Fuzzy Logic Control Implementation for DC Motor RPM Control

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Abstract

This project aims to design and implement a fuzzy logic control system for regulating the rotational speed (RPM) of a DC motor using an Arduino microcontroller. Fuzzy logic is a powerful control technique that can handle the nonlinearities and uncertainties inherent in DC motor speed control. The system consists of a 12V DC motor, IR sensor for RPM measurement, a potentiometer for user input, L298N motor driver and Arduino Nano. The fuzzy inference system is designed using MATLAB's Fuzzy Logic Designer tool. After the design, resulting system is exported from toolbox by MATLAB operations and embedded as lookup table to Arduino. Then the required parameters RPM error and change of RPM error is calculated, and resulting motor voltage change is applied to dc motor as a PWM signal to drive the motor. Then resulting RPM is compared to desired RPM to see the effectiveness of fuzzy logic control on motor RPM control application.

Introduction

DC motors are widely utilized in many different applications, such as automation, robotics, and industrial control, where accurate speed control is essential to reliable and effective operation. However, because DC motors' behavior is characterized by nonlinearities and uncertainties, precisely controlling their speed can be difficult. Fuzzy logic is one of the sophisticated control strategies that have been investigated to address this problem. With its more resilient and adaptable control method, fuzzy logic control presents a viable way to manage the nonlinearities and uncertainties in DC motor speed control. This project intends to use an Arduino microcontroller to create and implement a fuzzy logic control system for adjusting a DC motor's rotational speed (RPM). Fuzzy logic systems are based on the concept of fuzzy sets, which allow for the representation of linguistic variables and their relationships using fuzzy rules. The methodology of fuzzy logic control involves the design of a fuzzy inference system, which uses fuzzy rules to map input values to output values, and defuzzification techniques to convert the fuzzy output into a crisp value. The fundamentals of fuzzy logic control include the use of fuzzy membership functions to define the input and output variables, fuzzy rules to describe the relationships between these variables, and defuzzification techniques to convert the fuzzy output into a crisp value.

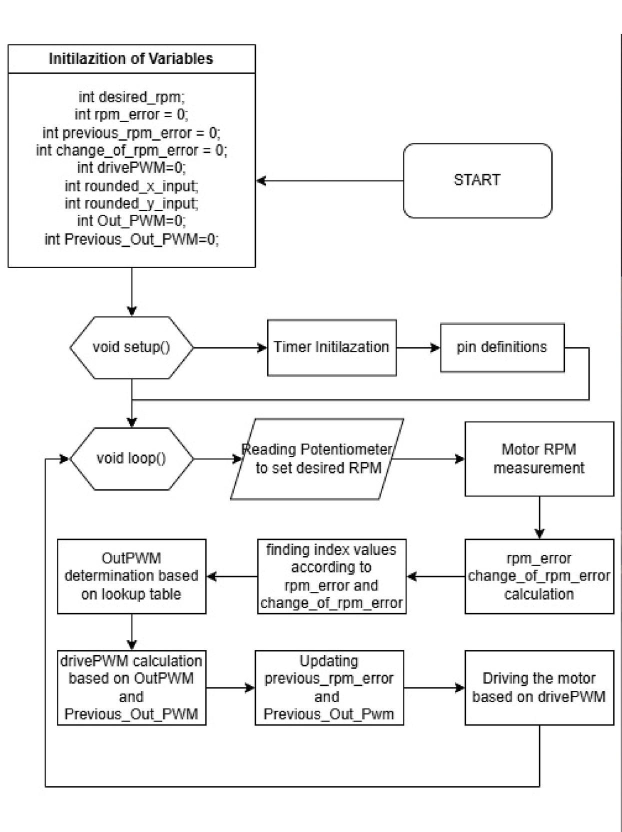

Figure 1. Flowchart of the system.

