Development of Vision Based Path Tracking Algorithm with Kinematic Motion and Fuzzy Controller

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Abstract— This paper intends to develop the path tracking algorithm for Differential Drive Mobile Robot (DDMR) with MATLAB/Simulink. The input data for vision system of DDMR are taken from the captured images. In order to get the desired result, the control data from the captured images, fuzzy logic controller, the kinematics equations and MATLAB/ Simulink are used in this research. The error heading angles/inputs values of the captured images are controlled by the fuzzy logic controller to get the minimum error heading angles for path tracking. There are two parts in this research. Ones is to develop the fuzzy controller by using the control data/heading error from the captured images with Hough Transform. The second one is to control of the robot platform by using Kinematic based on fuzzy control system. The velocity outputs of fuzzy logic control are applied for kinematics motion of DDMR. The gains of fuzzy controller are tuned to achieve the desired speed and then Simulink model is prepared for DC motors with gear of DDMR. The algorithm/program of path tracking for DDMR are developed in this research with the MATLAB/ Simulink.

Keywords— Kinematics equation, Fuzzy Logic Controller, DDMR, path tracking, MATLAB Simulation.

I. INTRODUCTION

Differential Drive Mobile Robots (DDMR) have different applications in the field of industry, military and security climate. The problem of path tracking and controls of wheel mobile robots have enhanced of research interest in the field of robotics [6] [7]. Path tracking problem is generally pertinent to mobile robots in industrial and manufacturing climate as well as to mobile robots in farming applications [7]. To accomplish path tracking for DDMR robot view of environmental factors, driving path tracking and robot control algorithm are key features. In this research, differential drive mobile robot (DDMR) have proposed to track the path and to construct a mobile robot is to utilize four-wheel drive [5].

Fuzzy logic is used in the design of possible solutions to perform local navigation, global navigation, path planning, steering control and rate control of a mobile robot [10].

In this paper, a camera is utilized to catch picture of the path forward of the mobile robot [7]. The vision framework decides the parallel balance, heading mistake and the curvature of the path [7]. The inputs to the fuzzy system is taken by the capture image of the mobile robot [3]. The simulation is performed in MATLAB Fuzzy Logic Toolbox [9].

In this research, the kinematic equation is utilized to control the differential drive mobile robot (DDMR) [5] [7]. Fuzzy Logic Controller for tracking trajectory and navigation behaviour of mobile robot is presented [3][4][6]. System has two fuzzy controllers that each of them has single input and two outputs for tracking task. The data from vision system structures contribution to the regulator while yields controlling the speed of the wheels [7]. A controller based on Fuzzy Logic supplied velocity to the order of the right and left of each wheel to the mobile robot to ensure its confluence towards the target. Differential drive wheeled mobile robots are the most commonly used mobile robots. The drives of the wheeled mobile robot can be a differential drive [5][12]. The differential drive comprises of four fixed controlled wheels mounted on the left and right half of the robot stage. The four-wheels are freely determined. Wheels are utilized for equilibrium and steadiness. On the off chance that the wheels turn at a similar speed, the robot moves direct or in reverse or bended way [5] [12]. In the event that one wheel is running quicker than the other, the robot follows a bended way along the way. On the off chance that wheels are pivoting at a similar speed in inverse ways, the robot turns about the midpoint of the four driving wheels [5] [12].

Fuzzy controller based on kinematic modelling is used to control the speed of the DC motor and/or whole robot platform [5] [12].

More details could be found in following sections. The paper is organized as follows: The second section is Literature Review. Background theory is described in third section. Methodology are explained in fourth section. The fifth section are described in Testing and Simulation Results. The sixth section concludes the paper.

A. Aim and Objectives

The main aim of the paper is to develop the path tracking algorithm for differential drive mobile robot with kinematics motion and fuzzy logic controller along the predefined path without human intervention.

- To construct the kinematic motion of the mobile robot
- To generate the path tracking algorithm for differential drive mobile robot (DDMR) with fuzzy logic controller
- To build the simulation block for differential drive mobile robot (DDMR)

B. Problem Statement

The previous researches had developed the vision based path tracking algorithm with PID. But in this research, the author must develop this algorithm which it is vision based path tracking depending on the non-linear system by using Fuzzy technology.

