Faculty of Electronic Engineering and Computer

PID CONTROLLER WITH KALMAN FILTER DESIGN FOR QUADCOPTER DJI F450 SYSTEM

Nur Salma Binti Mohd Mokhtar

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NUR SALMA BINTI MOHD MOKHTAR

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DECLARATION

I declare that this thesis entitle “PID Controller with Kalman Filter Design for Quadcopter DJI F450 System” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :……

Name : NUR SALMA BINTI MOHD MOKHTAR

Date :……

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature :……

Name :DR. KHAIRUDDIN BIN OSMAN

Date :……

DEDICATION

To my beloved mother and father, and all my family members, thanks for your support towards my success for my project supervisor Dr. Khairuddin Bin Osman, many thanks for your support and guidance to complete this project. Lastly to all friends and classmates' thanks for your advice and support and it's really appreciated. This duration of time was one of the hardest points of my life, but still, we must have faith in our one and truly God for everything.

ABSTRACT

This thesis presents the design of quadcopter DJI F450 stability controller design that consists of PID and Kalman filter. Quadcopter DJI F450 is a type of UAV that for unmanned aerial vehicle. Deeper in the type of the aircraft is it's a VTOL where the long term is vertical takeoff and landing vehicle where it has the capability of taking off from the ground without having to have accelerating. Flight stability for an aerial vehicle is important because of the disturbance of external forces in higher altitude can affect it even more. When having noise inside the feedback signal, a PID only closed loop controller may have difficulties in maintaining the stability of the quadcopter, and a prediction filter may can solve this problem, thus Kalman filter is one of the prediction control systems that can be used. Usually for the reading of the attitude sensor that is supposed to be the feedback of the overall control system have some in accuracy problem, where the reading might have some continuously spike error where the signal input might not be stable for the input feed of the system. Kalman Filter is one of a great method to smoothen out the sensor signal by making predictive signal output. From here the motivation of designing PID and PID KF was initiated to implement on the quadcopter DJI F450 using simulation which is MATLAB and Simulink. In this research the mathematical model of the quadcopter DJIF450 were used, and the attitude sensor input were used from the actual quadcopter attitude with a small delay, and a random noise were added to the signal that would imitate the real sensor. Three environments were set up and compare which are the first experiment not using a PID and KF, second experiment only using PID and the last using both PID and KF and the result from the three experiments were evaluate. The results show that indeed using the combination of PID and KF shows the most stable flight and higher accuracy based on the desired attitude given because of the sensor output filtered from the KF as the input of the PID.

PENGAWAL PID DENGAN REKA BENTUK PENAPIS KALMAN UNTUK SISTEM KUADKOPTER DJI F450

ABSTRAK

Tesis ini menampilkan reka bentuk pengawal quadcopter bermodel DJI F450. Gabungan PID dan Kalman Filter. Quadcopter DJIF450 adalah salah satu UAV (kenderaan udara tanpa pemandu). Jenis quadcopter DJIF450 adalah VTOL iaitu terbang secara vertikal dan ia tidak perlu memecut secara mendatar jika ingin terbang. Stabiliti penerbangan adalah penting kerana di altitud yang lebih tinggi gangguan kepada isyarat input mungkin boleh memberi impak yang lebih kepada gangguan penerbangan. Apabila ada gangguan dalam isyarat input hanya menggunakan PID sebagai sistem kawalan akan ada kesusahan dalam mendapatkan penerbangan yang stabil, oleh itu, penambahan sistem kawalan ramalan boleh mengatasi permasalahan ini dan Kalman Filter adalah satu sistem kawalan yang sesuai untuk digunakan. Oleh itu, motivasi untuk penggunaan PID dan PID KF untuk mengenal pasti kestabilan antara dua telah diaplikasikan pada quadcopter bermodel DJIF450 menggunakan simulasi MATLAB dan Simulink. Dalam kajian ini, model matematik DJIF450 digunapakai dan bunyi putih rawak telah di tambah dalam sistem kawalan untuk simulasi dunia sebenar. Tiga eksperimen telah dilakukan iaitu yang pertama tanpa menggunakan sistem kawalan, kedua hanya menggunakan PID dan ketiga menggunakan gabungan PID dan Kalman Filter. Penemuan dari eksperimen tersebut mendapati penggunaan gabungan sistem kawalan PID KF dapat memberikan hasil yang lebih tepat daripada hasil isyarat yang ditapis oleh Kalman Filter sebagai input PID.

