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Auto Vertical Takeoff and Landing on Quadrotor Using PID-Fuzzy

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Abstract: Quadrotor is one type of UAV (Unmanned Aerial Vehicle) which has considerable complexity in the regulation stability. This condition causes quadrotor requires a control system capable of keeping it stable. The quadrotor can do a Vertical Take-Off and Landing (VTOL), so it does not require a large runway for take-off and landing. That is one of the advantages compared to fixed wing aircraft. However, this VTOL capability requires good control. So, when quadrotor is taking off or landing, it still flies in a stable state without any interferences. These interferences make the quadrotor lose stability, undirected or fall. We can use several methods to control quadrotor. One of them is the control of the PID (Proportional control and Derivative). PID control system can work well depend on all three constants. The third tuning PID constants can be done independently by using fuzzy. The parameters of the self-tuning are the angle error and the difference in angle error that occurred during the flight.

Key words: Control, height, pitch, roll, VTOL, constant

INTRODUCTION

UAV (Unmanned Aerial Vehicle) is an unmanned aircraft that can move autonomously or remotely controlled by a user (Gupte *et al*., 2012). This ability depends on the control system applied to it. Now a days, the UAV has been applied to help people, especially in matters relating to the retrieval of information through the air. UAVs are widely used for various things such as taking aerial imagery to be used for military purposes (Chen *et al*., 2009). UAVs have several different types. One of them is multirotor. Multirotor is a UAV that has more than one propeller. Multirotor which has four units propeller designed symmetrically with crossed configuration is called quadrotor (Carrillo *et al*., 2013). Each propeller of quadrotor arms produces great thrust in the vertical direction. As with other types of multirotor, The quadrotor has advantages compared with fixed-wing UAV types. Quadrotor has a system of Vertical Take Off and Landing (VTOL), so it does not need a runway to take off and land.

Ability generated by quadrotor proportional to the complexity of its balance settings. Quadrotor flight balance depends on the angular velocity of each propeller. There are several factors that can disrupt the balance of the quadrotor flight such as wind disturbance factor and so on. These disruptions are associated with changes quadrotor tilted levels of the previous state.

There are several methods of control are used to maintain quadrotor to be able to keep a balanced fly in the air. One of them is a method of control PID (Proportional Integral Derivative) (Argentim *et al*., 2013). In PID control method, there are three pieces of gain that work to correct or reduce the error which consists of Kp, Ki and Kd. Kp is a proportional constant, Ki is an integral constant and Kd is a derivative constant. Kp is used to improve the transient response rise time and settling time of course. Ki works to improve steady-state response. Kd is used to improve the transient response by way of predicting error will occur in the future (Priyambodo *et al*., 2015).

Optimization of PID system depends on upon the value of Kp, Ki and Kd. When all three constants are not exact, the resulting response will deviate from the desired results. That requires tuning the value of Kp, Ki and Kd is accurate to obtain a constant value which is appropriate to support the response of the system to be optimal (Ogata, 2010).

The fuzzy logic controller is a control system that resembles the human mindset. In contrast to digital logic, fuzzy logic concepts defined not absolute. By using fuzzy logic, human expertise can be implemented in the machine language easily and efficiently (Klir and Yuan, 1995). Therefore, in the design of fuzzy logic does not require complex mathematical equations of the object to be controlled. There is research in fuzzy logic controller

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algorithm for controlling quadrotor hover stability before (Raharja and Cahyadi, 2014). The inputs of this system are height and height changes. Triangular membership functions are used to process these inputs. The membership function output is then applied to maintain the quadrotor hover position. Simulation results show that quadrotor can hover at a height of 5 m and with a setting time of 15 sec.

It concludes that by combining these two methods of PID and fuzzy logic where fuzzy logic is used to tune the component Kp, Ki and Kd is expected to obtain a more optimal control system (Priyambodo *et al*., 2015).

MATERIALS AND METHODS

Control design

The design of the control system: By the needs of the system so in this study was designed a method of tuning PID constants automatically based on fuzzy logic. The fuzzy system works by the rules of "if" "the" is embedded in the system. PID equation has input u, output y, the reference input r and e as input error obtained from e = r-y. PID method has the form of equation as shown in Eq. 1:

$$u(t) = Kp\times e(t)+Ki\int_0^t e(t)dt+kd\left(\frac{de(t)}{dt}\right) \quad (1)$$

Where:

Kp = The proportional constant
Ki = Integral constant
Kd = The derivative constant

The fuzzy logic system is used to optimize the response of the control system concerning the characteristics of the three constants.

