# A Comparison of Fuzzy Logic Controller and PID Controller for Differential Drive Wall-Following Mobile Robot

Ratnayake R.M.N.B.
Department of Electrical and Computer Engineering
Sri Lanka Institute of Information Technology
Malabe, Sri Lanka
namal.b@sliit.lk

De Silva T.S.
Department of Electrical and Computer Engineering
Sri Lanka Institute of Information Technology
Malabe, Sri Lanka
subashini.d@sliit.lk

Rodrigo C.J.
Department of Electrical and Computer Engineering
Sri Lanka Institute of Information Technology
Malabe, Sri Lanka
chamanthi.r@sliit.lk

***Abstract*— This paper presents a comparison between PID controller and Fuzzy rule based controller of a differentially steered wall following mobile robot. Four different maps, generated using Mapper3 software are used to simulate the robot in MobileSim platform. The code was implemented using C++ language in ARIA development package. The robot simulation is performed with Pioneer P3-DX robot. In this study, the data was collected for each cases such as: left wall following and right wall following. In order to validate the results, maximum of 40 runs were conducted for each map and the results were compared with the illustrated methods.**

***Keywords—Fuzzy, PID, wall following, multi-type-wall, sonar sensors***

## I. INTRODUCTION

Developing and designing algorithms for wall following robots are one of the important studies in mobile robotics. The algorithms developed always depends on the different environments which have different types of walls and obstacles. Hence the accuracy and the reliability of the algorithms constantly vary. Wall following can be defined as a primitive method in indoor navigation due to limitations in the developed methodologies and algorithms. To overcome many drawbacks of developed methodologies in early days [1], researches have focused on methodologies based on sensor fusion algorithms such as Kalman filter, Bayes, Probabilistic approach, Least Squares method, Fuzzy and neural networks, etc. The Fuzzy logic approach is identified as an effective solution for representing certain relationships as it does not require mathematical models to realize reasoning on uncertain information as explained in [2].In recent years researches have focused more in developing fuzzy controllers for behavior modules in robot navigation.

A multi sensor data fusion algorithm has been developed based on Fuzzy Neural Networks by Yi Zhang, Yuan Luo for a wall following robot explained in [3]. In this study Pioneer 3 robot is used as the robot to collect data for three sorts of walls in an unknown environment i.e. straight walls, concave walls and convex walls. Five sonar data are fused using Fuzzy Neural Network and provided feasible and effective results. In [4] usage of Fuzzy Wall-Following controller using ultrasonic is implemented and discussed for a wheelchair. The researchers have compared the results obtained with the model-based controller. Also a study of a Fuzzy logic based intelligent controller has been conducted using a low cost single chip AT89C52 microcontroller [5] for a differentially steered mobile robot with three ultrasonic sensors. The controller for the wall following behavior was designed to follow the wall on left side in a set distance which tested with various shapes of walls including straight, curved and square trajectories.

Interval Type-2 Fuzzy (IT2F) can be used with uncertainty, proximity or uncompleted information to obtain satisfactory performance [6, 7] in reaching goal avoiding obstacles on the navigation path of the wall following mobile robot. To improve the efficiency in wall following different approaches and methodologies have been used. The advantages and disadvantages of Rough-Fuzzy algorithm compared with the Conventional Fuzzy based control have been studied and illustrated in [8] using visual sensor measurements. In [9, 10], Fuzzy based controllers were implemented for a Wall-Following Mobile Robot. In the studies, to maintain the distance of the robot from the wall is maintained using Fuzzy logic controllers in order to make the mobile robot run smoothly in an indoor environment. The behavior based approaches were used as coordinators to manage the switching among various behaviors to solve the multi-type-wall following problem. In the study of [11] a two stage learning approach were used for the Fuzzy controller considering the multi-objective orientation and velocity control of two robots. Each stage of the study was optimized through Multi-objective Front Guided Continuous Ant-Colony optimization (MO-FCACO) algorithm. To improve the efficiency the use PID controllers with Fuzzy controller is discussed in [12] including three different parts in navigation such as obstacle avoidance behavior, target seeking behavior and a behavior supervisor. In the study the obstacle avoidance behavior achieved through evolutionary fuzzy control, a Pareto set of fuzzy controllers through a multi-objective continuous and ant colony optimization algorithm. Target seeking behavior is achieved by controlling the robot through hybrid PID controllers. However a manual setting of three unknown parameters of PID controller often precisely increase instability. Study in [13] discuss an approach to obtain PID parameters automatically by utilizing the role of Genetic Algorithm. The study has shown the effectiveness of reducing the dynamic error of the wall-following robot through a simulation using MATLAB and tested in a real robot.