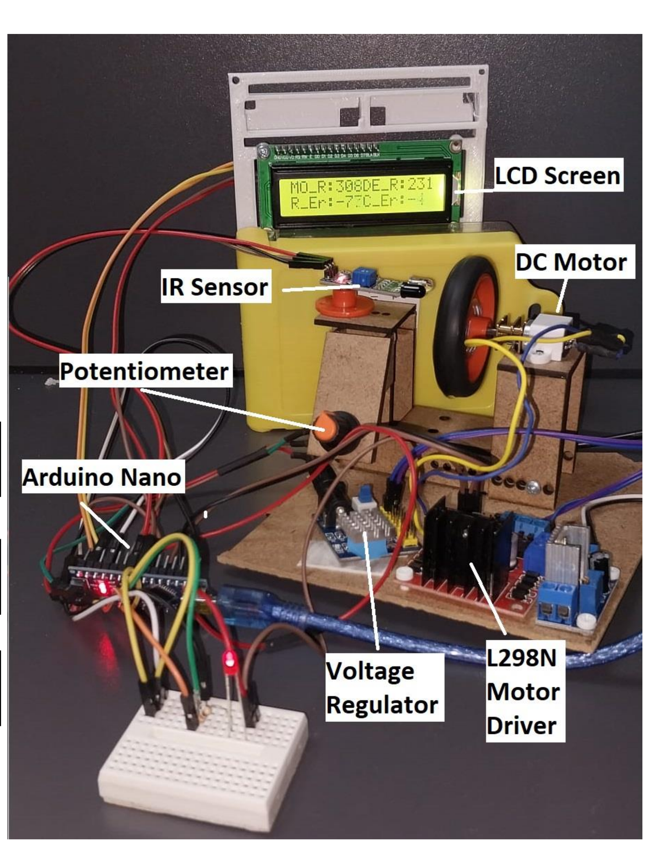

Figure 2. System Diagram.

Methodology and Tools

The implementation of fuzzy logic control to microcontroller involves two main steps: designing fuzzy inference system and implementation of the fuzzy inference system on microcontroller such as Arduino. To design a fuzzy inference system, firstly the linguistic variables of inputs and output are determined. In this case, RPM error and change of RPM error is defined as input variables, and output PWM value change is used as output variable. The definitions of these variables are below.

RPM Error = Desired RPM – Measured Motor RPM.
Change of RPM Error = RPM Error – Previous RPM Error.
Output PWM Change= Output PWM – Prev. Output PWM.

Then, the membership functions are generated for input and output linguistic variables. The membership functions are influenced from (Freitas, Rameli, & EAK, 2017), but the range of the functions are adapted to our DC motor. The DC motor that used can deliver 1000 RPM at 12V according to its datasheet. (Figure 6) The consideration of the voltage drop of motor driver and safe operating margin, the motor RPM is maximized to reach 600 RPM. Then, the rule base is generated. (Table 1) After completation of fuzzy inference design, the system is exported as lookup table and implemented to Arduino as an array. The fuzzy output membership function can be seen at figure 3 and the control surface is represented at figure 4.

Results

The desired RPM and motor RPM is measured via adjusting desired RPM using potentiometer. The measurements made by transferring serial monitor data to excel, then these raw data is converted to graph which can be seen at figure 6. From the figure 5, the motor RPM and desired RPM can be tracked, also the error variables of our fuzzy system RPM error and change of RPM error can be observed. From this output, one can say that the fuzzy inference system's fuzzy output PWM matches with change of rpm error. Also, the motor tracks the desired RPM with significant error margin. Although desired RPM and motor RPM aligns, there is an error gap occurred. The error is around -80 RPM. The oscillations in the motor RPM proves the effort of correction, which is represented at figure 7.

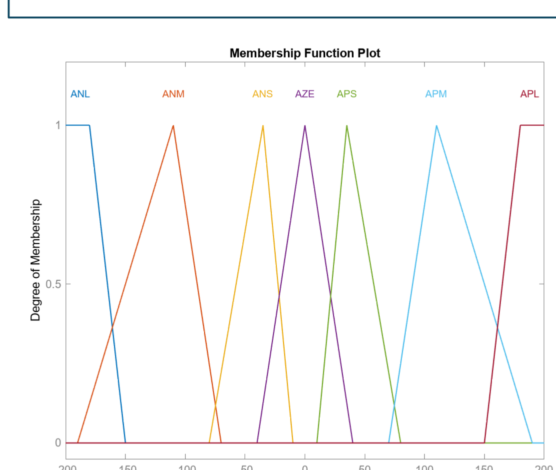

Figure 3. Output Membership Function.

