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Improved performance of Hexacopter's roll balance control system

Al Al[1], Fajrin Fajrin[2], Asnal Effendi[1], Antonov Bachtiar[1], Aswir Premadi[1]
[1]Department of Electrical Engineering, Faculty of Vocational, Institut Teknologi Padang, Padang, Indonesia
[2]Geodetic Engineering Department, Faculty of Engineering, Institut Teknologi Padang, Padang, Indonesia

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ABSTRACT

One of the obstacles in determining the constant of the proportional integral derivative (PID) control system for the stability of the Hexacopter is due to the dynamic response of the system. Changing the speed and direction of the aircraft's motion through the throttle is translated into a control system concept into a set-point change. If you have used PID control, which is constant, cannot adjust to changes in set-points or external influences, the stability and reliability of the aircraft cannot be guaranteed. This study proposes PID control, with adaptable constants, using a fuzzy logic controller (FLC). The influence of internal changes and factors outside the aircraft control system, in principle, will accumulate on the size of the error and delta-error. Thus, FLC performs tuning for the PID constant according to the error and delta-error. The design of fuzzifications and defuzzification is based on the maximum limit value of error and delta-error, and sets the value of the constant obtained by the Ziegler-Nichols method as the default value. After the real-plant test, the system performance is obtained as follows: settling time = 34mS; peak time 21mS; rise time = 9.2 mS; delay time = 5.7mS; percent overshoot and steady state error = 1%.

Corresponding Author:

Antonov Bachtiar
Department of Electrical Engineering, Faculty of Vocational, Institut Teknologi Padang
Gajah Mada Kandis-Nanggalo Street, Padang 25143, Indonesia
Email: antonov_bach@yahoo.com

1. INTRODUCTION

The Hexacopter is a kind of unmanned aerial vehicle (UAV) with six propellers driven by six brushless motors [1], [2]. The Hexacopter movement consists of four basic movements, namely throttle (acceleration movement), roll movement, Pitch movement, and yaw movement [3], [4]. Hexacopter has several functions such as in the military field, it is used to photograph enemy territory, conflict areas or to spy on the enemy. As for civil purposes, the hexacopter is used for mapping remote areas, monitoring volcanoes, monitoring congestion or taking images of areas after the tsunami disaster [5]. Related to these functions and needs, in order to get better results, there are still many interesting aspects to be improved such as security and stability issues. the better the safety and stability of a hexacopter aircraft, the easier and more effective it is to carry out its functions. Hoshu *et al*. studied multirotor configurations to compare their energy efficiency to standard helicopters while preserving the maneuverability and simplicity of conventional multirotor. They used a multilevel PID control approach to achieve better flight performance, with each stage of the cascade structure being designed through an automatic setup process. The study found that the proposed approach results in a stable and robust attitude control with improved transients and a steady response [6]. Sun *et al*. conducted research with sliding mode control of a Hexacopter, and they found the optimized sub-controller has improved in ascending time, peak time, overshot, completion time, and ITAE. In theory, optimization for a single corner sub-controller could result in a 58.3% reduction in ITAE. However, due to equipment limitations, only a 10.4% increase was measured in the experiment [7].

By looking at several previous studies, it can be seen that they used the same method, namely PID control. In principle, the performance of this control system can be further improved to get a more reliable Hexacopter control system. In connection with the above, it is quite interesting to discuss in this study, and report on how to get better values of Kp, Ki and Kd constants, by applying the Ziegler-Nichols method. Furthermore, how to improve the control system parameters if the PID has not been obtained a more optimal value.

A hexacopter is an unmanned aerial vehicle with six rotors as a lift power source. Each rotor rotates in a different direction, with each pair of three rotors, three of which are mounted clockwise and three of which are mounted counterclockwise [8]. This aims to stabilize the flying performance of the vehicle. The Hexacopter has different settings, (+) settings and (x) settings and the distance for each motor is 60° with asymmetrical frame shape. Roll movement, the rotor is adjusted right and left to produce right and left maneuvers. While in the Pitch movement, the rotor speed settings are carried out on the front and rear rotors to produce forward and backward maneuvers. When the front rotor speed is increased/decreased and the rear rotor speed is decreased/increased, a backward/forward maneuver will occur. So that it can be used as a way to apply Hexacopter when maneuvering. Yaw movement is a movement made to rotate the Hexacopter position with the core remaining in the same position. This movement is achieved by reducing the speed of 2 rotors that have the same rotational direction and increasing the rotation of 2 rotors that have the opposite direction of rotation of the previous two rotors. If the left and right rotor speeds are decreased along with the front and rear rotor speeds, the Hexacopter rotates counterclockwise with the core as the shaft. And vice versa [9], [10].

The proportional integral derivative (PID) control system mode is the main control system applied in this system. With PID controller parameters used to control motor balance. The tilt angle read by the MPU6050 sensor (gyroscope) against the desire state value of each setpoint. While the output parameter is a PWM pulse with a certain width which will be used to adjust the rotational speed of the BLDC motor [11]. Furthermore, to carry out the system stabilization process, a PID controller is used. While the general equation of the PID controller is as (1).

$$x(t) = xd(t) - x(t)$$
$$u(t) = Kp.e(t) + Ki\, e(t)\, dt + Kd\, de(t)/dt \tag{1}$$

Where u(t) is the control input and e(t) is the difference between the desired state and x_(d)(t) the current state x(t). k_p, k_I and K_d are parameters or constants for proportional, integrative and derivative elements of PID control. The general form of the PD controller in (2) is as (2).

$$u\,(k) = Kp.ek + 1/T.KD\,(ek - ek - 1) \tag{2}$$

Furthermore, in (3), an integrative component is added to correct the steady state error that occurs in the system so that the PID controller is formulated as (3).

$$u\,(k) = Kp.ek + Ki.\Sigma k0\; ek + 1/T\; KD\,(ek - ek - 1) \tag{3}$$

In (3) is then applied to the program to be made using (4).

$$u(k) = Kp * error + Ki * \; integral\; Error \; + Kd * (error - Last\_error) \tag{4}$$

$$Error = SP - PV$$
$$IntegralError = Lastintegral\; Error + erro * Ts$$

Where: U(k) = Plant output value of PID; Kp is the value of the proportional constant; Ki is the value of the integrative constant; Kd is the value of the derivative constant; last_erro is the last error value (error value t-1); set points = SP; process variable = PV; system sampling time = Ts.

