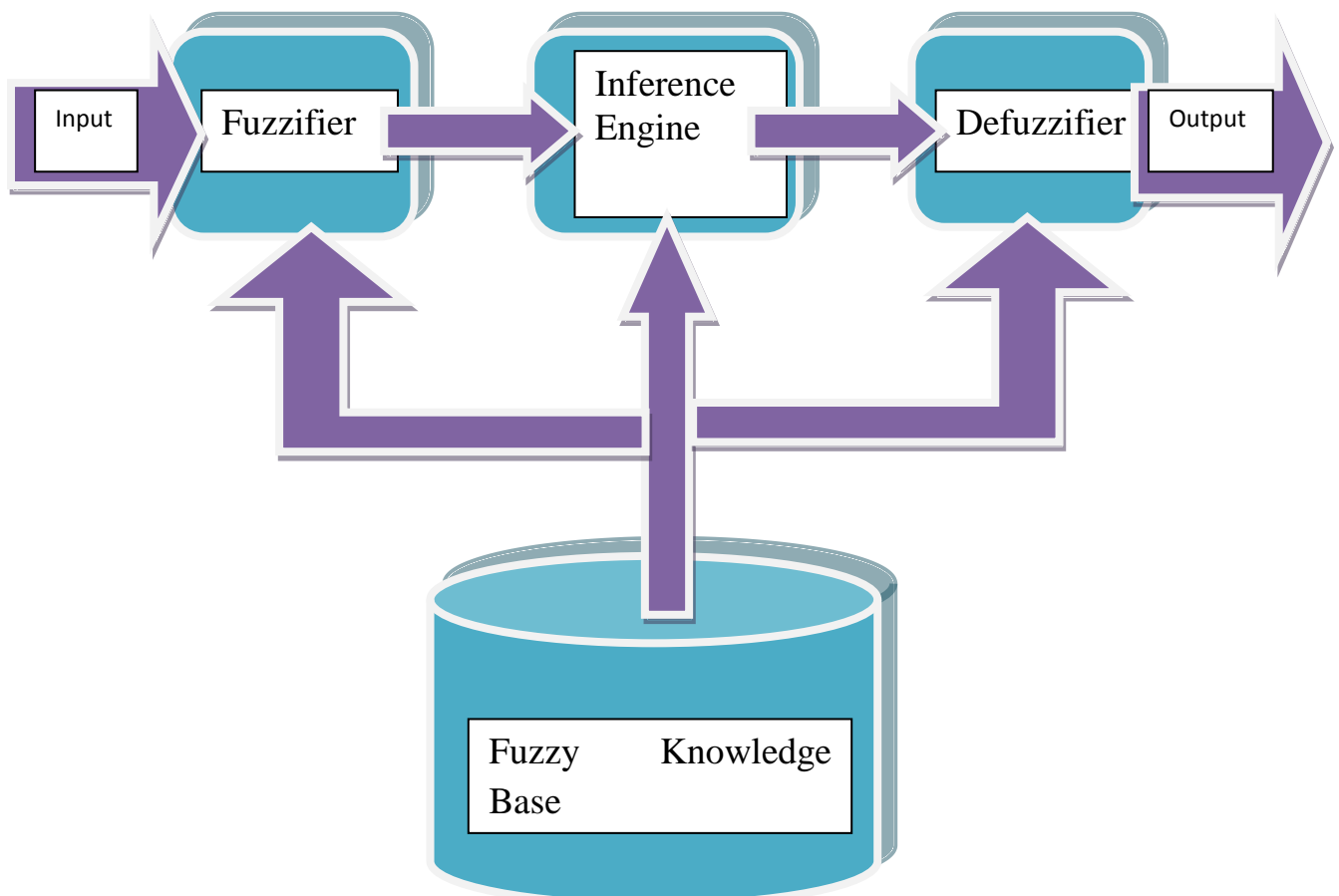


Fig.4.1: Architecture of fuzzy inference system

The steps of fuzzy reasoning (inference operations upon fuzzy IF–THEN rules) performed by FISs are:

1. Compare the input variables with the membership functions on the antecedent part to obtain the membership values of each linguistic label. (This step called fuzzification.)

2. Combine (usually multiplication or min) the membership values on the premise part to get firing strength (degree of fulfillment) of each rule.
3. Generate the qualified consequents (either fuzzy or crisp) or each rule depending on the firing strength.
4. Aggregate the qualified consequents to produce a crisp output. (This step called fuzzification.)

Fuzzy Knowledge Base:

The rule base and the database jointly referred to as the knowledge base.

- Rule base containing a number of fuzzy IF–THEN rules;
- Database defines the membership functions of the fuzzy sets used in the fuzzy rules.

Fuzzifier:

Converts the crisp input to a linguistic variable using the membership functions stored in the fuzzy knowledge base.

Defuzzifier

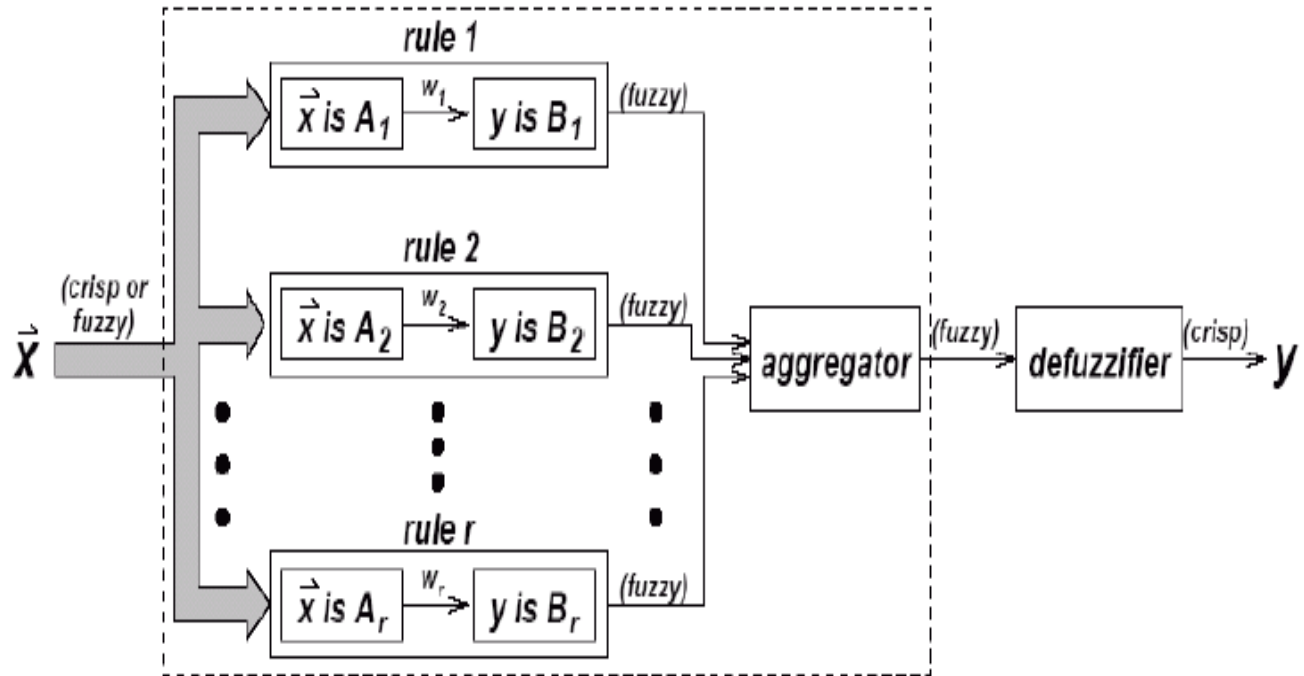
Converts fuzzy output of the inference engine to crisp using membership functions analogous to the ones used by the fuzzifier.

