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Performance Analysis Fuzzy-PID versus Fuzzy for QuadCopter Altitude Lock System

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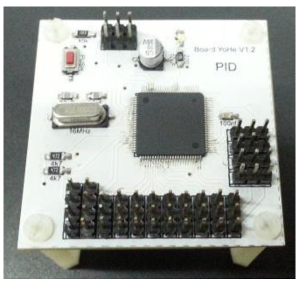
Graphical abstract



Abstract

Mostly quadcopter has a flight controller to receive signal from remote control to control four brushless motor speed. In this paper, the researchers introduced a new control method to make quadcopter altitude lock system using Fuzzy-PID and perform a comparative performance analysis between the Fuzzy controller and the new Fuzzy-PID controller. Fuzzy controller has ability to solve uncertainty within the system, by incorporating with altitude sensor data. On the other hand, Fuzzy-PID has the ability to gain the target level with Kp, Ki, Kd values controlled. In this paper the researchers present an analysis to compare the control method between Fuzzy and Fuzzy-PID with regards to the stability altitude lock system. The stability of the altitude lock system can be measured by how small the oscillations occurred. Fuzzy control has shown to produce better result than Fuzzy-PID control. Fuzzy control has 14 cm as its average oscillation, while Fuzzy-PID recorded 24 cm as its average oscillation.

Keywords: Quadcopter altitude lock system, Fuzzy, Fuzzy-PID controller, YoHe board

1.0 INTRODUCTION

The quadcopter concept has existed many years ago. The first quadcopter were developed by George DeBothezat and Etienne Oemichen in 1922 was powered by simple controllers. The most popular flight controller today is the KK2.0 which have autonomous attitude control only, but not the autonomous altitude control yet. The autonomous altitude control is important for imaging application [1]. Altitude stability is needed to obtain focused image captured and quadcopter altitude lock system had been developed using several control methods. The researchers started a study using PID controller [2], Fuzzy controller [3], T2-Fuzzy controller [4] in the quadcopter. The researchers designed and implemented a control method in a real time using the YoHe board which contained ATMega2560 AVR microcontroller to control a quadcopter which is symmetrically designed with four similar sized rotor and four equal length rods [5]. Quadcopter research has been growing fast in the last few decades because quadcopters can be used for many applications. Quadcopter can be categorized as a helicopter which has a Vertical Take Off and Landing (VTOL) system which has many advantages over other flying principles including airplane flying method [6]. With the VTOL system, a quadcopter can fly omni-directionally with additional ability to fly in hover conditions. All movements can be controlled by given a varying speed to the rotors where each rotor produces different torque and thrust. With varying speed of the four rotors, a quadcopter has three motions, i.e. pitch motion, yaw motion, and roll motion [7].

Minimum components a quadcopter should have include 4 units of propellers, 4 units of brushless motor DC (BLDC), 4 unit of Electronic Speed Controller (ESC), accelerometer sensor and gyroscope sensor [5], [8],

[9]. In a quadcopter, the front and rear rotors rotate clockwise, while the left and right rotors rotate counter-clockwise. Vertical motion is controlled by the throttle input, where the sum of the thrusts of each motors are presented in Figure 1 [7].

Studies on quadcopter modeling and control had increased rapidly in recent years. Examples of some studies are as follows: developments of flying robots includeing dynamic modeling, vehicle design optimization and control, new controller to improve the ability to control the orientation angles [6], low cost development of an autonomous hover for quadcopter [10], design and control of quadrotor prototype with 3-axis accelerometer and compass as its sensors, introduction of the Kalman filter, sensors and motors dynamics in the control loop [11], a simpler method for segmentation and horizon detection based on polarization, the catadioptric sensors used, and a comprehensive review on attitude estimation approaches from visual sensors [12]. In the development of hybrid controller, the researchers believed that the control performance of the Fuzzy PD controller was slightly better then the classical PD controller in simulations and experiments, as the biggest advantage of the hybrid fuzzy PD controller is the robustness against noise, and its ease for implementation [13]. The development of an adaptive hybrid Fuzzy Logic based PID (FPID) algorithm for attitude stabilizing flight control system is successfully simulated using MATLAB Simulink [14].

