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Design of Fuzzy Based Intelligent Controller for Autonomous Mobile Robot Navigation

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Abstract— **In this paper, design of an intelligent fuzzy based inference system is presented for autonomous mobile robot navigation, wherein the robot can navigate in its own path without continuous human intervention. The ranging information is provided by multiple sensors (Ultrasonic, LiDAR, and Infrared) for effective environment perception. The data fusion algorithm placed within the system ensures the highest level of accuracy for obstacle detection and collision avoidance. Maneuvering of the mobile robot is made possible by an intelligent fuzzy inference system. The proposed prototype of the mobile robot finds various applications in the domains of autonomous navigation, surveillance systems, managing factory floors etc. Also, it can be act as a test-bed to evaluate various algorithms related to autonomous navigation.**

Keywords: Obstacle Avoidance, Fuzzy Inference System, Data Fusion, LiDAR, Ultrasonic, Autonomous mobile robot

I. INTRODUCTION

In robotics, research problems on navigation algorithms of autonomous mobile robots always grab a special attention. These navigation problems were basically applied to environment perception, localization and mapping and path planning related areas. The design of the mobile robot starts from the selection of the most appropriate sensor. Sensors play a vital role for providing meaningful data such as distance from the obstacle, position, steering angle and velocity of the robot etc.

The use of smart sensors (sensors with built-in noise removal hardware) offers superior accuracy. Further, use of additional hardware/ software filter provides sensor data with very small percentage of error. The controllers integrated within the robot convert these data into meaningful information using suitable algorithms.

In this paper, a fuzzy based intelligent inference system was designed and tested for the effective environment perception and obstacle avoidance for a mobile robot. The ranging data provided by ultrasonic, LIDAR, infrared sensors, mounted on the front as well as on the sides of the robot model act as the input of these fuzzy inference system. The controller works based on two independent fuzzy Inference Systems (FIS). The first 'FIS' is primarily focused on fusing the sensor data from the sensors equipped at the front side of the vehicle, whereas the other 'FIS' provides a meaningful information about the degree of closeness with the obstacle in a Two-Dimensional plane. By analyzing the real-time behavior, suitable modifications were done upon the designed fuzzy rule set.

Section II gives a brief idea about fuzzy logic and its relevance in autonomous vehicle navigation. In section III, explains the different sensors used (LiDAR, IR and Ultrasonic) and their characteristics. In section IV, design and operation of obstacle avoidance robot has been described with the aid of MATLAB/Simulink model.

II. FUZZY LOGIC FOR AUTONOMOUS VEHICLE NAVIGATION

Fuzzy logic is extensively used for solving various navigation related research problems. Most of the manoeuvring related controls, such as speed control, steering control and adaptive cruise control etc. were successfully implemented on an Autonomous vehicle using fuzzy logic. In addition, lot of problems were addressed on an automatic parking robot, which uses various types of sensors. Using singleton method for fuzzification and Mamdani method for reasoning, a fuzzy system introduced for obstacle avoidance [1]. Ultrasonic sensors were used for sensing the obstacles for this fuzzy system. The design of an obstacle detection and avoidance algorithm for an underwater autonomous vehicle (Guanay II AUV) with 3 degrees of freedom - surge, sway and yaw with SONAR sensor interface for real time data acquisition[2]. Individual behaviour design using fuzzy logic technique, by analysing sensory input for navigation is presented in this paper [3]. Using fuzzy inference system, the on-line navigation of a mobile robot [4] in an unknown environment was implemented. Using ultrasonic sensor, a SONAR map was created for the obstacle avoidance [5]. The Percentage error analyses in that work indicates that fidelity is satisfactory. Another work based on an e-puck robot with eight IR sensors controlled by fuzzy logic system for obstacle avoidance applications [6].

Various path planning related works also use fuzzy logic addressing navigation problems [7]. Using SIAM navigation platform and MATLAB-Simulink, a mobile robot was designed with trajectory tracking [8]. In addition to ultrasonic ranging sensors, camera sensors can also be integrated for navigation applications using fuzzy logic [9]. Using the tool Webots Pro simulator, the system behaviour was analysed. Autonomous mobile robots equipped with different types of sensors can always provide a better environment perception. The fuzzy inference systems designed for such systems basically work with the sensors, in a competitive/ co-operative mode of sensor fusion.