Fuzzy logic, which was first introduced by Lotfi A. Zadeh, has membership degrees in the range 0 (zero) to 1 (one), in contrast to the conventional control system which defines something with true and false categories (1 or 0). Fuzzy logic is not only in the form of a value of 1 or 0, but several values will be output that will be used to process the control system [12]. There were many reasons why people use fuzzy logic, including the concept of fuzzy logic is easy to understand. Fuzzy logic is very flexible, meaning that it can adapt to changes and the uncertainty that accompanies problems. Fuzzy logic has tolerance for imprecise data. Fuzzy logic can model very complex nonlinear functions. Fuzzy logic can build and apply the experiences of experts directly without having to go through the training process. In this case, often known as fuzzy expert systems is the most important part [13].

In general, the basic structure of fuzzy logic consists of a knowledge base, fuzzification process, inference engine, and defuzzification process. All procedures that will be used in the process of fuzzification, interference, and defuzzification refer to what is in the fuzzy knowledge base. Therefore, the fuzzy knowledge base plays an important role in the fuzzy system [14]. Fuzzification is part of a fuzzy system that functions to change definite values (Crispt) into linguistic variables. This process consists of forming a membership function that is by the fuzzy knowledge base. Furthermore, the inference process aims to map out the logic for making decisions. This section is usually described with a fuzzy associative map (FAM) table [15].

A system transient response to a unit step depends on the initial conditions. The transient response of a practical control system often exhibits damped oscillations before reaching a steady state. In determining the transient response of the control system with the input step, it is determined by the parameters as follows [16], [17]:

- Delay time (td): is the time required for the response to reach 50% of the step value
- Rise time (tr): is the change time from 10% to 90% of the step height
- Setting time(ts): is the elapsed time from initial start until the system reaches stability
- Peak time (tp): Peak overshoot time is the time it takes to reach the peak of the overshoot
- Percent peak overshoot (%Mp): is when the signal or function exceeds its target
- Steady state error (Ess): the average error after the system reaches stability

The Ziegler-Nichols method was a method other than mathematical calculations that were used to obtain the appropriate PID parameter values for the system. Two Ziegler-Nichols methods are used in open-loop systems and closed-loop systems, namely the step response method and the frequency response method. The step response method is used in the open-loop tuning experiment. Where, this method has 2 parameters, namely L (dead time) and T (delay time). In Figure 1 can see the line that is tangent to the curve line. The line will intersect with the axis of the abscissa and the maximum line. The intersection of the tangent line with the abscissa axis is a measure of the dead time, and the intersection with the maximum line is the delay time measured from the time point L. By experimentally obtaining the plant response to the unit-step input will produce an S curve. Determine the PID control parameters for plants that do not it is known that the mathematical model can apply Ziegler-Nichols tuning [18].

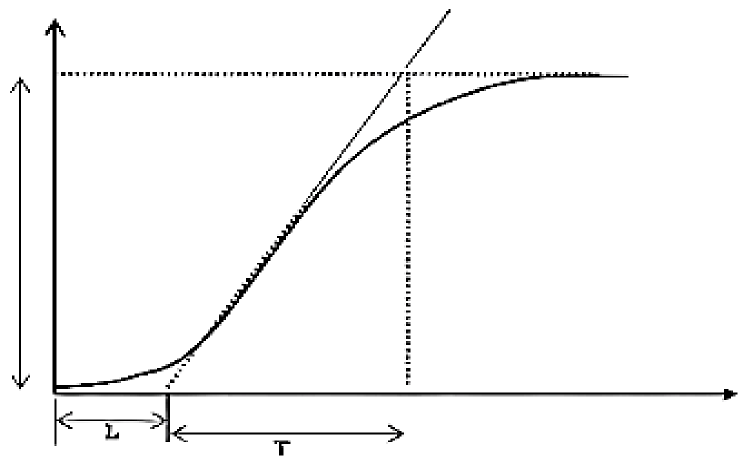

Figure 1. Response curve step [18]

This frequency response method is used in closed-loop systems. This method is applied by setting the magnitude of the integral parameter and the derivative parameter to zero. The proportional parameter is increased gradually starting from zero until it reaches an oscillating system state. The proportional gain value when the system reaches the sustain oscillation condition is called the ultimate gain (Ku). The period of sustained oscillation is called the ultimate period (Tu). It can be seen in Figures 2 and 3 [19]–[21].

This study aims to improve the performance of the hexacopter PID control system. The hexacopter PID control system is enhanced by applying adaptive PID constants assisted by a fuzzy logic controller. The fuzzy logic controller automatically adjusts the PID constant values (Kp, Ki, and Kd) according to the instantaneous error and delta error values.

