Speed Control of a Mobile Robot Using Fuzzy Logic Controller

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Abstract. Applying a speed control system to a mobile robot needs to be done to make the robot move stably in an uneven environment with the variation of load. This study purpose is to designed a speed control system for a mobile robot to follow setpoints with a fast response to reach a predetermined speed. The speed controller used the fuzzy logic control method. The input is a speed error and the change in speed error is known from an encoder sensor and the output of the system is pulse width modulation (PWM) in the range of 8-bit converted to fuzzy forms. The rule formation and rule analysis with its implication function use the MIN function and defuzzification use the weighted average method. By implementing this fuzzy control the results of the robot move at the speed corresponding to the setpoint both on flat or uneven terrain, with load or without load. In experiments carried out on robots with a setpoint of 9,000 rpm from rest, the response time (in rise-time) is less than 47ms and steady-state error close to zero.

1. Introduction
The speed of a mobile robot with an open loop system can be done by giving pulse with modulation (PWM) to each motor [1, 2]. A mobile robot with DC motor drives is widely used due to DC motors that can be controlled easily and have linear characteristics of the increase in DC voltage given [3]. Through the PWM technique, the robot is given a signal to drive a DC motor at a certain speed. However, the speed of the robot will experience a slowdown if given a load or through the uphill road and will increase rapidly when crossing the road downhill [4].

In control system theory, the design of a system's control can be carried out by several methods like classical control [5, 6, 7], in which the system is modeled as a Laplace transfer function with control still popular and widely used today like the Proportional Integral Derivative (PID) control, lag-lead compensator through the design and analysis of root position, Nyquist and Bode diagram [8, 9]. The design of the DC motor speed control system using PID has been carried out including [10] which designs and implements the DC motor speed control into the microcontroller with the PI control method. The speed is changed by setting PWM switching. In determining the parameters in the PI control, tuning is done by finding the proportional constant values and the right integral constants. Testing is done by looking at the actual speed compared to the desired reference speed. The speed response is shown in Simulink MATLAB with various variations of the sinusoidal, box signal reference speed. It was concluded that the implemented PI control was good enough, able to follow the desired setpoint speed reference.

The intelligent control system without using mathematical models with fuzzy logic which was introduced by Zadeh in the 60s also began to be popularly used to design control systems, one of which was carried out by [11, 12] designing drivers and speed control of two Brushless Magnet Permanent
Motor that are expected to run straight track and turn based on microcontrollers by applying fuzzy logic control methods that are implemented into the microcontroller [13]. This study designed the speed control of two DC-motors on a mobile robot which is expected to run in uneven environments both with load or no load according to the speed set by applying fuzzy logic control methods implemented into the microcontroller.

2. Method

As shown in Figure 1, a motor speed setpoint is set to provide input for the robot’s speed. There is an encoder installed which is used to determine the actual speed of the robot. If the speed does not match the predetermined setpoint, the system will calculate the speed error (e) and change in error (Δe). Input and output are converted into fuzzy (fuzzification) forms. The rule formation and rule analysis with its implication function use the MIN function and the defuzzification use the weight average method.

The actuator used in this study is two DC motors that have 0-12 VDC input specifications with a maximum turn of 18,000 rotation per minute (rpm) at a 12 VDC voltage installed by the gearbox versus 34:1. In the final gear, a four-centimeter diameter chain tank was installed. A ten fold encoder is installed on a DC motor directly as input to be able to know the actual speed of each DC motor. Figure 2 shows a characteristic curve of a DC motor that is used as a driver of the left and right wheels.

Figure 1 Block diagram of the system

Figure 2 (a) Characteristic curve of Left DC motor, (b) Characteristic curve of Right DC motor
2.1 Fuzzy Logic Controller Design

This design uses two fuzzy inputs which are an error (e) to express the difference in actual speed with setpoints. And an error change (Δe) to describe the current error change with the previous error. (See Figures 3 and 4).

![Figure 3 Fuzzy sets for input](image1)

![Figure 4. Fuzzy sets for output](image2)

Fuzzy rules are shown in Table I. Based on the rule base output, fuzzy set is found and the membership degree is given by MIN Function. The outputs obtained from rule evaluation are combined to form a single distribution. This is done by performing union operation on output fuzzy sets. Crisp output is obtained by weight average.

| e/Δe | NP | NM | NL | Z  | PL | PM | PH |
|------|----|----|----|----|----|----|----|
| NH   | NH | NH | NH | NM | NL | NL | Z  |
| NM   | NH | NM | NM | NL | NL | NL | Z  |
| NL   | NM | NM | NL | NL | Z  | PL | PM |
| Z    | NM | NL | NL | Z  | PL | PM | PM |
| PL   | NL | NL | Z  | PL | PM | PM | PM |
| PM   | NL | Z  | PL | PM | PM | PH | PH |
| PH   | Z  | PL | PM | PM | PH | PH | PH |

2.2 System Implementation

The setpoint value is given from the main microcontroller in the form of values 0-18,000 (in rpm) that has been converted from the 8-bit PWM value to each microcontroller of each motor as a speed reference. The microcontroller on left and the right motor will read the rotary encoder data with a
sampling time of 10 ms. If there is an error in the number of flips that sets the point, then the fuzzy control that has been implemented to the right and left microcontrollers will increase or decrease the speed to each motor to reduce the error to zero. Figure 5 shows the block diagram of the implementation system.

3. Results and Discussion
The main goal of this research is to make the left and right motor speed always follow the desired setpoint both when the robot is running on the floor that is flat, uphill or down, so that the results of the robot movement are relatively straight. The parameters that are referred to in this test are the system response to the setpoint (rise-time) and stability in maintaining setpoint (steady-state error is equal to or close to zero).

The open-loop robot movement system by only giving the speed through PWM value results in the system is still able to follow the setpoint if there is no-load on the robot as shown in Figure 6, but when the robot is given the load both motors cannot catch the set point determined.

![Figure 6. System testing without and with the fuzzy logic controller](image-url)
The system with fuzzy control and without fuzzy control as shown in Figure 6 graph a and b shows the same relative response time which is in the range of 37–46 ms for right and left motors. Both systems can still achieve and maintain the specified setpoint (setpoint in 9,000 rpm).

Different results are obtained when the robot is given a load (the weight of the load is the same value when tested in control and without control). In Figure 6 graph D, a robot with a load can still follow setpoint (steady-state error equal to zero) with slower response time (in rise-time) of 20 ms that is needed in 61 ms compared to no load. However, the system without fuzzy control with the given load cannot follow the setpoint as described as shown in the Figure 6 graph C. System testing with setpoint changes can be seen at Figure 7.

Figure 7. System testing with setpoint changes

Figure 8 shows the system response with the given setpoint changing. The robot response is tested by giving 6,000, 12,000, 18,000 and down again to 12,000 rpm. At 6,000 rpm the accelerated robot with rise-time equal to 35 ms, rise-time equal to 43 ms to 12,000 rpm and 114 ms goes to 18,000 rpm.

Then, the robot was tested through a slope with a slope angle of 15 degrees and derivatives with a steepness of 15 degrees. Seen in figure 10, robot with fuzzy control systems can still follow the specified setpoint while the system without control is not.
Robots with open loop systems cannot catch the desired setpoint due to the lack of checking the speed given. By implementing this fuzzy control the results of the robot move at the speed corresponding to the setpoint both on flat or uneven terrain, with load or without load. In experiments carried out on robots with a setpoint of 9,000 rpm from rest, the response time (in rise-time) is less than 47 ms and steady state-error close to zero.

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Figure 8. Testing the system through Slanting Upward Way and Descend Road
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