II. LITERATURE REVIEW

According to the literature, Authors have applied vision based, PID control for path tracking and kinematics motion based controller for differential drive mobile robot (DDMR). Boru et al., used PID controller based on kinematic modelling to control the speed of the DC motor and/or whole robot platform [12]. U. Dinesh, et al., proposed to design and incorporate into the differential drive mobile robot using PID controller. The PID control algorithm is developed for reducing the initial inertia error [13]. Inertial errors affect the robot's programmed velocity which intrun causes the robot to deviate from the user defined trajectory. The PID based CLCS periodically checks and corrects the individual wheel speed online to place the robot in trajectory [13]. Do et al., considered that a design of a fuzzy-PID controller for path tracking of a mobile robot with differential drive is proposed. The fuzzy-PID controller consists of a PID controller and a fuzzy controller with two inputs and three outputs. When the system response has the error and the error rate, the fuzzy controller can tune the parameters of the PID controller. The fuzzy-PID controller and the classical PID controller are compared by simulation. The path tracking of a mobile robot with differential drive was tested using MATLAB/Simulink. The simulation results show that the fuzzy-PID controller has a better performance than the classical PID controller. The proposed controller has better assembly rate in comparison with the classical PID controller for a mobile robot with any self-assertive starting state [14]. It has the advantages of quick react, high solidness, following exactness and great enemy of obstruction, so the fuzzy-PID controller is the proper decision for path tracking control of mobile robots with differential drive [14].

In my paper presents to develop the path tracking algorithm for Differential Drive Mobile Robot (DDMR) with MATLAB/Simulink. The input data for vision system of DDMR are taken from the captured images. To get the desired result, the control data from the captured images, fuzzy logic controller, the kinematics equations and MATLAB/ Simulink are used in this research. The error heading angles/inputs values of the captured images are controlled by the fuzzy logic controller to get the minimum error heading angles for path tracking.

III. BACKGROUND THEORY

Background theory consists of kinematics motion of the mobile robot, fuzzy logic controller, differential drive mobile robot (DDMR) and simulation. The kinematics motion of the mobile robot is used to calculate the kinematics equations of the mobile robot [5] [8]. The path tracking of the mobile robot kinematic modelling is to find the velocity of the mobile robot as a function of the velocity of the two wheels [1] [2] [4] [8]. Fuzzy logic controller is applied to ensure that the mobile robot can track target trajectory [8]. The FLC is searched to error in the position and error in the angle of the robot. Differential Drive Mobile Robot (DDMR) is four-wheel drive, where each wheel is driven independently [7] [8] [9] [10]. The simulation is used to drive differential drive mobile robot for path tracking.

Kinematics Motion of DDMR

A kinematic model of the robot is to communicate on the movements of individual wheels. The robot has a differential drive framework with four wheels. The situation of the mobile robot in the world wide casing X(O)Y can be defined by the situation of mass focus of robot C (x, y) which is the center of mobile gear; and the angle between the local frame XmCYm and the global frame (θ) [1] [5] [8] [9].

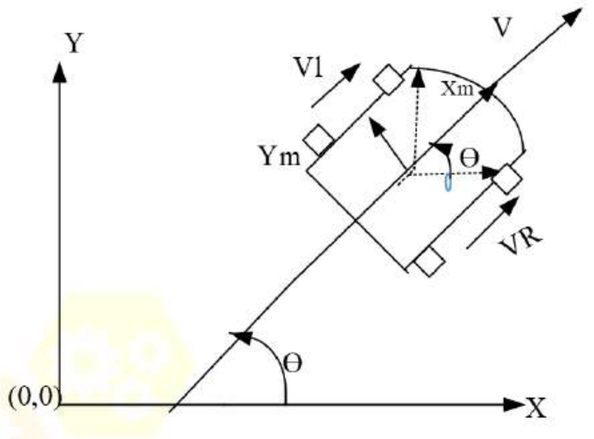

Figure 1. Ideal wheel and Kinematics model of robot.

The center of mobile robot (x, y, θ) is expressed in the inertial coordinate frame. The condition of robot is defined by its position (x, y) and direction (θ) and by the speeds of the mobile robot.

A basic design of robot is appeared in Figure 1. In this research, a differential drive model is considered to compute the kinematic conditions of the mobile robot. The path tracking of the robot kinematic modelling is to find the velocity of the mobile robot as a function of the velocity of the four wheels [1] [5] [8] [9]. The kinematic model of the robot

depends on the linear velocity (v) and angular velocity (ω) are described in below [5] [8] [11].

$$v_r = r * \omega_l \tag{1}$$

$$v_l = r * \omega_l \tag{2}$$

Where v_R means linear velocity of the right wheel, v_L means linear velocity of the left wheel, ω_R means angular velocity of the right wheel, ω_L means angular velocity of the light wheel and r means radius of wheel [1] [5] [8] [9].