III. SENSORS AND CHARACTERISTICS

Sensors are the integral components for any intelligent system. In this paper, the autonomous mobile robot makes the environment perception through a set of different sensors. The ultrasonic sensor (HC-SR04), LiDAR Sensor (GARMIN LiDAR Lite v3) and infrared sensor (SHARP) connected on the front side as well as on left/right sides of the robot are capable of detecting both static and dynamic obstacles. Sensors connected with the front side of the vehicle (Ultrasonic, Lidar and Infrared) and on both sides of the vehicle are capable of acquiring the real-time data.

The sensors mounted on the front side of the vehicle platform work in the 'competitive' type of data fusion algorithm, whereas the sensors on the sides work in the cooperative type fusion method. The basic data fusion schematics used in this work is of a combination of competitive-cooperative algorithm, and the fuzzy based fusion exercise was carried out in this paper. Table 1 provides the specifications of the three sensors.

A. *Infrared Sensor (IR Sensor)*

The infrared sensor (IR) works based on optical triangulation technique [10]. The sensor used here is shown in Fig.1 (SHARP GP2Y0A21YKOF), which has an Infrared transmitter and an optical receiver. Based on the intensity of the received light wave, distance can be calculated.

Fig.1: IR Sensor

The response of the sensor varies on different surfaces [11]. Various studies were carried out to identify the type of obstacle based on the analysis of reflex coefficient [12]. This sensor is less immune to lighting conditions.

B. *Ultrasonic Sensor (US Sensor)*

Ultrasonic sensors are widely used for obstacle detection problems in the area of robotics. In addition to the same, some of the mapping and localization were addressed using this type of sensor. This sensor basically emits sound wave of 40 kHz frequency with the help of a piezo electric transducer. Another transducer attached with the sensor, detects the returning pulses (echo) and coverts to an equivalent voltage value [13]. US Sensor as shown in Fig. 2. The time of flight of the sound waves were computed based on analyzing the timestamp of 'transmitted pulse' and 'received echo'. As the distance with the obstacle increases, this time of flight parameter also increases. The sensor reading can be affected by the variations in Temperature, Humidity, Ambient noise etc.

Fig.2: US Sensor

C. *LiDAR Sensor*

Lidar (Light Detection and Ranging) sensor were widely accepted for handling navigation related research problems. Under harsh weather conditions such as rain, fog etc., these sensors can perform well [13]. The sensor used for this work is GARMIN Lidar Lite v3 (Fig 3.), which provides a coverage upto 40 meters. The Lidar Lite can be interfaced with the hardware through the I2C/ PWM interfaces. Compared with other sensors, the resolution of the lidar based sensor is quite higher, which makes the sensor to perform better in bad weather conditions [14]. Distance towards the obstacle can be calculated based on the speed of light and time of flight parameters.

Fig.3: LiDAR Sensor

Sensor specifications are mentioned in below Table:1.

Table 1: Sensors Specifications

Parameters	**IR Sensor (SHARP GP2Y0A21 YKOF)**	**Ultra Sonic Sensor (HC SR-04)**	**LiDAR Sensor (GARMIN LiDAR Lite v3)**
Range	10cm-80cm	2cm-10m	0m – 40 m
Beam-width	75 Deg.	30 Deg.	~ 0.5 Deg.
Beam Pattern	Narrow (line)	Conical	Pulsed (256 pulse max. pulse train)
Frequency	353 THz	40 KHz	400 KHz
Unit Cost	~ 750 INR.	~ 130 INR.	~ 15000 INR

IV. DESIGN OF OBSTACLE AVOIDANCE MOBILE ROBOT

The obstacle avoidance mobile robot has been designed as illustrated in the block diagram shown in Fig.4. The robot has five input variables viz. infrared, lidar and ultrasonic sensors (for front obstacle distance measurement) and two ultrasonic sensors for left and right side obstacle distance measurements. Output of the system is the angle in which the robot turns depending on degree of closeness (based on left, front and right side obstacle distance) value.

