UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Development of the Unmanned Aerial Vehicle in Hexacopter for Attitude Control

This report submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Electrical Engineering Technology (Industrial Automation & Robotics) (Hons.)

by

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ABSTRAK

Pada masa kini, *Unmanned Aerial Vehicles* (UAVs) terutamanya *multi-copter* dalam ketenteraan, pengawasan, penyiasatan meteorologi dan penyelidikan robotik telah semakin umum dalam dunia. *Hexacopter* adalah salah satu jenis *multi-copter* yang mempunyai kestabilan yang tinggi disebabkan ia boleh meningkatkan jumlah muatan dan menyelesaikan permasalahan jika salah satu atau lebih enjin gagal berfungsi. *Hexacopter* ini menggunakan pengawalan PID dalam APM sebagai *microcontroller* untuk mendapat kestabilan yang baik dalam halaju sudut. Model matematik dibentangkan dengan mempertimbangkan semua pengaruh luar dan kedudukan. Secara umumnya, *multi-copter* sebagai satu badan tegar, tingkah laku dinamik digambarkan dari persamaan pembezaan yang diperoleh daripada *Euler-Lagrange* memasukkan model matematik diprogramkan ke dalam Arduino untuk mengawal algorithm. Akhir sekali, perkakasan dan perisian yang digabung bersama. Kawalan algorithm dalam hexacopter dicipta dan dikawal dengan cara menggunakan pengawal radio yang mesra pengguna semasa menjalakan data analisis dengan Mission Planner di dalam rumah untuk mengelakkan ganguan dan menyiasat pretasi hexacopter.

ABSTRACT

Unmanned aerial vehicles (UAVs) nowadays has become increasingly common application in military options, surveillance, meteorological investigation and robotics research especially multi-copter. Hexacopter is a type of multi copter which has high stability due to it possibility manage one or more engine failure and increase the total payload. The attitude of the hexacopter is implemented by PID controller in APM as microcontroller to tune for good stability control in angular velocity. The mathematic model presented by considering all its external and influences. It is well known that, assume the multi copter as a rigid body, its dynamic behaviour described from the differential equations derived from the Euler-Lagrange equations leading to equivalent mathematical model are programed into Arduino for control the algorithm. Lastly, the hardware and software combined all together. With developed the control algorithm in hexacopter was controlled by using RC controller which more user friendly interface when doing the data analysis on test pad with Mission Planner under indoor environment due to neglect all the disturbance for investigate the attitude performance of developed hexacopter.

DEDICATION

To my beloved parents, I acknowledge my sincere indebtedness and gratitude to them for their love, dream and sacrifice throughout my life. Their sacrifice had inspired me from the day I learned how to read and write until what I have become now. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to achieve my dreams.

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ABS	-	Acrylonitrile Butadiene Styrene
AMF	-	Additive Manufacturing File
APM	-	ArduPilot Mega
CAD	-	Computer Aided Design
COM	-	Communication Port
CMM	-	Coordinate Measuring Machine
DC	-	Direct Current
DOF	-	Degree of Freedom
ESC	-	Electronic Speed Control
FBW	-	Fly by Wire
FDM	-	Fused Deposition Modeling
GPS	-	Global Positioning System
IDE	-	Integrated Development Environment
IMU	-	Inertial Measurement Unit
I/O	-	Input Output
LiPo	-	Lithium Polymer
LQRs	-	Linear Quadratic Regulators
MAVs	-	Multi-Rotors Micro Aerial Vehicles
MEMS	-	Micro-Electrical Mechanical System
PD	-	Proportional Derivative
PID	-	Proportional Integral Derivative
PM	-	Power Module
PVC	-	Polyvinyl Chloride
RC	-	Radio Control
RP	-	Rapid Prototyping
UAVs	-	Unmanned Aerial Vehicles
3MF	-	3D Manufacturing Format

CHAPTER 1
INTRODUCTION

1.0 Introduction

In this chapter 1, it provides an introduction about this projects. Basically, it start with describe the background of the project, problem statement, objective, work scope and conclusion of development of the unmanned aerial vehicles, UAVs (Hexacopter) for stability and attitude control.