The kinematics of the differential drive mobile robot depends with the understanding of unadulterated rolling and there is no slip between the haggle. The straight speed v and precise speed w of robot is determined as following condition [5] [8] [9].

$$v = \frac{v_l + v_r}{2} \tag{3}$$

$$\omega = \frac{d\theta}{dt} = \frac{v_r - v_l}{d} \tag{4}$$

Where d means distance between two wheels.

B. Fuzzy Logic Controller

In design of fuzzy logic controllers, we used Mamdani type of fuzzy control that comprises fuzzification, defuzzification and rule base [2][3][4][7]. The path tracking fuzzy controller task is to direct the robot to track the desired trajectory in a smooth and continuous manner with suitable precision.

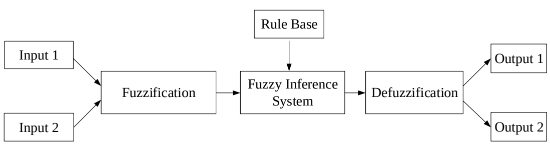

Figure 2. The structure of designed fuzzy logic controller.

Fuzzification is the way toward changing a fresh info esteem over to a fuzzy value that is performed by the utilization of the data in the information base. Although different kinds of bends can be found in writing, Gaussian, three-sided, and trapezoidal MFs are the most normally utilized in the fuzzification interaction [2][3][4][7].

Fuzzy inference system (FIS) is a framework that utilizes fuzzy set theory to map inputs (highlights in the case of fuzzy classification) to yields [2][3][4][7]. Two FIS will be examined here, the Mamdani and the Sugeno.

Defuzzification is the way toward delivering a quantifiable outcome in Crisp logic, given fuzzy sets and relating participation degrees. It is the process that maps a fuzzy set to a crisp set. It is commonly required in fuzzy control systems [2][3][4][7].

IV. METHODOLOGY

In this work, a camera is utilized to capture images of the path ahead of the mobile robot. The inputs to the fuzzy system are given by the vision system of the mobile robot.

The result of the velocity from the fuzzy logic control are applied for kinematics motion using differential drive mobile robot.

There are four sections to generate the Path tracking algorithms for differential drive mobile robot. They are:

1. Generating of heading angle from the captured images
2. Building of fuzzy controller
3. Modeling of PMDM with gear and
4. Path Tracking Method

A. Generating of heading angle from the captured images

Three main parts of testing: preprocessing, edge detection and line detection. The qualities of the captured images are not the same because depending on the light intensity and resolution.

The captured images are pre-processed for enhancement of the image quality. The captured RGB image is converted to gray scale image before the gray scale image is converted into black and white image.

The result image is converted into binary image. The processing result for gray scale image, black and white image and binary image is shown in Figure.3. Edge detection is used to identify the edges in an image.

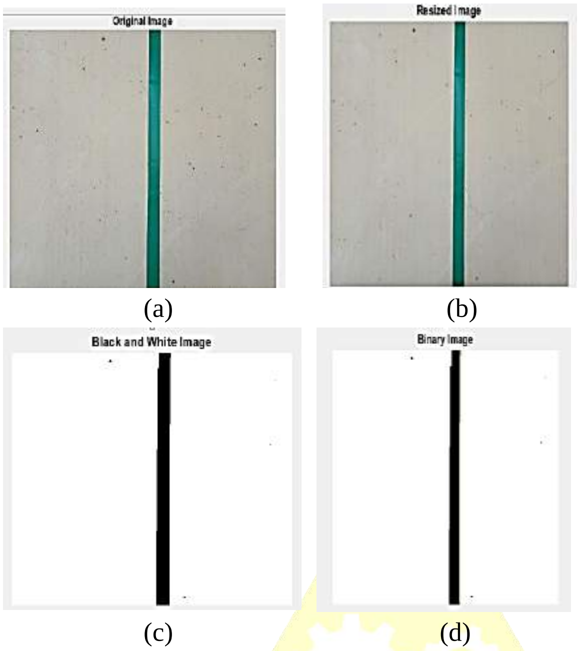

Figure. 3 (a) original image, (b) resized image, (c) gray scale image (d) binary image

The various angles of the captured images describe detail in Figures.and Table.There are angle of Hough Transform and title heading of the angle (degree) in detail are shown in Figure.3 to 4 and Table 1.