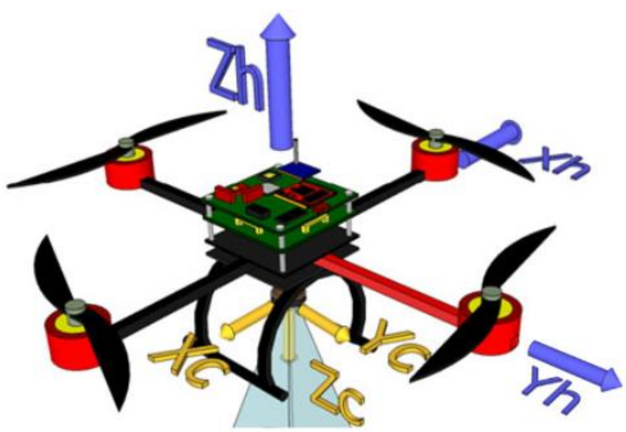


Figure 1 Visual system of quadcopter [7]

A Fuzzy control method in the last few decades was implemented upon various systems which have different uncertainty levels. Some examples of these Fuzzy studies can be summarized as follows: optimized fuzzy logic controller using the Fuzzy Logic Toolbox and Simulink to control an inverted pendulum system [15], a modular fuzzy logic for the autonomous control of quadrotors in general, without the need for a precise mathematical model of their complex and ill-defined dynamics [16] as well as modeling and tye hybrid Fuzzy PD control of a four-rotor helicopter [13].

The basic form of Fuzzy-PID is the PID controller. In an industrial control processes, PID control is mostly used because of their simple structure and robustness for wide range of operation conditions [17]. The PID design needs specification for three parameters such as proportional gain, integral gain, and derivative gain [17]. The problem was solved using Fuzzy for control gain scheduling whereby the PID parameters can be determined on-line based on errors and their derivative [17].

The body of the paper is organized into 6 sections. Section 2 describes quadcopter system that used in this paper. The Fuzzy and Fuzzy-PID theory and control strategy is given in section 3 and section 4. Section 5 describes the experimental results and finally the summary are given in section 6.

2.0 QUADCOPTER SYSTEM

Figure 2 shows the complete quadcopter system. A YoHe board based on AVR ATMega 2560 was chosen as an onboard microcontroller with 256 Kb memory as shown on Figure 3.

Figure 2 Quadcopter system

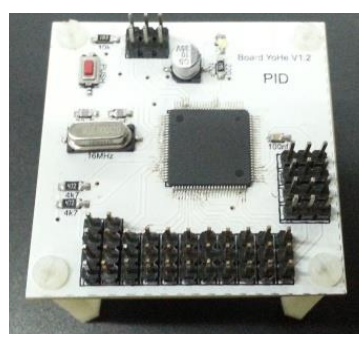


Figure 3 YoHe board

In this paper, quadcopter used a frame with X - copter models like seen in Figure 2. This quadcopter comes completed with a propeller, motor brushes, Electronic Speed Controller (ESC), flight controller

KK2.0. Quadcopter parts in Figure 4 and parts specification seen on Table 1.

