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A Performance Comparison of PID and Fuzzy Logic Control Methods for Trajectory Tracking of Wheeled Mobile Robot

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ABSTRACT

Trajectory tracking involves with the geometric path and the timing law of a two-wheeled mobile robot (WMR). Due to its unlimited work area, mobile robots have a broad spectrum of applications. Trajectory tracking feature in a WMR is designed to enable the robot to follow a reference path. To further analyse this feature, this paper discusses a two-wheeled mobile robot mathematical model using a kinematic model and then compares the trajectory performance of two controllers; namely PID and Fuzzy Logic. The presented controller was designed using MATLAB/Simulink software. The observation on the controllers performance is by Integral Square Error (ISE) where Fuzzy Logic Controller was found to increase the performance of the PID controller by 50%. The result indicated that Fuzzy Logic Controller performs better than the PID controller because of its ability to minimize the error produced during the WMR trajectory tracking.

Keywords: Trajectory tracking, wheeled mobile robot, Fuzzy logic, PID, kinematic model

1. INTRODUCTION

Modern robot nowadays indicates the rapid development of the technology when many researchers are now involve with the research on the tracking control of wheeled mobile robot when compared to the situation of several years ago. Thanks to their unlimited work area, mobile robots have a wide range of applications [1]. Mobile robots may be used in many purposes; for entertainment, manufacturing, building, military and social needs (vacuum cleaners and lawnmowers, etc.) to facilitate the needs of human beings [2].

The Wheeled Mobile Robot (WMR) is one such robot that has gained broad popularity due to its usability and ease of control. The wheeled mobile robot comprises of two independently driven wheels. Wheeled mobile robots are dynamic systems where a suitable torque must be applied to the wheels to obtain the platform desired motion.

Many significant advances have been made to solve many WMR-related problems such as path following, mobile robot positioning, regulation, obstacle avoidance and trajectory tracking [3][4]. Figure 1 shows that the mobile robot generally consists of two mechanical subsystems, actuators, sensors, and mechanical design. Control of these subsystems requires two electronic steps, the power stage and the phase of acquisition and control.

Stability and low tracking error are the main goals of developing the mobile robot's control system. The classical proportional–integral–derivative (PID) controller has been used in

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controlling the WMR. The control methods aim to ensure that the system's output value tracks the desired path [2]. With the certain controller applied to the system, the error is attempted to be minimized [5][6].

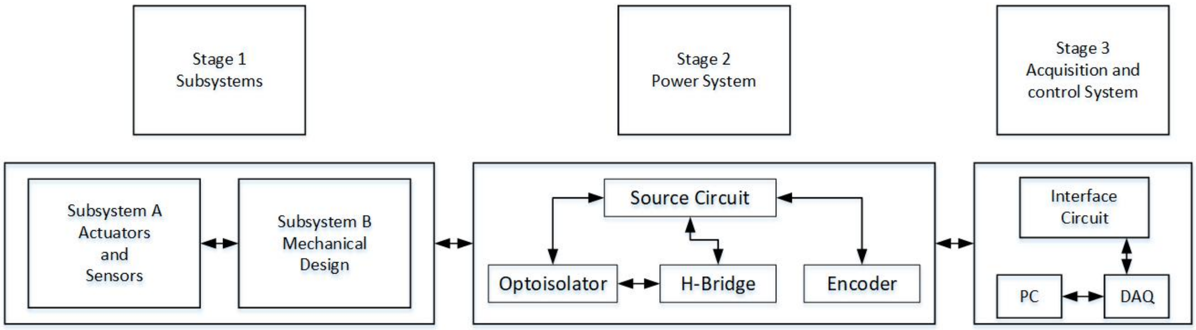

Figure 1. General block diagram of the WMR prototype.

Zadeh [7] invented the fuzzy logic controller, which is now commonly used in some engineering applications including handheld robotics. Fuzzy logic has developed as a tool for gathering human intelligence, experience and dealing with complexities in the control process. In recent years, fuzzy logic has become a common subject in control engineering. There has been many studies and applications in this emerging field for control systems [8].