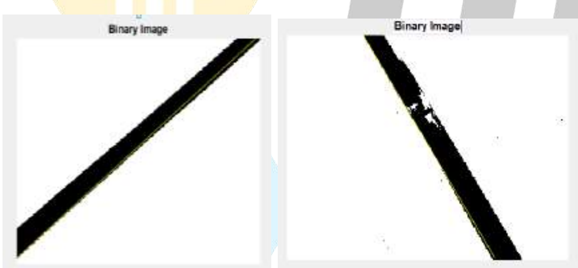

Figure. 4 various angle of the capturing image

Table.1. Heading Angle of DDMR with Hough Trasform

Sr.no	Angle of Hought Trasform (β)	Heading Angle of DDMR (90- β)
1.	-36.52	126.52
2.	-54.4170	144.4170
3.	-66.4839	156.4839
4.	-76.1331	166.1331
5.	30.96	59.04
6.	48.42	41.58
7.	57.88	32.12
8.	68.53	21.47
9.	90	0

B. Building of fuzzy controller

Fuzzy logic controller (FLC) is applied to ensure that the mobile robot can track the straight line and curved path. The FLC used has single inputs, this input has taken values from the image based. Thus, the FLC has two outputs such as left velocity and right velocity of the DDMR wheel as shown in Figure 5.

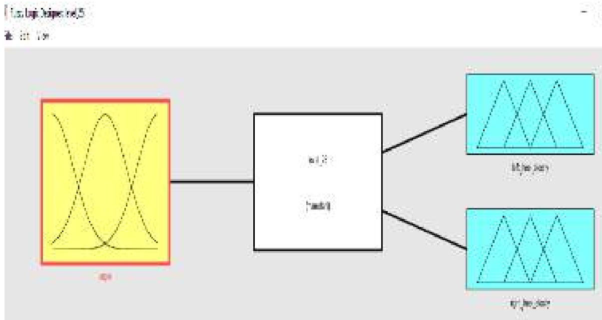

Figure. 5 Fuzzy Logical Control

The fuzzy set value is set overlapping esteems represented by triangular shape that is called the fuzzy membership function. The triangular membership functions are utilized for their simplicity.

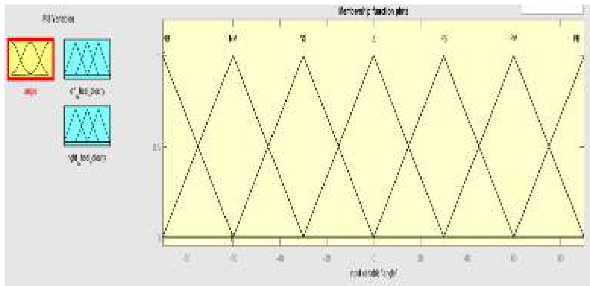

Figure. 6 Fuzzy membership function for Angle.

The output of FLC are the velocity of the left wheel and right wheel that will deliver velocity to the two wheels. They are between 0 to 70.

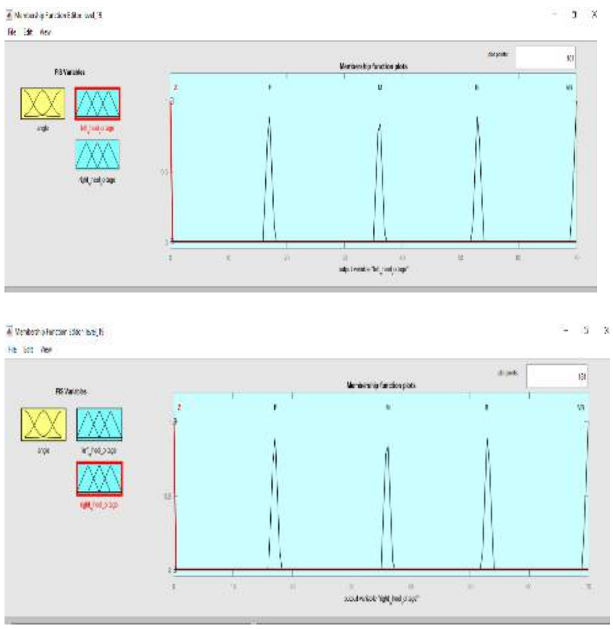

Figure. 7 Fuzzy membership function for output of left wheel velocity(VL) and right wheel velocity (Vr).

