Voice robot control using advanced fuzzy control techniques

M. Elsayed, M. Ib. Sokar, S. Abd Rabbo, M. El_Arabi

Abstract — nowadays, mobile robots has a significant status in real life and industrial applications. A mathematical model of the Tricycle Mobile Robot (TMR) as a closed loop transfer function is introduced. A prototype of TMR with steering wheel was established. The current research presents different control techniques of TMR with auditory systems to further enhance human–robot interaction. Controlling the velocity and azimuth angle of the TMR was discussed and examined by three methods. They are fuzzy logic controllers alone, fuzzy logic based on PID controller and Fuzzy Inference System (FIS) with the lookup table. All of each controller is examined with trapezoidal, triangular and Gaussian membership function, also compared with two inputs as unit step and unit sinusoidal input. The results show that the FIS with lookup table has the best output response and control signal at the sinusoidal input. Also, the minimum error signal occurs for FIS with lookup table with trapezoidal membership function at the unit step input.

Index Terms— FIS with lookup table, Fuzzy controller, Fuzzy PID, Modeling, Mobile robot, Voice Recognition.

1 Introduction

The main area of research on mobile robots has been activated over the last three decades. The common drives for mobile robots are differential drive, tricycle or car-like drive, synchro-drive and omnidirectional steering. The Improvements of mechanical designs and mobility control systems have helped using wheeled mobile robots in an autonomous mobile robot applications. Wheeled mobile robots have application in nuclear and explosives handling, warehousing, security and mobility for disabled. Although legged and treaded locomotion also has been studied, and the majority of the mobile robots that studied are those, which use wheels for motion. In order to have the mobile robot perform well, two important parameters, the accuracy and reliability of its motion control should be improved. Based upon fuzzy logic, speed control and turn control of a mobile robot are determined by goal orientation and obstacle proximity. Without keeping the track of the reliability and accuracy of robot's motion, we cannot make a robot follow a certain trajectory. If we don't have a stable and efficient controller, the mobile robot's motion cannot be controlled. By studies on other types mechanisms of mobile robot by [1], [2], [3], [4].

Discussion on simulation and analysis of controller design for speed control of a DC motor actuator used in agricultural platform distinguished by [5]. It was showed that the fuzzy logic controller has better performance over conventional PID and filter compensator design for sinusoidal changes of motor speed. The effect of fuzzy membership function especially its slop for PI-like fuzzy control system has focused by [6].

It has a fuzzy system that consist of three membership functions. Also, it was proven that the fuzzy system confirm that the output meet to the desired value. The improvements of performance of the brushless DC motor drive could be validated by changes of slops of a triangular membership function via fuzzification the error and the sum of error.

Many solutions are presented to enhance the performance of wheeled mobile robots has a small coefficient of friction in motion conducted by [7]. The wheeled mobile robots can endure loss of adhesion force and therefore, slide along the surface. On the unicycle robot, it has a fuzzy logic control on a wheeled mobile robot through wireless reported by [8], also the wireless communication is preferably on colored line tracking that intends to introduce mobile robots for handling and manipulation in warehouse environments so complicates the navigation of a swarm of mobile robots.

Other studies investigated the design of a fuzzy PID controller by using modified triangular membership functions discussed by [9]. Two useful knowledge-based fuzzy reasoning's were presented for the tracking error, and conventional triangular membership functions in fuzzy inference systems are then modified for performance improvement. Therefore, the parameters used in the proposed controllers are evaluated by using a Genetic Algorithm (GA) with a defined fitness function that is associated with the performances indices – tr, OS, and IAE. The design of Fuzzy PID and Fuzzy PI+D controllers for different nonlinear systems was done by using 'Gaussian' Membership functions by [10]. It was observed that the speed of the response is faster with Fuzzy PID controller. However, the Fuzzy PID is exhibiting slow settling and unwanted over shoots many a times. In case of Fuzzy PI+D controller the rate of rise is slow but it is reaching final set point in less time and not producing any unwanted over shoots compared to that of Fuzzy PID controller. The real-world experiments involving contact in PUEs demonstrated that we cannot say that the fuzzy-PI controller is better than the PI controller by [11], [12].

