FUZZY LOGIC CONTROLLER DESIGNED FOR AUTONOMOUS MOBILE ROBOT

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Abstract: ***An effective collision avoidance technique is required for accurate navigation. The proposed model is implemented by integrating multiple ultrasonic sensors for recording the data, visual sensors to validate the robot is following the right direction, tactile sensor to observe the minor obstacles below the robot that cannot be sensed by the other sensors present in the robot, wheel speed sensors to denote the number of rotations per minute and its direction. The sole purpose is to implement a fuzzy logic controller that rules the behaviour and auto navigates. It takes in all the data from all the input sensors to a central processor and sends to the motor and steering actuator to perform the action. The results obtained reassures a stable satisfactory performance proposed by the fuzzy logic controller. Additionally, the mobile robot meets the expectations of the design objectives.***

Keyword: Mobile robots; Collision avoidance; Fuzzy Logic; Controller; Auto navigation

I. INTRODUCTION

Autonomous self-driving mobile robot navigation research has attracted many researchers attention and is a popular field of scientific research. Fuzzy logic can take values from a variety of sensors. This paper presents a fuzzy logic controller that is designed to sense and avoid obstacles. It also auto navigates the mobile robot to the targeted destination using an electric motor and a steering actuator. The FLC includes ultrasonic sensors, a laser sensor, a tactile sensor and GPS sensors. It is implemented using fuzzy toolbox in mat lab, where the system is automated.

A logical operational method that depends upon multivalued variables mainly the truth value would be between 0 and 1 i.e. 0 considered to be false and 1 as true. Hence the degree of truth is used as a mathematical model for fuzzy logic.

The logic depends upon people's observation which leads to imprecise information and vagueness, therefore the term fuzzy. Fuzzy models have the ability to recognise, manipulate and utilise the given information that lacks certainty.

The classic logic allows only results which are either true or false. There may also be various answers, such as when the group is asked to recognize a picture. In this case, it is reasoning for results based on vague or partial knowledge that are samples and mapped on to a spectrum.

II. RELATED WORK

This publication by Ching-Han Chen has given a consequential advantage to the fuzzy logic controller of mobile robots. According to which the FLC in Obstacle avoidance consists of a central system with a spinal cord that is dependable for integration of the signal from sensors and brain that causes the execution of the instructions that are connected with various parts of the sensory network[1].

The design of Obstacle Avoidance was intended to navigate the robot in such a way that is must avoid obstacles and collision. Which consists of three input ultrasonic sensors front, left, right as the obstacle avoidance fuzzy controller the controller calculates the speed of the robot and instructs the direction of the robot to be changed by a predetermined angle[2]. All the inputs are assigned to member functions. The results were fairly good. And the intelligent behaviour control research was effective on the robot actions analysis[3]. Planning a direction depending on a fuzzy logic module for steering control was proposed by reflective navigation. It had all the intellectual behaviour-based control.

The basic method was the use of an ultrasonic sensor for obstacle detection and Arduino microcontroller board the robot was responsive for all the environmental behaviours [4] i.e. accordingly aggregating the distance data although the same technique of using ultrasonic sensor failed in detecting an obstacle according to the study symmetrical objects such as a cylinder. The beam of the sonar sensor strikes the surface along with the incidence object and reflected further away echo in place of going back hence, no obstacle was detected [5]

The primary study in the development of FLC with the use of sensor data that can control the speed and the angle that it turns[6]. The Outcome was very successful and was applied on their mobile robot e-pock that could find a safe path for a goal point the result of it was also successful.[7] These implementations were simulated using the WEBOT Pro software.

III. METHODOLOGY

The design is implemented using the type to Mamdani fuzzy logic which is a most commonly used interference system a four-stage fuzzification process as shown in the figure below
It takes all the input values and analyses the degree that it belongs to appropriate to the fuzzy sets that range between 0-1.