1.1 Project Background

Aerial robot or flying robots or unmanned aerial vehicles (UAVs) is an aircraft with no pilot on board which can be remote controlled or can fly autonomously based on preprogrammed flight plans like GPS or waypoints. Nowadays UAV has become increasingly common and extend a huge range of size and shape. Application of UAVs include military options, surveillance, meteorological investigation and robotics research especially in multi-copters. Multi-copter have recently not only focused by researched, beside it has been already used for some practical task such as aerial photography and surveillance due to their high stability, i.e. hexacopter and octocopter, possibility manage one or more engine failure and increase the total payload. In particular, benefit of more rotors appear will provide more power and lift, that mean more time travel on fly. However, the increasing of drone size and weight as well as its production cost counts against. So the hexacopter seem to be a good comparison.

In addition, there are big comparison of the stability and attitude control of UAVs in the market due to the cost or the base controller setup problem. The cheapest of the UAVs may implement low cost several advanced sensors inside an

Inertial Measurement Unit (IMU). IMU is an electronic device and will provide information about the velocity, orientation, and gravitational forces of rigid body. An IMU system has three types of inertial sensors which are gyroscopes, accelerometer and magnetometer will provide three inertial measurement for three different axis (x, y and z axis). Due to the low cost sensors, may be affected by noise. For example, Micro-electrical mechanical system (MEMS) gyroscopes is used to measure angular rate of rotation along roll, pitch and yaw axis, it usually suffer from measurement noise due to vibration. Besides that, poor implementation process for the linear controllers will also affect the attitude and stability of the UAVs. Hence, this study is going to design and fabricate robust attitude control with low cost hexacopter that propose a stable attitude state feedback linear controller model used for behavior and control algorithm testing under indoor environment which neglect all the disturbance, before implementation on the experimental setup.

At the starting of this project, before the linear controller model offered, an hexacopter deliberated with six rotors are constructed at the vertex of the hexagon and equidistant from the center of gravity. Furthermore, the propulsion of system include three pairs of counter rotating fixed pitch propellers. A good way to implement the characteristic of the hexacopter dynamic behavior, the mathematical model offered by considering all its external and internal influences. It is well known that, expect the hexacopter as a rigid body, its dynamic conduct defined from the differential equations derived from the Euler-Lagrange equations leading to equivalent mathematical model.

The project is to come up low cost and robust hexacopter, for the structure of body frame have to be own designed in 3D Printing. 3D printing era has primarily been evolved in the manufacturing industry to help rushing up the development of the new products. This design using Fused Deposition Modeling (FDM) method and Coordinate Measuring Machine (CMM) to implement dimensional error analysis of synthetic parts. The proposed controller method is implemented into cascade PID loop controller. The PID loop essential tuned for good stability control to reduce noise in angular velocity.

1.2 Problem Statement

Nowadays, unmanned aerial vehicle (UAV) has become increasingly common and extend a huge range of size and shape. In last few decades, fixed wing aircraft in Figure 1.1 and single rotor helicopter in Figure 1.2 are the most common types of unmanned aerial vehicle. Until now, the latest generation of unmanned aerial robots is multi-rotors micro aerial vehicles (MAVs) as shown in Figure 1.0.

Figure 1.0 Multi-rotors

Multi-rotors MAVs are encountered in an increasing number of application such as aerial photography and surveillance, which cannot be accomplished by fixed wind drones and single rotor drone helicopter. Fixed wind drones use a wing like a normal aeroplane to provide lift force rather than vertical lift rotors due to the energy used to move forward only, so it will more efficiency. However, the main downside of fixed wing drones is inability to hover in one spot. This will makes the trickier on launching and landing it as depending on the size. Besides that, fixed wind drones are much more expensive than multi-rotors and that is more difficult to repair with fixed wing drones.

Figure 1.1 Fixed Wing Drone

Single rotor drone helicopter has just only one rotor and a single tail rotor to control its heading. A single rotor helicopter has greater efficiency and also can powered by a gas motor for even longer endurance. It refer a general rule of aerodynamics that the larger the rotor blade and slower it spins, it will be higher efficiency. Nevertheless, due to its complexity, high cost, vibration at low frequency harder to tune and also the danger of their large spinning blades if get in its way, and there have been a number of fatalities from drone helicopter.

Figure 1.2 Single Rotor Drone Helicopter

In contrast to fixed-wing and traditional helicopter UAVs, multi-rotors MAVs are much safer to operate, can easily hover above the target and able to fly at low altitude, are highly maneuverable and do not require complex mechanical control linkages. In addition, multi-rotors are more stable in calm condition and able to tune easily due to its higher frequency in vibration. However, the increasing of drone size and weight as well as its manufacturing value counts towards. Therefore, the hexacopter seem to be a good comparison and possibility manage one or more engine failure and increase the total payload. In particular, benefit of more rotors appear will provide more power and lift, that mean more time travel on fly.