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In the simulation and experimental studies significant by [13], the μ-Law method was combined with simplex optimal algorithm to an automatically adjust the parameters of the structures of the FLCs. The improvements significantly the performance of FLCs through μ-Law tuning method was showed by Simulation and experimental results.

As aforementioned the almost studies in mobile robot modeling and control mainly studies the differential drive on four wheels robot. There was a shortage in an implementation on modeling of tricycle mobile robot that differ from a differential drive on four wheels robot especially in the advanced application of fuzzy control also in artificial intelligence platforms. The current research apply implementation on a tricycle mobile robot called 'Sofie' and the mathematical model driven in Cartesian coordinates. Thus, in this study three controllers was built and designed to investigate the TMR prototype in order to control robot speed by energy of speaker sound.

2 Methodology

The layout of the complete system is illustrated in Fig. 1. The system mainly divided into three parts. The first part deals with signal pretreatment for recording voice signal. So, a high-quality microphone able to record sound and able to reduce noise. Therefore, utterance recording for training and testing must be able to filter the noise and highlight the main signal. All previous sequences must be repeated for a new command to have a clear signal to be compared with dataset in training that will happen at comparison and recognition part. The end of this part, the program able to recognize the sound and utterance of the word. The second part is the fuzzy logic control that work as brain of all given system. The input of fuzzy logic control is the energy of sound and its rate, also the output is the speed of robot expressed for the emotion of speaker. After this, it will be compared with the word and transfer the command to the robot with the suitable speed. The third part deals with converting a current position into location mapping related to previous position and repeated it until end of program. The Fig. 2 describe the voice signal recognition process as occurred in the robot.

A standard structure of a Fuzzy Logic Controller (FLC) is shown in Fig. 3. It consists of four stages first, a preprocessor the inputs that had as crisp values generated from error (e) and change of error (de). Second, the fuzzification process is transform an input data to degrees of membership functions and deals with conditions of rules. At the base rule commands, the inference engine (Mamdani-type) is determined the ability of a degree of functionality rules. Third, the fuzzy output taken and crisp values returned all of this is the defuzzification process. The outputs of the fuzzy sets converted to crisp values through centroid defuzzification method. Fourth, a post-processing is converted the crisp values into standard control signals. The experimental knowledge is obtained from error and change of error.

Fig. 2. Block diagram of speech recognition

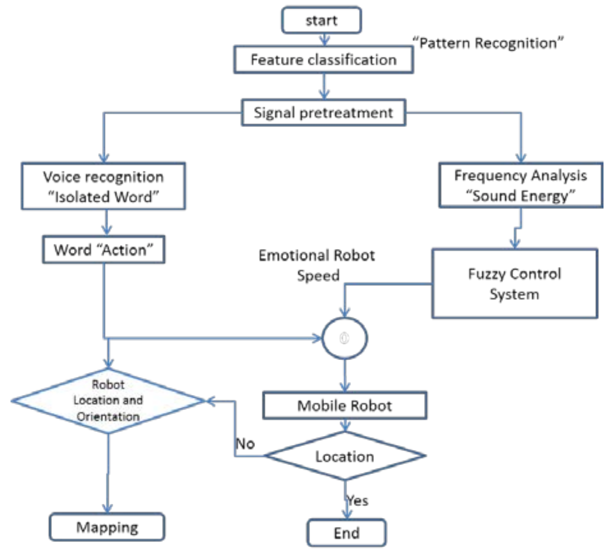

Fig. 1. Flow chart of the Algorithm

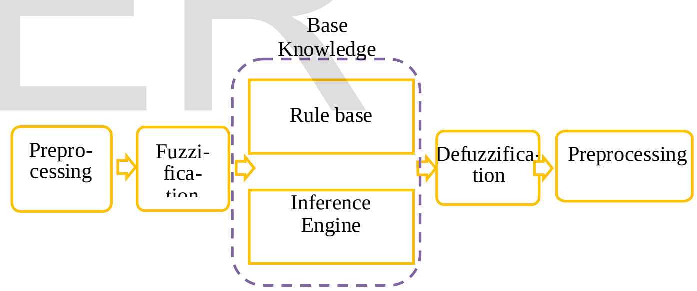

Fig. 3. Block diagram of fuzzy control

Table 1 include rules that relates inputs-output in the fuzzy logic controller with a trapezoidal, triangular, and Gaussian membership function and it was implemented in the simulation. The rules make control efforts based on if-then statements about (e) and (de). Each control variable is normalized into seven linguistic levels: positive big (PB), positive medium (PM), positive small (PS), zero (Z), negative big (NB), negative medium (NM), and negative small (NS). The grade of each level is described by a fuzzy set. The if-then statements determined based on tests and tuning of the system. Plots of fuzzy Gaussian and trapezoidal membership functions of two inputs (e) and (de) and the output (c) are shown in Fig. 4 and Fig. 6.