Five commonly used defuzzifying method:

- I. Centroid of area (COA)
- II. Bisector of area (BOA)
- III. Mean of maximum (MOM)
- IV. Smallest of maximum (SOM)
- V. Largest of maximum (LOM)

Inference Engine

Using If-Then type fuzzy rules converts the fuzzy input to the fuzzy output.



4.2: MAMDANI FUZZY SYSTEM:

Mamdani fuzzy inference is commonly seen in inference method. This method [31] introduced by Mamdani and Assilian in 1975.

To compute the output of this FIS given the inputs, six steps have to be followed:

- I. Calculating set of fuzzy rules.
- II. Fuzzifying input with help of input membership functions.
- III. Mixing the fuzzified inputs according to fuzzy rules to create rule strength (Fuzzy Operations)
- IV. Finding the outcome of the rule by mixing the rule strength and the output membership function (implication)
- V. Combining the consequences to get an output distribution (aggregation)

VI. Defuzzifying the output distribution (this step is only if a crisp output (class) needed).

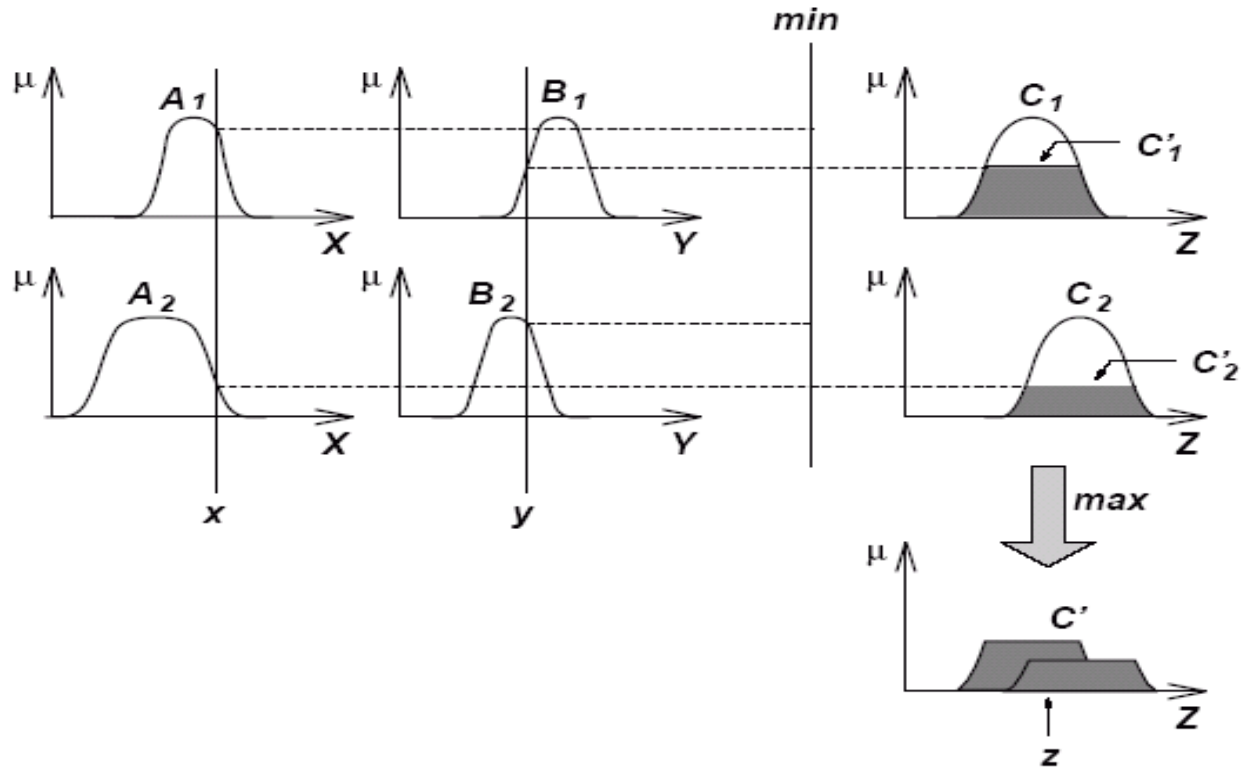


Fig.4.2. Mamdani Fuzzy System

It first used to control the steam engine and boiler combination by a set of linguistic control rules obtained from experienced human operators. The above Figure shows illustration of how a two-rule mamdani fuzzy inference system derives the overall output Z when subjected to two crisp inputs X and Y.

4.3: SUGENO FUZZY SYSTEM:

It is also known as TSK Fuzzy Model [32] because it planned by Takagi, Sugeno and Kang. It generating the fuzzy rules from a given input output data set.

A typical fuzzy rule in a sugeno fuzzy model in the form of:

If X is A and Y is B then $Z=f(X, Y)$

Where, A and B are fuzzy sets while $Z=f(X, Y)$ is a crisp function. Usually $f(X, Y)$ is a polynomial in the input variables X and Y but it can be any function as long as it can be described the output of the model within the fuzzy rule. When $f(X, Y)$ is a first order then it called as first order sugeno fuzzy model. When f is constant, then it called as a zero order sugeno fuzzy model and which is a special case of madmani fuzzy inference system.

Fig.4.3 shows fuzzy reasoning procedure for first order sugeno fuzzy model. Here each rule has a crisp output so overall output obtained via weighted average. Therefore, we avoid the time consuming process of defuzzification that is required in madmani inference system. Sometimes weighted average replaced by weighted sum operator to reduce the computation especially in the training of fuzzy inference system.