In this paper a study has been conducted to evaluate the efficiency of a PID controller and a Fuzzy based controller in

978-1-7281-3706-3/19/$31.00 ©2019 IEEE

wall following. In the study simulations have been carried out for different maps using ARIA development package and the MobileSim simulator. P3-Dx differential mobile robot has been used for simulations with eight sonar range sensors. The organization of this paper is arranged as follows. Section II, describe the methodology of the approach, implementation of the Fuzzy logic controller and the PID controller. In section III the experimental results and discussion are shown to illustrate the performance of each controller. In Section VI conclusion and future works are elaborated.

## II. Methodology

### A. Mobile Robot Architecture

The Mobile robot model which was taken for the simulation process is Pioneer P3-DX robot [14]. This robot model is widely used in the mobile robotic researches [15] [16] [17] because, this robot is a combination of various sensors such as: video camera, ultrasonic sensors, gyroscope etc. The sensors used in this study were ultrasonic. There were eight of them in front of the robot as shown in the Fig. 1. The main objective of the study was to design and simulate Fuzzy and PID control model for a wall following robot. Hence, the designing can be discussed in two topics such as: Fuzzy controller development and PID controller development. In next paragraphs, the detailed discussion on these two sections is given. For each cases, usage of sonar sensor reading was similar.

### B. Kinematics of the Robot

A robot with two wheels had to be simulated by taking care of the kinematics on differential steering. This can be explained using the following Equations (1) and (2).

$$V = \frac{V_R + V_L}{2} = \frac{\omega_R + \omega_L}{2} r \tag{1}$$

$$\omega = \frac{V_R - V_L}{d} = \frac{\omega_R - \omega_L}{d} r \tag{2}$$

Here, $V$ is the velocity and $\omega$ is the rotational velocity of the robot. Velocity is calculated by determining the average velocity of two wheels. $r$ is the radius of the wheel and $d$ is the distance difference between two wheels. According to this information, the controllers are designed.

### C. PID controller designing

Designing PID controller was carried out as the flow chart given in the Fig. 2.

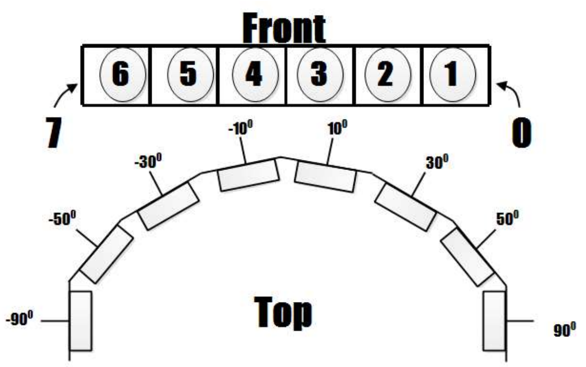



Fig. 1. Sonar array of Pioneer 3 robot [18]