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Table 1
Trapezoidal and Gaussian rule table

De/e	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PM	PS	PS	PS	Z
NM	PB	PM	PS	PS	Z	Z	Z
NS	PM	PM	PS	PS	Z	Z	NS
Z	PM	PS	Z	Z	Z	NS	NS
PS	PS	PS	Z	NS	NS	NM	NM
PM	PS	Z	NS	NS	NM	NB	NB
PB	Z	Z	NS	NM	NM	NB	NB

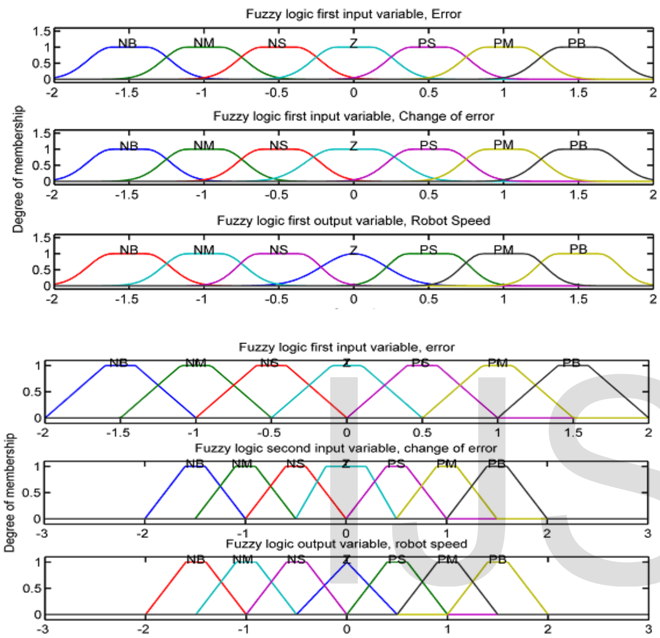

Fig. 4. Fuzzy membership function of input and output variables (a) Gaussian (b) trapezoidal membership function

The mesh plot corresponding to the rules of two break-points for an FIS with lookup table controller is provided in Fig. 5 that shows the regularity of the change in the control signal.

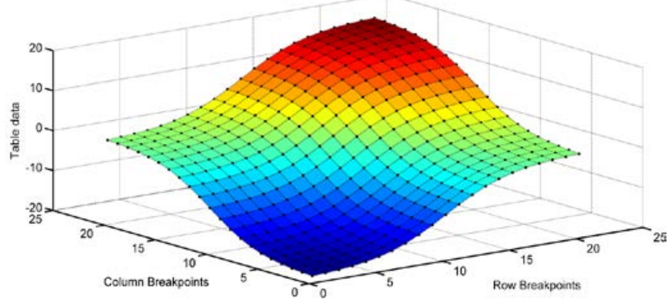

Fig. 5. Mesh plot of look up

3 Mathematical model for Tricycle mobile robot

The prototype of a tricycle type robot driven by two rear wheels autonomously and a two front wheel as a castor called "Sofie Robot" as shown in Fig. 7. The kinematic model of a non-holonomic constraint of pure rolling and without slipping based on the configuration shown in Fig. 8.