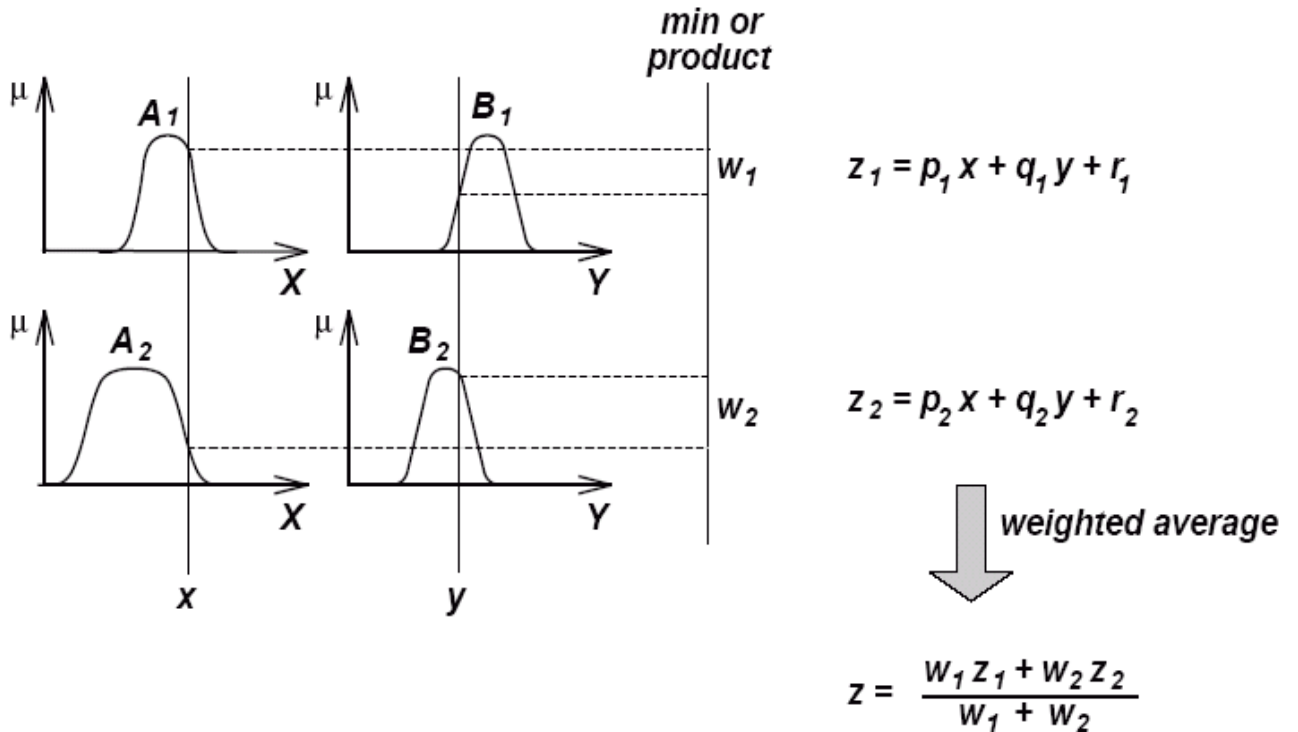


Fig.4.3: Sugeno Fuzzy System

4.3: KOHONEN NEURAL NETWORK:

It is one of the fundamental types of self-organizing neural networks [33]. The capability of self-organizing gives fresh promises - adjustment to previously unfamiliar input information. It looks to be mainly ordinary way of learning, which is used in our brains, where no patterns are defined and those patterns takes the profile throughout learning process, which is united with normal work. It is a synonym of entire assembly of net, which makes the use of self-organizing, competitive type learning method. In this, we set up the signal on net's inputs and then choosing the winning neuron, the one that correspond with input vector in the finest manner. There are different sub-types based on challenge, which differ themselves by accurate self-organizing algorithm.

Single neuron is an easy mechanism and it is not capable to do much by itself. Only compound neurons make complex operations possible. Because of our little knowledge about the actual rules of human's, brain performance many different architectures produced, which trying to replicate the arrangement and behavior of human's nervous system. The majority often one-way, one-layer type of network structural design is used. It determined by the fact that all neurons compulsory participate in the challenge with the same rights due to that each of them must have as many inputs as the whole system.

Functioning of self-organizing neural network separated into three types:

- construction
- learning
- identification

System, which is supposed to realize functioning of self-organizing network, should consist of few basic elements. First of them is a matrix of neurons which are stimulated by input signals and this signals should explain some attributes of effects which occur in the environment. Information about the events translated into impulses that stimulate the neurons. Group of signals

is transferred to each neuron and it does not have to be identical, even its number may be various. However, they have to realize one condition: definitely define those events.

Another part of the net is a mechanism that defines the stages of relationship of each neuron's wage and input signal. Additionally it assigns units with perfect match - the winner. At the start the income are small unsystematic numbers. It is important that no symmetry may occur. While learning, those wages being modified in the finest way to shows an internal structure of input data. On the other hand, there is a hazard that neurons could link with some values before groups are correctly recognized. Then the learning process should be repetitive with different wages.

At last, absolutely necessary for self-organizing process is that the net is able to adapt wages values of winning neuron and his neighbors, according to response strength. Net topology defined in a very easy way by determining the neighbors of every neuron. Then choose the unit whose response on stimulation is higher one. Then we can assume that the net is in order, if topologic relations between input signals and their images are identical.

5

EXPERIMENTAL SETUP

TABLE 5.1: MOBILE ROBOT SPECIFICATIONS

Microcontroller	Arduino UnoATmega328
Flash Memory	32 KB (ATmega328)
Operating Voltage	5V
SRAM	2 KB (ATmega328)
Input Voltage (recommended)	6-12V
Input Voltage (limits)	6-21V
Digital I/O Pins	14 (of which 6 provide PWM output)
ANALOG Input Pins	6
Motors	2 Direct Current, 30RPM DC Motor
Motors Driver	L298, Up to 46V, 2A Dual DC Motor Driver
Speed	Max: 30RPM, Min: 12RPM
Sensors	1 IR Range Sensor Distance measuring range: 20cm to 150cm
Sensors	2 Ultrasonic Range Finder sensor Distance measuring range: 2cm to 400cm
Communication	USB connection Serial Port
Size	Height: 7.5cm, Length: 27cm, Width:33cm,
Weight	Approx. 1.4kg
Payload	Approx. 400g
Power	Rechargeable Lithium Polymer 3 Cell, 11.1V, 2000mAh, 20C Battery

5.1: ULTRASONIC SENSOR:

5.1.1: Working Principle:

It works on the same principle of RADAR and SONAR. In this, evaluate the attributes of targets with the help of the echoes from the radio in case of Radar and sound waves in case of Sonar. It emits the small, large-frequency noise pulses at customary interval. After that, it circulates in air at the speed of sound. If they hit thing, then they reflect reverse as an echo signal to sensor, which itself calculates the distance from the destination depend on the duration between signal emitting and receiving the echo.