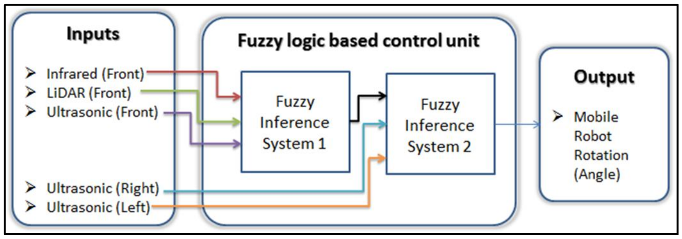

Fig 4: Block Diagram of Obstacle Avoidance Mobile Robot

The infrared sensor provides a better response for the obstacles at a distance from 20 cms to 60 cms. The ultrasonic HC-SR04 sensor can provide a coverage from 0 cms to 200 cms range. Where as, LiDAR Lite v3 sensor can perform well for the distace between 100 cms to 40 meters; which is the largest coverage parameter range, amoung all the sensors. Now it is essential to fuse the data from these sensors for better accuracy for front obstacle measurement within the range of 0 to 40 meters. There are two more ultrasonic sensors provided on both sides of the mobile robot for the detection of the obstacles on the sides. The data form all these sensors, connected to the controller, which works based on fuzzy logic for obstacle detection and avoidance. The system uses Ardiuno Mega – 2560 controller, for the implementation. As this controller provides more serial interfaceing capabilities and matlab-simulink support (Hardware Support Package), we have considered this for the Implementation of autonomous mobile robot for testing the data fusion algorithms on obstacle detection and collision avoidance.

Design of Simulation Model:

The real-time sensor data is captured and processed in MATLAB-Simulink, using separate S-Functions. A wrapper C-MEX S-function is created by this S-function builder block from the C code with multiple input /output ports along with a variable number of scalar, vector, or matrix parameters. The TLC (Target Language Compiler) file is to be used with Simulink Coder for Code Generation for the effective customization. With the help of MATLAB/Simulink, simulation model was designed as shown in Fig. 5.

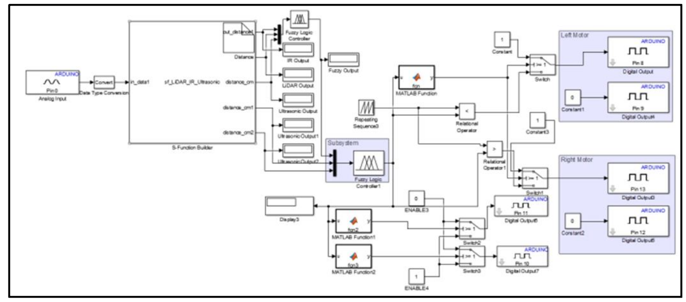

Fig. 5: Simulink Model

The left and right motors of the mobile robot are controlled by the PWM signals generated based on the Degree of Closeness value [0,1]. Whether to turn left or right and what angle it should turn are decided by the fuzzy rules in second fuzzy inference system output degree of closeness. The system uses multiple fuzzy inference systems, and the details of the systems are as below.

Obstacle Avoidance robot - Fuzzy Inference System 1:

The infrared, LIDAR, ultrasonic sensors positioned at the front side of the vehicle provides the ranging data to this system. Each sensor uses three membership functions (triangular type) at the input side of the system. The range definition of the sensors for the membership functions are as follows;

Infrared Sensor: Low (0cm-30cm), Medium (10cm-70cm), High (50cm-80cm) as mentioned in Fig. 6.

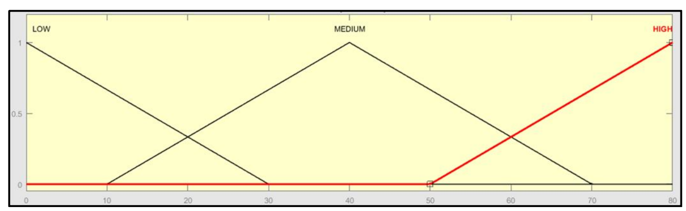

Fig.6: Infrared sensor input membership function of fuzzy inference system 1

LIDAR Sensor: Low (0cm-160cm), Medium (40cm-360cm), High (240cm-400cm) as mentioned in Fig. 7