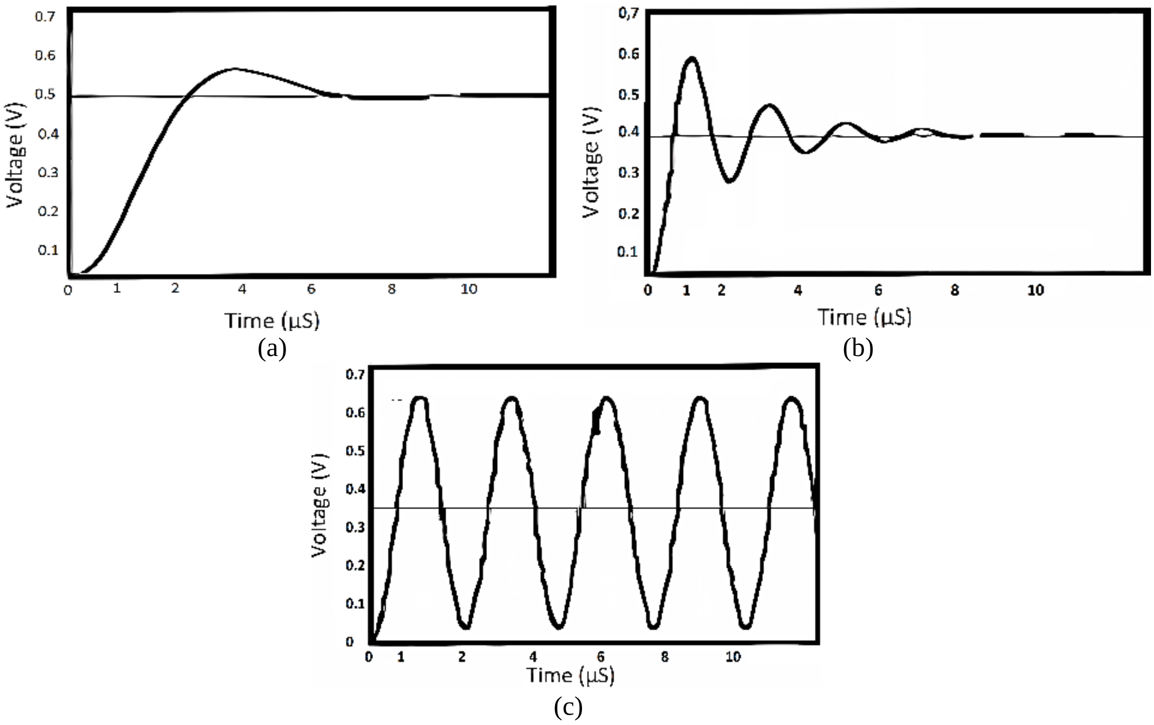

Figure 2. Output characteristics with addition of KP on the (a) Kp=1, (b) 1<Kp<Ku and (c) Kp=Ku

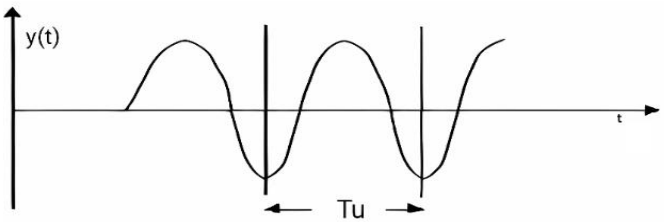

Figure 3. Ultimade periode (Tu)

2. METHOD

This research was conducted using experimental methods at the electrical engineering laboratory of ITP Padang, for simulation, measurement of component and aircraft parameters. To obtain real test data and simulation test data, in this study several equipment and materials were needed. Besides that, MATLAB software and Arduino IDE software are also needed. Muresan and Keyser in designing PID control for Hexacopter aircraft control, the approach of the Hexacopter PID controller automatic adjustment method is used [20]. Experimental Test Equipment is designed to allow Hexacopter to be under feedback control, so that input and output data can be collected safely for estimation into dynamic PID control parameters. The obtained value of this PID constant is then compared with the Ziegler-Nichols PID constant tuning method [22], [23]. Muresan stated that the results of his research were better than just using the Ziegler-Nichols PID constant tuning.

While the research presented here is an experimental method approach to the response of an open-loop system for analysis and identification of mathematical models. Open-loop system response data is taken for identification using the system identification toolbox (SIT). Mathematical models are used to perform simulations with Simulink MATLAB. Simulation with Simulink obtained an open-loop response to determine whether the response is close to the open-loop response of the real plant. Furthermore, the open-loop response is also used to obtain the value of the PID constant using the Ziegler-Nichols method, as an initial benchmark for conducting trial and error trials on the system in a simulation. After obtaining a more optimal PID constant value for one of the set-point values, a trial was conducted on various other setpoint values. To the changes in some of the setpoint values, the system response was observed to obtain the fuzzification value. By using a fuzzy logic controller, PID tuning is done automatically so that the value of the PID constant changes or can adapt automatically to the set-point value or the amount of change in the error value. This condition, in principle, is because when manipulating a movement or an instruction on the remote control (throttle) it becomes a set-point change instruction in its technical language [24]. The steps involved in carrying out this research method can be explained as follows [25]: study of literature; hardware assembly work; measurement of system parts; measurement/testing of PWM control signals and rotor speed; testing of an open-loop system; measurement data collection; open-loop data processing to obtain a mathematical model of the system; mathematical model validation test simulation; open-loop model data processing to get the PID constant value using the Ziegler-Nichols method; testing the closed-loop model to obtain the performance achieved by the system using the PID constant obtained by the Ziegler-Nichols method; trial of the closed-loop model with various setpoint values; fuzzification and defuzzification; model testing with PID control with automatic tuning Fuzzy. In this study, various equipment and materials will be used including: personal computer; Hexacopter aircraft; Gyroscop MPU 6050 sensor; oscilloscope; power supply, as a power supply for laboratory indoor testing; arc, as a factual angle test that is read by the Gyroscop; Arduino IDE, functions as programming for the control system; MATLAB as simulation and system identification software.

The hardware design for the rotor speed controller for each component of the receiver, MPU-6050, BLDC motor, and overall can be seen in Figure 4. In carrying out laboratory measurements and testing, a Pitch, Roll and Yaw movement test stand is required. The test stand has three degrees of freedom of movement, namely for Pitch, Roll and Yaw movements which are equipped with a Gyroscope sensor to monitor the position of the resulting movement. The test stand has been assembled and its construction is shown in Figure 5. Meanwhile, the position of the aircraft, rotor or BLDC motor in the test system is shown in Figure 6. Figure 6 also shows the placement of each ESC in numbers 1, 2, 3, 4, 5, and 6.