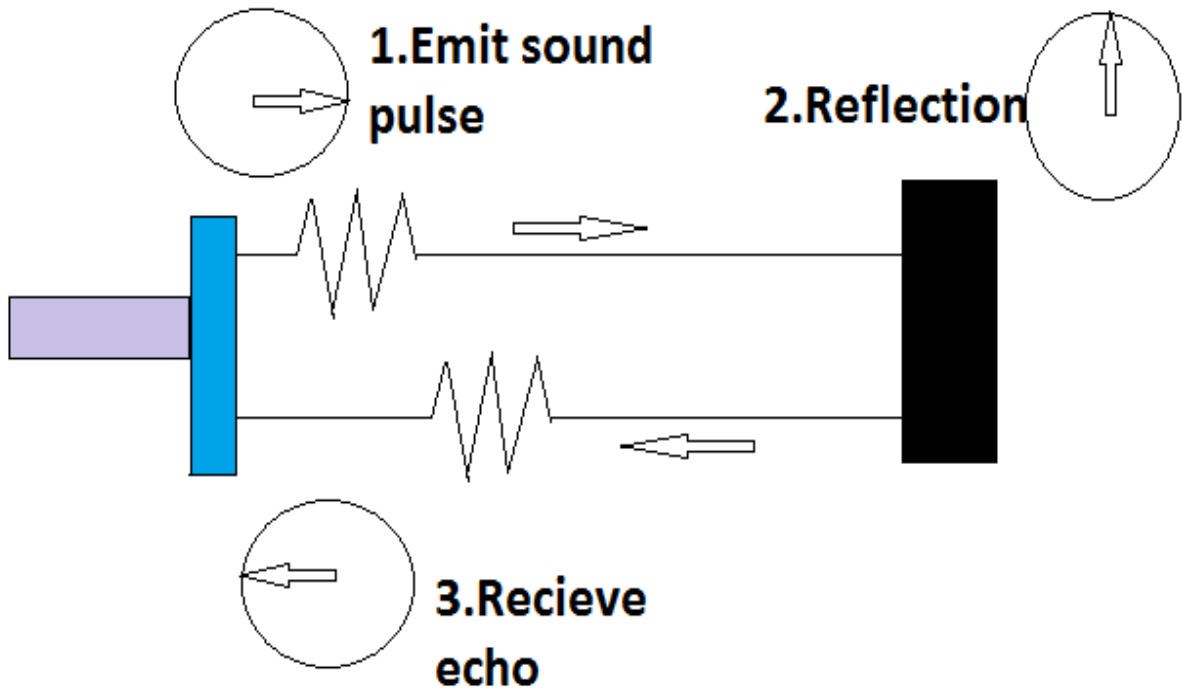


Fig 5.1: Working Principle of Ultrasonic Sensor

It provides the simple way for distance measurement so it used in field of robotics. The ultrasonic sensor capable to emitting pulses because of transducer converts between the electrical, mechanical and sonic energies. It is just right for every come to application that necessitate you to carry out the measurements between dynamic or static things in the surrounding.

TABLE 5.2: SPECIFICATION OF ULTRASONIC SENSOR

Range	2 cm to 3m
Weight	8 Gram
Power Requirements	+5 volt DC Supply
Communication	+TTL pulse
Dimension	20*45*15mm
Operating Temperatures Range	0 to +70 degree centigrade

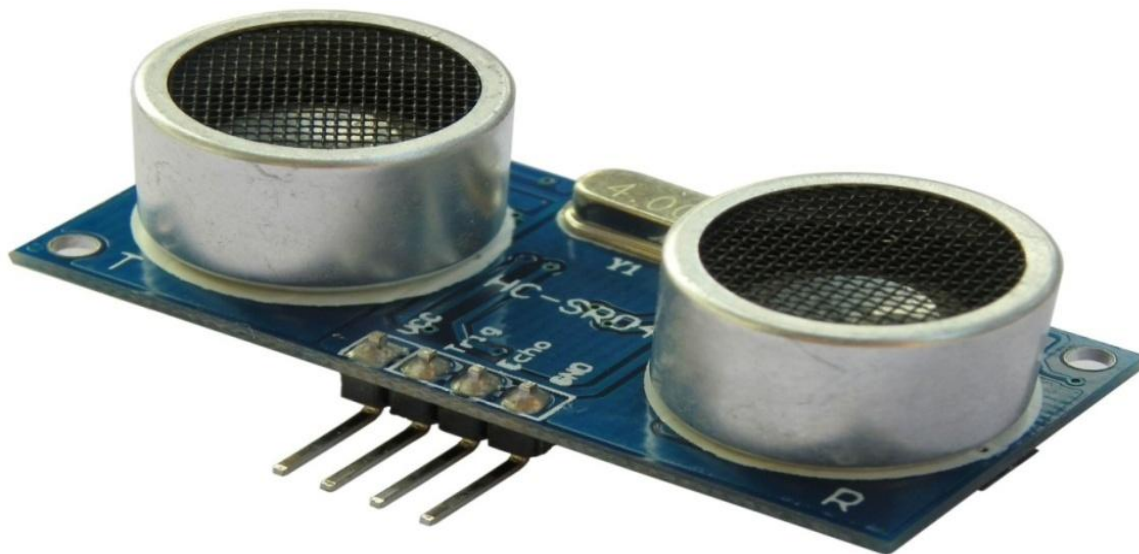


Fig 5.2: Ultrasonic Sensor

5.1.2: APPLICATION OF ULTRASONIC SENSOR:

- Used in Medicine
- Automated factories and process plants
- Navigation of Mobile robot
- Security Purpose

5.2: INFRARED SENSOR:

5.2.1: WORKING PRINCIPLE:

Usual scheme for detect the infrared radiation with the help of infrared sensors consists the infrared source which is nothing but tungsten lamps, , silicon carbide and black body radiators. In active infrared sensors, the input is infrared lasers and LEDs of particular infrared wavelengths. Second step is communication medium that is using for the transmission purpose, and transmission medium consist of atmosphere, optical fibers and the vacuum.

Third step is the visual components as visual lens is using for the combine and focusing on the infrared radiation. Similarly, control the ethereal reaction, and the band-pass filters are idyllic.

Final step is, infrared detector complete the method for the finding out the infrared radiation. Amount produced from detector is generally extremely minute, so that pre-amplifiers attached to circuitry are supplementary for throughout method of conventional signal.

5.2.2: TYPES OF INFRARED SENSOR:

- Thermal infrared sensors:

Photosensitivity is independent on the wavelength. This sensor does not require cooling and it has sluggish reaction time and short revealing ability.

- Quantum infrared sensors:

Photosensitivity is dependent on the wavelength. This sensor requires cooling to obtain the accurate measurement and it has high response time and high detection capability.

TABLE 5.3: SPECIFICATION OF INFRARED SENSOR

Detection range	20cm to 150cm
Weight	5 Gram
Output Type	ANALOG
Refresh rate	36ms
Usable ambient temperature	20 to 60 degree centigrade (not using in freezing and condensation temperature)
Power supply voltage	4.5 to 5.5 volt
Average current consumption	33mA
Package size	30*12*22mm
Circuit stability time	30 seconds
Output current	100 micro ampere



Fig.5.3: Infrared Sensor

5.2.3: APPLICATION OF INFRARED SENSOR:

- Office automations equipment's such as fax machine, printer and copiers.
- Vending machines
- Gaming products

- Home entertainment products
- Medical / health care equipment
- Automatic Teller machine
- Testers, encoders

5.3: CASTOR WHEEL

Ball caster wheel is an Omni directional wheel. This wheel used as neutral wheel for the robot. It used in various applications such as shopping malls, office chairs and material handling equipment. High capability and heavy responsibility caster used in industrial applications such as platform tank, assembly lines. It used mostly in the smooth environment and flat surfaces.

TABLE 5.4: SPECIFICATION OF CASTOR WHEEL

Weight	45 gram
Base plate diameter	38.2mm
Caster wheel diameter	21.3mm
Wheel height	22.8mm
Mounting hole	Three
Angel between the hole	120 degree apart
Hole diameter	3.4mm



Fig.5.4: Castor Wheel

5.4: BORE WHEEL

It is a large wheel and low cost wheel and it used for medium duty applications. It is compatible with almost all the motors having 6mm diameter shaft. Wheel has very good quality rubber grip but surface finish of the wheel is moderate. Here we are using two-bore wheel that operated by DC motor.