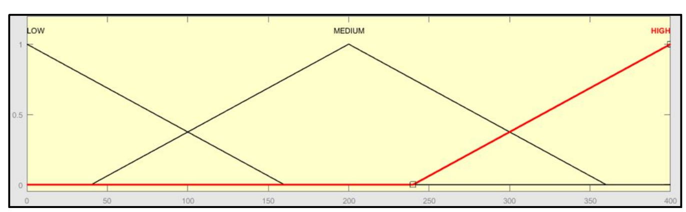

Fig.7: LIDAR sensor input membership function of fuzzy inference system 1

Ultrasonic Sensor: Low (0cm-80cm), Medium (20cm-180cm), High (120cm-200cm) as mentioned in Fig. 8

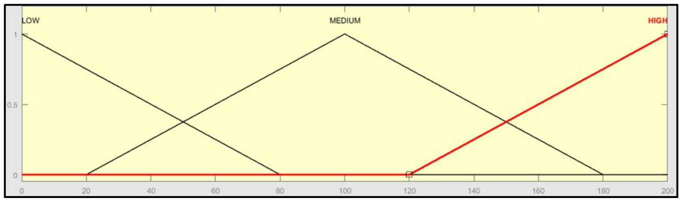

Fig.8: Ultrasonic sensor input membership function of fuzzy inference system 1

The system uses fuzzy based sensor data fusion system to fuse data, from different types of (Two light based sensors and One Sound based sensor). The output memberships function of the system, after data fusion is shown in Fig. 9;

Sensor fusion output: Low (0cm-200cm), Medium (40cm-360cm), High (200cm-400cm) mentioned in Fig. 9

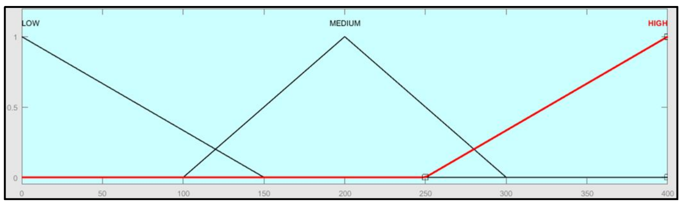

Fig. 9: Fused sensor Output membership function of fuzzy inference system 1

The surface plot of the fuzzy system, after fusion is shown in Fig.10. The Triangular membership function (with 3 MFs), provides a better response in real-time.

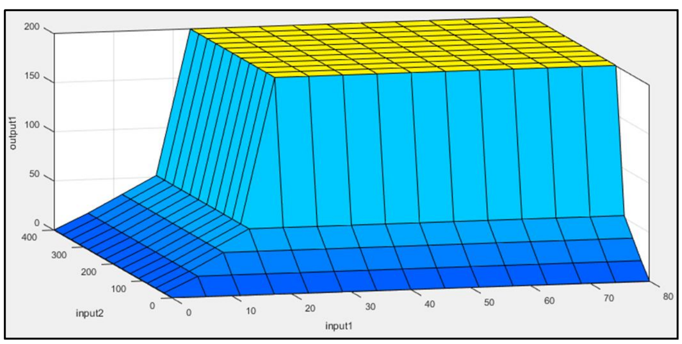

Fig. 10: Fuzzy inference system 1Rule surface viewer

Obstacle Avoidance robot - fuzzy inference system 2:

Two ultrasonic sensors were placed on the left side and right side of the mobile robot for obstacle detection on the sides. The input of these two sensors' are combined with the fused output from the fuzzy inference system 1 for the effective environment perception and maneuvering. With appropriate membership functions and fuzzy rule sets, degree of closeness is calculated and maneuvering was made accordingly. The range definition of the sensors for the membership functions as follws;

Fused output from fuzzy inference system 1: Low (0cm-200cm), Medium (80cm-320cm), High (200cm-400cm) as mentioned in Fig. 11.

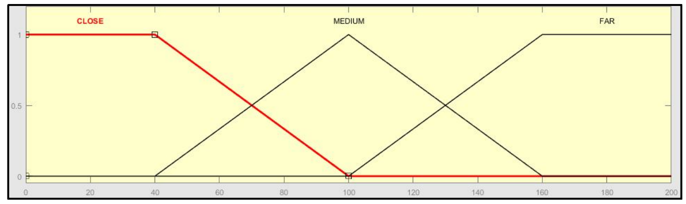

Fig. 11: Fused sensor input (from fuzzy inference system 1) Input membership function of fuzzy inference system 2

Ultrasonic Sensor (Left Side and Right Side): Low (0cm-80cm), Medium (20cm-180cm), High (120cm-200cm) as mentioned in Fig. 12. and Fig. 13.