Inputs of this system are values obtained from the calculation of the angle sensors. Outputs of this system are the values of PID constants. Set points given in this system are the values of pitch and roll angles. The fuzzy system will tune PID constants which consist of values KP, Ki and Kd based on the error and delta error. The results of this method in the form of PID control signal delivered to the ESC (Electronic Speed Control) and a brushless motor that is used as a plant. Broadly speaking fuzzy system that works on this system is described by the block diagram in Fig. 1.

The design of the fuzzy system: A fuzzy logic control strategy can be applied to control this quadrotor using the fuzzy method of Mamdani (1974). The decision to be taken by the controller desired combination of some parameters, i.e., pitch and roll angle. This action can increase or decrease the strength of each motor to obtain specifications and follow the track.

Looking at the characteristics of the control system of the plant that is operating is the task of the fuzzy system in this study. The data obtained previously from the system can become input parameters for fuzzy logic. These parameters describe quadrotor control response. We use some inputs as feedback from quadrotor system consists of the values of the results angle sensor readings IMU (Inertial Measurements Unit). Therefore, we process the data in the of the value of the angle or the data value associated with the angle. This study uses two fuzzy input parameters, namely the error and delta error as a representation of the control response that occurs when the system is operating. There are three steps in applying fuzzy PID method which consists of:

- Fuzzification
- FIS (Fuzzy Inference System)
- Defuzzification

Fuzzification: We use three linguistic groups in the design of the input fuzzy sets. They describe the error and delta error. These groups are N (Negative) Z (Zero) and P (Positive). The error is variable degrees of membership function in error and delta error is the degree of membership function in the delta error. The fuzzy input set design of error input and delta error input are shown in Fig. 2.

FIS (Fuzzy Inference System): We analyze the input values using FIS (Fuzzy Inference System). We design the FIS using fuzzy rules (rule-base) that had been developed before. Fuzzy rules (rule base) has the basic shape "If" X = A, "Then" Y = B, so the fuzzy rules are often referred to as the rule "If-Then". In this quadrotor system, rule base which is used, based on the design of fuzzy set for error, error delta, Kp, Ki and Kd. Table 1 shows the fuzzy rules are used to determine the value of Kp and Ki while Table 2 shows the fuzzy rules are used to determine the value of Kd. Thus, there are 25 fuzzy rules (rule base) used in this study.

Defuzzification: By using the results of the inference, then we do defuzzification process to obtain crisp outputs in the form of the value of Kp, Ki and Kd. The crisp outputs are working on the PID to control the stability of the motor actuators. At fuzzy sets outputs, there are three

Table 1: Fuzzy rule for Kp and Ki

Delta errors	Errors				
Codes	NB	N	Z	P	PB
NB	VB	B	M	B	VB
N	B	M	S	M	B
Z	M	S	Z	S	M
P	B	M	S	M	B
PB	VB	B	M	B	VB