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LIST OF ABBREVIATIONS

UAV	-	Unmanned Aerial Vehicle
VTOL	-	Vertical Take-off Landing
CTOL	-	Conventional Take-off and Landing
FPV	-	First Person View
PCB	-	Printed Circuit Board
PID	-	Proportional Integral Derivative
KF	-	Kalman Filter
LQG	-	Linear Quadratic Gaussian
CW	-	Clockwise
CCW	-	Counter Clockwise
6 DOF	-	6 Degree of Freedom
ESC	-	Electronic Speed Control
DC	-	Direct Current
BLDC	-	Brushless DC motor
PWM	-	Pulse-width Modulation
PI	-	Proportional Integral
PD	-	Proportional Derivative
COM	-	Center of Mass
DIY	-	Do It Yourself
RPM	-	Rotation Per Minute
MEMS	-	Micro-Electro-Mechanical Systems
IR LED	-	InfraRed Light- emitting Diode
EDR	-	Enhance Data Rate

LIST OF SYMBOLS

B	-	Body Frame
E	-	Earth Frame
ξ_E	-	Linear Position of Earth Initial Frame
ϑ	-	Euler angles
v	-	Linear Velocity
ω	-	Angular Velocity
R	-	Rotation Matrix
T	-	Transfer Matrix
$\vec{T}$	-	Thrust Force
$\vec{F}_{drag}$,	-	Drag Force
$\vec{F}_{mg}$	-	Gravitational Force
$\vec{H}$	-	Hub Torque
$\vec{\omega}_{bl}$	-	Angular Velocity from the Motor
$\vec{\tau}$	-	Torque
t	-	Time
m	-	Mass
$\vec{p}$	-	Linear Momentum
$\vec{L}$	-	Angular Momentum
J	-	Inertia
g	-	Gravity

LIST OF PUBLICATIONS

Journal Paper

1. Salma, N.M., Osman, K., 2020. Modelling and PID control system integration for quadcopter DJIF450 attitude stabilization. *Indonesian Journal of Electrical Engineering and Computer Science*, 19 (3), pp. 1235-1244. DOI: 10.11591/ijeecs.v19.i3.pp1235-1244

Conferences

1. N.M. Salma, Khairuddin Osman, 2017. Multispectral Image Segmentation Using Localized Spectral Binarization. *International Technical Postgraduate Conference (Tech-Post).*
2. Salma, N.M., Osman, K., 2019. Modelling and PID control system integration for quadcopter DJIF450 attitude stabilization, *International Conference on Electrical, Electronic, Communication and Control Engineering (ICEECC2019),* 24-25 November 2019 at the Hatten Hotel, Melaka, Malaysia.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Quadcopter is considered in the Multirotor Vertical Take-off and Landing (VTOL) type Unmanned Aerial Vehicle (UAV). The VTOL capability is that it can handle Conventional Take-off and Landing (CTOL), whereby it will be easy for the quadcopter to fly off the ground with a small surrounding space, and able to fly through small, and narrow path. UAV also known as Unpiloted Aerial Vehicle competent to fly without any human pilot onboard. The technology is favored to use in the military department mostly surveillance in remote, and dangerous places where it can save valuable human recourses. There are various version of quadcopter that had been developed found in research literature such as micro or nano sized quadcopter usually used in swarm and surveillance (Murmu and Sharma, 2021; Madhusudhan, 2016; Venkatraman, 2017), aerial cinematography type, where the quadcopter able to lift a specific camera (Quilter and Anderson, 2000; Tang and Shao, 2015). Moreover, there are also sport FPV H-type frame quadcopter where it specialized in racing (Alkamachi and Ercelebi, 2017a; Alkamachi and Ercelebi, 2017b). The modelling behavior of the quadrotor is premeditated in this work and focusing on improving the take-off stability and overall flight performance.