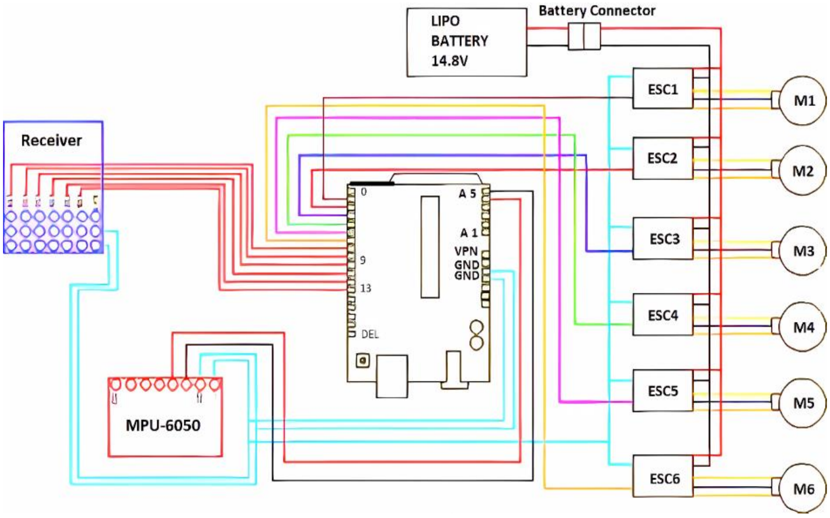

Figure 4. Measurement systems electronic circuits

Figure 5. Hexacopter movement test stand

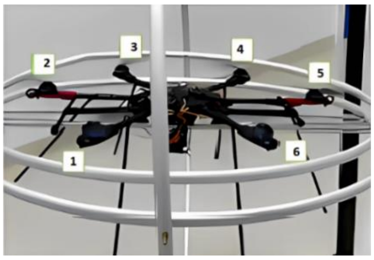

Figure 6. Motor position on Hexacopter

To test the open loop response to the system model, a simulation is carried out with SIMULINK MATLAB as shown in the block diagram of Figure 7 [26]. The identification results obtained with the help of SIT MATLAB are used as a mathematical model of the plant to be treated with various PID control action constants until the most optimal value is obtained as shown in Figure 8.

To improve the system response more optimally, on this occasion a fuzzy logic controller (FLC) is added which functions as a control part that performs PID constant tuning during the control process. The setting of the PID constant by FLC is based on the size of the error value and the rate of change of error or delta-error (de) [27], [28].

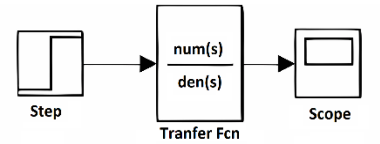

Figure 7. A open loop system simulation

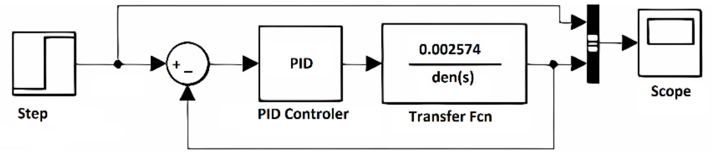

Figure 8. A closed loop PID controller system simulation

3. RESULTS AND DISCUSSION

Testing the percentage of PWM pulses on the electronic speed controller (ESC) is done by increasing the throttle/remote control from the lowest point to the full point. Thus, the PWM pulse range will be read on the Oscilloscope layer. The test results are shown in Figure 9 and Figure 10.

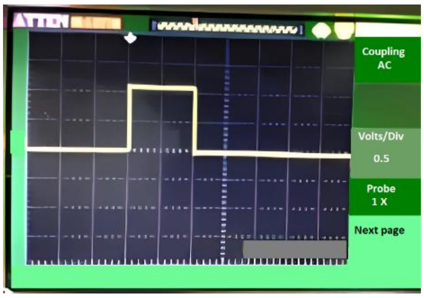

Figure 9. PWM pulse at minimum throttle

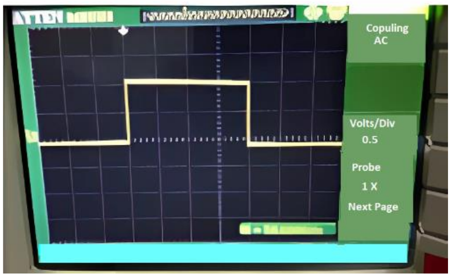

Figure 10. PWM pulse at maximum throttle

At the minimum throttle, the resulting PWM pulse is visible on the Oscilloscope layer as shown in Figure 9. Where the pulse has Period T = 20000 uS and the positive pulse length is 1000 uS, so % PWM = 5%. While at the time of throttle the maximum pulse length is 2000 uS as shown in Figure 10, so % PWM = 10%. So, it can be said that the control signal given by the throttle is from 5% to 10%. The Duty Cycle measuring process of the PWM control signal and its relevance to the rotational the rotor speed. Where in this system the PWM control signal can be given between 0.05 mS (5%) to 0.1 mS (10%). The control signal is injected into the ESC and can provide a rotor speed between 519 to 6422 rpm. The complete measurement results are shown in Table 1.

In Table 1, it can be seen that the effect of the control signal level is not the same as to the rotational speed of each motor, where each motor has the same specification data. When the PWM control signal is given 5% Motor M1 rotates at a speed of 522 rpm, Motor M2 rotates at a speed of 519 rpm, while Motor M3 rotates at a speed of 906 rpm and so on for the other control signal values there is a slight difference in speed. This fact is due to differences in the characteristics of different BLDC motors even though the manufacturer's specifications are the same. Therefore, the importance of this measurement method, to be able to compensate for the differences in the characteristics of these components, in formulating the control algorithm.

