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

Hendi Wicaksono*, Yohanes Gunawan, Arbil Yodinata, Leonardie

University of Surabaya, East Java, Indonesia

**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

© 2015 Penerbit UTM Press. All rights reserved

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 altitude control only, but not the autonomous altitude control yet. The autonomous altitude control is important for imaging application [1]. Attitude 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 including 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].

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.

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 the hybrid Fuzzy PD control of a four-rotor helicopter [13].
KK2.0. Quadcopter parts in Figure 4 and parts specification seen on Table 1.

![Quadcopter main parts](image)

**Figure 4 Quadcopter main parts**

<table>
<thead>
<tr>
<th>No</th>
<th>Part</th>
<th>Total</th>
<th>Merk</th>
<th>Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X-Copter Frame</td>
<td>1</td>
<td>Whirlwind</td>
<td>FY450</td>
</tr>
<tr>
<td>2</td>
<td>Propeller</td>
<td>2</td>
<td>DJI 10x4.7</td>
<td>Plastic</td>
</tr>
<tr>
<td>3</td>
<td>Brushless Motor</td>
<td>4</td>
<td>NTM Prop Drive</td>
<td>30 A</td>
</tr>
<tr>
<td>4</td>
<td>ESC</td>
<td>1</td>
<td>Li-Po 3 cell</td>
<td>2.2 A</td>
</tr>
</tbody>
</table>

**Table 1 Quadcopter parts specification**

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.

![Quadcopter wiring in physically form](image)

**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 ΔError (Error(n)-Error(n-1)) as the two inputs and throttle as the sole output.

![Structure of altitude lock fuzzy design](image)

**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 (ΔError) as inputs, and throttle as output. Error is defined as height(n) - height(desired), while ΔError is defined as Error(n) - Error(n-1). If a system is designed with three IMF for Error label and also three IMF for ΔError 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.
The next step is to decide the fuzzy rules in inference step for three Error IMF}s and three DError IMF}s 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>
<thead>
<tr>
<th>Table 2 Fuzzy rule inference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delta Error</td>
</tr>
<tr>
<td>ERROR</td>
</tr>
<tr>
<td>NE</td>
</tr>
<tr>
<td>ZE</td>
</tr>
<tr>
<td>PE</td>
</tr>
</tbody>
</table>

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:

\[ COA = \frac{X \cdot u(X) + Y \cdot u(Y) + Z \cdot u(Z)}{X + Y + Z} \]

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 Figure 9. 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.

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.
Like any Fuzzy design, this Fuzzy-PID needs IMF and OMF. The Fuzzy control in Fuzzy-PID has a task to handle/tune $\Delta K_p$, $\Delta K_i$, and $\Delta K_d$ which means this Fuzzy of Fuzzy-PID has two inputs, i.e. Error and dError, and also three outputs, i.e. $\Delta K_p$, $\Delta K_i$, and $\Delta K_d$. 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.

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.

4.0 RESULT AND DISCUSSIONS

The fuzzy control results can be seen in Figure 18 and Figure 19 while Fuzzy-PID control results are shown in Figure 20 and Figure 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.
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.

Acknowledgement

We are grateful for the Dikti Indonesia Research Grant to Author 1 and Author 2.

References

Jurnal Teknologi (Sciences and Engineering) is an international research journal and invites contributions of original and novel fundamental research. The journal aims to provide an international forum for the presentation of original fundamental research, interpretative reviews and discussion of new developments in the area of Mathematics, Natural Sciences and Applied Sciences. Papers which describe novel theory and its application to practice are welcome, as are those which illustrate the transfer of multi-disciplinary techniques from other disciplines. Reports of carefully executed experimental work, which is soundly interpreted are also welcome. The overall focus is on original and rigorous research results which have generic significance. Jurnal Teknologi (Sciences & Engineering) invites manuscripts based on original research in any area of Mathematics, Natural Sciences, Physical Sciences, Physics, Chemistry, Astronomy, Earth Science, and Applied Mathematics and Natural Sciences (Building Physics, Mechanical Engineering, Chemical Engineering, Civil Engineering, Material Science, Biotechnology, Medical Engineering). Jurnal Teknologi (Sciences & Engineering) does not limit itself to a single perspective or approach, but seeks to represent the diversity of the aforementioned field. Comments and Proposals: Jurnal Teknologi (Sciences & Engineering) is interested in receiving comments/feedback on this and our other journals and welcome publication proposals for books, electronic products, new journals and co-operation for existing journals.
About the Journal