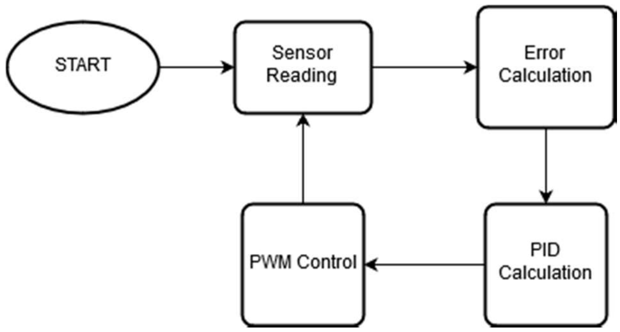



Fig. 2. PID control loop

As shown in this flow chart, the first step was reading the sonar array. The designed system is capable of following either Left wall or Right wall as instructed. Hence, the sensor readings that need to be considered in each cases were different. In left side wall following, Sensor 7, 6 and 5 were considered while in right side wall following, Sensor 0,1 and 2 are considered. These sensor readings were taken in to an array called "Sensor[8]" and stored the values respectively.

Once sensor readings were fetched to the system, as the second step, the error of not being parallel to the wall was calculated using the Equation (3).

$$\cos\theta = \frac{a}{b} \tag{3}$$

Where, $a$ is the Sensor[7] and b is Sensor[6] reading. $\theta$ is the angle between the sonar sensor 6 and 7. In the Fig. 3, the above notation is shown for the left side wall following.

The clearance distance from the wall to the robot was hard corded in the program itself and for the simulation it was taken as $600\,mm$. Since $\theta$ is $40°$, the value of $b$ is approximately become 783 mm. Hence the error could be calculated as in the Equation (4).

$$Error = Sensor[6] - 783 \tag{4}$$

This error was calculated for keeping the robot in parallel to the wall. Using the calculated error a PID controller was implemented to keep the robot parallel to the wall in the navigation path. The above correction has affected the input reading of Sensor[7]. Hence, it was necessary to use another PID controller to steady the distance from wall to the robot by correcting Sensor[7] data. The implemented PID controller was consisted with a combination of two PID controllers.

Once the errors were calculated, the PID gains were calculated in the next stage. PID tuning was done using the Zigner Nicolus method [19]. According to the PID tunings, the simulation gains were taken as follows.

1. Wall – Robot Distance PID
    a. $K_p = 9.0$
    b. $K_i = 0.23$
    c. $K_d = 1.5$

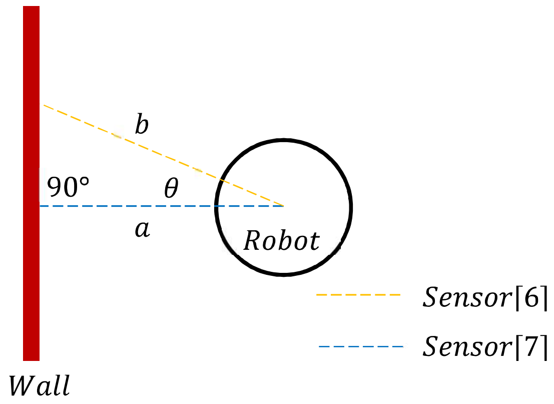



Fig. 3. Left Side wall following

2. Wall – Robot Parallel PID
   a. $K_p = 3.5$
   b. $K_i = 1.0$
   c. $K_d = 0.5$

The final step was to calculate the PWM values. It was calculated using the Equations (5) and (6), shown below.

$$LEFT_{PWM} = LEFT_{PWM} + (PID * 10) \tag{5}$$

$$RIGHT_{PWM} = RIGHT_{PWM} - (PID * 10) \tag{6}$$

*D. Fuzzy Controler Design*

Fuzzy rule based controllers are widely used in many researches [20] [21]. The architecture of this method is shown in the Fig. 4 below.