The process of measuring the resultant Roll movements is carried out by providing the configuration of the rotational speed of the M1 to M6 motors through the variation of the PWM control signal given to this measurement system. In this method, the measurement of the tilt angle of the Roll movements is detected through the Gyroscope sensor. Data from the Gyroscope through the Arduino is sent to a PC for data storage and can display the graph in real time. Furthermore, an example of this measurement data can be explained as follows; Roll movement is a movement that is generated due to the configuration of the rotational speed of motors 1, 2 and 3 as well as motors 4, 5 and 6. When motors 1, 2 and 3 rotate faster than motors 4, 5 and 6 then Roll Up occurs, as well as on the other hand, if the motors 4, 5 and 6 are faster than the motors 1, 2 and 3, then Roll Down will occur, as shown in Table 2.

Table 1. Motor rotation speed measurement with variable control signal

Coding Program setting	PWM (%)	Motor rotation speed and sensor output											
		M1		M2		M3		M4		M5		M6	
		Rpm	Volt	Rpm	Volt	Rpm	Volt	Rpm	Volt	Rpm	Volt	Rpm	Volt
1100	5	522	0.13	519	0.13	906	0.22	526	0.13	839	0.2	3756	0.94
1200	6	1262	0.31	1241	0.31	2223	0.55	1257	0.31	1476	0.37	4432	1.1
1300	6.5	2537	0.63	2455	0.6	3988	0.99	1953	0.49	2592	0.65	5021	1.25
1400	7	2935	0.73	2814	0.7	4283	1.07	2432	0.61	2870	0.72	5982	1.5
1500	7.5	3431	0.75	3337	0.83	4706	1.17	3164	0.79	3043	0.76	6422	1.6

Table 2. Measurement results of angular slope on roll movement

Motor rotation speed configuration						Relevance	
M1 Rpm	M2 Rpm	M3 Rpm	M4 Rpm	M5 Rpm	M6 Rpm	Resultant movement	Angular degree (^{0})
719	711	707	712	708	712	Balance	0
1253	1222	1231	602	799	558	Roll up	25
1375	1485	1463	596	672	557		50
602	598	615	1220	1600	1362	Roll down	-25
1414	1424	1423	2836	1583	1692		-50

Furthermore, the measurement process of the open-loop system can be carried out using this method, to obtain data and graphs, so that they can formulate a mathematical model of the aircraft system that is the object of measurement. Besides, this open-loop response is also used to determine system performance before adding a control system [29]. Furthermore, the results of testing this system's open-loop response and the graph plot results are shown in Figure 11. An analysis of system performance is carried out for the open loop step response. The results are shown in Figure 12. By observing Figure 12, the system performance analysis shows that the aspects shown can be explained as follows: settling time TS = 275 mS = 350 mS; peak time TP = 75 mS = 95 mS; rise time TR= 40 mS = 50 mS; delay time TD = 25 mS = 32 mS; percent maximum overshoot % MP= 75 %; error steady state ESS = 12.5%.

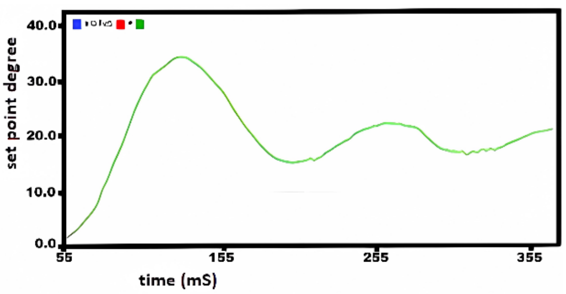

Figure 11. Response of open loop system

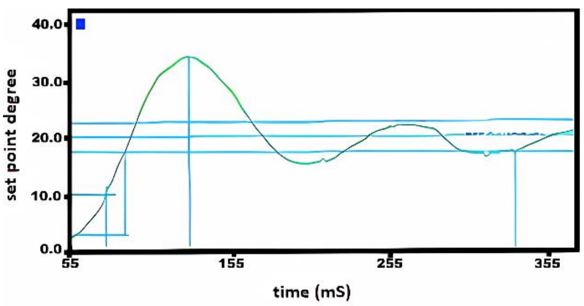

Figure 12. Results of open loop system performance

The parameter value changed because of the time in the test through interfacing Arduino to MATLAB after calibrating it with Google real time, it turned out that the unit of time in the measurement and simulation had to be multiplied by 0.0126 seconds. So that the data setting time of 275 mS must be multiplied by 0.0126 S, to = 350 mS, and the same for the other parameters.

The PID controller can be tuned in several ways, including Ziegler-Nichols tuning, loop tuning, analytical methods, optimization, pole placement, auto tuning and hand tuning [30]. On this occasion the Ziegler-Nichols method was used. Here the test is carried out using the plant response experiment from the input unit step in an open-loop circuit. By analyzing the displayed graph data, the values of the PID constants Kp, Ki and Kd can be calculated as follows:

Kp = 1.2 T/L = 1.2 40/12 = 3.33; Ti = 2 × L = 2 x 12 = 24; Td = 0.5 × L = 0.5 x 12 = 6; Ki = Kp/Ti = 3.33 / 24 = 0.14; Kd = Kp *Td = 3.33 *6 = 19.98.

In addition to determining the PID constant, the open-loop response is also used to identify mathematical models or transfer functions of the system. The processed open-loop response data is entered into the MATLAB work sheet. With the help of the system identification tool box (SIT), the identification process is carried out and after being validated, a mathematical model of the system is obtained as shown in Figure 13.

Figure 13. A system mathematical model

The mathematical model is then used to perform simulations on Simulink MATLAB. Simulations were carried out to obtain the optimal value of the PID constant using the Ziegler-Nichols method and the trial-and-error method. The next simulation is carried out using the control system proposed in this study, namely the PID self-tuning method. PID constant tuning itself is done by fuzzy logic controller (FLC). FLC performs PID constant tuning based on the error value and changes the error value from time to time. The optimal value of the PID constant that was obtained earlier is used as a benchmark for the default value (middle) in the formulated fuzzy rule. Simulation results using the PID constant, tuned by the Ziegler-Nichols method, have not yet produced a stable and better response as shown in Figure 14. Then, it was tried using automatic tuning available at the Simulink MATLAB facility and the results were still showing a slow response as shown in Figure 15.