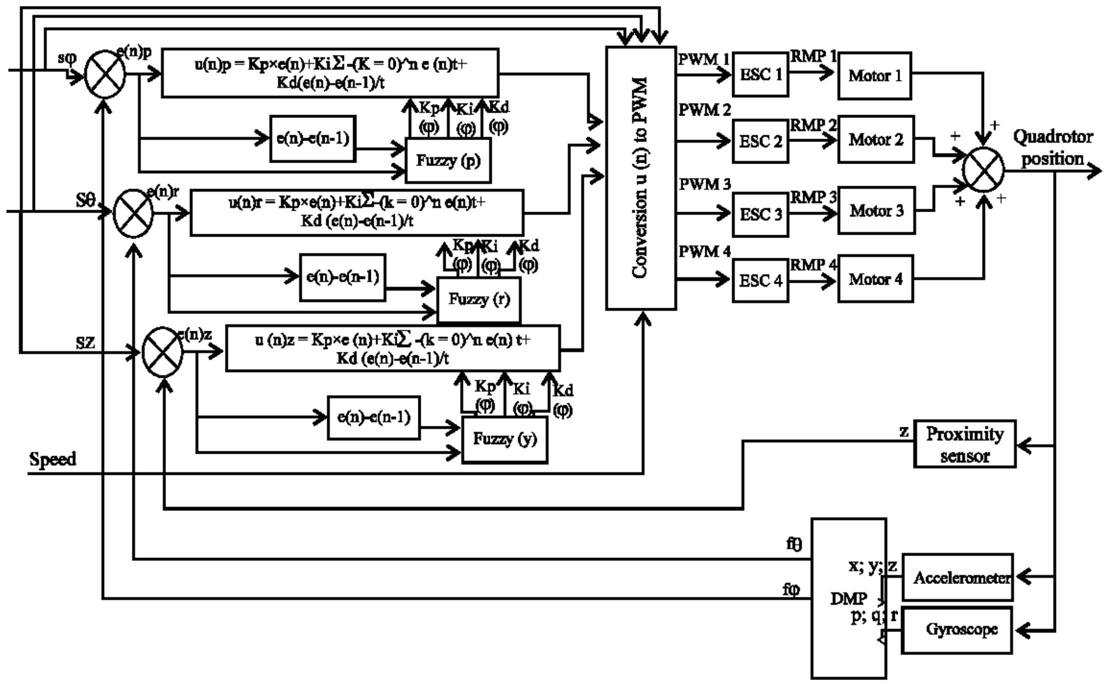

Fig. 1: Control block diagram of the system: DMP = Digital Motion Processin; ESC = Electronic Speed Control; PWM = Pulse Width Modulation; $\ddot{x}$ = Accelration in the x-axis; $\ddot{y}$ = Accelration in the y-axis; $\ddot{z}$ = Accelration in the z-axis; θ = Pitch angle; φ = Roll angle; e(n) = Error; p = Velocity along x-axis; q = Velocity along y-axis; r = Velocity alon z-axis; Kp = Proportional constant; Ki = Interal constant; Kd = Derivative constant and z = Position on the z-axis

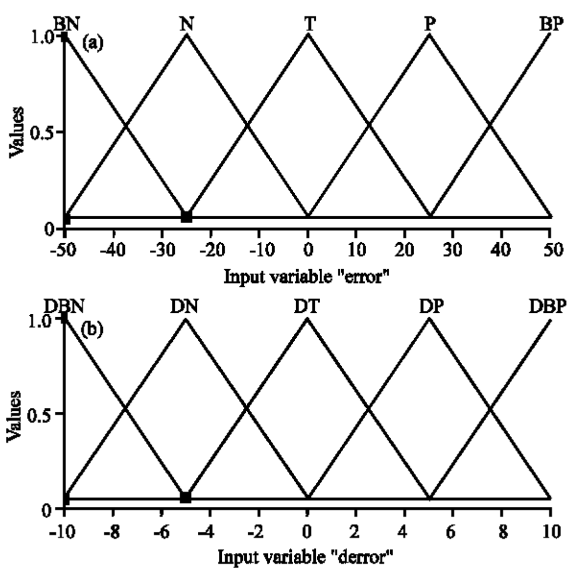

Fig. 2: Fuzzy input set design: a) Error input and b) Delta error input

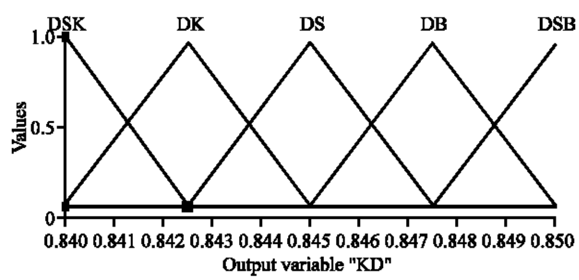

Fig. 3: Fuzzy output set design for pitch and roll angles) Kd

Table 2: Fuzzy rule for Kd

Delta errors	Errors				
Codes	NB	N	Z	P	PB
NB	N	Z	P	PB	
NB	VS	S	M	S	VS
N	S	M	B	M	S
Z	M	B	VB	B	M
P	S	M	B	M	S
PB	VS	S	M	S	VS

groups which describe the magnitude of linguistic constants Kp, Ki and Kd. These groups are S (Small) M (Moderate) and B (large). The μKi is fuzzy membership degree in Kp, μKp is fuzzy membership degrees on Ki and μKd is the fuzzy membership degree in Kd. The design of fuzzy sets Kp, Ki and Kd are shown in Fig. 3 and 4. The fuzzy ouput set design for pitch

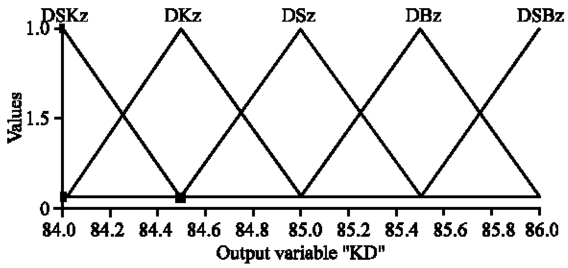

Fig. 4: Fuzzy output set design for height

and roll angles are shown in Fig. 3 and then the fuzzy ouput set design for height of the quadrotor are shown in Fig. 4.