This system is consisted with four main steps such as:

1. Fuzzification
2. Inference System
3. Defuzzification
4. Plant

In the Fuzzification, the membership functions were implemented using the inputs and outputs of the system. Then, inference system was designed using number of IF-ELSE statements to give the reasonable outputs. At the Defuzzification step, the data fuzzifyed, converted back to the numerical numbers that can be used to control the plant. Knowledge base was involved in each step of the above mentioned to get the advantage of the Fuzzy system.

The complete Fuzzy rule base was implemented on visual studio 2015 environment with the collaboration of Advanced Robotics Interface for Applications (ARIA) development package. Implementation can be discussed using the following example in the Fig. 5.

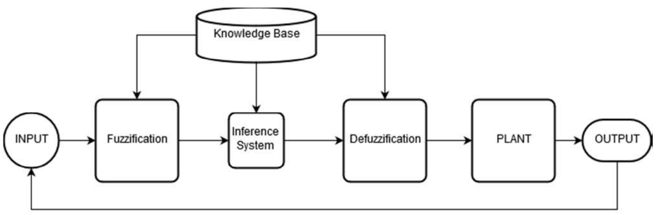



Fig. 4. Fuzzy system implementation

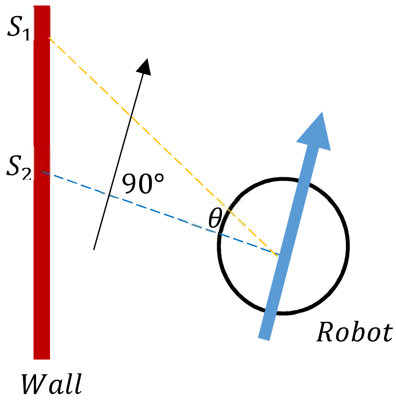



Fig. 5. Example wall following instant

Let the set range of $S_0 = x$ and set range of $S_1 = y$. Then, max range of $S_0 = 2x$ and max range of $S_1 = 2y$. As the first step of the Fuzzy system, calculating a variable being low or high depending on the threshold was as in Equation (7) and (8).

$$Truth\ of\ S_0\ being\ LOW = 1 - \frac{S_0}{2x} \tag{7}$$

$$Truth\ of\ S_0\ being\ HIGH = \frac{S_0}{2x} \tag{8}$$

TABLE I. FUZZIFICATION TABLE

| $S_0$ | $S_1$ | Equation |
|---|---|---|
| LOW | HIGH | $\min(S_0(LOW), S_1(HIGH))$ |
| HIGH | HIGH | $\min(S_0(HIGH), S_1(HIGH))$ |
| LOW | LOW | $\min(S_0(LOW), S_1(LOW))$ |
| HIGH | LOW | $\min(S_0(HIGH), S_1(LOW))$ |

The above combination of being HIGH/LOW gives four combinations for $S_0$ *and* $S_1$ sensors. Then for each case the probability can be calculated as the following TABLE I.

The next step of the Fuzzy system is the Defuzzification. Here a weight table was implemented as shown in the TABLE II below.

TABLE II. WEIGHT TABLE

| Weights | |
|---|---|
| L+2 | 2 |
| L+1 | 1 |
| R+1 | -1 |
| R+2 | -2 |

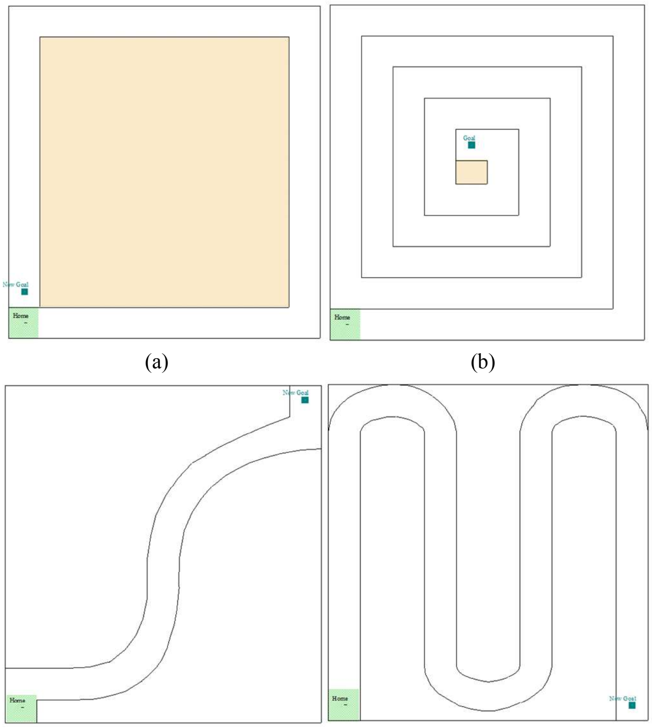
The output was achieved by using the following Equation (9).