The quadcopter has a lot of advantages compared with other types of aircraft, whereby it have good maneuverability, simple assembly and it have a great room of improvements and innovation that can be done with the quadcopter itself. Basic component of a quadcopter consist of four brushless motors and its propellars, a battery to power the quadcopter, embedded processor, and sensors. The quadcopter model itself is a common symmetrical frame that have four arms. Each motor is assigned at the far end of the arms

while the electronic speed controller (ESC) which is the abbreviation of electronic speed controller, was placed beneath the middle of the arm. The battery of the quadcopter is placed on the center of the quadcopter as in a common quadcopter setup (Gazal, 2017). The custom power distribution PCB and custom controller was embedded on the center of the frame.

The challenge in the project is how to design the controller of the quadrotor system to obtain stability and achieve the desired state when there are many uncertainties in the environment system, for example, external disturbance, motor actuation degradation, time delays, and also sensor error (Venkatraman, 2017). The project focuses on modelling the DJI F450 quadcopter as shown in Figure 1.1, and design the controller for it using simulation and test using three different types of controllers. There are types of control system method in controlling the altitude of the quadcopter are using proportional integral derivative (PID) closed loop based on these research (Bright and Suryaprakash, 2021; Praveen and Pillai 2016; Alkamachi and Ercelebi, 2017a), other than using just only PID are enhancement of sensor reading by stacking another control system before feeding into the PID which is P-PID cascade control system (Burggräf and Martínez, 2019), and another example of control system used are L1 adaptive control (Thu K.M and Gavrilov, 2017), Linear Quadratic Regulator (LQR) and an implementation of combining the LQR as the tuning closed loop for the PID based on the research (Argentim and Rezende, 2013). The mathematical model of the quadcopter is refered from previous research (Bresciani, 2008; Praveen and Pillai, 2016; Alkamachi and Ercelebi, 2017a) and the DJI F450 frame parameter was embed into the model. Figure below shows the 3D model of the quadcopter modelled using 3D MAX Autodesk. The DJI F450 quadcopter frame was used because the components are widely available online, the structure of the quadcopter is sturdy and it can survive multiple low altitude crashes, the embedded controller are not fixed to one, but can be customized in easing the experiments and analyzing data in this project. The modelled quadcopter is used

in the simulation, and the hardware of the quadcopter is also developed and the results data from both hardware test and simulation test will be analyzed and compared. The analysis result can improve the modelling of the quadcopter and enhance the development of the control system of the quadcopter more rapidly and implement on a real hardware in the future.

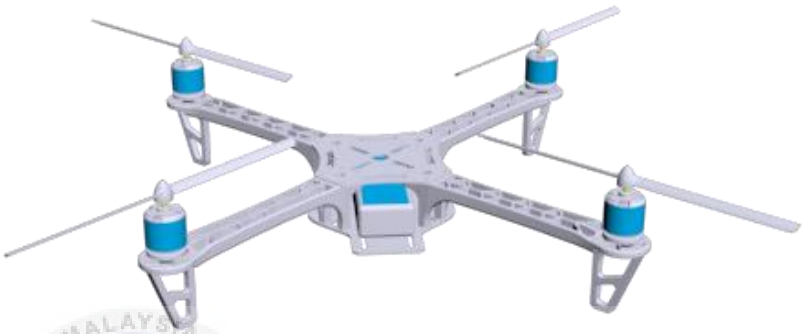

Figure 1.1: DJI F450 Quadcopter 3d Model

1.2 Problem Statement

The popularity of quadcopter among various industries demanding more reliable and high quality unit that satisfied in terms of good quadcopter flight stability, follows the specified range communication and can complete the task given perfectly are the concerns that need to be optimize by researches. The DJI F450 model are one of the famous models among most of the hobbyist, researchers, and for integrating it with many other external modules that can not only fly the device but to do some tasks as the user intended, moreover, the parts of making this specifically model are also widely available thus as a conclusion of choosing this model for the base of the aircraft for the experiment. The mathematical model for the quadcopter modelled DJI F450 are needed to be investigate and apply the findings in a simulation based model to make the experiment reliable and more accurate. Some of the vital factors that can affect the simulation is the modelling of the quadcopter drag force, moment of inertia, gravity, mass of the quadcopter aerodynamic parameters of constant