TABLE 5.4: SPECIFICATION OF BORE WHEEL

Weight	123 Gram
Wheel diameter	106mm
Wheel thickness	44mm
Hole diameter	6mm



Fig.5.5: Bore Wheel

5.5: ARDUINO UNO

It is single panel microcontroller depend on the A Tmega 328 datasheet. It consists of fourteen digital key in and output pins in which six of them can be used as a power jack, a 16 MHz ceramic resonator, 6 analog inputs, a USB connection, PWM outputs, a reset button and ICSP header. It containing the all parameters which supporting microcontroller and it easily connects to a computer with the USB cable.

Kit contains:

- 1- Arduino Uno
- 1- USB Cable

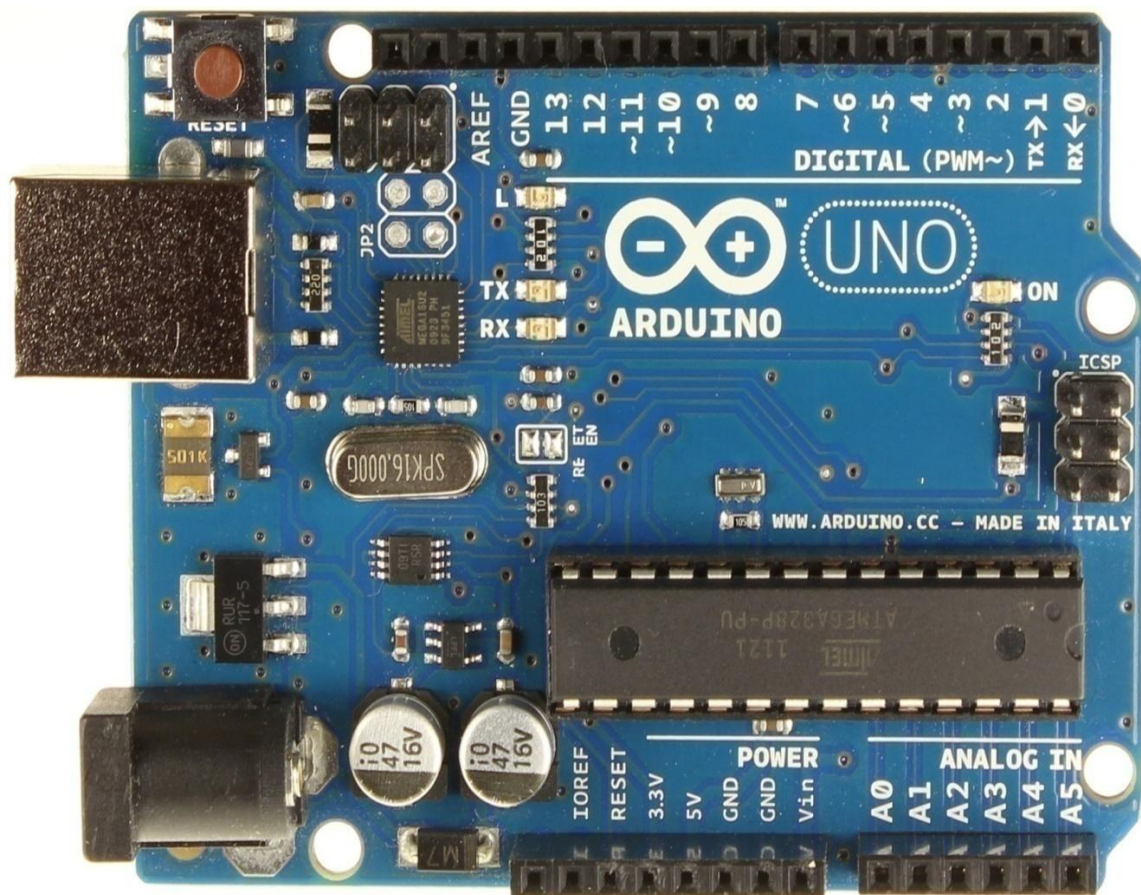
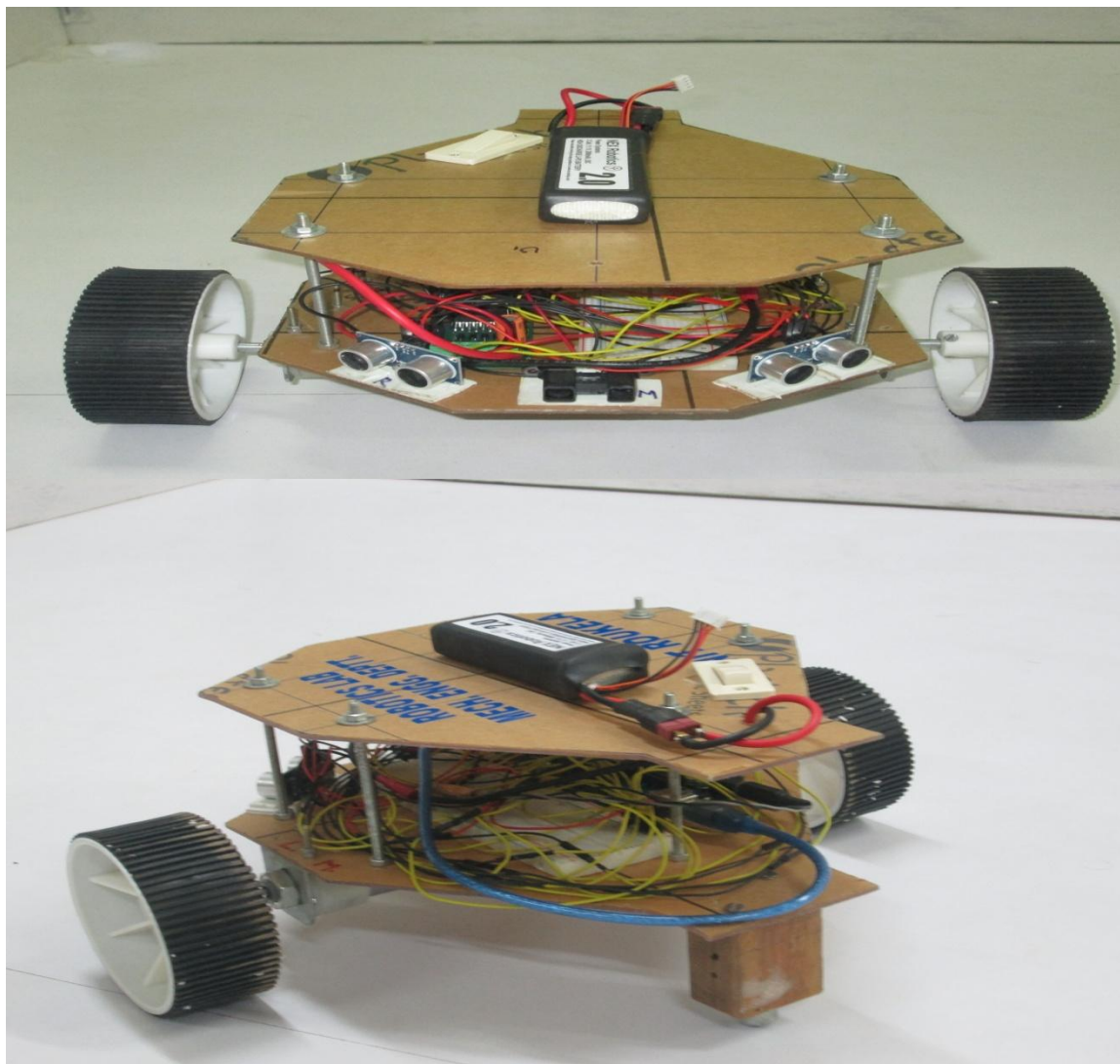