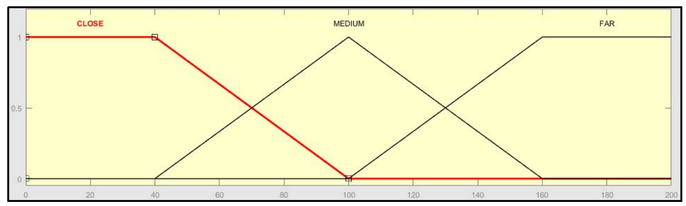

Fig.12: Ultrasonic sensor (Left Side) input membership function of fuzzy inference system 2

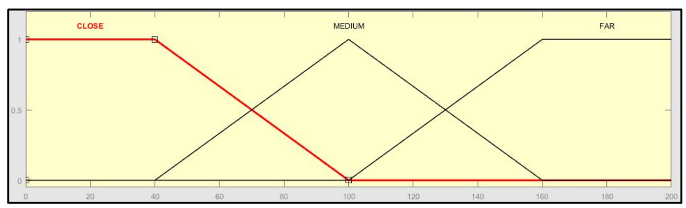

Fig.13: Ultrasonic sensor (Right Side) input membership function of fuzzy inference system 2

The fuzzy inference system 2 is providing the output parameters such as 'degree of closeness' with the obstacle and 'rotation angle' for collision avoidance. The fuzzy rules for the system 2 were made based on the fused output from the fuzzy inference system 1 and the sensors fitted with the left and right sides of the vehicle. For example, if an obstacle is detected on the left side ultrasonic sensor placed at the left side, the vehicle may take a 45 Degrees/ 90 Degrees turn in clock-wise direction. This was done by adjusting the PWM signals of the individual motors connected to the driveline of the autonomous robot.

The details of the membership function are as mentioned in the Table 2 below;

Table 2: Fuzzy Rule set for Fuzzy Inference System 2

Inputs			Output
1st FLC Output (front obstacle distance)	**Left US Sensor**	**Right US Sensor**	**Robot Rotation (Angle)**
Close	Close	Close	+90◦
Close	Close	Medium	+90◦
Close	Close	Far	+90◦
Close	Medium	Close	-90◦
Close	Medium	Medium	+90◦
Close	Far	Close	-90◦
Close	Medium	Far	+90◦
Close	Far	Medium	-90◦
Close	Far	Far	+90◦
Medium	Close	Close	0◦
Medium	Close	Medium	+45◦
Medium	Close	Far	+45◦
Medium	Medium	Close	-45◦
Far	Far	Far	0◦
Medium	Medium	Medium	0◦
Medium	Medium	Far	0◦
Medium	Far	Close	-45◦
Medium	Far	Medium	0◦
Medium	Far	Far	0◦
Far	Close	Close	0◦
Far	Close	Medium	+45◦
Far	Close	Far	+45◦
Far	Medium	Close	-45◦
Far	Medium	Medium	0◦
Far	Medium	Far	0◦
Far	Far	Close	-45◦
Far	Far	Medium	0◦

The output membership functions of the fuzzy inference system 2 as shown below in Fig. 14.

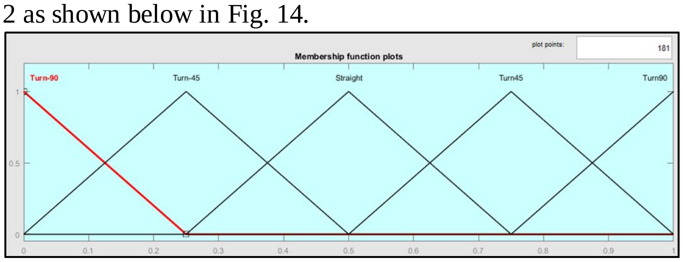

Fig. 14: Output membership function of Fuzzy Inference System 2

The surface plot of the Fuzzy Inference System 2, after fusing the ranging data from Fuzzy Inference System 1and individual ultrasonic sensors as mentioned in Fig.15. The Triangular membership function with five different membership functions were considered for the implementation.