The fuzzy rule evaluation using fuzzy operators (AND, OR) the use of many antecedents to obtain a single output the expert fuzzy system makes use of the classical union operation

According to the mobile robot implemented we derive the member function based on a simple derivation for both the operators for AND its max for OR its min i.e. product together calculated as

$$\mu A \cup B(X) = MAX\ [\mu A(X), \mu B(X)]$$
$$\mu A \cap B(X) = MAX\ [\mu A(X), \mu B(X)]$$

$$\boxed{\therefore \mu A \cap B(X) = PROD\ [\mu A(X), \mu B(X)]}$$

The rules are then aggregated to a single fuzzy set for each variable output. Deffuzzification the last stage of the process is where the outputs are evaluated into a crisp output value. Which helps in analyzing the rules and uses the centroid technique to do so, mathematically defuzzification is expressed as

$$\text{Centroid of area } z_{COA} = \frac{\int_z \mu_A(z) z \mathrm{d}z}{\int_z \mu_A(z) \mathrm{d}z}$$

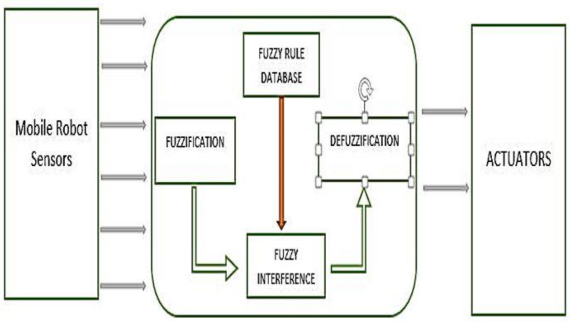

Figure 1: Fuzzy Logic Structure

Obstacle detection

Autonomous mobile Robot where the inputs are the three ultrasonic sensors, visual sensors for validity of the target, tactile sensor in the front and the laser sensor for the rare then, as it is expensive these inputs are signaled to a central motor board which in resultant controls the direction in such a way that it a detects and avoid the obstacle signals the actuator to move in following directions FORWARD, BACKWARD, RIGHT, LEFT and STOP.

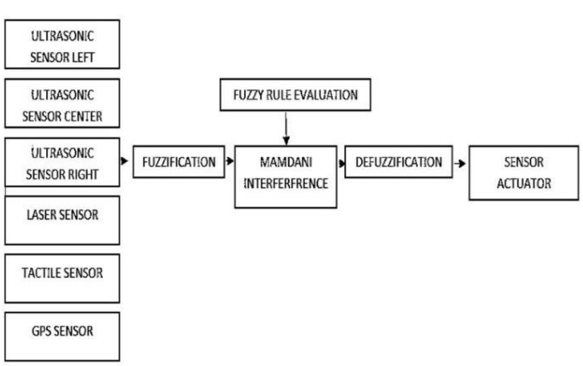

Figure 2: Fuzzy Flow for Obstacle Detection

IV. Construction

This section discusses the construction and positioning of various sensors on the robot. There are three ultrasonic sensors used at the front each at an angular difference of 45˚. This ensures that there is a wide area of coverage and the robot is able to calculate other alternate paths in case of an obstacle present ahead of it. There is a tactile sensor suspended from a flexible arm at the lower front region of the robot. Under certain circumstances, if the ultrasonic sensor fails to sense a low-lying obstacle, a tactile sensor can detect this and stop the robot immediately.

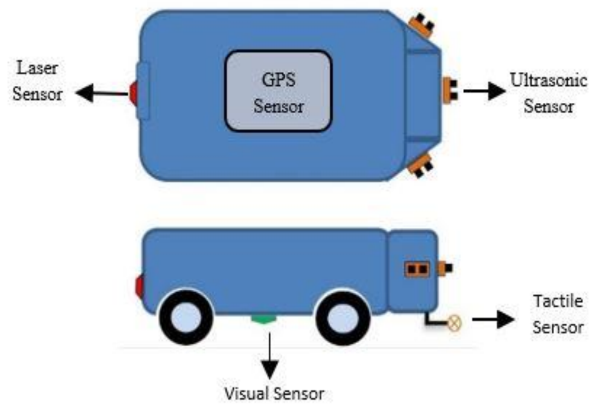

Figure 3: Robot Structure

A visual sensor is present at the rear section of the robot in order to assist the robot with obstacle detection. If a situation arises for the robot to reverse itself and navigate around the obstacle, the laser sensor is used to check for any obstacles behind the robot.

The robot has a visual sensor present under it such that it detects the colour painted on the floor and takes directions to follow that line. This is also used to check if the robot is moving on the right track. There is a GPS sensor present inside the robot also assisting with navigation and re-routing operations.