$$\frac{\min(S_0(LOW),S_1(HIGH))*(L+2)+\ \min(S_0(HIGH),S_1(HIGH))*(L+1)+ \min(S_0(LOW),S_1(LOW))*(R+1)+\min(S_0(HIGH),S_1(LOW))*(R+2)}{\min(S_0(LOW),S_1(HIGH))+\ \min(S_0(HIGH),S_1(HIGH))+ \min(S_0(LOW),S_1(LOW))+\min(S_0(HIGH),S_1(LOW))} \tag{9}$$

Finally, this output was added to the nominal PWM of the motors as in the Equations (10) and (11).

$$RIGHT_{PWM} = Nominal + OUTPUT \tag{10}$$

$$LEFT_{PWM} = Nominal - OUTPUT \tag{11}$$



(a) (b) (c) (d)

Fig. 6. Simulation Envioirenments, (a) Map-1, (b) Map-2, (c) Map-3 and (d) Map-4

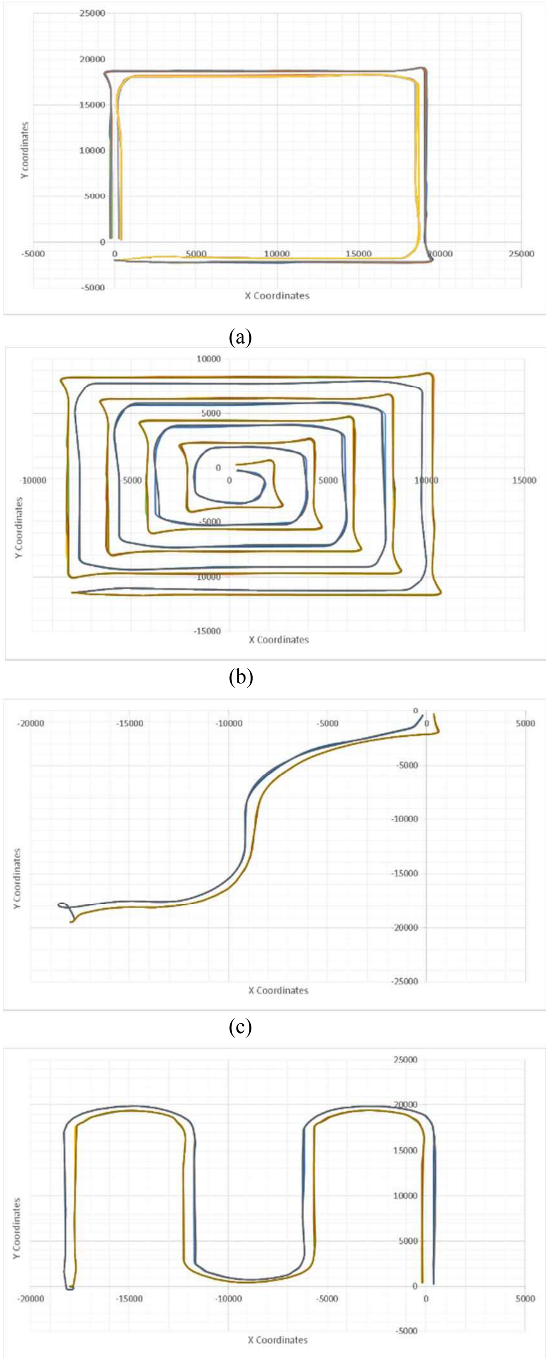
## III. Experimental Results and Discussion