1.3 Objective of Research

Development of the low cost robust hexacopter decide designed by using 3D printing technology using SolidWorks and implement a linear feedback controller by using Arduino. In this project, there are three objectives that need to be achieved. The objective of this project are:

a. To design and fabricate own low cost hexacopter components in 3D printing.

b. To analysis the linearity in stability and attitude control with hexacopter dynamics model implemented by cascade PID controller.

c. To investigate the degree of controllability in attitude with hexacopter when it has one or two rotor stopped.

1.4 Work Scope

In this project, the aim is to design and fabricate own low cost hexacopter components in 3D printing by using SolidWork and set up the hardware with the Ardupilot. Then will program into the APM by using the Arduino software with implement a feedback controller using cascade PID controller. This project will be focusing on the algorithm implementation and testing on test pad under indoor environment due to neglect all the disturbance with proceed the data analysis using software Mission Planner. The test shall be done in following situation:

a) In full rotor on mode:

The 6 rotors are fully functional to analysis the linearity in stability and attitude control with hexacopter dynamics model.

b) In one or two rotor off mode:

When one or two rotor are stopped, this test is to investigate the degree of controllability in attitude.

1.5 Conclusion

This chapter mainly brief about the introduction of this project. Nowadays, Multi copter has been already used for few practical project which include aerial photography and surveillance due to their excessive stability, especially are hexacopter and octocopter, due to possibility manage one or more engine failure and increase the total payload. In particular, gain of more rotors seem will provide more power and lift, that imply more time travel on fly. However, the increasing of drone size and weight as well as its production cost counts against. Therefore, the hexacopter seem to be a good comparison to minimize the cost. In addition, there are big comparison of the stability and attitude control of UAVs in the market due to the cost or the base controller setup problem. Hence, this study is going to design and fabricate robust attitude control with low cost hexacopter using 3D printing and propose a stable attitude state feedback linear controller model cascade PID loop controller and control algorithm testing under indoor environment which neglect all the disturbance, before implementation on the experimental setup. This chapter also discussed about the objectives and work scope of this project where the main objective is to analysis the linearity in stability and attitude control with hexacopter dynamics model. Moreover, also investigate the degree of controllability in attitude with hexacopter when it has one or two rotor stopped. In short, this project will be focusing on the algorithm implementation and testing on test pad with proceed the data analysis using software Mission Planner under indoor environment due to neglect all the disturbance.

CHAPTER2

LITERATURE REVIEW

2.0 Overview of Multi-copter

Nowadays, the continuous enhancements and developments in electronic technology (particularly Micro Electrical Mechanical Sensor, MEMS) will growth the performance of many modern structures. Virtually, it will permit the developments of UAVs with traits presently no longer even foreseen. Application of UAV encompass military options, surveillance, meteorological investigation and robotics research mainly in multi-copters. Multi-rotor or multi-copter is a rotorcraft with more than two rotors. Besides that, advantages of the multi-rotor UAVs are the simpler rotor mechanics required for flight control. In contrast to the usage of complicated variable pitch rotors whose the pitch varies as the blade rotates for flight stability and manipulate with the aid single and double rotor helicopter. However, the multi-rotors often use fixed-pitch blades to govern the movement of the vehicle and completed by using various relative speed of each rotors to change the thrust and torque produced by each. Multi-rotors UAVs are often used in radio control and names as tricopter, quadcopter, hexacopter and octocopter to able permit greater power stability at reduced weight coaxial rotors can be hired with every arm has two motors strolling in opposite direction.

2.0.1 Mathematic Modeling and Control of Hexacopter

The literature overview (Almaimo, Artale, Milazzo, Ricciardello & Trefiletti, 2013) show that the fundamental mathematical model of mini rotor craft with six rotors and its manipulate has been supplied which used to increase stabilization and trajectory control. The micro-copter includes six rotors and three pairs of counter rotating fixed pitch blades on every rotors are positioned at the vertices of an hexagon and equidistant from the center of gravity. The micro-copter is managed with the resources of adjusting the angular velocities of the rotors which are spun via manner of electric powered motors. Futhermore, the hexacopter is expected as a rigid body shown in Figure 2.0, so the differential equations can be derived from Newton-Euler and Euler-Lagrange equations. Euler perspective parameterization of three dimensional rotations consists of singular points inside the coordinate space that can purpose failure of each dynamical model and control. In order to avoid singularities, the rotations of the micro-copter are parameterized in phrases of quaternions. This preference has been made deliberating the linearity of quaternion method, the steadiness and efficiency.