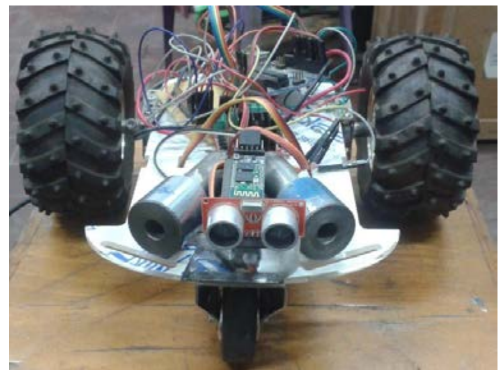

Fig. 6. Sofie robot

$$R(t) = d/\tan\alpha \quad (1)$$

$$\dot{\theta} = \omega_t = \frac{v_s}{d}\, sin\alpha = \frac{\omega_s r}{d}\, sin\alpha \quad (2)$$

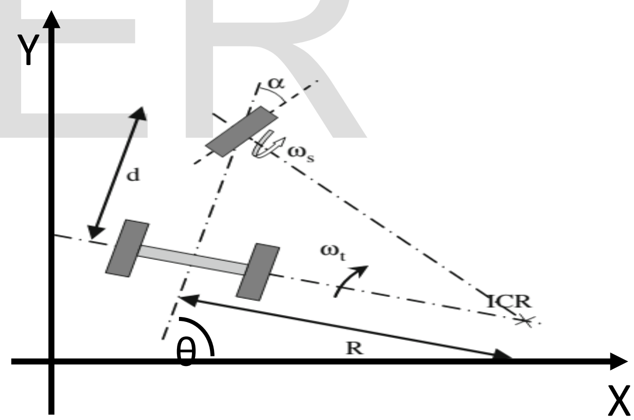

Fig. 7. Kinematics of tricycle mobile robot

where, $\dot{x}$ and $\dot{y}$ are components of forward velocities; x(t) and y(t) denote the position of the wheeled mobile robot along the X and Y Cartesian coordinate frames and θ(t) represents the angle between the heading direction and the x-axis. The robot rotates with an angular speed ω_t around the ICR whose distance R to the robot. Also, v_s , ω_s *and* r are respectively the linear speed of the front wheel, its angular speed and its radius.

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Kinematic model in the robot frame:

$$\begin{bmatrix} v_x \\ v_y \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\alpha \\ 0 \\ \frac{\sin\alpha}{d} \end{bmatrix} [v_s] \quad (3)$$

Kinematic model in the world frame:

$$v_t = v_s \cos\alpha \quad (4)$$

$$\dot{x} = v_s \cos\alpha \cos\theta \quad (5)$$

$$\dot{y} = v_s \cos\alpha \sin\theta \quad (6)$$

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \cos\theta & 0 \\ \sin\theta & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} v_t \\ \omega_t \end{bmatrix} \quad (7)$$

The simulation results based on state space model (open loop transfer function) of the TMR is shown in Fig. 8.

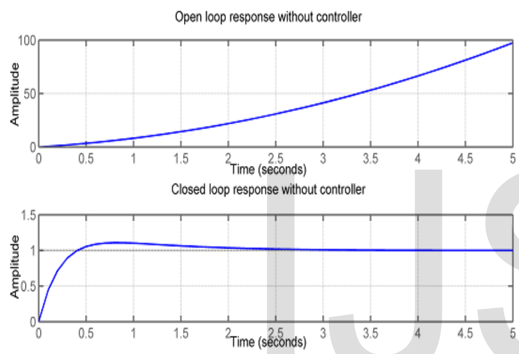

Fig. 8. TMR response without controller

Open loop transfer function without a controller

(5.518 s^2 + 7.747 s + 2.668)/(s^3 + 0.4481 s^2)

Closed loop transfer function without a controller

(5.518 s^2 + 7.747 s + 2.668)/(s^3 + 5.966 s^2 + 7.747 s + 2.668)

The TMR response for each three parameters of the position (X, Y, θ) is shown in Fig. 9, also distinguished from given transfer function of TMR. Also, characteristic parameters of TMR at world coordination are given in the Table 2.