V. Sensors Selection and Application

1) Ultrasonic

An ultrasonic sensor works similar to a radar where it transmits high-frequency sound waves when the waves hit an obstacle in its path and are reflected back the ultrasonic sensor. Based on the time taken for the wave to return after reflection from the obstacle, the distance is calculated. Ultrasonic sensors may not provide accurate data but are economically viable.

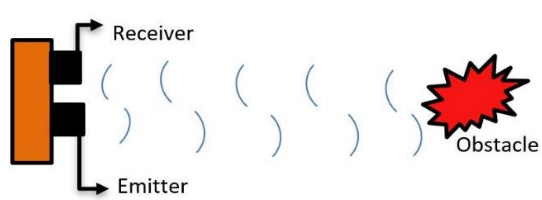

Figure 4: Ultrasonic sensor flow

2) Laser

A laser sensor emits a laser light to obtain the distance of an object. It has the capability to measure distance accurately. Although laser sensors are highly precise, they are very costly.

3) Visual

A visual sensor is used to detect the various colours in the Red, Green, Blue (RGB) spectrum. This sensor can detect and differentiate the different colours present in front of it.

4) TACTILE

A tactile sensor is more like a physical sensor, it passes a signal only if an external object physically is in contact with it. This cannot be

5) GPS

This is simply expanded as the Global Positioning System. This device locates the position by identifying the latitude and the longitude of that location. It is used to find the instantaneous position of the robot in order to guide it to its destination.

VI. WORKING / FUNCTIONS

1) Obstacle Detection

The Robot has 3 ultrasonic sensors at the front positioned at different angles to obtain a combined obstacle scanning area of 270˚. The ultrasonic sensor present at the center scans for an obstacle right in front of the robot whereas the other sensors look for any elements present on the side. The additional ultrasonic sensors on the right are used to scan the side area of the robot so that it can choose an alternate path when there is an obstacle in front of the robot.

CASE 1:
When there is an obstacle towards the front and side of the robot.

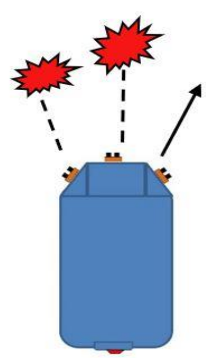

Figure 5: Obstacle Avoidance

In the example shown below, there is an obstacle present in front of the robot and towards its left. In such circumstances, the robot moves 45˚ right as there is no obstacle in that path. There is sufficient distance maintained from the obstacle to ensure that the robot has enough space to turn itself and move around the obstacle.

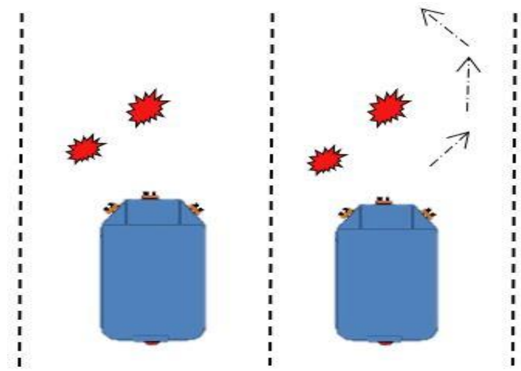

Figure 6: Robot Sensor Path navigation angle

CASE 2:
When there is an obstacle in all three directions ahead of the robot, the robot moves back until there is no obstacle ahead of it and takes a detour.

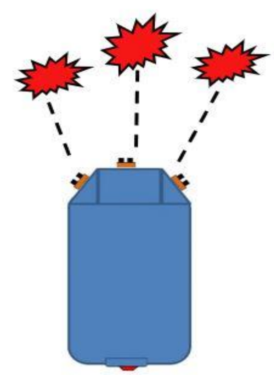

Figure 7: Robot sensor detected with obstacle in all ways

The Robot moves back from the obstacle and at this instant, a laser obstacle sensor placed at the rear ensures there is nothing behind the robot in order to avoid any rear-end collision.