RESULTS AND DISCUSSION

PID constants determination using the Ziegler-Nichols method: This testing phase uses the Ziegler-Nichols method to provide a variation of the value of the proportional constant (Kp) until we obtain the value of Kp which can make the system oscillate stably. In this process, we set the value of the integral constants (Ki) and the value of the derivative constant (Kd) become 0. Kp value obtained is then regarded as the Ku value. The next step is to find the value of Pu. Pu value obtained by finding the value of the wave period established by the Ku value. Then the value of Kp, Ki and Kd is calculated based on the formula in Table 3 where:

$$Ki = \frac{Kp}{Ti}$$

$$Kd = Kp \times Kd$$

Pitch and roll angle: The experiments show the best value of Ku for pitch angle stabilization is 0.0331. It is resulted in a continuous and stable oscillation as shown in Fig. 5. So, we choose the value of Ku = 0.0331.

From Ku = 0.0331 and graphs generated by it, the value of Kp, Ki and Kd can be calculated. Thus, the PID constants are obtained by Ziegler-Nichols method are Kp = 0.01986, Ki = 0.019188 and Kd = 0.004965. The response generated by the application of these constants is shown in Fig. 6. The response generated by the three constants still oscillates but moved closer to the set point. We will implement the constant values applied to the previous pitch angle using Ziegler-Nichols method to the roll angle. We do this method because the physical form of the quadrotor is symmetrical (Fig. 7).

Height: The experiments show the best value of Ku for height stabilization is 0.040227. It is resulted in a

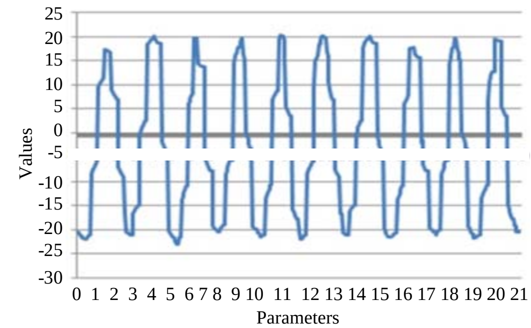

Fig. 5: Pitch angle vs. time on Ku = 0.0331

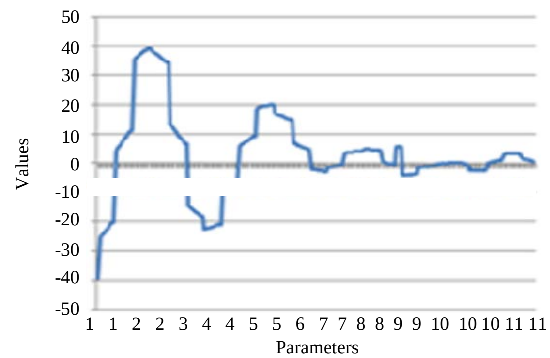

Fig. 6: Pitch angle vs. time at Kp = 0.01986, Ki = 0.019188 and Kd = 0.004965

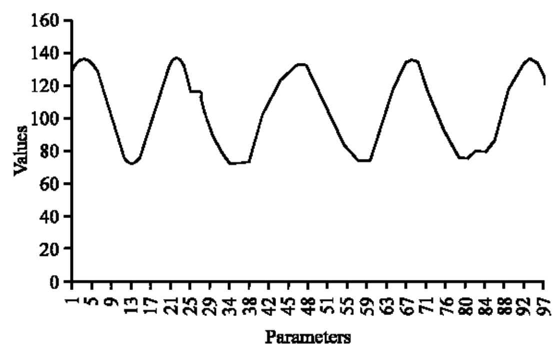

Fig. 7: Height vs. time on Ku = 0.040227

Table 3: Tuning-based Ziegler-Nichols second method (Ogata, 2010)

Controller type	Kp (Ku)	Ti	Td
P	0.50	0	0
PI	0.45	Pu/1, 2	-
PID	0.60	Pu/2	Pu/8

continuous and stable oscillation as shown in Fig. 7. So, we choose the value of Ku = 0.040227. From Ku = 0.040227 and graphs generated by it, the value of Kp, Ki and Kd can also be calculated by Table 3. Thus, the PID constants are obtained by Ziegler-Nichols

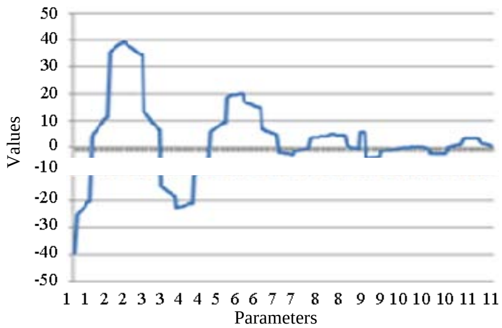

Fig. 8: Height vs. time at Kp = 0.0241362, Ki = 0.0091425 and Kd = 0.015929892

method are Kp = 0.0241362, Ki = 0.0091425 and Kd = 0.015929892. The response generated by the application of these constants is shown in Fig. 8. The response generated by the three constants still oscillates but moved closer to the set point.