Fig.5.6:Arduino Uno

TABLE 5.6: SPECIFICATION OF ARDUINO UNO

Weight	27 Gram
Operational Voltage	5 Volt
Digital input output pin	Fourteen
Suggested Input Voltage	Seven to Twelve Voltage
Direct Current per Input Output pin	40 mA
Synchronous dynamic random-access memory	2KB
Electrically Erasable Programmable Read-Only Memory	1KB



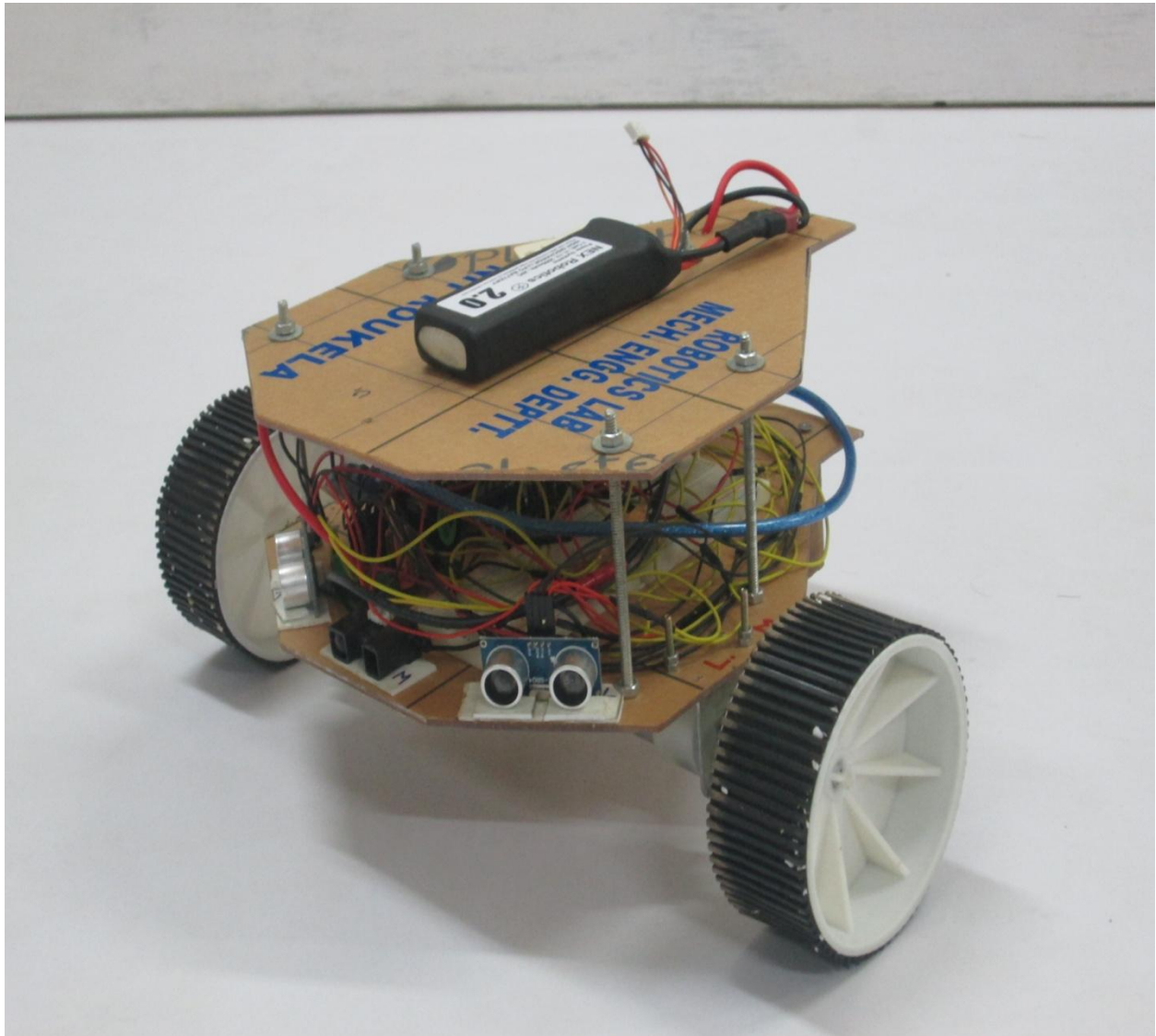


Fig. 5.7 Mobile robot

6

RESULT AND DISCUSSION

Navigation of Mobile Robot in Cluttered Environment

In result, we are considering some simulation on the mobile robot. In lab, build mobile robot, we using two ultrasonic sensors and one infrared sensor. Ultrasonic sensor detects the right and left side obstacles respectively and infrared sensor detects the front side obstacle. From the position of robot and position of target, we calculate the distance to target and heading angle. Here we are also simulated the performance of robot using mamdani fuzzy logic and calculate the distance and time to reach the mobile robot to the destination in different environmental conditions with avoiding the obstacles. If an obstacle is not present then it follows the straight path. Fig 6.1 shows the various postions of obstacles and according to obstacles it follws the path for the navogation of robot.