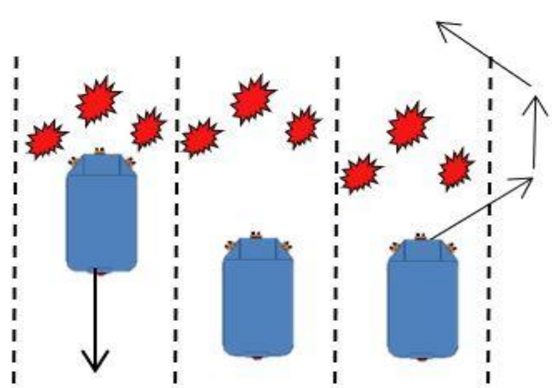

Figure 8: Path detection in worst case scenarios

The robot reverses itself unless there is no obstacle present ahead of the robot and auto navigates itself around the obstacle.

CASE 3:
When the ultrasonic sensor fails to detect an obstacle, but the tactile sensor detects the obstacle. In such circumstances, the robot reverses itself (same as case 2) unless there is no object detected and navigates itself at the safest path around the obstacle

2) Autonomous Navigation around the obstacle

The robot is programmed with the intent of it being able to reach from the start point to the destination with the capability of avoiding any obstacles on the way. The navigation is achieved by using a GPS sensor onboard the robot in order to track its live position.

There is a visual sensor present under the robot that constantly scans the ground for various colours, this technique is implemented such that the robot can follow a colour coded line on the ground.

The GPS is only used when there is an obstacle present and if the robot must navigate itself around the obstacle else the visual sensor is used to follow the colour coded line. As the GPS takes time to process, the visual sensor is used to increase data processing speed. Hence for regular operations, a visual sensor is used whereas for special navigation tasks the GPS is used.

The floor is colour coded and each colour gives a different navigational command to the robot as shown in the table below.

Colour	Navigational Command
White	Move Forward
Red	Stop
Green	Turn Right by 90˚
Blue	Turn Left by 90˚

Table 1: Visual Sensor Parameter

Based on the various colours present on the ground the robot takes directions as shown in the figure below.

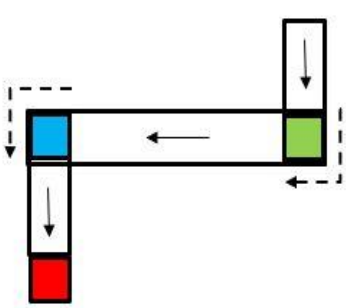

Figure 9: Visual Sensor Color Detection:

In case of an obstacle present in the path, the robot first moves out of the path and then tries to navigate itself around the obstacle. Under such circumstances there will be no colour coded line for the robot to follow hence the use of GPS is essential at this moment.

The GPS sensor works by constantly communicating with a minimum of three to four satellites to obtain the latitude, longitude and the altitude of a location. For this application, we consider and use only the latitude and longitude.

When the robot encounters an obstacle in its path, based on the different sensor inputs the robot moves towards the area where there are no obstacles. Once the robot reaches this spot away from the obstacle the position of the robot is obtained through the GPS. The map and coordinates of the robot's path are pre-programmed into the robot.

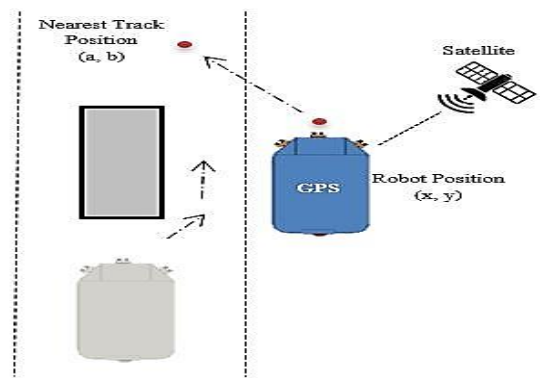

Figure 10: Robot GPS positioning

The Controller now compares the coordinates of the shortest route that would take the robot from its current position back to the path of intended travel. Once the controller decides the shortest path, the ultrasonic sensors validate that the path is clear else the robot keeps moving forward until it finds a clear path back to the original track. Once the robot is back on track, the visual sensor takes over the navigational tasks.

VII. RESULTS

Simulation results were validated while varying their antecedent parameters. The simulation was taken place using Matlab with fuzzy logic toolbox under window 8.1 operating system. An autonomous mobile robot is taken into consideration that it has 4 ways to move forward, backward, right and left.