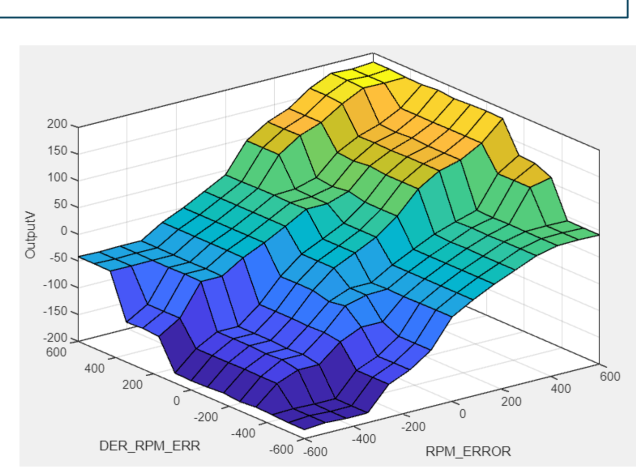

Figure 4. Control Surface.

Table 1. Rule Base of Fuzzy Inference System.

RPM ERROR \ CHANGE OF RPM ERROR	NL	NM	NS	ZE	PS	PM	PL
NL	ANL	ANL	ANL	ANL	ANL	ANM	ANS
NM	ANL	ANM	ANM	ANM	ANM	ANS	ANS
NS	ANM	ANS	ANS	ANS	ANS	AZE	AZE
ZE	ANS	ANS	AZE	AZE	AZE	APS	APS
PS	AZE	AZE	APS	APS	APS	APS	APM
PM	APS	APS	APM	APM	APM	APM	APL
PL	APS	APM	APL	APL	APL	APL	APL

NL: Negative Low, NM: Negative Medium, NS: Negative Small, ZE: Zero.
ANL: Add Negative Large value, ANM: Add Negative Medium value, etc.