Both Implemented controllers were tested using four different maps generated with Mapper 3 open source software. In order to verify the feasibility of the proposed algorithms, ARIA and MobileSim by MobileRobots Cooperation were used with Pioneer P3-DX differential mobile robot. To test each model behavior 40 test runs were carried out. Then, the run time (time taken to reach the goal from the starting position) and the deviation from the set goal to the arrived position were recorded. Fig. 6, illustrates the maps used for the test runs. In the current study the robot followed concave walls, convex walls, and straight walls and curved walls to right or left were designed.

Each individual controller tested and recorded data for 20 runs for the left wall following and another 20 runs were carried out to record data for right wall following.

In each test run the home position (start position) and the goal position (end position) were same as given in generated maps in Fig. 6. And it neither consisted with any moving object during the simulation nor any obstacle in the navigation path of the mobile robot. The set distance from the robot to a wall was taken as 600 mm.

In Fig. 7, the path followed by the wall following robot with the implemented Fuzzy logic controller is plotted using the recorded data for each individual map. In each the left wall following (up) and the right wall following (bottom) trajectories are also given. Fig. 8, the trajectories of the mobile robot for left and right wall following using the PID controller for each individual map are given. The average run time of each map using the PID and Fuzzy controllers is given in TABLE III.



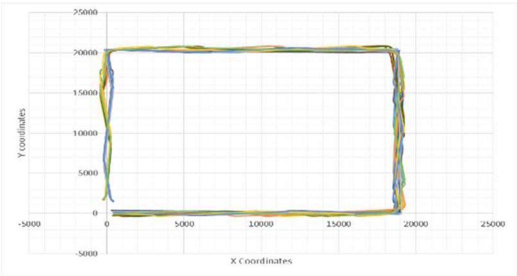

(a) (b) (c) (d)

Fig. 7. Trajectories plotted using simulation results of Fuzzy Logic Controller for Left and Right Wall Following, (a) Map-1, (b) Map-2, (c) Map-3, (d) Map-4

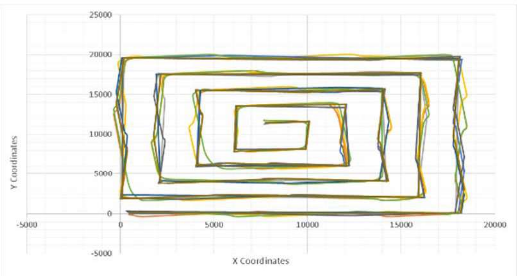
TABLE III. Average Run time of Each Controller

| **Map** | **Average Run Time (s)** | |
|---|---|---|
| | ***Fuzzy Logic Controller*** | ***PID Controller*** |
| Map-1 | 136.33 | 140.99 |
| Map-2 | 468.14 | 477.03 |
| Map-3 | 60.20 | 64.06 |
| Map-4 | 178.97 | 194.89 |

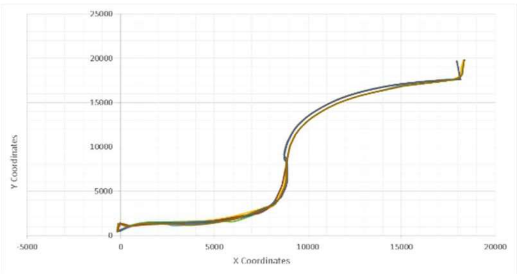
Comparing the results illustrated in Fig. 7 and Fig. 8, the trajectories of the wall-follower using the Fuzzy logic controller has a smooth performance than in the applied PID controller. It also represent that the PID controller was capable in taking sharp turns at the edges. Hence the behavior of the PID controller implemented robot, with the Concave and Convex type walls was accurate than the behavior of the Fuzzy logic controller implemented robot. Also it was noticed that the performance of Fuzzy logic controller with Curved and Straight type walls offered better results compared to the PID controller. According to the figures the capability of following the left or right wall, the Fuzzy logic controller was much effective than the PID controller.