To determine the member functions of the input sensors are analysed such that each of the input lines has 3 member functions, the triangular function is user defined by a lower limit of 0 and 3 for ultrasonic all sensor except the visual sensor is between 0-1. The GPS sensor has two member functions i.e. Latitude and Longitude it is used to locate the current position of the robot to the final target location. The Output sensor ranges between 0-10

Input			Output	
Ultrasonic Sensor			Navigational Output	Wheel speed Output
Left	Centre	Right		
Far	Far	Far	Move Forward	Fast
Far	Medium	Close	Move Left	Medium
Far	Close	Medium	Move Left	Medium
Medium	Far	Close	Move Forward	Slow
Close	Far	Medium	Move Forward	Slow
Close	Medium	Far	Move Right	medium
Medium	Close	Far	Move Right	Medium
Close	Close	Close	Move Backward	slow
Medium	Medium	Medium	Move Forward	Slow

Input			Output	
Laser Sensor	Tactile Sensor	Visual Sensor	Navigational Output	Wheel speed Output
Far	-	-	Move Backward	Fast
Medium	-	-	Move Backward	Medium
Close	-	-	Move Backward	0- Stop
-	Not Detected	-	Move Forward	Medium
-	Detected	-	0-Stop	0-Stop
-	-	White	Move Forward	Fast
-	-	Red	0-Stop	0-Stop
-	-	Blue	Move Left	Medium
-	-	Green	Move Right	Medium

Table 2: Fuzzy Rules

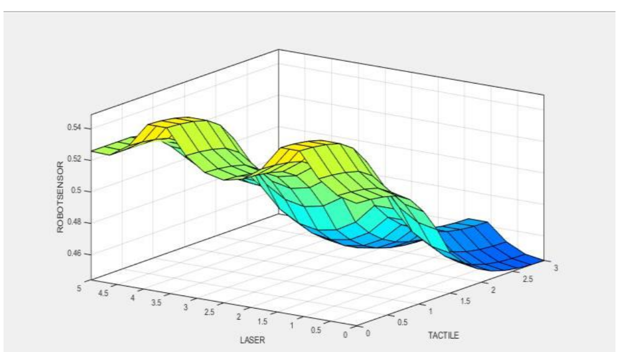

Figure 11: Tactile & Laser Sensor Plot

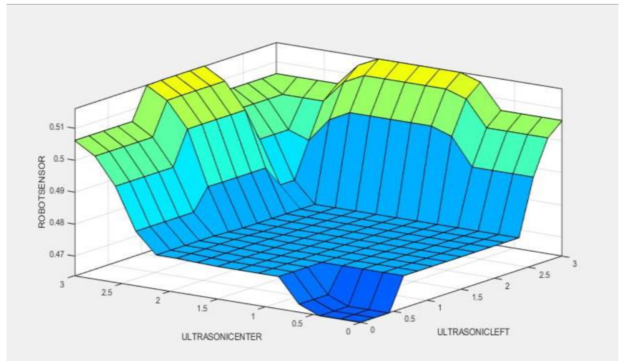

Figure 12: Ultrasonic sensor plot

These are the member functions rules that depict it, for example the position of the ultrasonic sensor is far from the obstacle then the robot moves forward and the wheel speed would be fast. And henceforth it continues. The analyses of the simulations have given a significant result that shows a better accuracy that is depicted through a surface plot below it

VIII. Hybrid Systems

In fuzzy logic and neural networks has two classifications first is the fuzzy neural-neural control, that interprets information's about processing before it is applied to fuzzy logic the other is known as neuro-fuzzy control aggregates the fuzzy logic and linguistic terminal rules into a neural network structure control. There consists of 4 types of hybrid systems where first the input is processed by fuzzification that use fuzzy systems in FLC the interference and the rules are set by the neural networks[8]. The structure was represented for an autonomous robot.

The fuzzy data is processed via fuzzy logic and then a model is built to perfection in neural networks. The functional operation for this is easy and simple due to the real learning ability of neural network it is a disadvantage from the fuzzy system. The function optimization in a neural network depends on the response of the errors through gradient descendent that can also be implied to the parameter of fuzzy structure[9]. To reduce certain errors is to reduce the dependency of uncertain data by classifying them into certain and uncertain out of which most of them were uncertain as it was processed by the fuzzy systems.

