# ADAPTIVE NEURAL CONTROLLER FOR ATTITUDE STABILIZATION OF QUADROTOR UNMANNED AERIAL VEHICLE (UAV)



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by

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## TABLE OF CONTENTS

**CHAPTER 2: LITERATURE REVIEW**



**CHAPTER 3: QUADROTOR DESIGN AND SPECIFICATION**

**CHAPTER 4: ATTITUDE CONTROL SYSTEM**



**CHAPTER 5: RESULT AND DISCUSSION**

**CHAPTER 6: CONCLUSION**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ABBREVIATIONS

| | |
|---|---|
| (CoG) | Center Of Gravity |
| (VTOL) | Vertical Takeoff and Landing |
| (UAV) | Unmanned Aerial Vehicle |
| (PD) | Proportional Derivative |
| (PID) | Proportional Integral Derivative |
| (ANC) | Adaptive Neural Controller |
| (FCB) | Flight Control Board |
| (RPV) | Remotely Piloted Vehicle |
| (TRAAC) | Transit Research and Attitude Control |
| (LQR) | Linear Quadratic Regulator |
| (AI) | Artificial Intelligence |
| (MRAS) | Model Reference Adaptive System |
| (RLS) | Recursive Least Square |
| (IMU) | Inertial Measurement Unit |
| (RAM) | Random Access Memory |
| (ISM) | Industrial, Scientific and Medical |
| (ESC) | Electronic Speed Controller |
| (PWM) | Pulse Width Modulation |
| (NiCd) | Nickel-Cadmium |
| (NiMH) | Nickel-Metal Hydride |
| (RPM) | Rotation per Minute |
| (MLP) | Multi Layered Perceptron |

| | |
|---|---|
| (ANN) | Artificial Neural Network |
| (DCM) | Direction Cosine Matrix |

# 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 ($Nms^2$) |
| $\phi$ | Roll angle (°) |
| $\theta$ | Pitch angle (°) |
| $\psi$ | Yaw angle (°) |
| *b* | Thrust factor ($Ns^2$) |
| $\omega_j^2$ | 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) |
| $\omega_j$ | 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 |

**Pengawal Mudah Suai Neural Bagi Kawalan Gerak-Geri Kenderaan Udara Quadrotor Tanpa Manusia (UAV)**

**Abstrak**

Sejajar dengan pembangunan dunia yang pesat didalam bidang teknologi, negara kita juga semakin matang dalam bidang penerokaan ilmu yang baru. Laluan yang diberikan oleh negara kita khususnya didalam bidang kejuruteraan amat luas. Para penyelidik masing-masing berlumba bagi menghasilkan teknologi yang berguna kepada masyarakat dan negara. Bidang teknologi udara menjadi perhatian terutama dalam menghasilkan kenderaan tanpa pemandu (UAV). Thesis ini akan membincangkan tentang penghasilan sebuah pesawat tanpa pemandu yang menggunakan konsep baru yang diberi nama quadrotor. Quadrotor ini merupakan gabungan daripada helikopter dan kapal terbang. Ini kerana quadrotor mampu berlepas dan mendarat secara menegak seperti helikopter dan mampu terbang dengan laju seperti kapal terbang. Quadrotor dibina dengan mempunyai empat rotor yang diletakkan secara simetri seperti bentuk tambah, Kelajuan Pengawal Elektronik (ESC), Pengukuran Unit Inersia (IMU) dan satu set bateri Lithium Polimer (Li-Po). Konfigurasi yang ringkas menyebabkan quadrotor menjadi pilihan utama sebagai kenderaan tanpa pemandu. Gerak-geri quadrotor hanya dikawal oleh daya tujah yang dihasilkan oleh empat rotor. Rotor dapat dikawal berasingan melalui pergaturcaraan yang diberikan didalam sistem kawalan. Masalah utama yang dihadapi adalah bagi mengawal gerak-geri keseimbangan quadrotor ketika melakukan penerbangan. Pengawal Mudah Suai Neural (ANC) digunakan bagi tujuan mengawal gerak-geri keseimbangan quadrotor tersebut. Sistem ini diguna pakai kerana ia dapat memberikan sambutan yang cepat serta tepat dengan berpaksikan rujukan yang diberi. Sebelum itu, analisis tentang kinematik dan dinamik untuk quadrotor perlu dilakukan. Melalui analisis tersebut kita akan dapat menentukan pemodelan quadrotor. Pemodelan quadrotor digunakan untuk mencari sistem asas supaya dapat mengenalpasti karakter quadrotor tersebut. Pengiraan dan ujikaji dijalankan bagi mencari parameter tetap supaya dapat digunakan didalam pemodelan quadrotor. Ujian simulasi dijalankan dengan menggunakan perisian Matlab bagi mencari kestabilan quadrotor pada satah gulung, anggul dan rewang. Setelah sistem pengawal memberikan sambutan yang baik, aturcara yang dibina harus diimplementasi didalam pengawalmikro dan harus dapat berkomunikasi dengan perkakasan quadrotor. Ujian sebenar penerbangan didalam kawasan tertutup dijalankan untuk menguji kestabilan dan jika quadrotor diberi daya luar. Untuk pembangunan dimasa hadapan penderia akan ditambah bagi menambahkan kebolehan quadrotor supaya terbang secara automatik tanpa sebarang bantuan dari stesen kawalan dan manusia.