The FLC has single inputs such as Angle. Angle has seven fuzzy set such as Negative Big (NB), Negative

Medium (NM), Negative Small (NS), Z (zero), Positive Small (PM), Positive Medium (PM), Positive Big (PB). The outputs are left voltage(VL) and right voltage (VR). They have five fuzzy set such as Zero (Z), Few (F), Medium (M), Big(B), Very Big (VB). The fuzzy inference rules of VL and VR are displayed as:

1. If (angle is NB) then (Vl is Z) (Vr is VB) (1).
2. If (angle is NM) then (Vl is Z) (Vr is B) (1).
3. If (angle is NS) then (Vl is Z) (Vr is M) (1).
4. If (angle is Z) then (Vl is Z) (Vr is Z) (1).
5. If (angle is PS) then (Vl is M) (Vr is Z) (1).
6. If (angle is PM) then (Vl is B) (Vr is Z) (1).
7. If (angle is PB) then (Vl is VB) (Vr is Z) (1).

The surface of the output variable as a function of the inputs is depicted in Figure. 8 that indicates the consistency of the adjustment in the control signal.

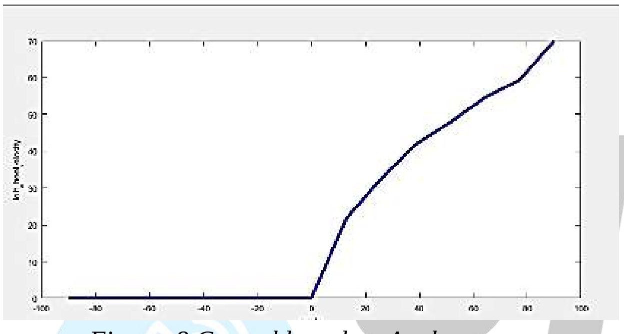

Figure. 8.Control based on Angle error

Modeling of PMBDC with gear

To test the Simulink model developed, we need the specification and the transfer function of DC motor. The DC motor used in this paper is 12V Permanent magnet brushed DC with gear head of gear ratio n=3 and feedback signal is used to angular speed of the wheel. In addition, some motor parameters are indicated in Table 2. The maximum dimension of the robot platform is as follows.

Table.2. parameter for DC motor with Gear

Parameter	Symbol	Value	Unit
Torque constant	Kt	0.062	Nm/A
Back EMFconstant	Kb	0.062	V/rad/s
Geared motor inertia	Jm	0.0551	Kg/m2
Viscous damping	bm	0.188	Nm/rad/s
Armature resistance	Ra	0.56	Ohms
Armature inductance	La	0.97	Mh

DC motor is the actuating device used to control the motion of differentially derived mobile robot. The equation of electric portion and mechanical portion is shown the below.

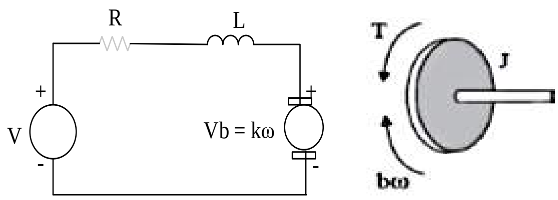

Figure.9. Schematic diagram of PMDC motor

From electric portion,

$$L\frac{di}{dt}+Ri+e_b=V \quad (5)$$

From mechanical portion,

$$T=j\frac{d^2\theta}{dt^2}+b\frac{d\theta}{dt}=k_tI_a \quad (6)$$

$$Js^2\theta(s)+bs\theta(s)=k_tI(s) \quad (7)$$

$$LsI(s)+RI(s)=V(s)-k_bs\theta(s) \quad (8)$$

From equation (8) I(s) can be generated as

$$I(s)=\frac{V(s)-k_bs\theta(s)}{l(s)+R} \quad (9)$$

From (9) the transfer function of the input voltage, V(s), to the output angle, $\theta(s)$, directly follows:

$$G\theta(s)=\frac{\theta(s)}{V(s)}=\frac{k_t}{s\{(Ls+R)(Js+b)+k_tk_b\}} \quad (10)$$

The transfer function can be shown in block diagram.

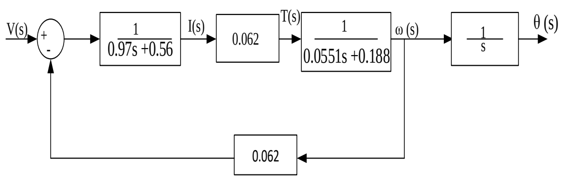

Figure. 10. Block diagram of the transfer function

Path Tracking Method

In this paper, differential drive mobile robot (DDMR) is carried out researches on, which is made up of four driving wheels. In this work, the fuzzy logic controller is used for path tracking. It has to track the straight line and curved path. Therefore, the current position and posture of DDMR can be got by controlling the fuzzy logic. This paper designs an algorithm of mobile robot path tracking through the theorem of line in schematics model of path tracking as depicted in Figure.11.