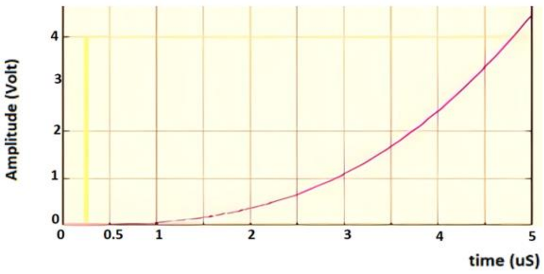

Figure 14. Ziegler-Nichols PID tuning simulation

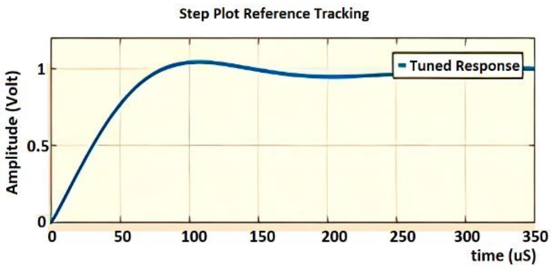

Figure 15. Automatic tuning Simulink simulation

The simulation results using the automatic tuning Simulink facility have not yet produced a stable system, here the PID constant values obtained are KP = 0.3225, I = 0.00413 and D = 6.323. Furthermore, to get a more optimal value of the PID constant, it is done by the “trial and error” method. While the results of trial-and-error PID tuning obtained the value of Kp = 3.33, the value of I = 24 (Ki = 1/Ti = 1/24 = 0.041), and the value of d = 900. The values of Kp and I here are in accordance with the Ziegler-Nichols method which are very much different, only D, with a value of = 900. The simulation results of the trial-and-error method are shown in Figure 16. This result shows that the system is stable with a faster response.

From the analysis of Figure 16 it can be seen that the system has started to improve, where, the system parameters have reached the values: settling time TS = 0.063 S; peak time TP = 0.022 S; rise time TR = 0.010 S and delay time TD =0.005 S; % MP = 10% and Ess = 0%. In the results of the analysis of the response parameters in Figure 16 the response time and steady state error are good, but the over shood is still 10%, this still needs to be found a solution again, namely by using a fuzzy logic controller (FLC). FLC is used to automatically tune the PID constant, according to the value of the error and the momentary delta-error. To improve the system response more optimally, on this occasion a FLC is added which functions as a control part that performs PID constant tuning during the control process. Setting the PID constant by FLC based on the size of the error value and the error change rate. The simulation diagram is shown in Figure 17.

Adding FLC to the PID control system to adjust the PID constants automatically based on the error and delta-error values is expected to be anticipated, while external influences can also adjust the situation to changes in set-points. This set-point change is identical to changing commands via remote control or throttle.

It should also be noted that the default constant value is the good PID constant value obtained through the Ziegler-Nichols and trial and error methods in the previous step. This default value is denoted by middle (M) in fuzzy rules. The default condition occurs when the system is approaching and or has reached stability. If viewed from the input member membership at the time of error and delt-error has reached zero. This fuzzy logic controller design requires two input and three outputs. Input 1 is error and input 2 is delta-error. While output 1 is KP, output 2 is Ki and output 3 is Kd. This membership function (MF) design diagram is shown in Figure 18.

Furthermore, the function error, delta error and output are shown in Figures 19, 20, and 21, respectively. Because the output membership functions Kp, Ki, and Kd are the same, only one image is shown, representing the others. Likewise, for the surface output, only one image is shown as shown in Figure 22. The membership function table designed before filling in Simulink is shown in Table 3.