**Adaptive Neural Controller for Attitude Stabilization of Quadrotor Unmanned Aerial Vehicle (UAV)**


**Abstract**

In line with the rapid development of the world science and technology, our country has matured in the exploration of new knowledge. Our country has given the very bright opportunity in an engineering field. The researchers intend to produce a useful technology to the community. Now on, air to space technology become famous for them, especially in the unmanned aerial vehicle (UAV) area. Therefore, this thesis also will present the development of an UAV that uses a new concept named quadrotor which are a combination of helicopter and airplane. This quadrotor capable of takeoff and landing vertically like a helicopter and can maneuver like an airplane. Quadrotor built with a four-rotor placed symmetrically like an added shape, Electronic Speed Controller (ESC), Inertial Measurement Unit (IMU) sensor and a Lithium Polymer (Li-Po) battery. Simple configuration causes quadrotor preferred used as unmanned vehicles. Quadrotor movement is controlled by the thrust produced by the four-rotor which means to move quadrotor the four rotor speed must be controlled independently. The rotor can be controlled separately through the programming provided in the control system. The main problem faced is to control the quadrotor attitude during flight time. Adaptive Neural Controller (ANC) is used to control the quadrotor attitude. This system was adopted because it can respond quickly and accurately following the reference model. Before that, the quadrotor kinematic and dynamic analysis must be done. Through the analysis, we can determine quadrotor modeling. Modeling quadrotor used to find the quadrotor plant so that the system will be able to identify the quadrotor characteristics. Constant parameters are getting from calculation and experimental test used in quadrotor modeling. Simulation tests carried out using Matlab software to find quadrotor stability in roll, pitch and yaw axis. After the controller gives a good response in simulation, the code converts into C programming and implement in the microcontroller and should synchronize with the hardware configuration. The actual test flights conducted in an indoor to test for stability. Disturbance test also will be conducted. For the future development several of sensors will be added to increase the ability quadrotor to fly autonomously without any guidance from the ground station and also human.

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

This chapter briefly describes about the research background for the development quadrotor and some of the control algorithm that has been used in quadrotor attitude control systems. This chapter will also tell about the problems statement, research objectives and thesis outline for all chapters.

## 1.2 Research Background

The origin of quadrotor is taken from the helicopter, equipped with four separate motors where the motor is placed symmetrically around its center of gravity (CoG). It can hover, maneuver forward and backward, turning clockwise and counterclockwise, vertical takeoff and landing. Therefore, quadrotor is classified as rotary wing aircraft Vertical Takeoff and Landing (VTOL).

Traditionally, quadrotor has not been used well in the aerospace industry, especially heavy load bearing as a normal helicopter could do so. However, quadrotor has its special characteristics. Their configuration does not require a complex mechanical structure as found in an ordinary helicopter. Each of every motor work independently, where it produces a different thrust. The different thrust enables quadrotor moving roll, pitch and yaw axis. Simple configuration will make quadrotor ideal for a small Unmanned Aerial Vehicle (UAV). Since last decade interest, in UAVs rapidly increased because of widespread application. It can do some surveys of large areas, fire and forest exploration, military spy vehicles and also can be used for agricultural purposes. The system used in order to control quadrotor is not as easy as expected. The control system to make quadrotor fly stably required complex algorithm. To ensure quadrotor can move even it required good control system, engineers have developed some controller concepts such as:

- Nonlinear control using feedback-linearization (Voos, 2004)
- Nonlinear State-Dependent Riccati Equation Control (Tayebi, et al., 2004)
- PD/PD$^2$ Controller Design (Bresciani, 2008)
- Enhanced PID Controller Design (Voos, 2004)

Therefore, the purpose of this thesis is to determine system modeling. The new control algorithm applied and real implementation on quadrotor for indoor application. Kinematics and dynamics studies help to understand the physics of the quadrotor and its behaviour. Together with the modelling, determination of the control algorithm structure is very important to achieve better stabilization.



### 1.3 Problem Statements

***Quadrotor Design***

The counter torque is the first priority that should be considered. Conventional helicopter used the tail rotor for counter torque, but quadrotor used a pair of rotors in order to counter torque of another pair of rotors. It means that each pair of rotors on the same axis will eliminate other pairs of rotor torque forces on another axis.

The second priority is about ground effect. As quadrotor ready to take off, the turbulent thrust will occur and causes quadrotor's stability dropped into the lowest level. The control system must adapt to this condition and to avoid too much ground effect, quadrotor must be able to take off as fast as possible. The last theory of flight is about scope air. If the propeller fails to scope air, the quadrotor will not be able to fly because there is no thrust force occurred. Therefore, installation propeller with surrounded ducting is prohibited.