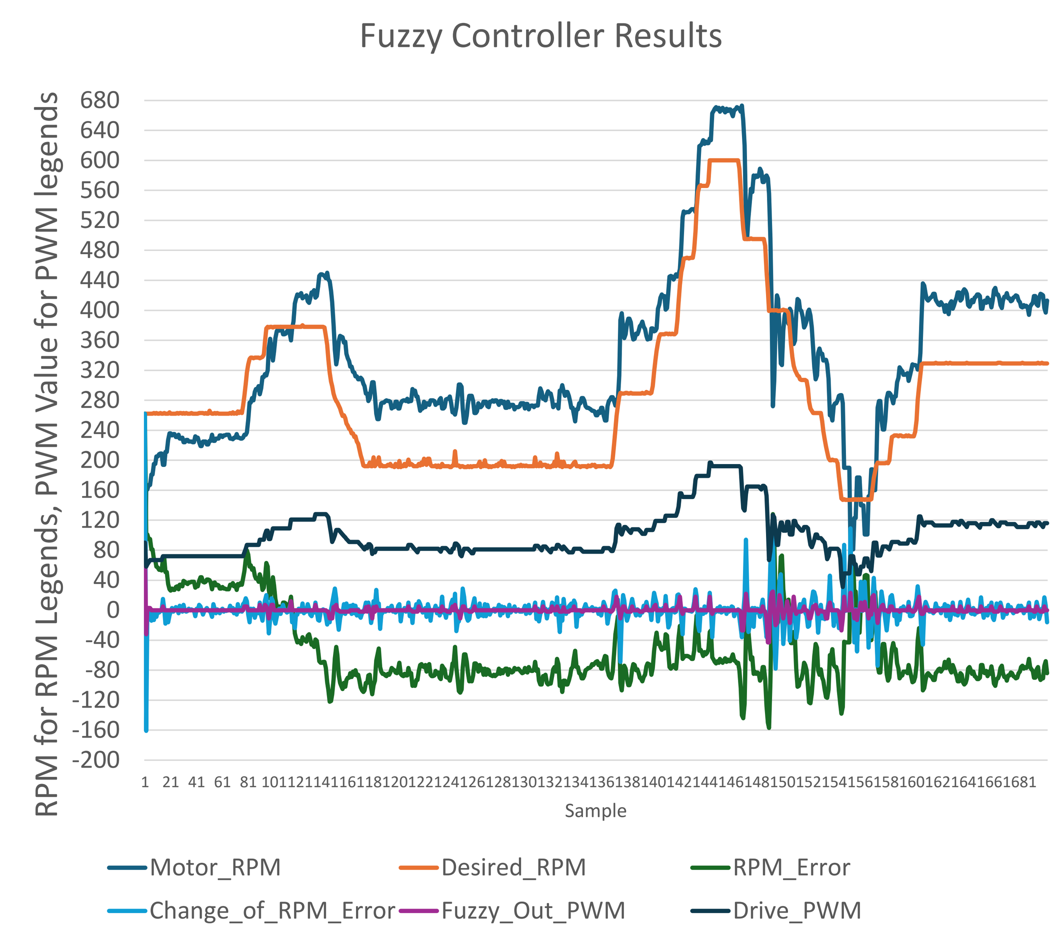

Figure 5. Fuzzy Controller Results.

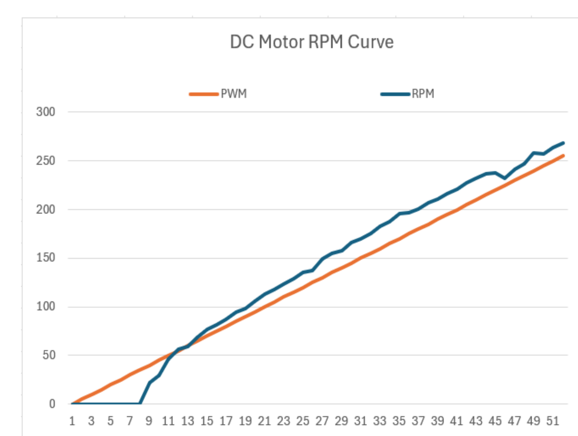

Figure 6. DC Motor RPM Curve.

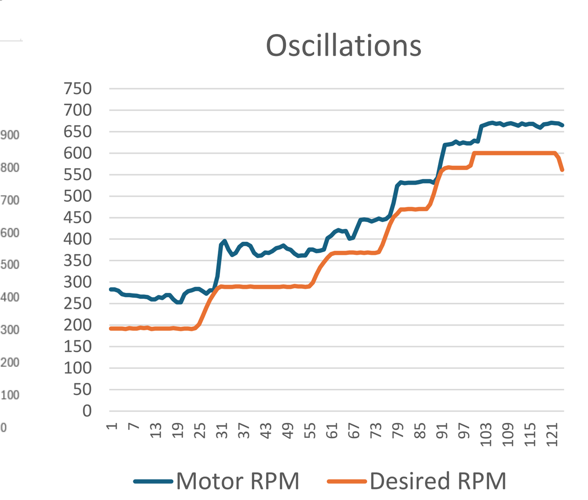

Figure 7. Oscillations of Controller.

Discussion

The performance of fuzzy logic control on DC motor RPM has significant error margin around -80 RPM. The reason causes error might be couple of reasons. One significant factor is that mamdani type fuzzy logic systems heavily relys on the knowledge of the operator. Due to that, adjusting the membership functions and generating a rule base has significant effect on the performance of the control system. In this case, lack of experience in operator might cause the error, but in general although error is high the fuzzy system keeps the same error margin around different RPM values which proves that system is trying to control the motor RPM. There are couple of improvements can be made. Firstly, the memebership functions can be arranged for better performance by trial and error. Then the rule base can be updated if there is an incorrect rule defined. Lastly, some preprocessing and post processing operations made to PWM value before driving the motor, as it is applied in PID and other control methods.

References

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