This paper aims to compare the performance between two methods of control as an initial study before further investigation on more advanced control techniques were carried out. The first method is a classical PID controller with tuning gains k_p, k_i, and k_d. Whereas, the second method is the Fuzzy Logic controller to mimic PD controller with tuning gains kfz_p, kfz_d , and kfz_u. Integral Square Error (ISE) is used as a performance benchmarking for the WMR during circle trajectory.

This paper is structured as follows. Section II briefly described the kinematic model of WMR, PID Control design and Fuzzy Logic design. Section III explained the findings from the simulation results of MATLAB Simulink. Finally, conclusions are presented in Section IV.

2. MATERIAL AND METHODS

Generally, a mobile robot primary control is to maintain its location in a plane, represented as a vector.

$$Q = [x\, y\, \psi\, \theta_R\, \theta_L]^T \tag{1}$$

Figure 2 indicates the actual robot centre of gravity (CoG) position in the global coordinates system (CGS) by Cartesian coordinates x, y, and Y axes. The angle ψ denotes the rotation of the robot local coordinate system in contrast to the global coordinate system. θ_R and θ_L on the other hand describe the right and left wheel angular positions.

The kinematic and dynamic models can be combined to form a mathematical model of a mobile robot. The kinematic model determines the robot location in GCS.

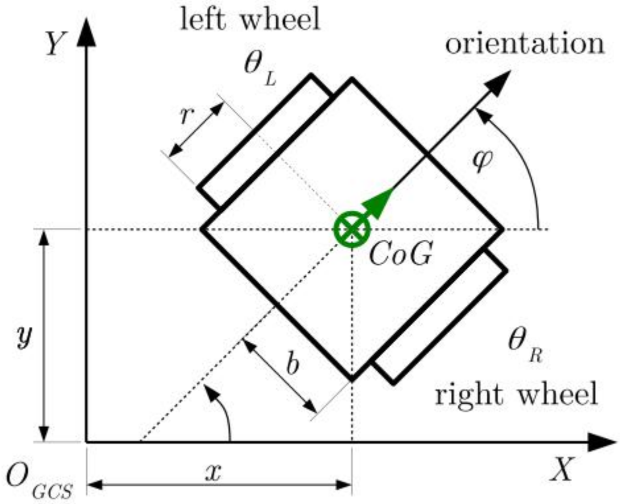

Figure 2. Mobile robot dimensions and position in GCS [9].

2.1 Kinematic Model

The mobile robot kinematic model [5][10][11][12][13] is given by

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} \cos\psi & -a\ \sin\psi \\ \sin\psi & a\ \cos\psi \\ 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ \omega \end{bmatrix} \tag{2}$$

For the WMR trajectory, the design of the kinematic controller is based on the kinematic model of the robot and given by

$$\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix} = \begin{bmatrix} \cos\psi & -a\ \sin\psi \\ \sin\psi & a\ \cos\psi \end{bmatrix} \begin{bmatrix} u \\ \omega \end{bmatrix} = A \begin{bmatrix} u \\ \omega \end{bmatrix} \tag{3}$$

with

$$A = \begin{bmatrix} \cos\psi & -a\ \sin\psi \\ \sin\psi & a\ \cos\psi \end{bmatrix} \tag{4}$$

the inverse of A gives

$$A^{-1} = \begin{bmatrix} \cos\psi & \sin\psi \\ -\frac{1}{a}\sin\psi & \frac{1}{a}\cos\psi \end{bmatrix} \tag{5}$$

Therefore, the inverse kinematics is given by

$$\begin{bmatrix} u \\ \omega \end{bmatrix} = \begin{bmatrix} \cos\psi & \sin\psi \\ -\frac{1}{a}\sin\psi & \frac{1}{a}\cos\psi \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \tag{6}$$

2.2 PID Controller Design

PID controller is ubiquitous in the development history of the control system because it is straightforward to implement and can operate well under a wide variety of operating conditions. Besides, the controller has direct outcomes of every one proportional, integral, and derivative control. Figure 3 depicts the block diagram of a PID control system for one side of the vehicle. Every side includes a PID controller for one position and another PID controller for the speed. The designed PID controller enables the mobile two-wheeled robot to find a suitable path [14][15].