Table 2.
Characteristic parameters of TMR

Parameter	*Value*
ζ	0.5169
ω_n	38.6899 rad/s
a	45^o
θ	90^o

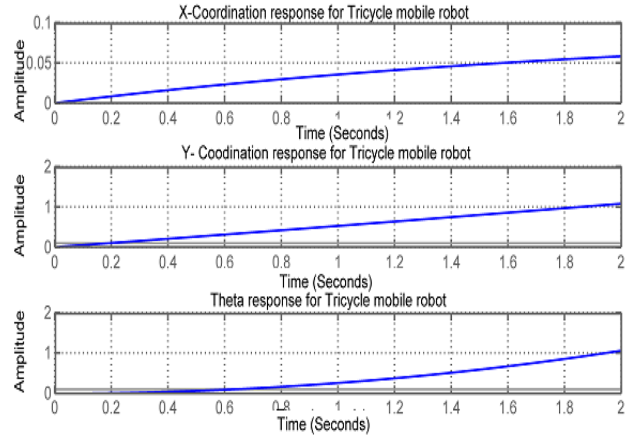

Fig. 9. Plots of tricycle mobile robot response

The given model examined by three controllers where simulated in MATLAB/Simulink© with block diagram shown in Fig. 10. A signal generator produces an input reference of step and sinusoidal functions for each control blocks. The transfer function of controller implemented in the simulation followed by the Tricycle mobile robot model.

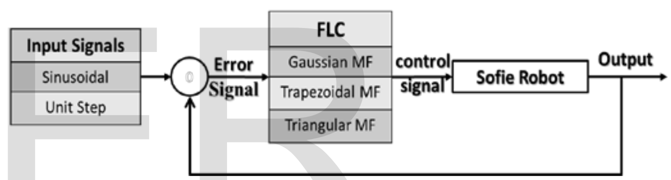

Fig. 10. A typical control system

In the current research the control system for tricycle mobile robot called Sofie robot consists of three parts (input signals – Controller – Plant "Robot") as shown in Fig. 11. The given system has the controller is based on Fuzzy logic control such, all of each controller are examined by three types of membership function at two types of input signals respectively. The fuzzy system base rule first one is Gaussian membership function and another one is trapezoidal membership function finally triangular membership function for two input variables error and change of error and output variable robot speed. The system consists of the three type controller first one, Fuzzy logic controller in a closed loop control system. The second one, the Fuzzy-PID system with input derivative gain and output integral gain. The third type, the Fuzzy inference system (FIS) with lookup table with two break points.

The fuzzy logic controller has a process that the inputs and output of fuzzy inference engine and generate control signal. The corresponding defuzzification sub-block is shown in Fig. 12. The aim of a controller is to maintain a plant in a specific situation, by control a set of variables and selecting the sufficient control actions. The Fuzzy-PID controller works like its classical homonym, but the linguistic terms consist of the input variables and the control action. Explanation of the influence of tuning parameter allows by an analytic development of

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fuzzy controllers on the system.

The new model design for implementation the fuzzy inference system by adding PID controller on Fuzzy model illustrated in Fig. 13. A last one controller consists of lookup table fuzzy inference system with two break points of two input variables as shown in Fig. 14.

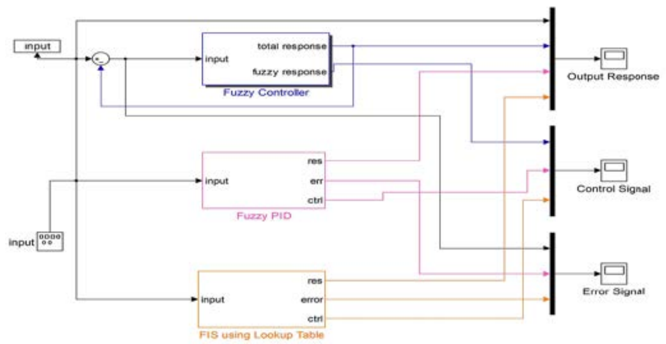

Fig. 11. Simulink model of different type's control-

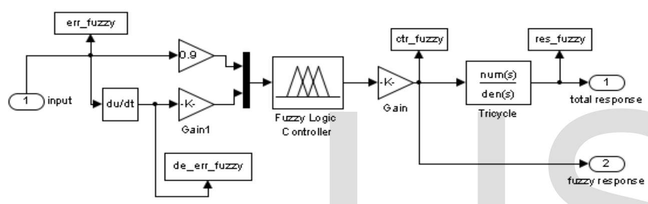

Fig. 12. Simulink model of fuzzy controller

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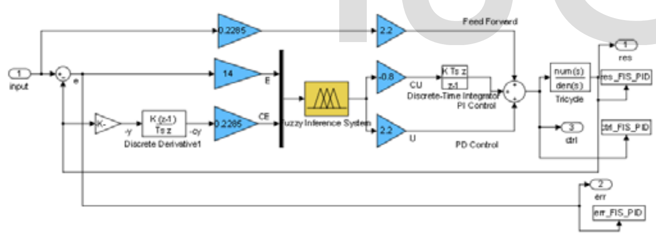