Figure 4 Quadcopter main parts

Table 1 Quadcopter parts specification

No	Part	Total	Merk	Specs
1	X-Copter Frame	1	Whirlwind FY450	280 g
2	Propeller	2 CW, 2CCW	Dji 10x4.7	Plastic
3	Brushless Motor	4	NTM Prop Drive	1000 KV
4	ESC	4	ZTW Spider	30 A
5	Flight Controller	1	KK2.0	
6	Battery	1	Li-Po 3 cell	2.2 A

Figure 5 shows the wiring for normal quadcopter components, while Figure 6 shows the changed wiring with YoHe board added. Normally, four channel signal from the receiver channel can be received by KK2.0. The four channels are aileron, elevator, throttle and rudder channel. KK2.0 with PID inside as a remote signal, can give a varying PWM signal to ESC which then makes motor speed. In contrast, as shown on Figure 6, only three channel from the receiver channel can be directly connected to KK2.0. One channel is the throttle channel which moves the connection to the YoHe board and from from the YoHe board there is one channel which is connected to KK2.0. For the altitude detection, SRF05 ultrasonic I used in this quadcopter. Figure 7 is the wiring outcome in physically form.

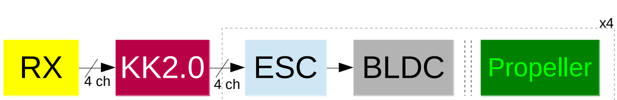


Figure 5 Normally quadcopter components wiring

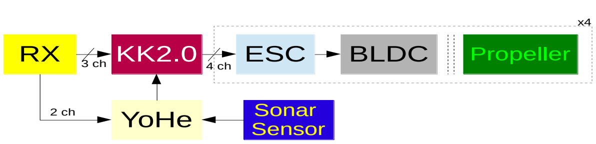


Figure 6 Quadcopter wiring with altitude lock system

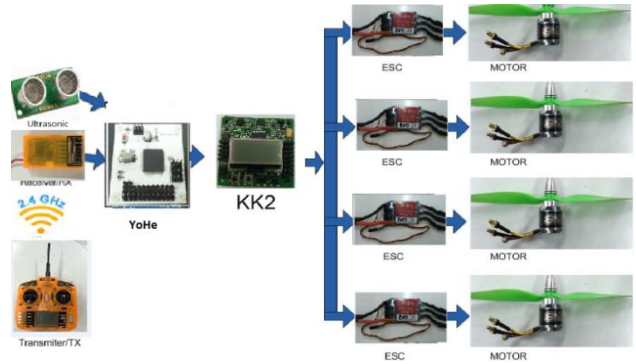


Figure 7 Quadcopter wiring in physically form

3.0 FUZZY and FUZZY-PID DESIGN

In the first step of design, Fuzzy control is designed to get the range of Input Membership Function (IMF) and Output Membership Function (OMF). Subsequently, Fuzzy-PID was designed to follow the IMF and OMF of Fuzzy control design. Figure 8 shows the structure of Fuzzy control design with Error and dError (Error(n)-Error(n-1)) as the two inputs and throttle as the sole output.

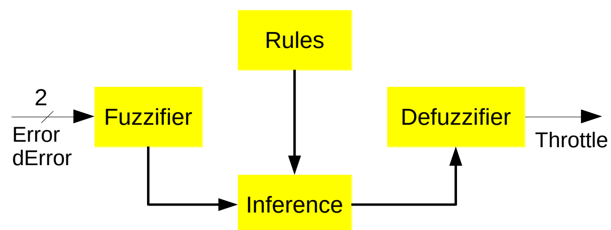


Figure 8 Structure of altitude lock fuzzy design

Figure 9 presents an overview on the Fuzzy control process. The Fuzzy control has two inputs and one output, i.e. Error and Delta Error (dError) as inputs, and throttle as output. Error is defined as height(n) - height (desired), while dError is defined as Error(n) - Error(n-1). If a system is designed with three IMF for Error label and also three IMF for dError label, the Error Membership Function will have three linguistic variables, i.e. NE (Negative Error), ZE (Zero Error) and PE (Positive Error) with values as shown in Figure 10.