thrust factor, and the distance between the motor and the center of the quadcopter frame (Salaskar, 2014) are needed to be apply to the modelling. The physical measurement of the quadcopter frame of the DJIF450 are also taken in consideration for the fixed parameter of the model. The research from (Agrawal, 2015; Tong and Ooi, 2015; Praveen and Pillai, 2016; Alkamachi and Ercelebi, 2017a), applied a filter because of the noise problem coming from the sensor that would affect the performance of the overall system feedback. Low pass filter and Kalman filter (KF) are some of the commonly used to reduce the noise coming from a sensor. This thesis is focused on research of obtaining the best result of control system model for the quadcopter DJIF450 model in terms of flight attitude stability. The control system that are used and needed to compare in this thesis is using an open loop, PID closed loop, and the combination of PID with KF applied to the feedback input sensor reading.

1.3 Objectives

The objectives are as follows.

i. To develop mathematical modeling of the quadcopter DJI F45 model.

ii. To design PID-KF controller and apply it to DJI F450 parameter.

iii. To analyze the controller performance under a sensor noise environment.

1.4 Scope of Research

The project scopes are as follows.

i. The mathematical model for the quadcopter modeling based on symmetrical quad rotor using the parameter of DJIF450.

ii. Using MATLAB/Simulink to embed the PID, PID KF controller using the parameter of DJI F450 on the simulation parameter, and compare the flight

performance using the same set of attitude trajectory, and same initial parameter for the quadcopter motor speed.

iii. Fixed noise will be implanted on the feedback input signal to simulate the noise of a sensor reading the attitude position, while trying to get a stable output using controller PID and PID KF.

1.5 Contributions

The project outcome that had been achieved are stated:

1. Developed mathematical model for quadcopter modelled DJI F450 for fast development of research who are using this model.
2. Combined control system and filter to overcome random noise error that are usually comes from our sensors.

1.6 Organization of Thesis

This thesis is organized as follows. In Chapter 1, the overall research are describe in general. Chapter 1 is the introduction of the thesis, all of the introduction on what the research about are stated. The problem statement is the motivation to do the research as to proves whether it is true or not, nor is it achievable or not. Objectives and scopes of the specific research are explained. The methodology is also included in this chapter that needed to be followed to ensure a success completing the objectives.

Chapter 2 explain most of the fundamentals that are used in this research. Survey from various kind of researches researching the same topic that includes the mathematical modelling, control system, and also some novelty usage that can be done using a drone. The

kinematics and dynamic of the quadcopter were elaborated extensively. The mathematical model of the quadcopter was also developed from the fundamentals that are shared.

Chapter 3 more focused on the controller design of the quadcopter. The full version of methodology was explained and shown. With the MATLAB Simulink the backbone of quadcopter simulation was finished. One open loop system was developed just to test whether the simulation is working.

Chapter 4 consists the proposed control system which was the closed loop control system with PID controller. A random continuous white noise was introduced on the feedback input of the controller to replicate the sensor error that usually researchers, and developers struggling with. After done with the PID simulation and results, another simulation was made which is including Kalman filter, KF, on the input feedback signal that had been compromised with error, and feedback the output from KF into the PID control system and everything went back normal.

Chapter 5 elaborate the discussion of the results that was obtain from the two closed loop simulation, which are the PID only simulation and also the PID with added KF on the simulation. The results of each attitude were discussed carefully.

Chapter 6 contains the conclusion and recommendation for the future works, or future research field that can be explore and maybe give more contribution in that pointed area.