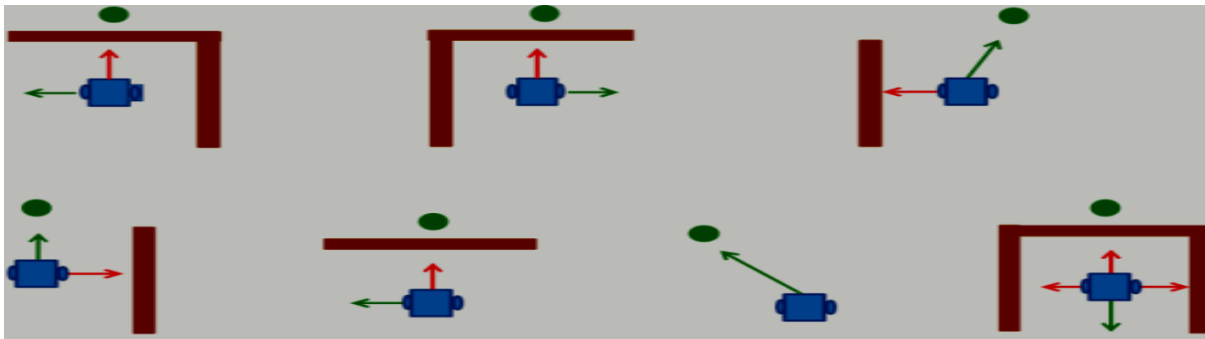


Fig.6.1: Various Positions of obstacles

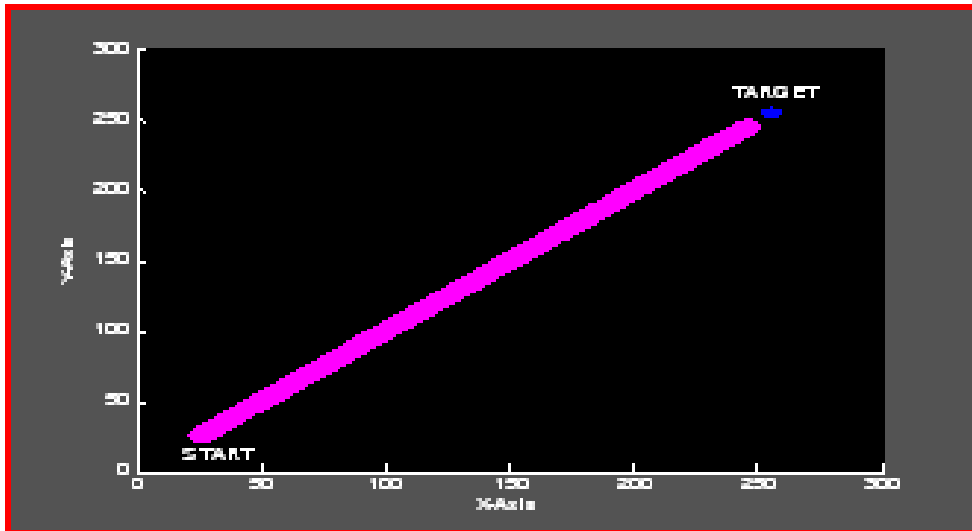


Fig.6.2. Target finding behavior for mobile robot

If no obstacle present in the surrounding then with the help of simulation using mamdani fuzzy logic mobile robot requires the 15.26 seconds to reach the destination and experimentally

Navigation of Mobile Robot in Cluttered Environment

with the help of mobile robot, it requires the 16.40 seconds to reach the destination. The error between the simulation result and experimental result is 7.47%.

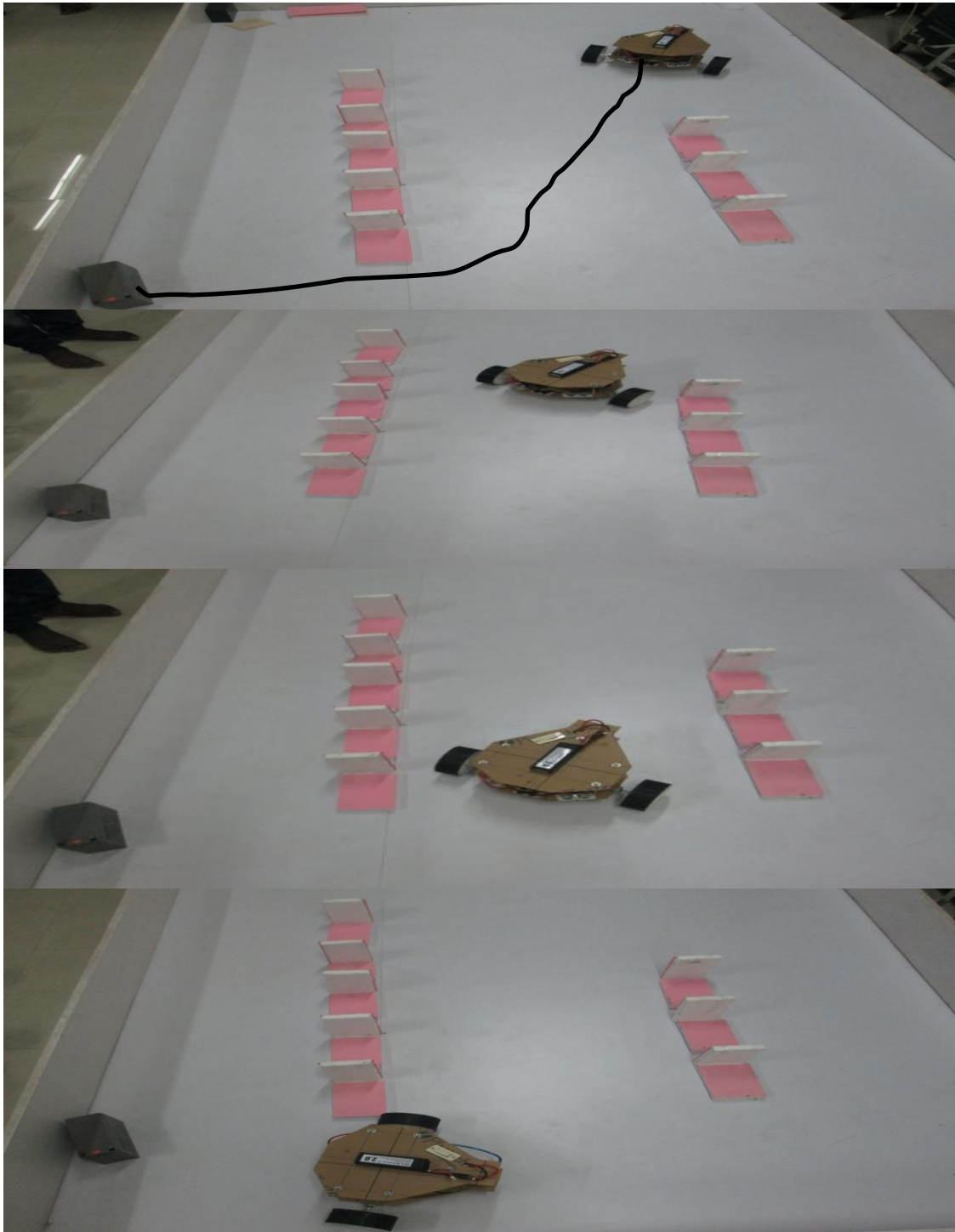


Fig.6.3: Simple Environment with the obstacles

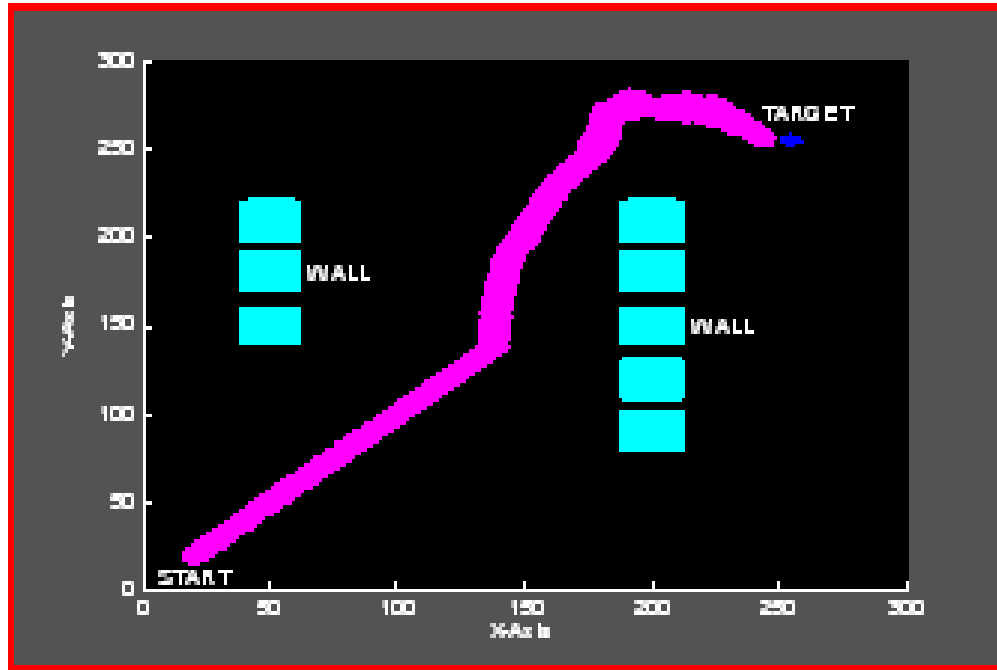


Fig.6.4. Wall following behavior for mobile robot

In other conditions, we are considering the eight obstacles that are located easily in the surrounding. In this cases lab build mobile robot detects the obstacles with the help of sensors and reached to the destination. The time required to reach the destination is 20.84seconds and due to obstacles present in the surrounding path length increased as compared to no obstacles present in the surrounding. The simulation is carry out by writing the code in MATLAB using mamdani fuzzy logic. The obstacles present in the surrounding having the different positions. In simulation, we move the robot to point (250cm, 250 cm). As in figures 6.4, robot turns gradually and smoothly toward target point and time required to reach the destination using mamdani fuzzy logic is 22.60seconds.