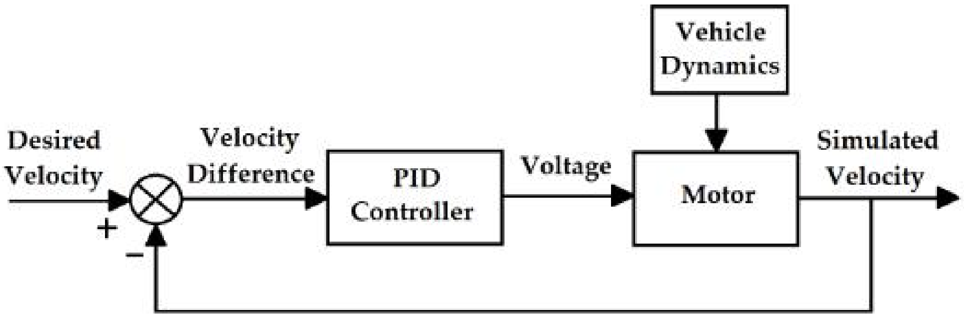

Figure 3. Block diagram of a closed-loop system for one side of the vehicle.

In this paper, the position trajectory controller for WMR is designed using classical PID and described as:

$$u = k_P^h e_h + k_I^h \int e_h + k_D^h \dot{e}_h \tag{7}$$

where $e_h = X_d - X$ is the error between the desired signal and actual signal, and k_P^h, k_I^h, and k_D^h are the PID gain parameter with vector $h = [x\ y]^T$.

2.3 Fuzzy Logic Controller Design

A fuzzy Logic Controller (FLC) is used to ensure that the mobile robot can track the reference trajectory [16][8]. The Fuzzy logic controller used has two inputs that are error and derivative error. Meanwhile, there is one output, u in this FLC as illustrated in Figure 4.

Figure 5 on the other hand displays the membership functions for both the inputs and the output, which are using triangle and trapezoid membership function with three fuzzy partitions referred to as zero (Z), positive (P) and negative (N). The range applied is between -1 until 1. The centroid of the area is applied as its defuzzification strategy, and the mapping of Fuzzy rules used in this paper are as stated in Table 1.

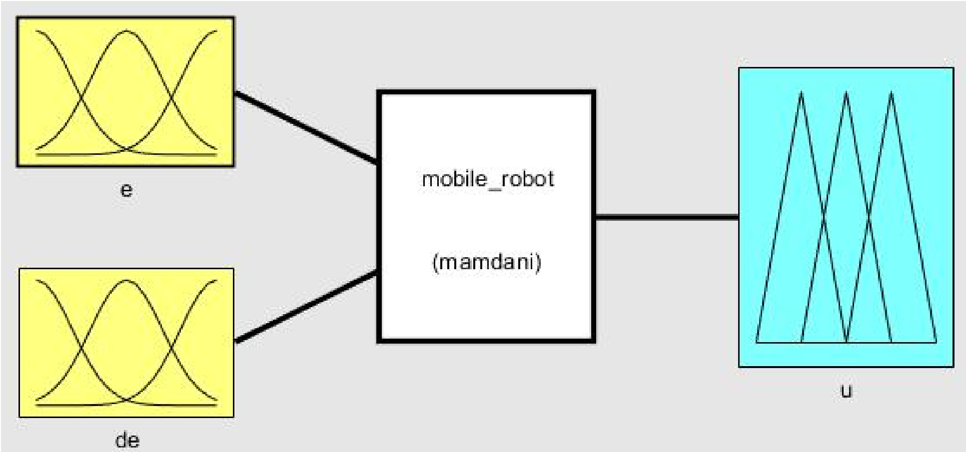

Figure 4. Fuzzy logical control.