Fig. 13. Simulink model of fuzzy-PID controller

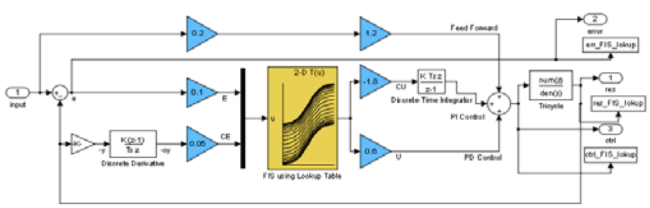

Fig. 14. Simulink model of fuzzy using look up table controller

4 Results and Discussion

From simulation results by three types of controller and three types of the Membership Function (MF). Fig. 15 and Fig. 16 plots fuzzy, fuzzy-PID and FIS with lookup-table for trapezoidal membership function at sinusoidal and unit step inputs respectively. At sinusoidal input the FIS with lookup table has the best output response. The FLC and FIS with lookup table have the similar error range. At unit step input the FLC and fuzzy-PID have the output response like the first order response but, in FIS with lookup table has scattered in its output response. The FLC and fuzzy-PID have the similar error range and change error rate.

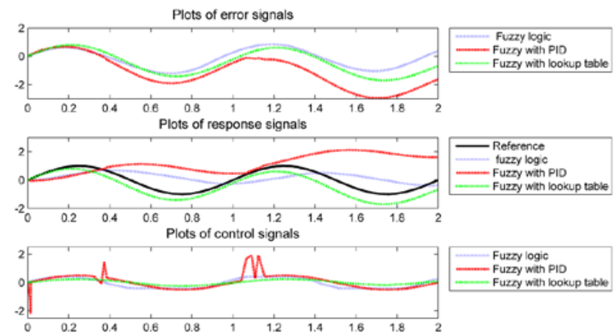

Fig. 15. Plots of fuzzy, fuzzy-PID and FIS with lookup-table for trapezoidal membership function at sinusoidal input

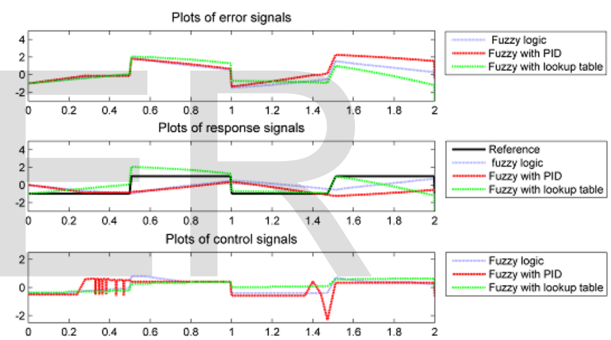

Fig. 16. Plots of fuzzy, fuzzy-PID and FIS with lookup-table for trapezoidal membership function at step input

Fig. 17 and Fig. 18 plots fuzzy, fuzzy-PID and FIS with lookup-table for triangular membership function at sinusoidal and unit step inputs respectively. At sinusoidal input the fuzzy-PID and FIS with lookup-table give the best output response. Therefore, the FIS with lookup-table has the best performance. The fuzzy-PID has the Minimum error range. At unit Step input the FIS with lookup-table has the nearest output response. The fuzzy-PID and FIS with lookup-table have the similar error range.

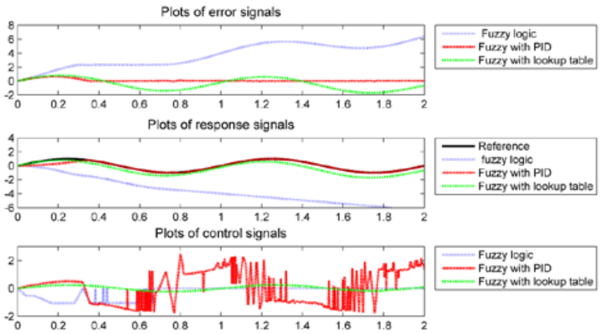

Fig. 17. Plots of fuzzy, fuzzy-PID and FIS with lookup-table with triangular membership function at sinusoidal input

