A NOVEL HYBRID FUZZY PID CONTROLLER FOR ATTITUDE STABILIZATION OF A REMOTE OPERATED QUADROTOR UNMANNED AERIAL VEHICLE

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TABLE OF CONTENTS

CHAPTER 2 - LITERATURE REVIEW

CHAPTER 3 - QUADROTOR SYSTEM

CHAPTER 4 - ATTITUDE CONTROLLER DESIGN

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UAV	Unmanned Aerial Vehicle
PID	Proportional-Integral-Derivative
LQR	Linear Quadratic Regulator
FCB	Flight Control Board
ESC	Electronic Speed Controller
BLDC	Brushless Direct Current
IDE	Integrate Development Environment
mAh	mili Ampere hour
Li-Po	Lithium Polymer
BDC	Brushed Direct Current
EMI	Electro-Magnetic Interference
RPM	Rotation Per Minute
PWM	Pulse Width Modulation
RF	Radio Frequency
FLC	Fuzzy Logic Controller
FPID	Fuzzy PID
DOF	Degree of Freedom
NB	Negative Big
NS	Negative Small
ZE	Zero
PS	Positive Small

PB	Positive Big
PM	Positive Medium
PL	Positive Large
DCM	Direction Cosine Matrix
GPS	Global Positioning System
mmH_2O	Millimeters of Water
FEA	Finite Element Analysis
N	Newton

LIST OF SYMBOLS

F_i	Force for motor *i* (N)
A_i	Thrust Factor for motor *i* (N)
B_i	Thrust Factor for motor *i* (N)
U_1	Input variable for take-off, landing and hover (Nm)
U_2	Input variable for roll (Nm)
U_3	Input variable for pitch (Nm)
U_4	Input variable for yaw (Nm)
td	Drag torque
d	Drag factor (Nms^2)
ϕ	Roll angle (°)
θ	Pitch angle (°)
ψ	Yaw angle (°)
b	Thrust factor (Ns^2)
ω_j^2	Motor speed square
T	Total thrust force (N)
g	Gravity (ms^{-2})
m	Quadrotor mass (kg)
I_{xx}	Inertias around x-axis (kgm^2)
I_{yy}	Inertias around y-axis (kgm^2)
I_{zz}	Inertias around z-axis (kgm^2)
L	Lever length (m)

ω_j	Rotational speed for motor j ($rads^{-1}$)
$\ddot{x}$	Acceleration on x-axis
$\ddot{y}$	Acceleration on y-axis
$\ddot{z}$	Acceleration on z-axis
$\ddot{\phi}$	Acceleration on roll axis
$\ddot{\theta}$	Acceleration on pitch axis
$\ddot{\psi}$	Acceleration on yaw axis
$\dot{\phi}$	Velocity on roll axis
$\dot{\theta}$	Velocity on pitch axis
$\dot{\psi}$	Velocity on yaw axis
K_p	Proportional gain
K_i	Integral gain
K_d	Derivative gain
Ke	Error gain
Kde	Derivative error gain
e	Error
φ_d	Desired roll angle
θ_d	Desired pitch angle
ψ_d	Desired yaw angle

Satu Pengawal Hibrid Fuzzy PID Asli untuk Penstabilan Gerak-Geri Pesawat Tanpa Pemandu Jarak Jauh Quadrotor