PID fuzzy: In this step, we vary the range of values of input and output concerning a constant value produced by the Ziegler-Nichols method previously. We do this method by implanting ranges of values of fuzzy input and output. Then, we observe the response of the system occurs.

We use fuzzy systems to stabilize orientation angle and height of each study use five groups of error as fuzzy inputs, five groups of delta error as fuzzy inputs, five groups of Kp as fuzzy outputs, five groups of Ki as fuzzy outputs and five groups of Kd as fuzzy outputs. We use 25 fuzzy rules for each study. Determination of the number of groups and fuzzy rules is determined based on the experimental results of the resulting response time. Fuzzy interference system used in this study is the method of Mamdani (1974). We use this method because output (consequent) in this system is in the form of fuzzy sets, not a constant and linear equations.

Research is carried out by giving some fuzzy output value range, namely the range of the output value of Kp, Ki and Kd. Ranges of the fuzzy input value are [-50, 50] for error inputs and [-10, 10] for delta error inputs. We obtain these values were by experiments. The results obtained are error can occur at system during operation in the range of -50 to 50° for pitch and roll angle stabilization and also the delta error occurs at the range of -10° to 10°.

The PID constants range that are obtained for pitch and roll angle stabilization consists of Kp = 0.0103-0.0104, Ki = 0.0102-0.01034 and Kd = 0.0084-0.0085. The resulting system response is shown in Fig. 9. The

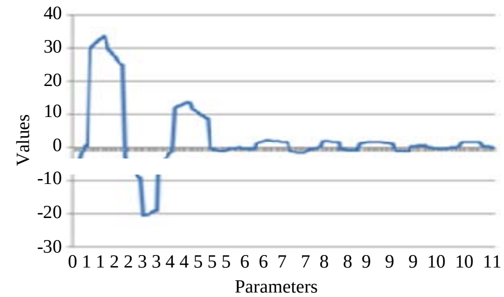

Fig. 9: Pitch angle vs. time using PID fuzzy method (Kp = 0.0103-0.0104, Ki = 0.0102-0.01034 and Kd = 0.0084-0.0085)

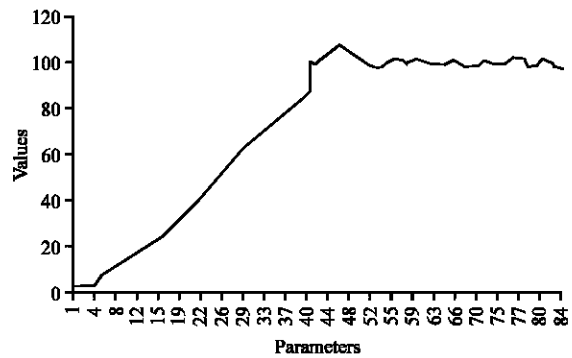

Fig. 10: Height vs. time using PID fuzzy method (Kp = 0.018135-0.0188137, Ki = 0.005423-0.005425 and Kd = 0.005084-0.005085)

graph shows the system still has a fairly high overshoot but the system produces an excellent stable response with minimal oscillation. Furthermore, the PID constants range that are obtained for height stabilization consists of Kp = 0.018135-0.0188137, Ki = 0.005423-0.005425 and Kd = 0.005084-0.005085. The resulting system response is shown in Fig. 10.

CONCLUSION

The method of PID tuning constants based on the fuzzy logic Quadrotor produces a better response than using Ziegler-Nichols method. Results of the testing go well with error input range from -50 to 50, delta error input range from -10 to 10. The results of PID constants output range for pitch and roll angle stabilization in this study consists of Kp = 0.0103-0.0104, Ki = 0.0102-0.01034 and Kd = 0.0084-0.0085. Furthermore, the results of PID constants output range for pitch and roll angle stabilization in this study consists of Kp = 0.018135-0.0188137, Ki = 0.005423-0.005425 and Kd = 0.005084-0.005085.

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