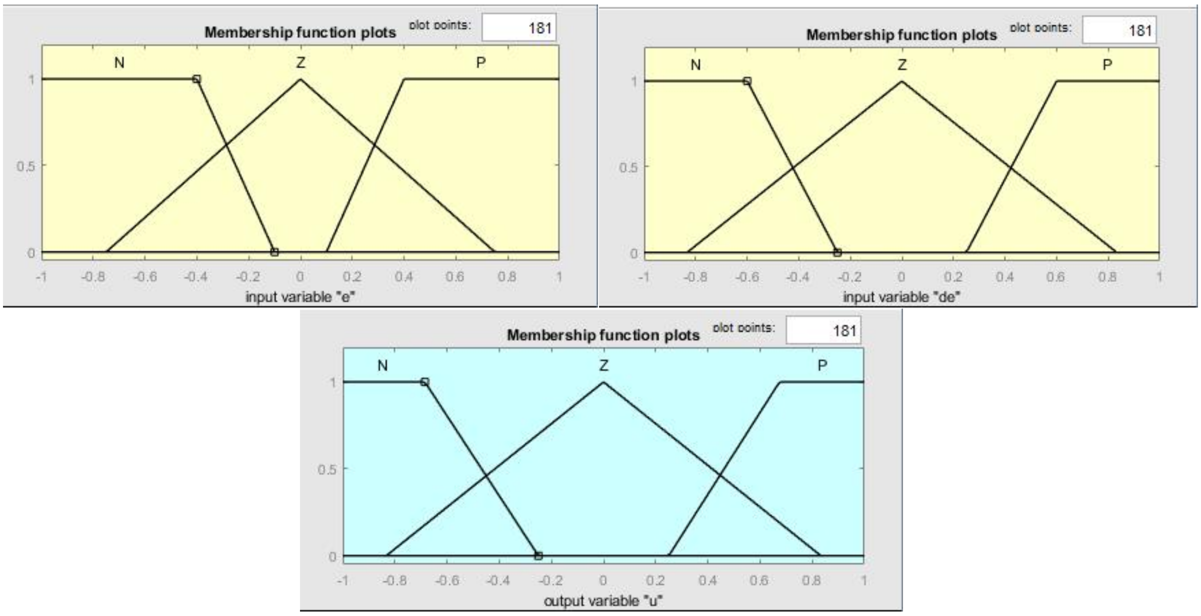

Figure 5. Membership functions.

In this Mamdani model, nine rules are created based on heuristics language using IF-THEN statements and combined with logical AND. For instance, IF error is "NEGATIVE" AND derivative error is "NEGATIVE", THEN output is "NEGATIVE". The nine fuzzy rules are:

R_1: If *e* is Z and *de* is Z then *u* is Z,
R_2: If *e* is Z and *de* is P then *u* is Z,
R_3: If *e* is Z and *de* is N then *u* is Z,
R_4: If *e* is P and *de* is P then *u* is P,
R_5: If *e* is P and *de* is N then *u* is P,
R_6: If *e* is P and *de* is Z then *u* is P,
R_7: If *e* is N and *de* is N then *u* is N,
R_8: If *e* is N and *de* is P then *u* is N,
R_9: If *e* is N and *de* is Z then *u* is N.

Table 1 Fuzzy Rules

e	de		
	N	Z	P
N	N	N	N
Z	Z	Z	Z
P	P	P	P

3. RESULTS AND DISCUSSION

Initially, the WMR is set at $h = [0\ 1]^T$ where, h is a position vector which equals to $[x\ y]^T$ and circular motion with radius 1m is set as the desired trajectory. The gains of PID were manually tuned to obtain satisfactory results and settling times. The gains used in this PID controller are $k_p = 8$, $k_i = 0.01$, and $k_d = 1$ for both x and y position. Meanwhile, the gains to tune Fuzzy Logic Controller are $kfz_p = 5$, $kfz_d = 0.1$, and $kfz_u = 5$ for both x and y position. To obtain a circle trajectory, a signal of $\sin(t)$ and $\cos(t)$ with amplitude of 1, is injected to x and y axis respectively.

The simulation results presented in Figures 6 and 7 illustrate the x-position, y-position and circle trajectory. In this simulation, the WMR was able to follow the circle trajectory within 10s. In Figure 6, the output signal of Fuzzy (blue) and PID (purpe) closely follow the desired signal (red) in x-position and y-position. Figure 7 shows the movement of WMR when plotted in x-y graph which is a circle and it shows that the output signal of Fuzzy (blue) and PID (purpe) closely follow the desired signal (red)[12].

