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Identification and implementation hybrid fuzzy logic and PID controller for speed control of BLDC motor

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Abstract. One of the problems in the optimization process in the Brushless Direct Current (BLDC) speed control system is to obtain a mathematical model in the form of a transfer function. The purpose of this study to mathematically model BLDC motors in transfer functions, and optimization using Proportional, Integral and Derivative (PID) controllers, and fuzzy logic to tune PID controller parameters. The first method used is the process of identifying input and output data from the BLDC motor physical system. The input and output data of the test results simulated to form a mathematical model. The mathematical model of BLDC motor used as the basis for carrying out the optimization process with open loop systems, PID controllers, and fuzzy logic. The results of the research on the optimization process of the BLDC motor speed control system with the fuzzy logic methods obtained the best value for rise time value of 1.25 seconds, settling time value of 382.10 seconds, and peak time is 382.2 seconds. With these results, it shows that the fuzzy logic has given a better transient response than the PID controller in increasing optimal stability.

1. Introduction

At present, the number of motor vehicle users in the world until 2030 is predicted to reach 2 billion [1]. The increase in the number of motorized vehicles causes air pollution, global warming, and the emergence of many diseases. Electric bicycles have many advantages, which are more environmentally friendly because they do not produce emissions, cheaper maintenance costs, and do not require payment of taxes or liability ownership [2]. BLDC Motor is the primary choice as a driving component for electric bikes because it has several advantages, namely having permanent (long enduring) magnets, better torque and speed characteristics, frictionless operation, high dynamic response, high reliability, and efficiency. Some Asian countries such as Japan have implemented variable speed drive of BLDC motor to increase energy savings such as Air Conditioner (AC) [3].

Therefore, with the increase in energy prices, the demand to improve the regulation of the BLDC motor speed is getting higher. Speed regulation is a method used to adjust the rotating speed of an electric motor in a certain range by changing the value of the frequency, current or voltage entering the motor [4]. The variable speed drive system has three main components, namely an electric motor, power converter, and a control system [5]. Several methods used to improve the BLDC motor speed control system, using the Proportional Integral Derivative (PID) controller, and PID combined with intelligent controls such as fuzzy logic [6,7], neural networks, and algorithms inspired by nature [8]. The intelligent control is used to tuning the PID controller parameters, so as to improve the performance of the BLDC motor such as overshoot, settling time and rise time values, indicate performance of setting BLDC motor speed [9].

In this paper, the process of increasing the speed setting performance 350-Watt BLDC motors used in electric bicycles, through mathematical modelling and optimization. The optimization method carried out in this study is by PID controller and hybrid fuzzy logic. The identified results used to determine the performance of the BLDC motor speed control are indicators of transient response. The sign of transient response is to be measured by the value of peak amplitude, rise time, and settling time.

2. Methods

In Figure 1 describe some of the main components of an electric bicycle, such as a battery, controller, throttle, and BLDC motorbike. The BLDC motor used in this study has a maximum power of 350 watts. Data input data includes pulse width modulation (PWM), voltage, and current. While the output data is in the form of motor rotational speed, input and output data used to identify the BLDC motor system, to obtain a mathematical model in the way of a transfer function. After getting a mathematical model in the form of a transfer function, optimization is carried out by using a PID controller, fuzzy logic and hybrid fuzzy logic PID controller

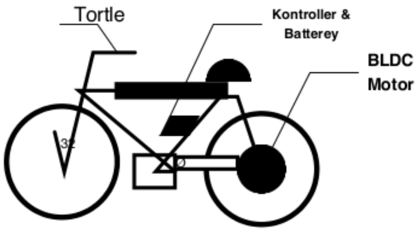


Figure 1. The main components of an electric bicycle.

Evaluation results to determine the performance of setting the BLDC motor speed then simulated using the MATLAB program for transient response values such as peak amplitude, rise time, and settling time

2.1. System identification of BLDC motor

Mathematical modelling of BLDC motors is done through an experimental process to obtain input and output data. Observation data modelled using the transfer function model in the MATLAB program. Mathematical modelling will determine the optimal performance of the BLDC motor speed regulation system. Figure 2, showed a chart of identification systems to obtain mathematic models that can replace physical structures [10].

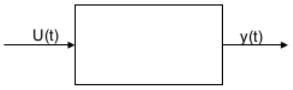


Figure 2. System identification for mathematical modelling.

In Figure 2, it explains the relationship between input and output which can be formulated as follows:

$$y(t) = \int_{\tau=0}^{\infty} g(\tau)u(t-\tau)d \tag{1}$$

where for $\{g(\tau)\}_{\tau=0}^{\infty}$ and u(s) for $s \leq t$, can be calculated.