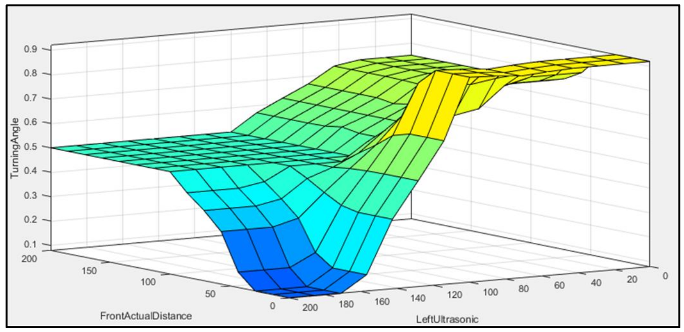

Fig. 15: Fuzzy inference system 2Rule surface viewer

Figures 16 and 17 show the snapshots of the autonomous mobile robot built for testing the basic data fusion algorithms using fuzzy logic.

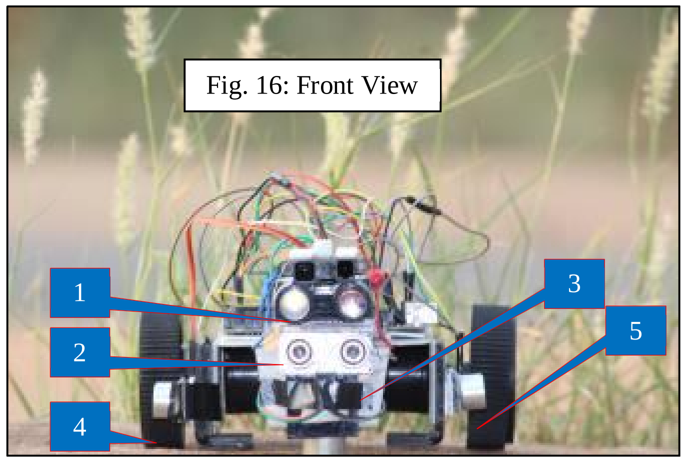

Fig. 16: Front View

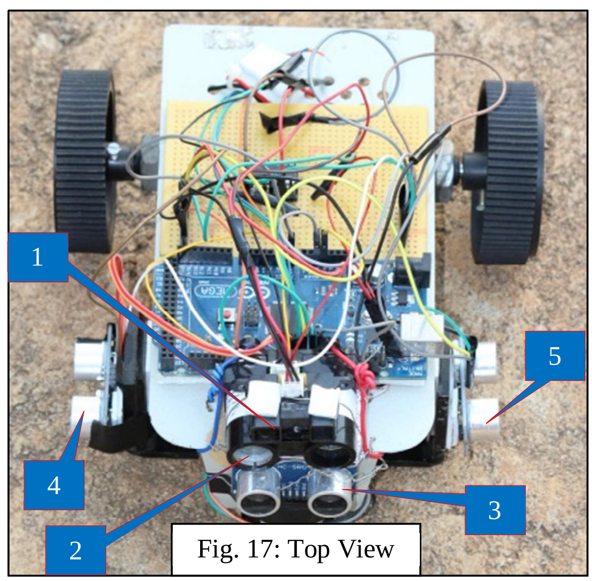

Fig. 17: Top View

The legends used in the diagram are Component 1: IR Sensor, Component 2: LIDAR Sensor, Component 3 - 5: Ultrasonic Sensor.

V. RESULTS AND CONCLUSION

An autonomous mobile robot platform was made, which is equipped with multiple sensors for environment perception. The fuzzy logic based sensor fusion system implemented in this model is based on Type-1 logic. The obstacle avoidance robot responds to the environment in real-time based on the real-time data acquired by the multiple sensors. The manoeuvring of mobile robot was tested. Using advanced fuzzy logic based algorithms such as ANFIS (Adaptive Neuro-Fuzzy Inference System), CANFIS (Co-Active Neuro-Fuzzy Inference System etc., the performance of the overall system can be improved. In addition to the same, type-2 based fuzzy engines also recommended.

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