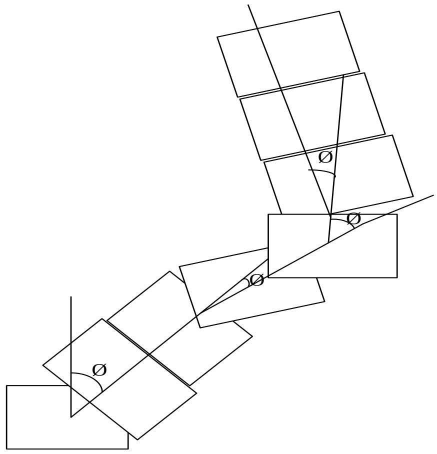

Figure. 11. Schematics Model of Path Tracking

TESTING AND SIMULATION RESULTS

The angle from Hough Transform delivers to the fuzzy logic controller. The result of this controller is generated the velocity for the wheels of the DDMR. The two outputs are send to the DDMR. The result from the mobile robot are displayed the simulation result of the path tracking.

Based on simulating model for the DDMR with fuzzy logic controller. The Simulink model can be developed for the whole robot system. Figure.12. display Simulink model for robot linear speed, angular speed, robot heading orientation angle theta and turning radius of the robot.

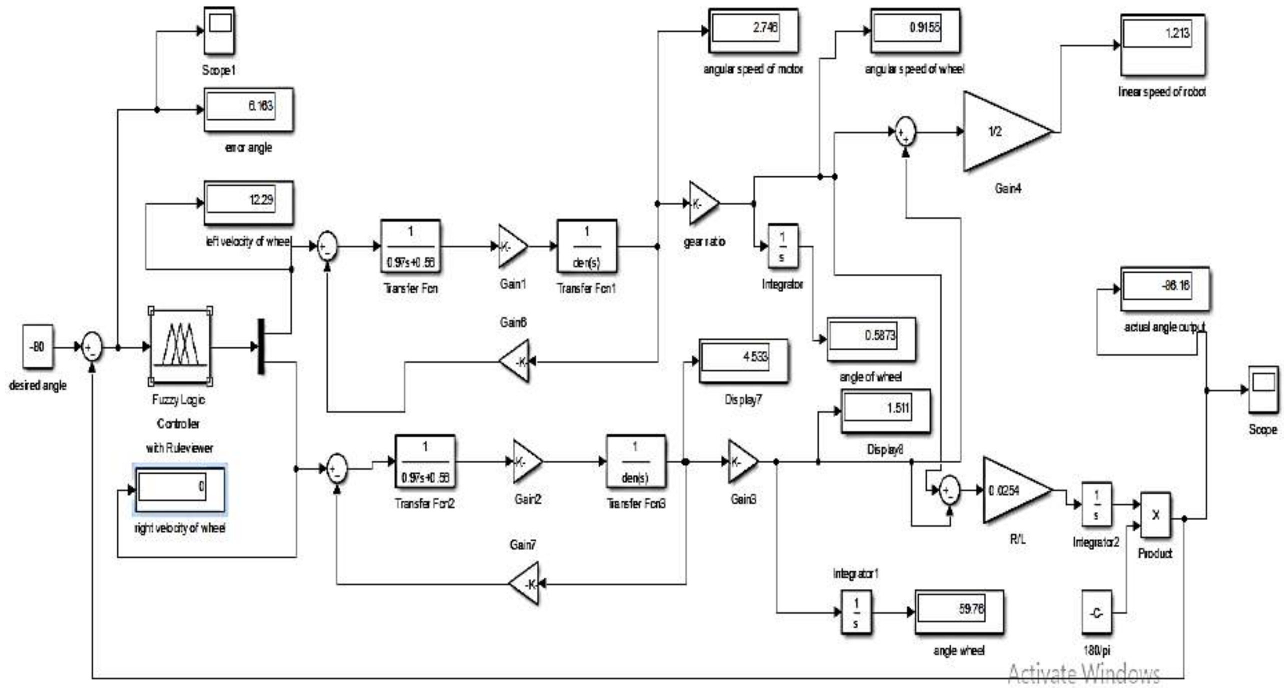

Figure.12. Simulink model for whole robot system

When the input (desired angle) is 80 degrees, the result of the actual angle is 86.163 and error angle is -6.163 as shown in Figure. 11 and 12. The various angle of testing result is indicated in Table. 3 and chart.