SCOPE OF PUBLICATION

Jurnal Teknologi welcomes quality research in the area of Mathematics, Natural Sciences (Biological Sciences, Physical Sciences: Physics, Chemistry, Astronomy, Earth Science) and Applied Mathematics and Natural Sciences (Building Physics, Mechanical Engineering, Chemical Engineering, Civil Engineering, Material Science, Biotechnology, Medical Engineering).

Indexed by: SCOPUS, ESCI-WOS, ACI, MYCITE, MYJURNAL.
Editorial Team

Chief Editor
Professor Dr. Rosli Md Illias, Universiti Teknologi Malaysia, Malaysia

Editors
Professor Datuk Dr. Ahmad Fauzi Ismail, Universiti Teknologi Malaysia, Malaysia
Professor Dr. Muhammad Hidayat Lee, Universiti Teknologi Malaysia, Malaysia
Professor Dr. Ruzaini Abdul Rahim, Universiti Teknologi Malaysia, Malaysia
Professor Dr. Hadi Nur, Universiti Teknologi Malaysia, Malaysia
Professor Dr. Mohammad Nazri Mohd. Jaafar, Universiti Teknologi Malaysia, Malaysia
Professor Dr. Sazlina Sharif, Universiti Teknologi Malaysia, Malaysia
Professor Sr. Gs. Dr. Mazlan Hashim, Universiti Teknologi Malaysia, Malaysia
Professor Dr. Hesham Ali El-Enshasy, Universiti Teknologi Malaysia, Malaysia
Prof. Dr. Norhaslina Md Noor, Universiti Teknologi Malaysia, Malaysia
Assoc. Prof. Dr. Mohd Hafiz Dzafar Othman, Universiti Teknologi Malaysia, Malaysia
Assoc. Prof. Ts. Dr. Goh Pei Sean, Universiti Teknologi Malaysia, Malaysia
Dr. Syazfiqah Saidin, Universiti Teknologi Malaysia, Malaysia
Assoc. Prof. Ts. Dr. Dailia Mat Said, Universiti Teknologi Malaysia, Malaysia
Professor Dr. Fahru Zaman Huyop, Universiti Teknologi Malaysia, Malaysia
Assoc. Professor Dr. Roswanira Ab. Wahab, Universiti Teknologi Malaysia, Malaysia

Editorial Board
Professor Craig D. Williams, University of Wolverhampton, United Kingdom
Professor I. S. Jawahir, University of Kentucky, United States
Professor Dr. Xianhe Feng, University of Waterloo, Canada
Professor Dr. Mustafizur Rahman, National University of Singapore, Singapore
Professor Dr. William McClusky, University of Ulster, United Kingdom
Professor Vijay K. Arora, Wilkes University, United States
Professor Dr. Muhammad Riaz, King Fahd University of Petroleum & Minerals Dhahran, Saudi Arabia
Assoc. Prof. Dr. G. Arthanareeswaran, National Institute of Technology, Tiruchirappalli, INDIA
Assoc. Professor Dr. Arun M Isloor, National Institute of Technology Karnataka, INDIA
Professor Dr. Jamaliah Md Jahim, Universiti Kebangsaan Malaysia, Malaysia, Malaysia
Professor Dr. Che Hassan Che Haron, Universiti Kebangsaan Malaysia, Malaysia
MODELLING OF HUMAN EXPERT DECISION MAKING IN RESERVOIR OPERATION
Wan Hussain Wan Ishak, Ku Ruhana Ku Mahamud, Norita Md Norwani

THE DEVELOPMENT OF WEB-BASED MANAGEMENT INFORMATION SYSTEM FOR THE CHILD MALNUTRITION SURVEILLANCE
Mera K. Delimayanti, Sigit Mulyono, Fajar T. Walyanti