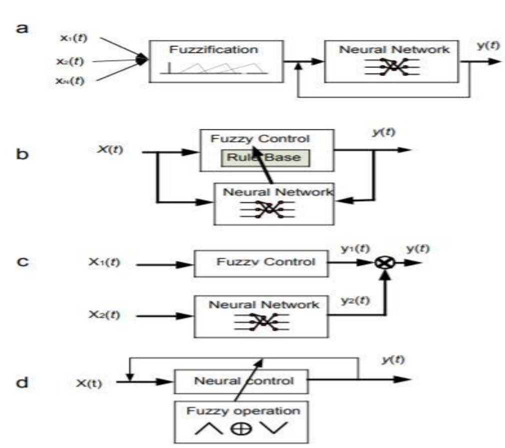

Figure 13: Fuzzy types for intelligent robot

Generally, autonomous robots need not necessarily receive the detailed data for moving in an uncertain environment in such situations fuzzy controllers are a reliable technique for robots yet a challenge to improvise fuzzy system.

This gave a broad view of computational intelligent techniques that can be implied to Industrial robot Control systems. Despite this technique being very common but the tool for building the intelligent controller is stronger .there are few factors to consider

The main goal must be to find the solution for the problem in the robot controller design, such that the method can be simple and reliable.

Considering the various types of computational technique that are needed for many robot controlling issues

Use of a single computational technique will not be sufficient enough to solve the practical problems. The traditional approach must be utilized with computational methods.

By far this approach of combining the neural systems, fuzzy logic and evolutionary optimized algorithms is the most reliable approach and increases the efficiency of the performance of the controller in an autonomous robot.

The significance of computational intelligence is automated optimization implied on parameters and control system structure of the robot.

IX. Conclusion

The stimulation analysis presents the best approaches to three main objectives i.e. Obstacle avoidance that can control the direction by auto navigation and the wheel speed can be defined depending on many criteria. Further the steady approach can brief on using a 360° usage of an autonomous robot that could help in resolving most of the sensor accuracy issues.

X. References

[1] C. Chen, C. Wang, Y. T. Wang, and P. T. Wang, "Fuzzy Logic Controller Design for Intelligent Robots," vol. 2017, 2017.

[2] I. N. Da Silva, F. A. C. Gomide, and W. C. Do Amaral, "Navigation of mobile robots using fuzzy logic controllers," in *AMC'98 - Coimbra. 1998 5th International Workshop on Advanced Motion Control. Proceedings (Cat. No.98TH8354)*, pp. 346–349.

[3] M. Faisal, R. Hedjar, M. Al Sulaiman, and K. Al-Mutib, "Fuzzy Logic Navigation and Obstacle Avoidance by a Mobile Robot in an Unknown Dynamic Environment," *Int. J. Adv. Robot. Syst.*, vol. 10, no. 1, p. 37, Jan. 2013.

[4] X. Li, X. Li, and B. Choi, "Design of Obstacle Avoidance System for Mobile Robot using Fuzzy Logic Systems."

[5] Institute of Electrical and Electronics Engineers, *2018 IST-Africa Week Conference : 09-11 May 2018, Gaborone, Botswana.* .

[6] A. shitsukane, W. Cheriuyot, C. Otieno, and M. Mvurya, "A Survey on Obstacles Avoidance Mobile Robot in Static Unknown Environment," *Int. J. Comput.*, vol. 28, no. 1, pp. 160–173, Mar. 2018.

[7] "(PDF) Fuzzy Logic Sensor Fusion for Obstacle Avoidance Mobile Robot." [Online]. Available: https://www.researchgate.net/publication/325333817_Fuzzy_Logic_Sensor_Fusion_for_Obstacle_Avoidance_Mobile_Robot. [Accessed: 20-Feb-2019].

[8] J. A. Bullinaria and X. Li, "An introduction to computational intelligence techniques for robot control An Introduction to Computational Intelligence Techniques for Robot Control," no. June, 2007.