In general, physical systems work with time representation, which expressed to be differential equations. With G (s) showing the Laplace transformation of the impulse response function.

$$Y(s) = G_c(s)U(s) \tag{2}$$

where for Y(s) dan U(s), the Laplace transform of the output and input, respectively.

The BLDC motor generally consists of three parts: motor structure, power drive circuit and position sensor. The working principle of BLDC motor is to implement an electric switch to replace the role of a mechanical commutator. The inverter topology PWM is a six-source voltage-source configuration with a constant dc-link voltage (Vd), which is identical to the drive induction motor and permanent magnet ac motor drive [11].

Then the transfer function for the BLDC motor formulated as follows:

$$G(s) = \frac{\omega_m}{V_s} = \frac{\frac{1}{K_E}}{\tau_m \tau_E s^2 + \tau_m . s + 1} \tag{3}$$

where ω_m, Vs, K_e, τ_m, τ_ϵ are angular velocity, source voltage, back emf constant, mechanical time, and electrical time.

2.2. *Hybrid fuzzy PID controller for BLDC motor*

The control system is generally divided into two types, namely open loop and close loop. The usual double close loop system model is used in the control system. The first close loop, which is called the inner loop, is used for current or torque control(8), while the outer loop is used for setting speed or voltage. The PID controller system is widely used in industrial applications because it has advantages, namely simplicity, robustness, reliability and easy adjustment parameters. The PID controller, composed of several models, namely proportional control, integral control, derivative control, and a combination of proportional, integral derivative controllers. The equation for the PID controllers, can be written in the following equation:

$$u(t) = K \ . e(t) + K \int_0^t e(t) d \ + K \ \frac{d}{d} \tag{4}$$

The difference in terms of the application can reduce maximum overshoot and dynamic deviation. But the drawback is that the plant that is controlled by high frequency interference. Therefore, to improve performance, PID controllers need to be combined with intelligent controllers, such as fuzzy logic.

Fuzzy logic controllers include four components, namely fuzzification, knowledge database (including the database and rule base), fuzzy inference and defuzzification. Fuzzy control method is an intelligent control method that can be implementing to control an object effectively with good adaptability [12].

The sensitivity of a fuzzy controller can be increased by means of the actual value of the e error and the change in error (delta error) quantized by using the quantization error (Ke) and Error change factors, then mapped with the fuzzy set domain such as:

$$X = \{-m, -m + 1, \dots 0, \dots, m - 1, m\} \tag{5}$$

The fuzzy logic procedure that in this system evaluates the rule with the Mamdani method. The linguistic variables specified are NB (Negative Big), NM (Negative Medium), NS (Negative Small), Zero (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big). To obtain the appropriate speed response, it is used to changing the membership function with a certain range of values. Speed data entered into the control system in order to obtain speed correction data (error) and the difference in speed correction (error), while the output is an increasingly smaller error. In table 1, describes the table of fuzzy control determination, which has 49 fuzzy control rules.

Table 1. Fuzzy-based initial rules.

				Error			
ΔError	***NB***	***NM***	***NS***	***Z***	***PS***	***PM***	***PB***
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

The form of membership functions used in setting the BLDC motor speed which consists of input error and delta error, and the output of fuzzy logic controller presented in Figure 3.

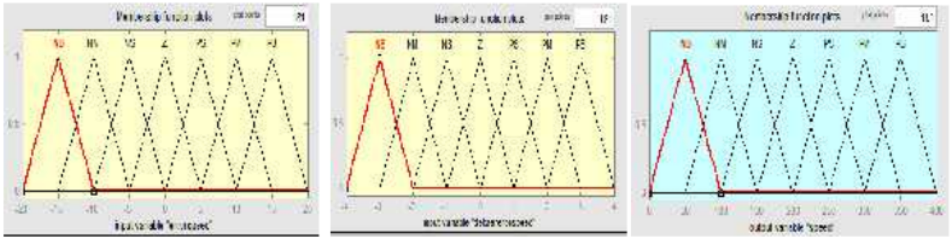


Figure 3. Input, Output Membership Functions for error and delta error FLC.

3. Result and discussion

The results of the implementation of the Hybrid Fuzzy PID controller are divided become several parts, first identifying system parameters to obtain mathematical models in the form of transfer functions, the second transient response in open loop conditions, and the third implementation of PID controllers and Hybrid Fuzzy PID in close loop conditions.