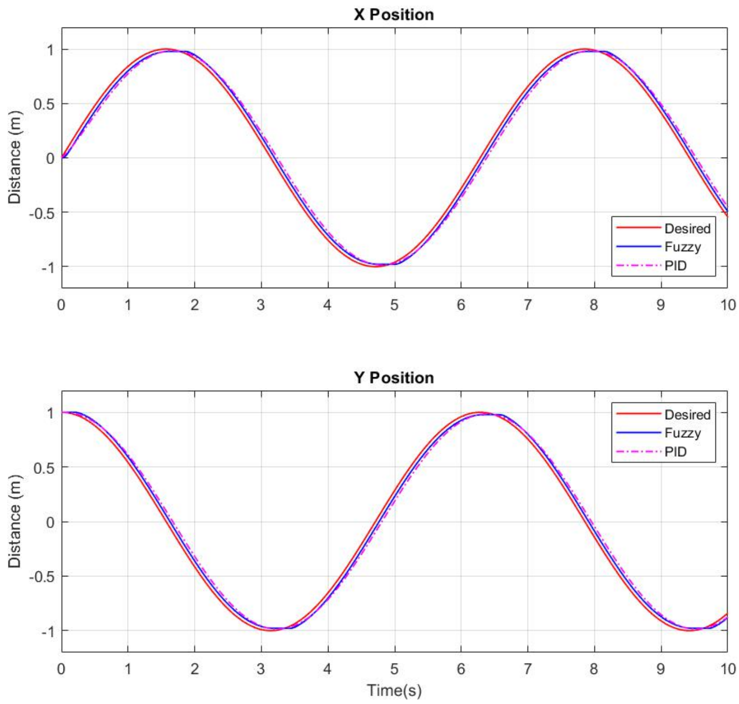

Figure 6. X and Y Responses, Fuzzy vs PID.

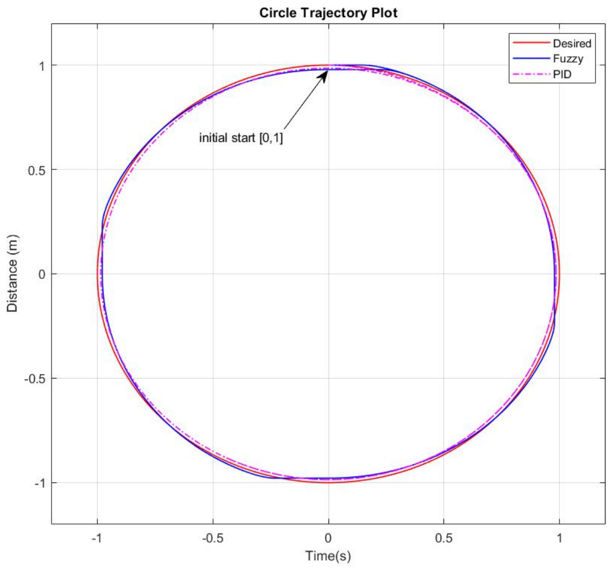

Figure 7. Circle trajectory using Fuzzy vs PID.

The controller execution is compared by using performance index. Hence, in x-position, the integral square error (ISE) is 0.048 and 0.020 for PID and Fuzzy Logic, respectively. While in y-position, the ISE give 0.045 and 0.019 for PID and Fuzzy Logic, respectively as tabulated in Table 2. Fuzzy logic ISE at about half of the PID ISE indicates that the proposed FLC system[8] produced a much more satisfactory performance when compared to the PID system.

Table 2 Integral Square Error performance index for circle trajectory

	ISE	
	PID	Fuzzy Logic
x	0.048	0.020
y	0.045	0.019

4. CONCLUSION

This paper focuses on the wheeled mobile robot (WMR) kinematic model and position controller. Two controllers PID and Fuzzy Logic, were proposed in this study. Both of the controllers were analyzed and compared by integral square error (ISE) performance index. A circle movement is the desired trajectory used in the simulation for the WMR. The comparison shows that the Fuzzy Logic controller gives a better and satisfactory performance of the trajectory response than the PID controller. In the future, other controllers such as the sliding mode and adaptive controllers will be included in the study to improve the system performance while perturbating the WMR.

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