[9] M. I. Ibrahim, N. Sariff, J. Johari, and N. Buniyamin, "Mobile robot obstacle avoidance in various type of static environments using fuzzy logic approach," in *2014 2nd International Conference on Electrical, Electronics and System Engineering (ICEESE)*, 2014, pp. 83–88.

MEMBER FUNCTION

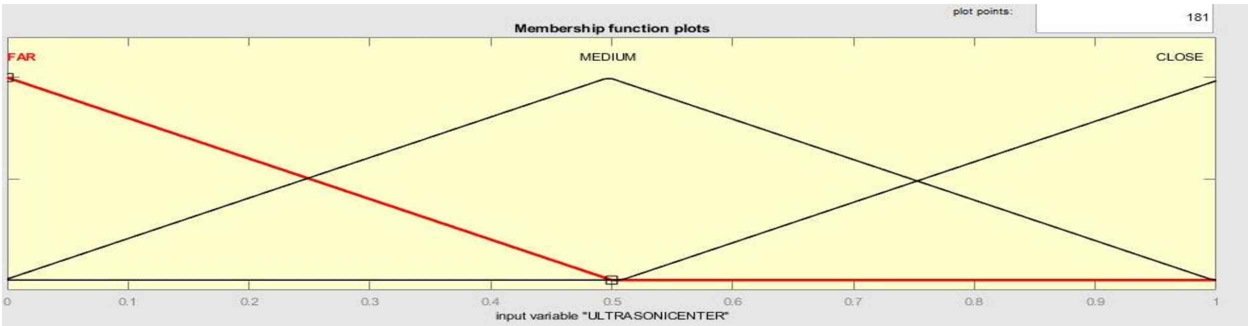

Figure 11: Ultrasonic Sensor Member functions

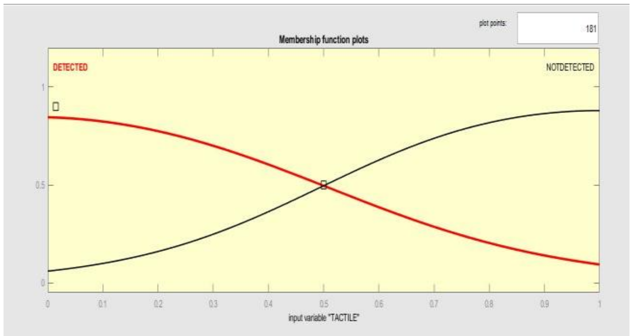

Figure 12: Tactile Sensor Member Function

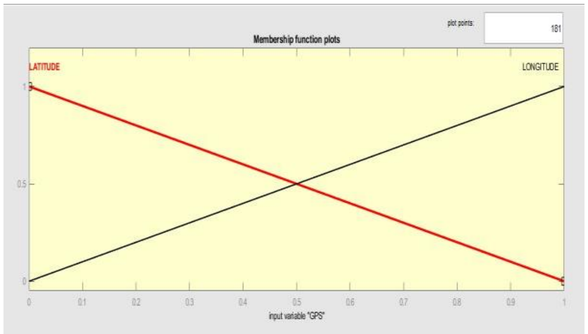

Figure 13: GPS Sensor Member Functions