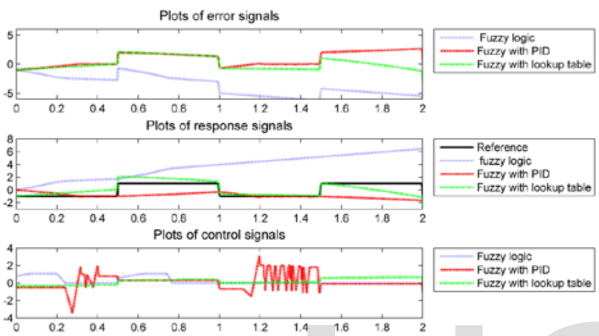

Fig. 18. Plots of fuzzy, fuzzy-PID and FIS with lookup-table with triangular membership function at step input

Fig. 19 and Fig. 20 plots fuzzy, fuzzy-PID and FIS with lookup-table for Gaussian membership function at sinusoidal and unit step inputs respectively. At sinusoidal input the FIS with lookup table has the best output response. Also, FLC and FIS with lookup table have the similar error range. At unit step input the FLC and fuzzy-PID have the output response like the first order response but, in FIS with lookup table has scattered in its output response. The fuzzy-PID with Gaussian MF has been minimum error signal and smoother amplitude from suddenly changes also change a direction of signals in trapezoidal from Negative side direction to the positive side by Gaussian MF. Although, the results proved that the FIS with lookup table has the best output response and a control signal at the sinusoidal input.

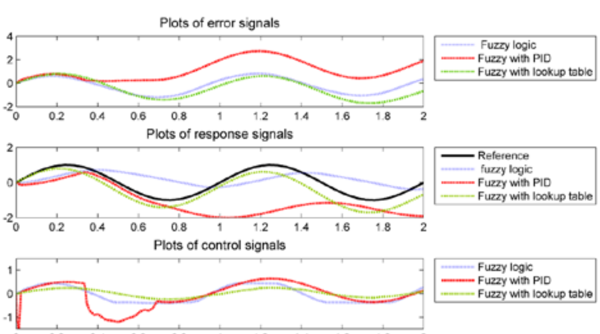

Fig. 19. Plots fuzzy, fuzzy-PID and FIS with lookup-table with Gaussian membership function at sinusoidal input.

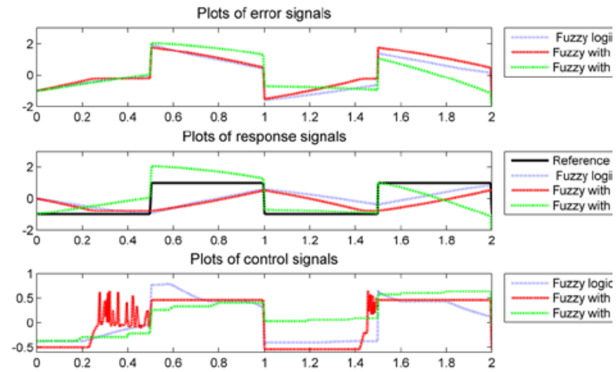

Fig. 20. Plots fuzzy, fuzzy-PID and FIS with lookup-table with Gaussian membership function at (a) sinusoidal (b) step input

5 Conclusion

The Tricycle Mobile Robot with steering wheel was built as a prototype. It has a variable traveling speed and steering mechanism by servo motor and without differential motion control. Also, it defined as autonomous robot with emergency stopping. The given model is divided into two part. First, the mathematical model of tricycle mobile robot was built as an open loop transfer function. Second, the control part which based on Fuzzy logic control system such, Fuzzy controller, Fuzzy controller along PID gains and an FIS with lookup table. All of each controller are examined with Trapezoidal, Triangular and Gaussian membership function. This work proved that at the Sinusoidal input an FIS with lookup table has the best output response, where it is always has a minimum deviation about reference input signal through a long period of time compared with other tested controller features and control signal. Although, the Minimum error signal occur FIS with lookup table with Trapezoidal membership function at unit step input. It has more benefits than the other controller FLC and Fuzzy-PID. The given Fuzzy-PID will be provided with more enhancement with Genetic Algorithms to eliminate the response error.

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