In another conditions, we are considering the complex environment with eight obstacles as shown in figure 6.5. In this also due to complex surrounding robot required more time to reach the destination as compared to previous conditions. In these conditions, experimentally lab build robots require 29.34 seconds and with help of simulation the time required to reach the destination is 26.96 seconds. The error between the simulation and experimental is 8.83%. So in this we taken different conditions then we conclude that the simulation result require less time as

Navigation of Mobile Robot in Cluttered Environment

compared to experimental. If we considering the complex environment then error between the simulation and experimentally is slightly increasing.

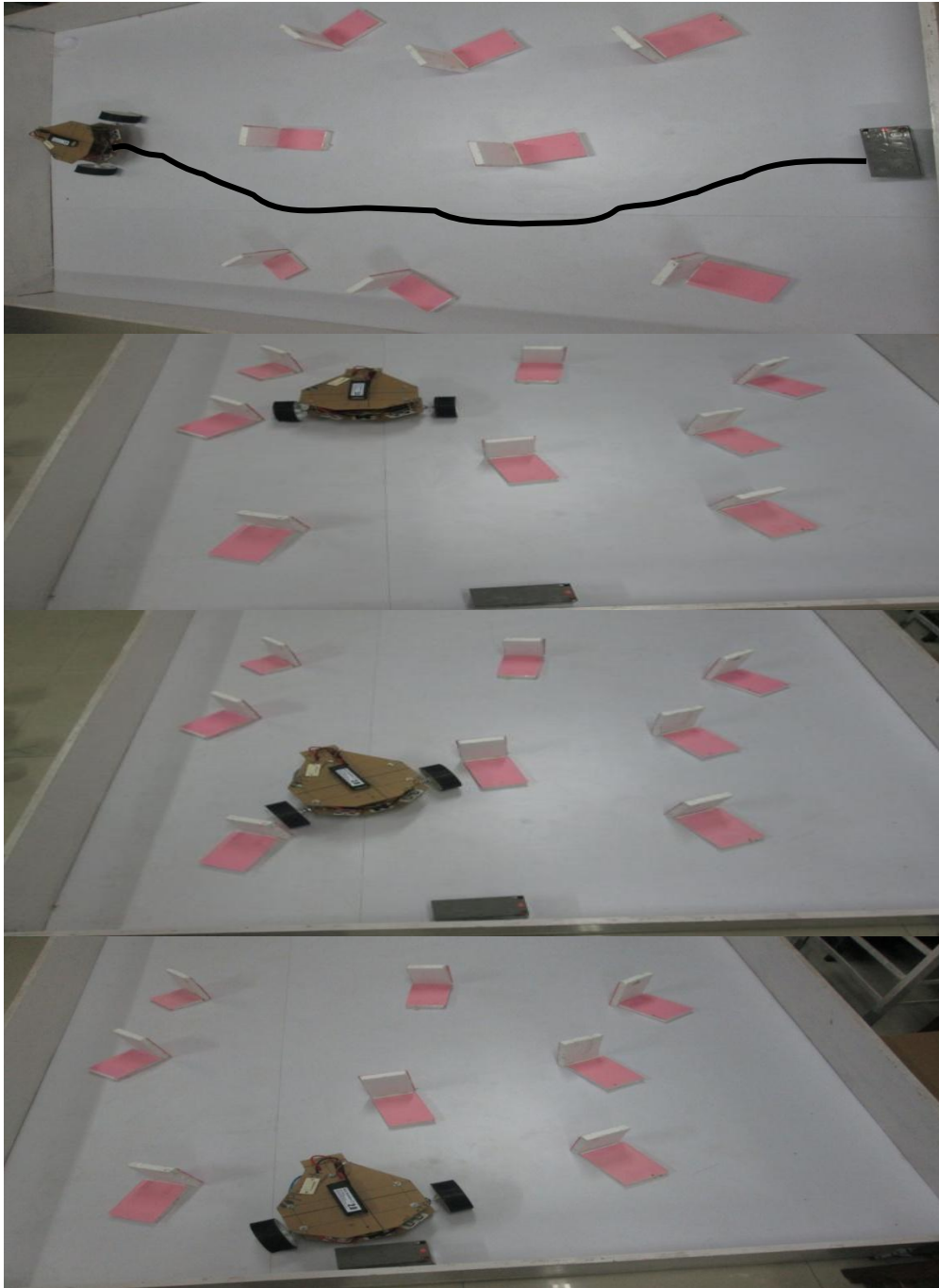


Fig.6.5: Complex Environment with obstacles

TABLE 6.1: EXPERIMENTAL AND SIMULATION RESULT

Sr. No.	Figure Description	Navigation Path length in pixels		Time taken to reach the target in seconds		Error between simulation and experimental Result
		Simulation Result	Experimental Result	Simulation Result	Experimental Result	
1	Target finding behavior for mobile robot	560.43	565.50	15.26	16.40	7.47%
2	8 Wall following the behavior for mobile robot in simple environment	655.48	662.40	20.84	22.60	8.44%
3	8 Wall following the behavior for mobile robot in maze environment	740.32	752.65	26.96	29.34	8.82%
4	12 Wall following the behavior for mobile robot	810.56	826.41	32.12	35.16	9.46%

7

CONCLUSION AND FUTURE WORK

Where the human being cannot work properly and different obstacles are present then with the help of mobile robot, work can be done easily. In the current research, different environments are considered to find out the navigation path for the mobile robot. The structure of the kinematic models of various types of wheeled mobile robots is also studied. The simulation is done by writing the code in MATLAB in different environment scenarios while avoiding obstacles present on the robot path. The success of the robot navigation depends upon the accuracy of complete measurements of positions (mobile robot, obstacles and destination point), velocities (or speeds of mobile robot) and its rate of change of heading angle (of a mobile robot). In this, we use fuzzy logic technique (FIS) for navigation of an autonomous mobile robot in an unknown environment. The simulation results showed that the proposed method enables the mobile robot to reach safely the destination (or goal) without colliding the obstacles. Experiments are also carried on lab build mobile robot. Comparison between the simulation and experimental results is done for establishing the authenticity of the technique developed. The mobile robot along with the technique can be used in different remote and hazardous applications.

Scope of 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.

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