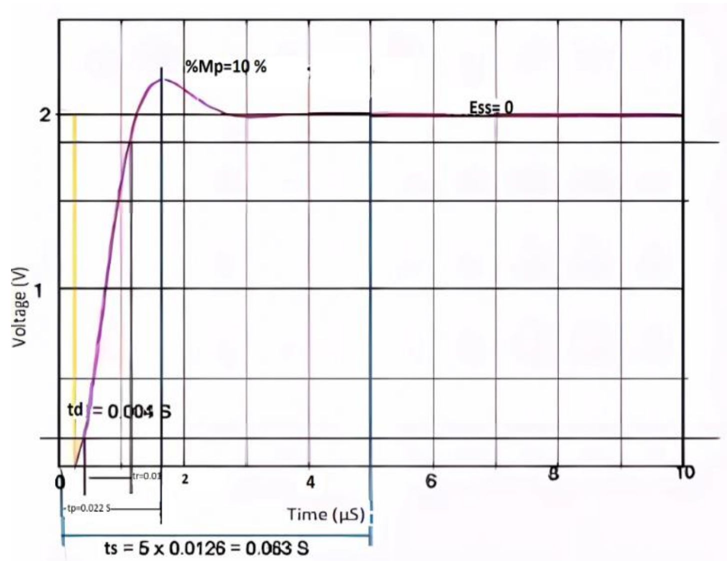

Figure 16. System performance analysis of the trial-and-error method

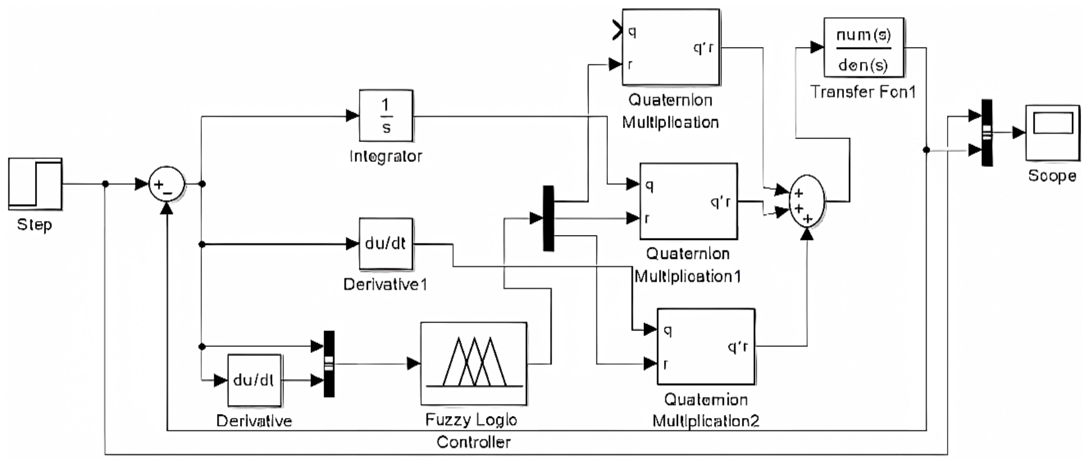

Figure 17. Self-tuning PID fuzzy controller simulation diagram

After simulating the self-tuning PID fuzzy controller control system, a better system response is obtained as shown in Figure 23. From Figure 23 it is clear that the system response is getting better, where it has been obtained, especially the percent overshoot (% Mp) is 1% and the steady state error (Ess) = 0.5%. While the other system response parameter values are: Settling time = 10.08 mS; peak time TP = 4.91 mS rise time TR = 2.52 mS; delay time TD = 1.9 mS.

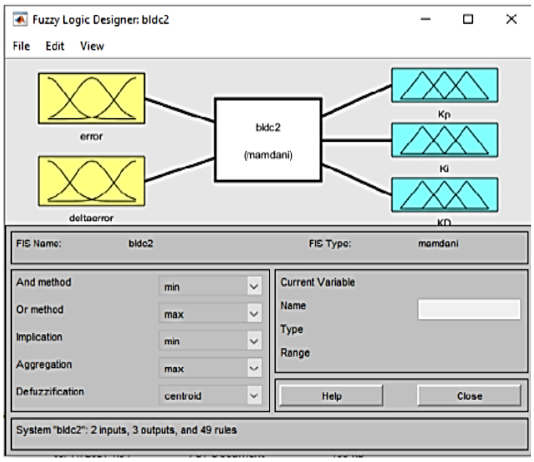

Figure 18. Fuzzy logic control design

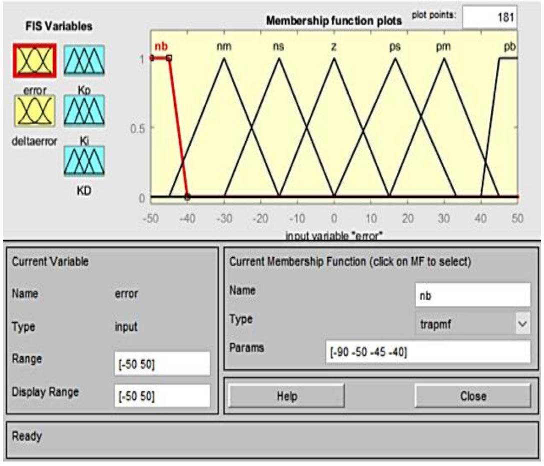

Figure 19. Error membership function

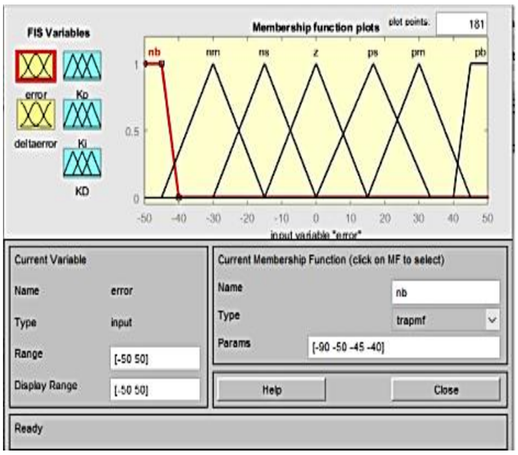

Figure 20. Delta-error MF

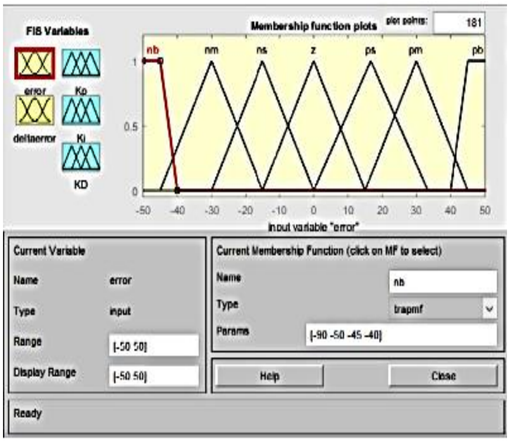

Figure 21. Kp, Ki, Kd and MF

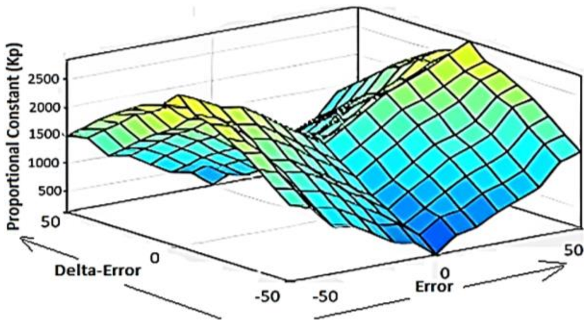

Figure 22. Surface output

Table 3. Distribution of Kp, Ki, and Kd membership function output

Error / D_Error	nb	nm	ns	Z	ps	pm	pb
nb	M	S	VS	VVS	VS	S	M
nm	B	M	S	VS	S	M	B
ns	VB	B	M	S	M	B	VB
Z	VVB	VB	B	M	B	VB	VVB
ps	VB	B	M	S	M	B	VB
pm	B	M	S	VS	S	M	B
pb	M	S	VS	VVS	VS	S	M