Table.3. Various Angle of Testing Result

Sr.no	Input (desired angle)	Output Angle (Actual Angles)	Error Angle (Degree)
1.	0	0	0
2.	10	10.04	-0.03921
3.	20	20.89	-0.8865
4.	30	32.2	-2.197
5.	40	43.47	-3.466
6.	50	54.69	-4.694
7.	60	65.58	-5.58
8.	70	76.11	-6.106
9.	80	86.163	-6.163
10.	-10	-10.04	0.03921
11.	-20	-20.89	0.8866
12.	-30	-32.2	2.197
13.	-40	-43.47	3.466
14.	-50	-54.69	4.694
15.	-60	-65.58	5.58
16.	-70	-76.11	6.106
17.	-80	-86.163	6.163

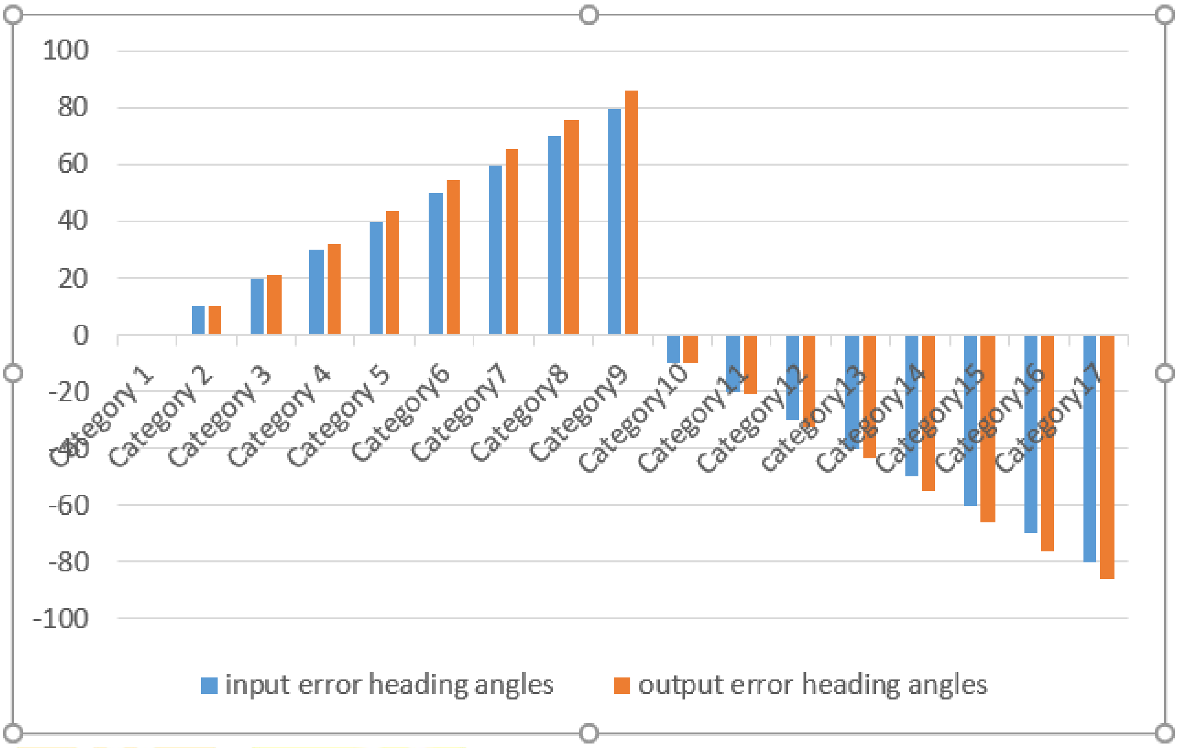

Figure.13. Chart of I/O of error heading angles

When the input (desired angle) is 80 degree, the result of the actual angle is 86.163 and error angle is -6.163 as shown in Figure. 14 and 15.

Next then, when the input (desired angle) is -20 degree, the result of the actual angle is -20.89 and error angle is 0.8866. Testing result is shown in Figure.16 and 17.