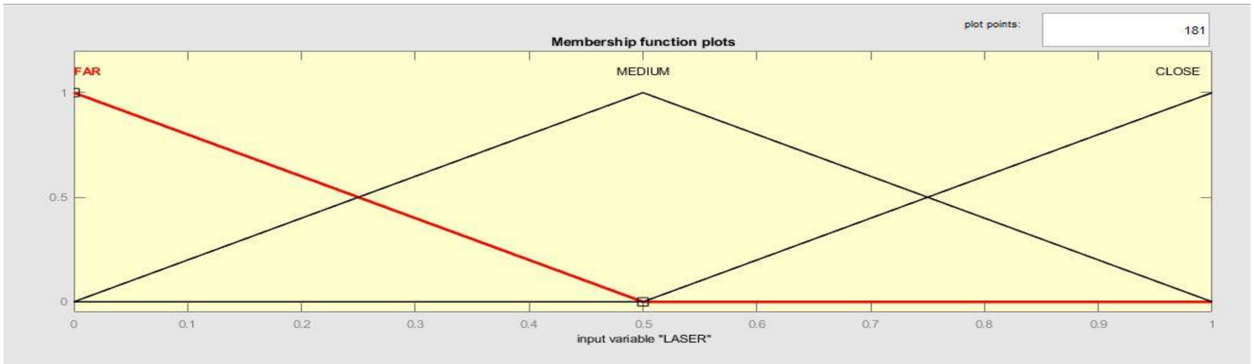

Figure 14: Laser Sensor Member Function

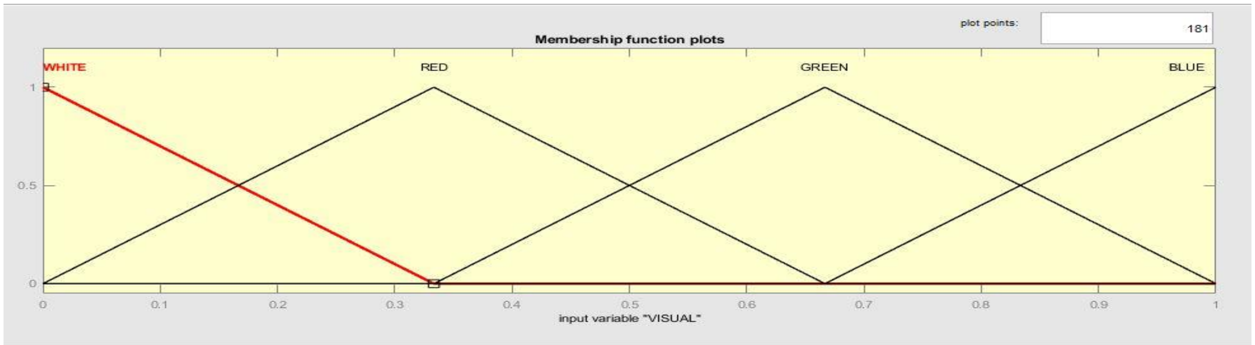

Figure 15: Visual Sensor Member Functions

SIMULATION RESULT

Figure 16:Robot Sensor Simulation Output

Surface Plots for various sensors inputs and Outputs.

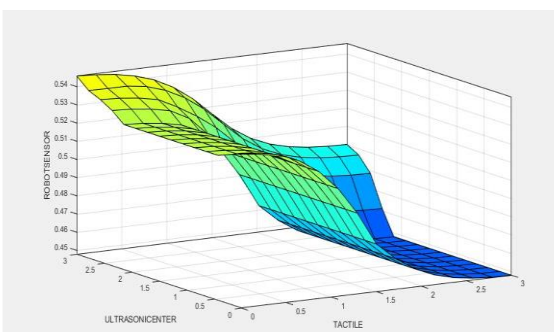

Figure 17:ultrasonic and tactile sensor detecting direction

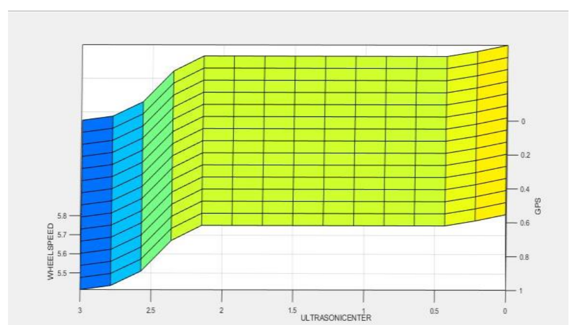

Figure 19: ultrasonic sensor detecting speed

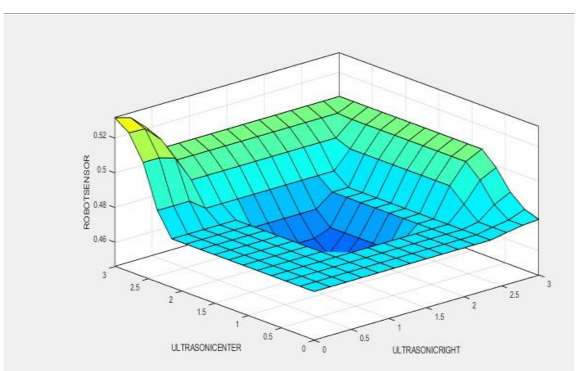

Figure 18: Ultrasonic sensors detecting navigation path