After obtaining the optimal algorithm and control system parameters by simulation, then testing the Hexacopter aircraft in the test booth using the optimal algorithm obtained through simulation with Simulink. After finishing writing the program listing for the PID fuzzy vehicle, the program is then uploaded to the Arduino Microcontroller control system as the flight controller of the aircraft. In this test, the aircraft is placed on the test stand to measure the speed of the system to reach the stable position of pitch movements. The response of the Hexacopter aircraft control system in the Test Stand test has the following parameter values: ts = 34 mS; tp= 21 mS; tr = 9.4 mS; td= 6.5 mS; %Mp = 7.5%; Ess = 1%. From the parameter data, it can be seen that there has been a lot of improvement in the system response. Even though over shoot (%Mp), it is still 7.5%, but the steady state error (Ess) can be overcome to one percent. With the self-tuning PID FLC method, better system performance has been obtained when compared to the system parameters under open loop conditions and conditions that only use PID, as shown in Table 4.

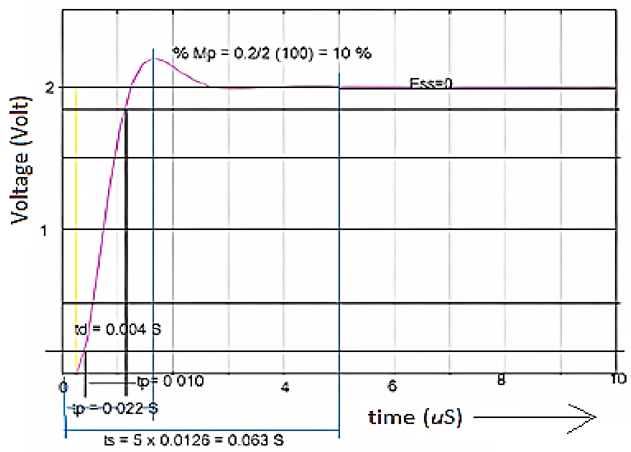

Figure 23. Self-tuning PID fuzzy controller system response

Table 4. Comparison of system parameters with various treatments

Parameter	Open loop riel test	Simulation test		Closed loop PID tuning fuzzy riel test
		PID	PID tuning fuzzy	Roll
Setling time (ts)	350 mS	63 mS	10.08 mS	34 mS
Peak time (tp)	95 mS	22 mS	4.91 mS	21 mS
Rise time (tr)	50 mS	10 mS	2.52 mS	9.2 mS
Delay time (td)	32 mS	5 mS	1.9 mS	5.7 mS
Persen overshoot (%Mp	75 %	10 %	1%	5 %
Error steady state (Ess)	12.5 %	0%	0.5 %	1 %

4. CONCLUSION

Pitch, Roll and Yaw manoeuvres are produced by varying the rotor speed of the M1 to M6 motors. The resultant movement of this manoeuvre is monitored using a Gyroscope sensor (IMU sensor), to provide feedback to the control system so that it immediately reaches the instructed position from the control throttle. The aircraft in measurement condition can be controlled via control instructions on the personal computer or via throttle. meanwhile, speed monitoring and stability position are monitored via computer.

The application of the PID tuning fuzzy logic controller control system has significantly improved the system parameters in a simulation, but in real plants or direct application to the actual system, it is slightly reduced. For response times such as: settling time; rise time; peak times; delay time, the fuzzy tuning PID recognition system is much better than ordinary PID. Even though there was a slight decrease in performance at the real plant, it was still better, such as the PID rise time was 10 mS and the PID fuzzy 2.52 mS, while the PID fuzzy real plant was between 9 mS to 9.2 mS. In terms of percent overshoot % Mp, it can also be seen that there was an increase in performance from PID 10%, PID fuzzy 1%, and PID fuzzy real plant was 5%.

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BIOGRAPHIES OF AUTHORS

Al Al from 2004 until now, he has been a lecturer in electrical engineering at ITP Padang, he received a Master of Engineering degree in Electrical Engineering at ITS Surabaya in 2002. He became a research assistant from 2010 to 2015 at Universiti Kebangsaan Malaysia. His research interests include power electronics, and applications such as wind turbines, PV systems, current drives, and adjustable speeds such as Bruceless DC Motors for Quadcopters and Hexacopters. He has twice received research grants from the Director General of Higher Education, Indonesian Ministry of Education and Culture in 2017 to 2018 and from 2021 to 2023. He can be contacted at email: al.mtdrs@gmail.com.

Fajrin Fajrin received an M. Sc degree in geography from the University of Indonesia, Indonesia, in 2016 and is currently pursuing a doctoral program in Environmental Science at Universitas Negeri Padang. Currently he is a Geodetic Engineering Lecturer at the Institut Teknologi Padang. He has authored or co-authored several referenced journals and conference papers. His research interests include the application of environmental remote sensing and the development of UAVs for environmental mapping. He can be contacted at email: fajrin@itp.ac.id.

Asnal Effendi received the B.Sc. from ITP Padang, M.Sc. degrees in electrical engineering from Universitas Gajah Mada in 2007, Indonesia. 2007. He has authored or coauthored several refereed journal and conference papers. His research interests include the applications of green energy, photo valtage systems and power systems engineering. He can be contacted at email: asnal.effendi@gmail.com.

Antonov Bachtiar received the B.Sc. from ITP Padang, M.Sc. degrees in electrical engineering from Universitas Gajah Mada in 2005, Indonesia. 2007. He has authored or coauthored several refereed journal and conference papers. His research interests include the applications of green energy for sea water and salt water, power systems engineering. He can be contacted at email: antonov_bach@yahoo.com.

Aswir Premadi received the M.Sc degree in electrical electronic and system engineering from Universiti Kebangsaan Malayasia in 2011. Currently, he is a lecturer in the Department of Electrical Engineering, Institut Teknologi Padang, Indonesia. He is a member of IEEE. His current research topics include control systems, telecommunication and renewable energy. He can be contacted at email: aswir.premadi@itp.ac.id.