3.1. System identification transfer function of BLDC motor

The data used for this study as many as 400 data. Observed data is simulated and modelled using the transfer function. After the program run by selecting the estimated transfer function model, the transfer function equation obtained for the BLDC motor speed control as follows:

$$G(s) = \frac{3544s + 7630}{s^3 + 21.39s^2 + 2080s + 4172}$$

3.2. Response transient for open loop system, PID controller, fuzzy logic, and fuzzy PID

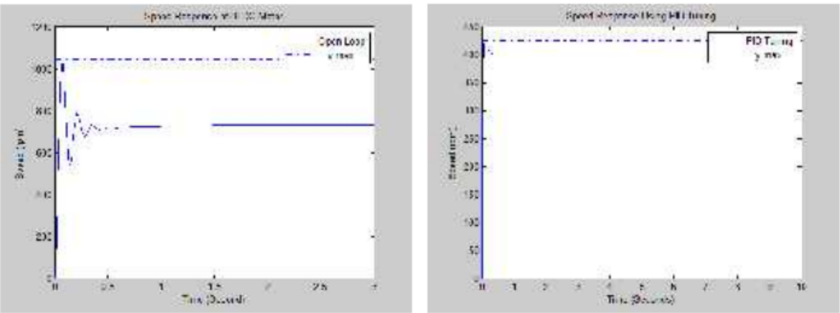
The transient response of the BLDC motor speed control was tested to see differences before and after optimization with PID, fuzzy logic, and fuzzy PID controllers. Testing is done through simulation by the Matlab program based on the equation of the transfer function obtained through the identification system of BLDC motor input and output data.

Table 2 showed transient response test results that include the value of peak amplitude, rise time, and settling time.

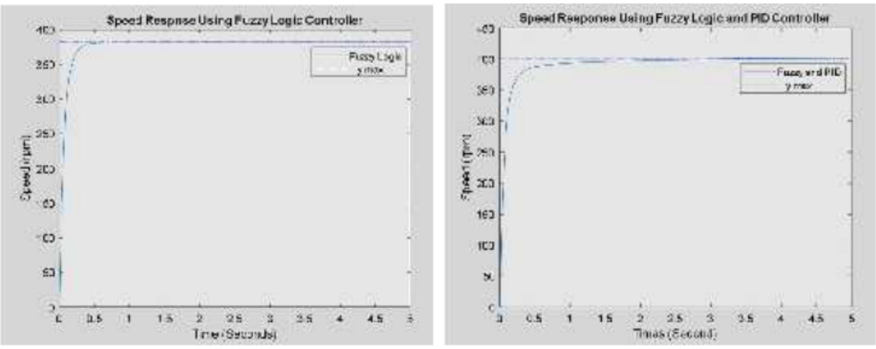
Table 2. Result performance optimization for speed response.

Model	Parameter Speed Response					
	k_p	k_i	k_d	Rise time	Settling Time	Peak Time
Open Loop	-	-	-	49.8	731.45	1047
PID	5.8	62.9	0.11	0.058	400.02	399.2
Fuzzy	-	-	-	1.25	382.10	382.2
Hybrid Fuzzy PID				14.6	402.03	402.1

In Table 2, the transient response value of the BLDC motor optimized with several controller models, such as PID controllers, fuzzy logic controllers, and fuzzy PID controllers. Fuzzy logic controller has the smallest settling time and peak time values compared to the other controllers, meaning that fuzzy logic reaches stability more quickly. The speed response graph for the control BLDC motor with different controller tests showed in Figure 4.



(a). Open loop system. (b). PID controller.



(c). Fuzzy logic controller. (d). Fuzzy PID controller.

Figure 4. Response transient of BLDC motor.

Graph transient response of speed control BLDC motor with several different controllers showed in Figure 4. From the graph, it can be seen that fuzzy logic controller is faster to achieve stability compared to other controllers.

4. Conclusion

From the results of research on the comparative study of the implementation of a Hybrid fuzzy logic and PID controller, it was carried out through two stages, identification and optimization. System identification is used to obtain the mathematical model of BLDC motor, and while optimization is used to improve BLDC motor performance.

The closed-loop control system has been able to improve speed response compared to the open loop system. From several comparisons of optimization methods, hybrid fuzzy logic and PID controllers can improve stability better than using PID controllers. When compared with the fuzzy logic method the results are not much different. Value for the ratio of peak amplitude, rise time, and settling time is 382.2, 1.25, and 382.10. Whereas value for fuzzy logic controller and peak amplitude are 402.1, the rise time is 14.6429, the settling time is 402.0296.

Acknowledgments

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