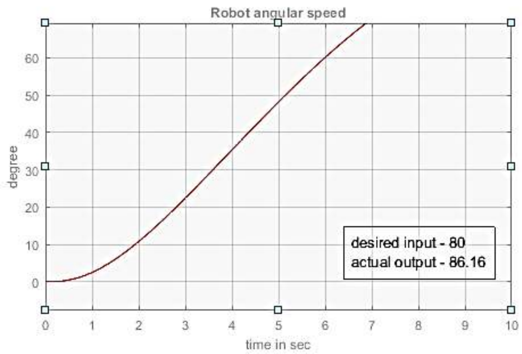

Figure.14. Simulink result of robot angular speed with fuzzy logic

Controller

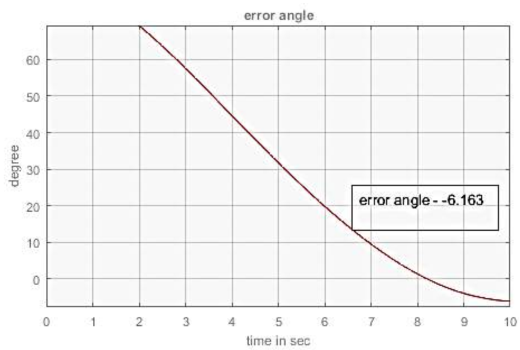

Figure.15. Simulink result of error angle

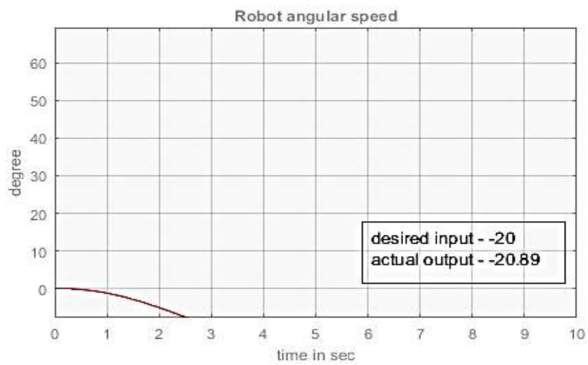

Figure.16. Simulink result of robot angular speed with fuzzy logic controller

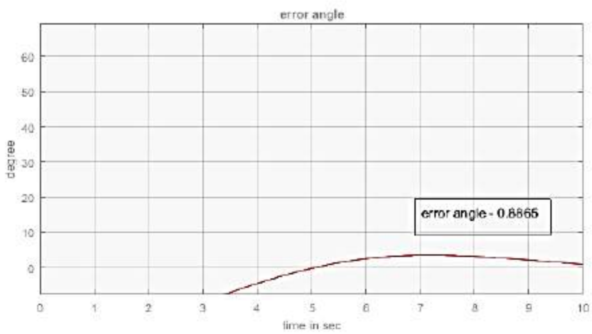

Figure.17. Simulink result of error angle

Desired angle is 40, actual angle is 43.47 and error angle is -3.466 depicted in following Figure. 18 and 19.

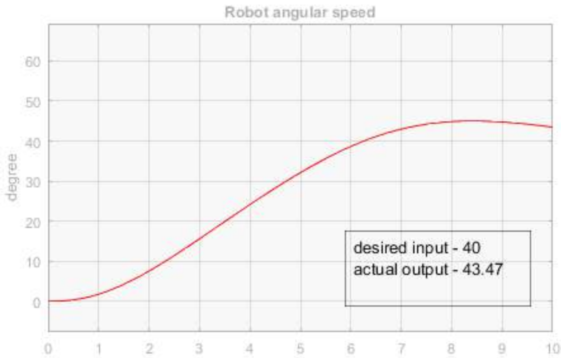

Figure.18. Simulink result of robot angular speed with fuzzy logic controller

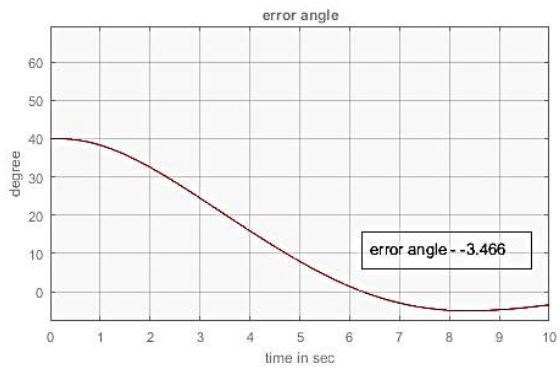

Figure.19. Simulink result of error angle

VI.CONCLUSION

In this fuzzy based control system, the inputs to the fuzzy system had been taken by the captured images for differential drive mobile robot. The path tracking algorithm has been developed by using these inputs for tracking the straight and curved path of different curvatures. The fuzzy logic based approach had been considered by designing two fuzzy systems, one for error heading angle and the other for velocity control. the kinematic equations have been also used to control the differential drive mobile robot (DDMR) in this research. The fuzzy controller can reduce the error of the mobile robot's heading angles to safely track both the bend and straight path. This fuzzy based control system can eliminate the error heading angles from 0.03921(minimum) to 6.163 (maximum). In future, the membership functions could be changed to have a smoother control response.

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