ABSTRAK

Thesis ini membentangkan satu pembangunan kawalan gerak-geri baru yang akan diimplementasikan di dalam litar kawalan penerbangan (FCB) pesawat kawalan jauh tanpa pemandu (UAV). Satu truktur yang mudah telah dibangunkan untuk menguji kawalan gerak-geri tersebut. Struktur quadrotor berbentuk silang "+" memudahkan ia untuk dibangunkan. Quadrotor kawalan jauh terdiri daripada empat buah motor arus terus tanpa berus (BLDC) dengan gegala kipas tetap yang dipasangkan di atasnya, sebuah FCB yang dilengkapi sebuah pengesan unit pengukuran inersia (IMU), empat buah kawalan halaju elektronik (ESC), satu set pemancar dan penerima alat kawalan jauh dan sebiji bateri lithium polymer (Li-PO) yang mempunyai kadar nyahcas yang tinggi. Quadrotor mempunyai kawalan penerbangan enam darjah kebebasan (DOF). Tingkah laku quadrotor adalah sama seperti helikopter tetapi ia boleh terbang selaju pesawat bersayap tetap. Bagaimanapun, hanya empat pergerakan yang dihasilan daripada penerbangan enam darjah kebebasan iaitu berlepas/mendarat, roll, pitch dan yaw. Pergerakan-pergerakan ini dihasilkan daripada perubahan halaju empat kipas yang akan menghasilkan jumlah daya tujahan yang berbeza-beza. Perbezaan daya tujahan ini akan menghasilkan arah penerbangan quadrotor yang berbeza-beza. Satu pemodelan matematik telah dibuat untuk menganalilsis keberkesanan sistem kawalan ke atas model sebenar quadrotor. Model matematik ini digunakan untuk mewakilkan model quadrotor yang sebenar yang mana akan disimulasikan manggunakan Simulink yang terdapat dalam perisian Matlab. Kawalan gerak-geri baru tersebut melibatkan penggabungan kawalan proportional-integral-derivative (PID) dan kawalan fuzzy logic (FLC). Kawalan hybrid Fuzzy-PID (FPID) ini dibangunkan adalah untuk meningkatkan prestasi kawalan tradisional PID. Pendekatan bagi menggabungkan pengawal-pengawal ini adalah dengan menggunakan teknik penyelarian. Semua struktur Fuzzy-P, Fuzzy-I dan Fuzzy-D akan digabungkan untuk membentuk kawalan FPID yang baru. Tujuan hibrid ini dilakukan ialah untuk menggunakn FLC sebagai penala secara autonomi bagi pangawal PID. Gandaan PID yang telah ditala dengan baik digabungkan bersama FLC untuk mendapatkan prestasi yang lebih baik daripada penggunaan kawalan PID secara bersendirian. Kemudian, kedua-dua pengawal akan disimulasikan menggunakan perisian dan juga diimplimentasikan ke dalam quadrotor sebenar untuk dibandingkan prestasinya. Satu ujian penerbangan dijalankan untuk melihat perbezaannya dalam kawalan quadrotor dalam penerbangan menggunakan kawalan baru FPID selain daripada manggunakan kawalan PID. Proses pembangunan dan keputusannya dibincangkan dengan jelas di dalam thesis ini. Keputusan ujian telah menunjukkan bahawa kawalan FPID adalah lebih baik berbanding kawalan PID dari segi tindak balas dan kestabilan. Kawalan FPID sangat cepat untuk mencapat sasaran yang dikehendaki dan menghasilkan kurang lajakan berbanding kawalan PID dan lantas membuktikan bahawa FPID adalah lebih stabil berbanding dengan kawalan PID konvensional.

A Novel Hybrid Fuzzy PID Controller for Attitude Stabilization of a Remote Operated Quadrotor Unmanned Aerial Vehicle

ABSTRACT

This thesis presents a new attitude control development to be implemented in the flight control board (FCB) of quadrotor unmanned aerial vehicle (UAV). A simple structure of quadrotor was developed to test the attitude stabilization control. The cross "+" shaped structure of quadrotor make it is very easy to develop. A remote operated quadrotor consists of four brushless DC motors (BLDC) with fixed pitch propeller attached on it, the FCB equipped with an inertial measurement unit (IMU) sensors, four electronic speed controllers (ESC), a set of remote controller transmitter and receiver and a high discharge lithium polymer (Li-PO) battery. Quadrotor have six degree of freedom (DOF) of flight control. The quadrotor flight behavior is same as helicopter but can fly as fast as fixed wing aircraft. However, only four movements are produced from 6 DOF flight control which are take-off/landing, roll, pitch and yaw. These movements are performed by varying speed of four propellers to produce different amount of thrust. The differences of thrusts will produce different quadrotor flight direction. A mathematical modeling was done to analyze the effectiveness of a control system to the real quadrotor. This mathematical model is used to represent the real quadrotor which was simulated using Simulink in Matlab Software. The new attitude control involved a hybrid controller of proportional-integral-derivative (PID) and a fuzzy logic controller (FLC). This new hybrid Fuzzy-PID (FPID) controller is developed to improve the performance of traditional PID controller. The approach to hybrid both of these controllers is using the parallel technique. All hybrid Fuzzy-P, Fuzzy-I and Fuzzy-D structures are combined together to form a new FPID controller. The purpose of designing the hybrid system is to use FLC as an automatic tuner for PID controller. The well-tuned PID gain of PID controller is combined with FLC to get a better performance compared to using the PID controller alone. Both controllers are simulated in Matlab software and then implemented to the real quadrotor to compare the performance. A test flight is conducted to observe the differences in controlling the quadrotor in flight using the new FPID controller instead of using PID controller. The result showed that the new FPID controller is better than PID controller in term of response and stability. The FPID controller is very quick to achieve the desired target and produce less overshoot than the PID controller and thus proof that the FPID controller is more stable compared to the conventional PID controller.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Attitude stabilization is an important concept that needs to be implemented in the aircraft flight control. A stable flight control is needed for safety and a better control of the aircraft. Quadrotor is an unmanned aerial vehicle (UAV) that can be flown remotely or autonomously without a pilot. Quadrotor is an aircraft that uses four propellers to produce lifting and other flight control movements. The quadrotor is designed to simplify the complexity of helicopter mechanism using swatch plate to control the flight movements. The swash plate used in helicopter has many parts moves which can possibly malfunction if not well maintained.