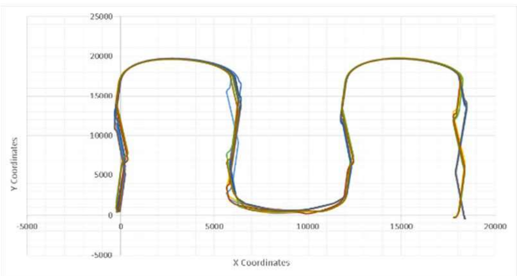

(a)




(b)




(c)




(d)

Fig. 8. Trajectories plotted using simulation results of PID Controller for Left and Right Wall Following, (a) Map-1, (b) Map-2, (c) Map-3, (d) Map-4

Compared to the average run time of each map simulation of both controllers, the Fuzzy logic controller is effective than the PID controller to navigate a robot in an indoor environment without colliding with the walls.

## IV. Conclusion and Future Work

In the current research, the proposed wall following strategies for a wall follower were implemented for various types of walls and the simulation results were observed to analyze the performance of each. The comparison of results illustrated the different capabilities of the implemetned PID controller and Fuzzy logic controller. It was shown that the PID controller was effective in taking shap turns whilst the Fuzzy logic cotroller had the proven capability of smoothly following curved and straight lines.

This study has been done to comparatively evaluate the performance of the implemetned logic controllers to their overall run time in each navigation path. Therefore conpmared to the PID controller, Fuzy logic controller is more practicable and effective. The Fuzzy logic controller has the advantages of, easyness in expressing aproximated knowledge, minimal reaction time and strong learning abilities.

Studying the influence of different strategies on different types of walls will an area of study for future reseraches. The study which was carried out depicted the posibility of utilizing different controllers to increase performance of different stages in the navigation path. Due to the aforementioned reason, and as the basis of future research it is pertinent to exploit the adaptability of wall followers in complex environments.

## References

[1] Yoshinobu AND0, Shin'ichi YUTA, "Following a Wall by an Autonomous Mobile Robot with a Sonar-Ring," in *IEEE lnternatlonal Conference on Robotics andd Automation*, 1995.

[2] K. Watanabe, J. Tang, M. Nakamura, S. Koga, T. Fukuda, "A Fuzzy-Gaussian Neural Network and its application to mobile robot control," in *IEEE Transaction on Cntrol Systems Technology*, 1996.

[3] Yi Zhang, Yuan Luo, "Application of Fuzzy Neural Networks in data Fusion for Mobile Robot Wall-Following," in *7th World Congress on Intelligent Control and Automation*, Chongqing, China, 2008.

[4] Ya-Ting Lee, Chian-Song Chiu, I-Tung Kuo, "Fuzzy Wall Following Control of a Wheelchair," in *IEEE 17th World Congress of International Fuzzy Systems Association and 9th International Conference on Soft Computing and Intelligent Systems*, Japan, 2017.

[5] Umar Farooq, Aisha Khalid Amar, Aleena Habiba, Shareen Shafique, Rabia Noor, "Design and Low Cost Implementation of a Fuzzy Logic Controller for Wall Following Behaviour of a Mobile Robot," in *2nd International Conference on Signal Processing Systems (ICSPS)*, 2010.

[6] Wanderson A.S. Silva, Ricardo A.L. Rabelo, A.M. Santana, "Safe Autonomous Navigation with a Wall Following Robot using Interval Type-2 Fuzzy System in Uncertain Enviorenments," in *IEEE International Conference on Systems, Man and Cybernetics*, San Diego, CA, USA, 2014.