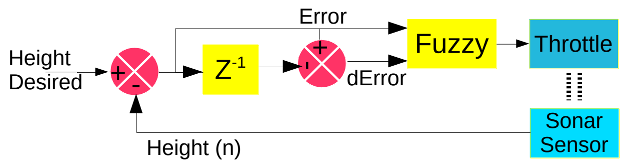


Figure 9 Fuzzy control process

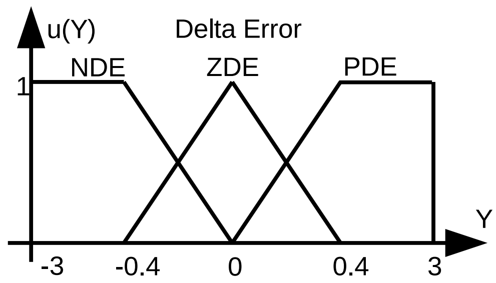


Figure 10 Error membership function for fuzzy control

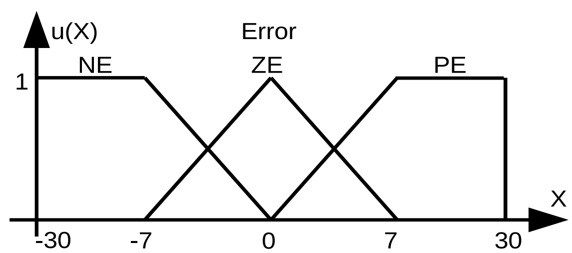


Figure 11 Delta error membership function for fuzzy control

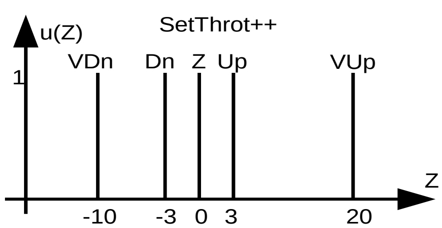


Figure 12 Throttle membership function for fuzzy control

DError Membership Function also has three linguistic variables, i.e. NDE (Negative Delta Error), ZDE (Zero Delta Error), and PDE (Positive Delta Error) as shown in Figure 11. The output, throttle has a Membership Function models which are different where Trapezoid fuzzy sets are used for IMF, and singleton fuzzy sets are used for OMF. The model based on singleton fuzzy sets used for OMF is shown in Figure 12

The next step is to decide the fuzzy rules in inference step for three Error IMFs and three DError IMFs whereby the setup has nine rules as follows:

- If Error is NE and Delta Error is NDE, then Throttle is VUp
- If Error is NE and Delta Error is ZDE, then Throttle is VUp
- If Error is NE and Delta Error is PDE, then Throttle is Up
- If Error is ZE and Delta Error is NDE, then Throttle is Up
- If Error is ZE and Delta Error is ZDE, then Throttle is Zero
- If Error is ZE and Delta Error is PDE then Throttle is Dn
- If Error is PE and Delta Error is NDE, then Throttle is doing
- If Error is PE and Delta Error is ZDE. then Throttle is VDn
- If Error is PE and Delta Error is PDE, then Throttle is VDn

A summary of the Fuzzy rules is shown in Table 2.

Table 2 Fuzzy rule inference

		Delta Error		
		NDE	**ZDE**	**PDE**
ERROR	**NE**	Vup	Vup	Up
	ZE	Up	Zero	Dn
	PE	Dn	VDn	VDn

Many methods can be used in the defuzzification step of which the Center of Area (COA) method was used in this research based on the following formula:

$$\mathrm{COA} = \big(X * u(X)\big) + \big(Y * u(Y)\big) + (Z * u(Z))/(X + Y + Z)$$

All parameters of Fuzzy included IMF range values and OMF range values as explained earlier was optimized many times until got that final range value.

Next, Fuzzy-PID was designed by Fuzzy design and its parameters as reference. PID control only has one input and one output as seen in . Error as an input, and throttle as an output. There are three parameters for PID control, i.e. Kp (proportional gain), Ki (integral gain), and Kd (derivative gain). in this experiment, the researchers used Fuzzy control for tuning/scheduling which needs Kp, Ki, and Kd prediction range values. The structure of control process of Fuzzy-PID is shown in Figure 14.