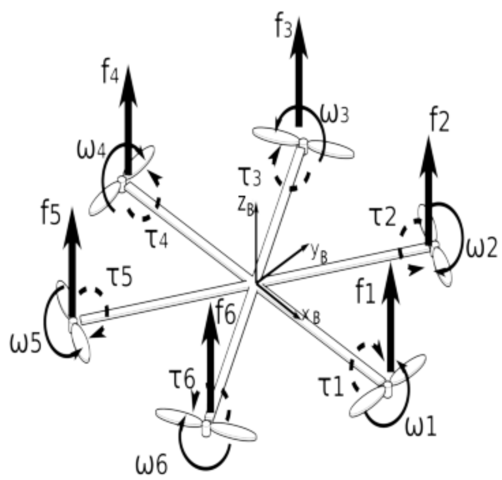

Figure 2.0 Rigid Body of the Hexacopter.

2.0.2 Overview of Controllers Design of Hexacopter

As present in (Ahmed, Latied, Ali & Akmeliawati, 2015) present a new control device thru cascade proportional through PD controllers of an self-existent hexacopter is proposed. In the meantime, the cascade PD controller is designed to stabilize and manage the altitude and heading of the hexacopter. Nested saturation is compared with this controller to control legal tips to manipulate horizontal trajectory of vehicle alongside X and Y axis. This controller design includes three layers display in Figure 2.1. The bottom layer controls the rotational velocity of the rotors to transport the hexacopter with the preferred velocity. The center layer controls the hexacopter attitude (roll, pitch, yaw angles) and the top layer controls the position of the vehicle alongside a given trajectory. Simulation results display the functionality of the proposed controller in using the unmanned aerial vehicles (UAVs) to the preferred pose effectively.

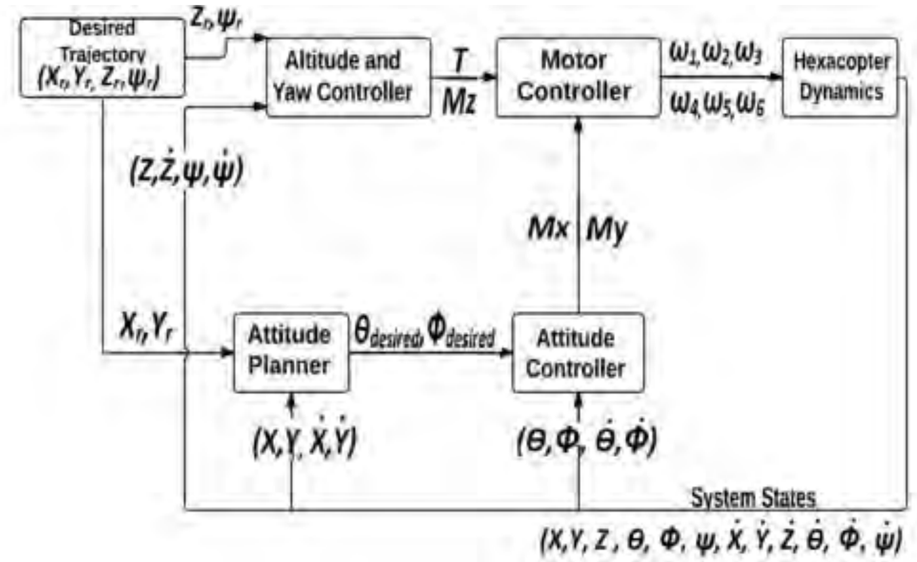

Figure 2.1 Hexacopter Control Loops.

In this paper by (Mohd Azizi and Kenzo Nonami, 2016) proposes a new practical robust attitude state feedback controller of low cost hexarotors micro aerial vehicle under the consequences of noise in angular velocity measurements and more than one uncertainties also referred to as the equal disturbance. The equal disturbance which consist of external time various wind disturbance, nonlinear dynamics, coupling and parametric uncertainties. The conventional methods to achieve autonomous flight on multi-rotor have relied on linear controllers which includes proportional imperative derivatives (PIDs) and linear quadratic regulators (LQRs). In comparison this two controllers techniques, LQR method give slight outcomes due to model imperfections, even as the PID show the ability for attitude control in presence of small quantity of uncertainly. By the way, the design and implementation process of linear controllers is straight forward and easy to analyse the performance of controllers. However, the overall performance of