[7] Poornima Varma N, Vivek A, Ravikumar Pandi V, "Intelligent Wall Following Control of Defferential Drive Mobile Robot Alogn with Target Tracking and Obstacle Avoidance," in *IEEE International Conference on Intelligent Computing, Instumentation and Control Technologies*, 2017.

[8] Tong Duan, Witold Kinsner, "A Rough-Fuzzy Perception-Based Computing for a Vision-Based Wall-Following Robot," in *IEEE 13th International Conference on Cognitive Computing*, 2014.

[9] Fahmizal, Chung-Hisen Kuo, "Development of a Fuzzy Logic Wall Following Controller for Steering Mobile Robots," in *IEEE International Conference on Fuzzy Theory and its Application* , Taiwan, 2013.

[10] Xiao Li, Dan Wang, "Behavior-based Mamdani Fuzzy Controller for Mobile Robot Wall-Following," in *IEEE International Conference on Control, Automation and Rbotics*, 2015.

[11] Chen-An Huang, Chia-Feng Juang, "Evolutionary Fuzzy Control of Two Cooperative Object-Carrying Wheeled Robots for Wall Following Through Multiobjective Continuous ACO," in *IEEE Joint 17th World Congress of International Fuzzy Systems Association and 9th International Conference on Soft Computing and Intelligent Systems*, Japan, 2017.

[12] Ching-Yu Chou, Chia-Feng Juang, "Navigation of an Autonomous Wheeled Robot in Unknown Environments Based on Evolutionary Fuzzy Control," *Inventions,* 2018.

[13] Heru Suwoyo, Yingzhong Tian, Chenwei Deng, Andi Adriansyah, "Improving a Wall-Following Robot Performance with a PID-Genetic Algorithm Controller," in *Proceeding of EECSI*, Malang, Indonesia, 2018.

[14] G. Robots, "https://www.generationrobots.com/en/402395-robot-mobile-pioneer-3-dx.html," 13 08 2019. [Online]. Available: https://www.generationrobots.com/en/402395-robot-mobile-pioneer-3-dx.html.

[15] T. Buratowski, A. Pietrzyk, T. Uhl and W. Zylski , "Identification in parallel structure of emulator mobile robot pioneer 2DX with the use of genetic algorithms," in *Proceedings of the Third International Workshop on Robot Motion and Control, 2002. RoMoCo '02.*, Bukowy Dworek, Poland, Poland , 2002.

[16] A. Adib and B. Masoumi , "Mobile robots navigation in unknown environments by using fuzzy logic and learning automata," in *2017 Artificial Intelligence and Robotics (IRANOPEN)*, Qazvin, Iran , 2017.

[17] B. Alves, H. Costelha and C. Neves , "Localization and navigation of a mobile robot in an office-like environment," in *2013 13th International Conference on Autonomous Robot Systems*, Lisbon, Portugal , 2013.

[18] A. m. robotics, "Pioneer 3 Operations Manual," MobileRobots Inc., 2006.

[19] W. Zhang and M. Yang, "Comparison of auto-tuning methods of PID controllers based on models and closed-loop data," in *Proceedings of the 33rd Chinese Control Conference*, Nanjing, China , 2014.

[20] Y. Chang, S. Chen and C. Liau, "Fuzzy Interpolative Reasoning for Sparse Fuzzy-Rule-Based Systems Based on the Areas of Fuzzy Sets," IEEE Transactions on Fuzzy Systems, vol. 16, no. 5, pp. 1285 - 1301, 2008.

[21] R.M. N. Bandara and S. Gaspe, "Fuzzy logic controller design for an Unmanned Aerial Vehicle," in 2016 IEEE International Conference on Information and Automation for Sustainability (ICIAfS), Galle, Sri Lanka , 2017.