In the quadrotor system, only motors and propellers are moving. Besides safety, it is maintenance less taxing on because of the only parts to be checked are the motors and the propellers. With a proper flight control, quadrotor can be used several times without maintenance. The differences in speed of each propeller will result various flight control movements. The rotation of propellers will produce thrust which will affect the flight control movements. The stabilization of the quadrotor is operated by controlling the speed of each motor. An algorithm to control the stability of the aircraft is designed by controlling the speed of the motors.

There are many types of methodologies that have been used for stabilization of attitude control. The method such as Kalman Filter is widely used in this application. There are also other methods such as using proportional-integral-derivative (PID) controller, Fuzzy Logic, and Neural Network.

1.2 Problem Statements

Quadrotor UAV Design

Quadrotor UAV structure design is not complicated and easy to build. Many researchers have developed this type of UAV for their research previously. There are enough references which can be used as guidance. But the main problem for developing this type of UAV requires a special type of propeller which is called contra-rotating propeller. Contra-rotating propeller is a pair of normal plane propeller with a contra pitch direction of the same propeller which is used to cancel the torque produced due to motor rotation. In Malaysia, this type of propeller is rare or may be do not exist is market. It is only available in other country such as USA, Germany, Denmark and Japan. This special propeller must be imported directly from the manufacturer in outside country.

Attitude Flight Control

A stable attitude control design must deal with the uncertainty parameter such as nonlinearity, noise, responses and much more. All this parameter must be taken and managed properly to produce a good result. In designing the control system, the sensor

readings are very important because the obtained data could be manipulated as the input references of an attitude control. The sensors used for this system commonly are accelerometers and gyroscopes which measure acceleration due to gravity and rate of rotation respectively. The sensor readings itself will be not consistent values because of vibration and drift effect. The sensor reading must be filtered properly before extracting data to be used to the control system.

Quadrotor UAV is an omni-directional aircraft similar to the helicopter. Actually quadrotor UAV is an aircraft which have the flight control liken to the helicopter. The directional controls for Quadrotor UAV are roll, pitch and yaw which controlled along X-Y-Z axis. The dynamic movement of this aircraft must be calculated precisely for each rotation and transition of the quadrotor. The changes of rotation and transition of the quadrotor give an algorithm that can be developed to determine how much quadrotor can rotate and transit along the X-Y-Z axis. This can be used as a parameter in stabilizing the aircraft using proper method.

The hardware development for this quadrotor must be lightweight and compact as well as easy for use. The flight duration is also the main problem to this type of aircraft. This aircraft type uses four electric motors and electronics components to operate and thus, need more power than a single motor which is usually used in the fixed wing aircraft. The heavy body structure design and additional load carried also consume more power from the motor and may drain the battery and thus may shortens the battery supply power and limit the flight duration as well.

1.3 Research Objectives

The objectives of this research are described below:

i. To design the remote operated quadrotor UAV.

ii. To develop stabilization attitude control of quadrotor UAV using hybrid Fuzzy Logic and PID controller.

iii. To simulate the attitude stabilization control system of quadrotor UAV using Matlab software.

iv. To implement the control system into flight control board (FCB).

1.4 Thesis Outline

This thesis consists of 6 chapters. Chapter 1 provides the introduction of the research and an overview on how the thesis is organized.

Chapter 2 briefly reports a literature review that necessitates about quadrotor, UAV, attitude control and Fuzzy PID controller. This chapter also provides a short overview of previous research works of the quadrotor system and the control system being used.

Chapter 3 describes the development of the quadrotor system and its components used to develop the system. The quadrotor kinematics and dynamics and identification of the constant are also be described in this chapter.

Chapter 4 presents the development of the hybrid Fuzzy PID controller for stabilizing attitude control system of quadrotor. The comparison between conventional PID and hybrid Fuzzy PID control system is discussed in this chapter.

Chapter 5 concludes with the simulation and testing results for attitude stabilization control system. The results are compared between the conventional PID and hybrid Fuzzy PID as the attitude stabilization control system for quadrotor.

Chapter 6 summarizes the contribution made in this thesis. Suggestions for the future research direction are discussed.