INVESTIGATION OF COCONUT SHELLS ACTIVATED CARBON AS THE COST EFFECTIVE ABSORBENT IN DRINKING WATER FILTER
Suriat Mohd Samdin, Lim Hooi Peng, Maryati Marzuki

REDESIGNING EFFECT OF AUTO TAPPING MACHINE SYSTEM IN SMALL PRODUCTION SCALE
Didi Istardi, Remon Sismatangpang

OBJECT QUALITY ENHANCEMENT OF MULTI-FRAME LOW-RESOLUTION VIDEO
Siti Aisyah, Fitri Arnia

PERFORMANCE ANALYSIS FUZZY-FID VERSUS FUZZY FOR QUADCOPTER ALTITUDE LOCK SYSTEM
Hendi Wicaksono, Yohanes Gunawan, Arbi Yudinata, Leonardie Leonardie

THE EFFECT OF JAMMING ATTACK DETECTION AND MITIGATION ON ENERGY POWER CONSUMPTION (CASE STUDY IEEE 802.11 WIRELESS AD HOC NETWORK)
Nur Cahyono Kushardianto, Yudhi Kusnanco, Elvian Syafurizal, Ahmad Hamim Tohari
SUSTAINABILITY: A NEW MANUFACTURING PARADIGM
Muhammad Inran Qureshi, Anran Md. Rasli, Ahmad Jusoh, Tan Kwee Kowang

ROLE OF ENTREPRENEURIAL LEADERSHIP AND COMMERCIALIZATION OF UNIVERSITY RESEARCH: A REVIEW
Sri Gustina Pane, Dilaep Kumar M

MODELLING THE TRIOLOGY OF INNOVATION, LEARNING AND PERFORMANCE
Sri Gustina Pane, Dilaep Kumar M, Muhammad Siddique

GLOBAL POSITIONING SYSTEM AND GLOBAL SYSTEM FOR MOBILE COMMUNICATION MODEM APPLICATION AS CAR POSITION AND FUEL MONITORING SYSTEM
Mazeu Anizah, Ahmad Taqwa, Amperawan Amperawan, Evelina Evelina, Sabili Razief

SYSTEM IDENTIFICATION OF CLAMPING FORCE CONTROLLER FOR SECONDARY PULLEY OF ELECTRO MECHANICAL DUAL ACTING PULLEY CONTINUOUSLY VARIABLE TRANSMISSION (EMDAP CVT)

IDENTIFICATION OF MOST SUITABLE Binarisation METHODS FOR ACHINESE ANCIENT MANUSCRIPTS RESTORATION SOFTWARE USER GUIDE
Fardian Fardian, Fiti Amira, Sayed Muchallill, Khairul Munadi

A REFERENCE-MODEL CONTROLLER TO MITIGATE THE EFFECT OF TIME DELAY CHANGE IN A NETWORKED CONTROL SYSTEMS
Ride Hucaya

AUTOMATIC DEVELOPMENT OF FUZZY MEMBERSHIP FUNCTIONS ON HEPATITIS PATIENTS DATA USING PARTICLE SWARM OPTIMIZATION (PSO)
Candra Dewi, Retna Putri P.S, Indriati Indriati

CALCULATION OF ROD FORCE OF THE TRUSS CONSTRUCTION
Saragih Darmo F, Purba Mardians, Winarsa Bambang

APPLICATION OF DISC SPRING IN CLAMPING FORCE MECHANISM FOR ELECTRO-MECHANICAL CONTINUOUSLY VARIABLE TRANSMISSION
Isheri Izumi Mazali, Kamarul Baharin Tani, Bambang Supriyo, Mohd. Sabri Che Koh, Nurulaskar Abu Husain, Mohd. Salman Che Koh

PERFORMANCE COMPARISON OF DECODING METHODS FOR HISTORICAL DOCUMENTS
Sayed Muchallill, Fiti Amira, Khairul Munadi, Fardian Fardian

A CASE STUDY OF THE WEAKNESS OF FRESHMEN CHOSEN PASSWORD FOR ACADEMIC INFORMATION SYSTEM
Ahmadzai Ahmadzai, Sayed Muchallill