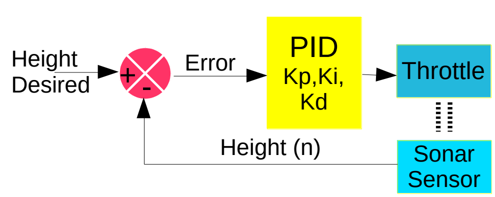


Figure 13 PID control process

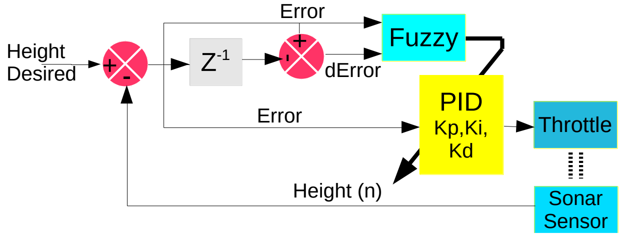


Figure 14 Fuzzy-PID control process

Like any Fuzzy design, this Fuzzy-PID needs IMF and OMF. The Fuzzy control in Fuzzy-PID has a task to handle/tune ΔKp, ΔKi, and ΔKd which means this Fuzzy of Fuzzy-PID has two inputs, i.e. Error and dError, and also three outputs, i.e. ΔKp, ΔKi, and ΔKd. The linguistic variable of Error Membership Function for Fuzzy-PID is shown in Figure 15 is the same with the Fuzzy Control. The delta error shown in Figure 16 is also the same as with the Fuzzy control.

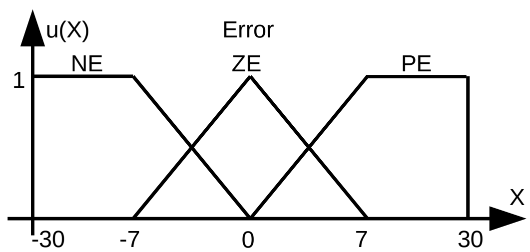


Figure 15 Error IMF for fuzzy-PID control

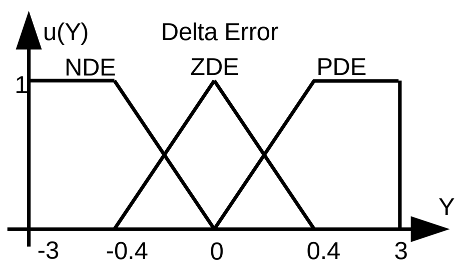


Figure 16 Delta error IMF for fuzzy-PID control

The difference between Fuzzy control and Fuzzy-PID control is in the OMF linguistic variable. Fuzzy-PID has three outputs as shown in Figure 17.

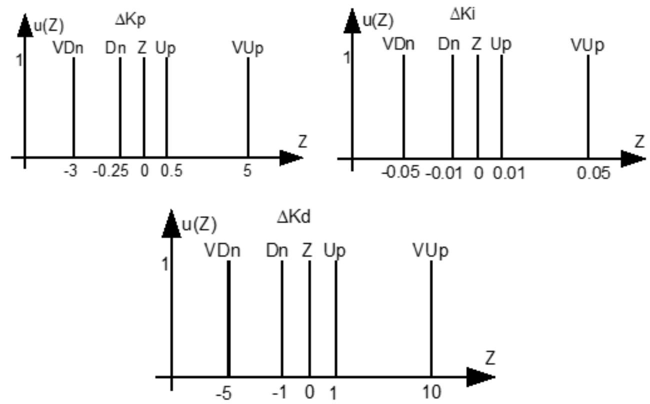


Figure 17 Three OMF fuzzy-PID

Figure 18 Result #1 of Fuzzy Control with 19 cm Oscillation

4.0 RESULT AND DISCUSSIONS

The fuzzy control results can be seen in and 19 while Fuzzy-PID control results are shown in

andFigure 21. In this paper, the researchers have shown only the two best results after doing many trial and error experiments to get the best performance. The altitude lock is activated around 100 cm and the data was sent to the computer via Bluetooth V3.