***System Modeling***

To determine the control algorithms can perform a given task succesfully, it is important to understand the quadrotor flight dynamics entirely. Failure to understand the flight dynamics will give some errors in selecting a suitable control system.

***Attitude Flight Control***

Attitude flight control used to stabilize quadrotor on roll, pitch and yaw axis. It must undergo several steps such as the calculation of the parameter's constant, thus modelling the system and then identify the new control algorithm. Several important experiments should be conducted to ensure the constant parameters approaching the actual values quadrotor model. Control structure to be built should be a fast response to make sure quadrotor is not tumbling and then collapse.

### 1.4 Research Objectives

The objective of this research has four parts as described below:

i. To develop and simulate stabilization attitude control of quadrotor UAV using Adaptive Neural Controller (ANC) in Matlab software.

ii. To implement a control system into flight control board (FCB) and quadrotor flight indoor testing.

### 1.5 Thesis Outline

Chapter 1 reveals about some characteristics of quadrotor, hardware configuration, and also the required control system that required to ensure stability quadrotor when flying on the air. With theory of flight as a guidance, the major problems arise can be identified to overcome the general problem of quadrotor such as ground effect and scoping air.

Chapter 2 describes the history of UAV, aircraft and how the quadrotor started from beginning until it becomes so popular. There are various traces of quadrotor produced for specific needs, especially for military. Structural basis for quadrotor also changes from time to time in accordance with changing times and needs. Each country is firmly committed to producing the future vehicle.

Chapter 3 describes the steps done from the beginning of configuring quadrotor hardware, experimental setup to compute constant parameters, quadrotor kinematics and dynamics modeling.

Chapter 4 describes the ANC controller design for attitude control system and the implementation on the quadrotor hardware.

Chapter 5 describes the simulation result of the roll, pitch and yaw axis coupled with the disturbance and noise to see the response given by the controller, whether it is good or poor. For the implementation, a result shows quadrotor orientation on the real situation and added some external forces as a disturbance to test its stability. Good response of the simulation and implementation realizing quadrotor to fly in the indoor environment. There are some situations that need to be taken into account because it will disturb quadrotor's stabilization process such as imbalance current for each motor, the accuracy of lever length among four motors and many more.

Chapter 6 only gives the conclusion of the project that has been done so well and will be conducted. With the completion of this thesis, the objectives for this project have been accomplished. However, this project still needs some improvement in order to bring the quadrotor became an autonomous aerial vehicle as soon as possible.

## 1.6 Summary

This project will focus on the development of attitude control for quadrotor. Adaptive Neural Controller will be design for attitude control and will be performed using Matlab software simulation and quadrotor response. After completed the attitude control designation, it will be implemented on the quadrotor and flight test will be conducted.

## CHAPTER 2

## LITERATURE REVIEW

### 2.1 Introduction

This chapter discusses the history about aircraft as unmanned aerial vehicles (UAV) that can be used in various applications. Early history tells us that the UAV is often used for military purposes. Quadrotor also be a part of UAV with capable of vertical takeoff and landing (VTOL) and its special characteristics of quadrotor make this flying vehicle perfectly suitable for UAV application. This thesis is intended on controlling the attitude stabilization for quadrotor so that information about the early history attitude flight controls system is also included. Fast response with minimal error makes the Adaptive Neural Controller (ANC) has selected for this quadrotor attitude stabilization project. Brief history about ANC controller also has been presented in this chapter.

### 2.2 Quadrotor UAV

Studies on the development of a UAV quadrotor have been started in the early twentieth century. Etienne Oemichen, France's engineer was one of the earliest inventors who produced the initial prototype of quadrotor. In years 1920, he succeeded in producing the quadrotor that consist of four thrusters. He named his quadrotor as Oemichen No.1. However, his quadrotor not be able to make its first flight. He did not give up. Over two year's studies and experiment, finally he could reproduce a second quadrotor version by adding the number of thrusters. This new method requires five thrusters to control aircraft stability, two thrusters for propulsion and another one thruster to make the aircraft turned in one axis. In April 1914, that Oemichen No. 2 flew about 525 meter distances and broke the FAI records for the helicopter that flew only 360 meters.

Meanwhile, in January 1921, Dr. George De Bothezat and Ivan Jerome also begin their study of quadrotor where to use by United States Army Air Corps. After a year of research, at the end of October 1922 in Dayton, Ohio, they have successfully flown this aircraft as shown in Figure 2.1. This quadrotor is designed with 1700 kg weight, which consists of four thrusters each having six blades along with 220-HP motor. This quadrotor can fly at 1.8 m height for 1 minute 42 seconds (Martin E. Dempsey, 2010).

Figure 2.1: De Bothezat quadrotor, 1923

In the mid 1950, quadrotor invented for civil and military purposes. During this time, it was known as Convertawings Quadrotor Model "A". This aircraft also has four thrusters where its shape just likes the letter 'H' as in Figure 2.2. However, after a flight