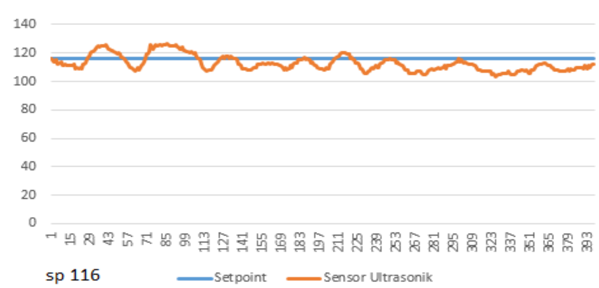


Figure 19 Result #2 Fuzzy control with 14 cm oscillation

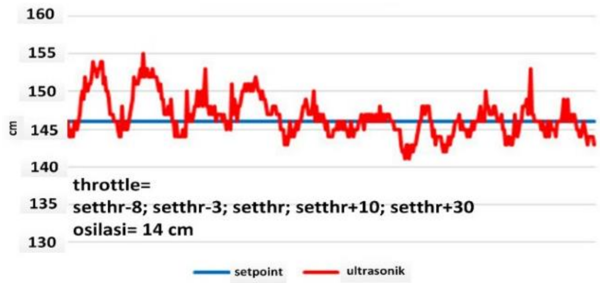


Figure 20 Result #1 Fuzzy-PID control with 27 cm oscillation

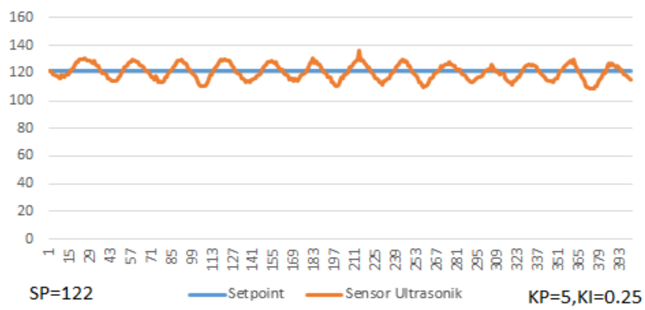


Figure 21 Result #2 fuzzy-PID control with 24 cm oscillation

5.0 CONCLUSION

In this paper, Fuzzy control and Fuzzy-PID control was successfully designed and real-time implemented based on AVR microcontroller on-board yeah. Although Fuzzy-PID has a fuzzy system, but the main controller still PID control. Comparison between Fuzzy and Fuzzy-PID control on how big an oscillation happened. The best result of Fuzzy controller is 14 cm in its oscillation, while Fuzzy-PID only reach a minimum oscillation is 24 cm. In Figure 22 shown variations of Kp which involved self-tuning of Fuzzy in the Fuzzy-PID system.

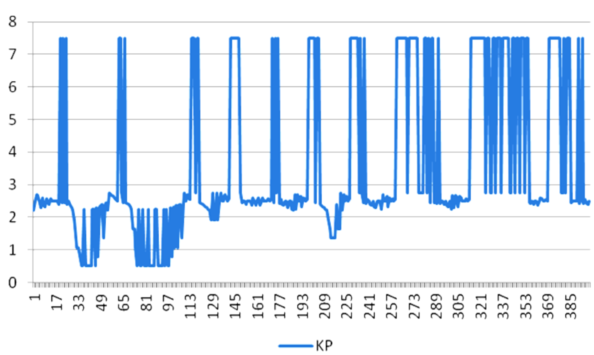


Figure 22 KP Changed by fuzzy in fuzzy-PID system

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