FAKULTI KEJURUTERAAN ELEKTRIK
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

LAPORAN PROJEK SARJANA MUDA

MODELLING OF A SMALL SCALE QUADROTOR SYSTEM

Lim Kian Wee

Bachelor of Mechatronics Engineering

2015

"I hereby declare that I have read through this report entitle "Modelling of a Small Scale Quadrotor System" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronics Engineering"

Signature : .....

Supervisor's Name : .....

Date : .....

MODELLING OF A SMALL SCALE QUADROTOR SYSTEM

LIM KIAN WEE

A report submitted in partial fulfillment of the requirements for the degree of Mechatronics Engineering

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA
MELAKA

2015

I declare that this report entitle "*Modelling of A Small Scale Quadrotor System*" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

To my beloved mother and father

ACKNOWLEDGEMENT

Firstly, I am grateful that I have Madam Norafizah Binti Abas as my supervisor for my final year project who has been guiding me throughout the period of the final year project. I would like to thank her for her patience and motivation while guiding me to a better track of conducting this final year project. Her guidance on the report has helped a lot as she has the willingness to sacrifice her time on checking my report words by words. I would also very appreciate her as she always share her experience with us.

Secondly, I would like to thank Ms. Nur Maisarah Bt Mohd Sobran, who is my supervisor for my final year project. She had been guiding me a lot on the writing of the report. Furthermore, she has gave me encouragement and taught me the knowledge of writing the report of final year project.

Besides, I would like to thank my friends who are also the final year students that are under the supervision of Madam Norafizah Binti Abas. Throughout the period of this final year project, I am able to learn extra knowledge through other projects via discussion among each other. The discussion is very meaningful as the topic that is being discussed is quite challenging where every student able to exchange their opinion with each other. Thus, this has make the final year project more interesting.

Finally, I would like to thank my family who have been always giving support to me throughout the whole research of my final year project in University Teknikal Malaysia Melaka. Since the beginning of my studies here, they kept encourage me to do my best as this is the last project in my university life.

ABSTRACT

Surveillance is very important to ensure safety of a country. Lack of surveillance causes terrorist intrusion that happened in Lahad Datu, Sabah on 12 February 2013. Eastern Sabah Security Command (ESSCOM) was established by Department of Prime Minister for surveillance on the Eastern Sabah Security Zone (ESSZONE). The surveillance is done by the authorities of the ESSZONE which consist of ten districts. However, the limitation of the vision of a human and the large area for surveillance may decrease the efficiency of surveillance. Therefore, the Quadrotor is proposed for surveillance purpose due to it is a rotorcraft with four horizontal rotors which designed in square configuration. Despite of that, Quadrotor is a highly non-linear system and the difficulties on requiring the state space representation of the Quadrotor system. In order to overcome the problems faced, the objectives of this research are to perform computationally and physically modelling of the Quadrotor system and performing the analysis of the performance of the modelling of Quadrotor in terms of steady state error. The methodology is to compare both the model computationally and physically the Quadrotor system. The CAD drawing of the testbed is converted into SimMechanics Toolbox using SimMechanics Link add-on for the modelling computationally while modelling physically by conducting physical realization experiments. Total of three experiments such as the physical measurement, force-lift test and speed test, and bifilar pendulum experiment of Quadrotor are conducted to obtain related parameters for the Quadrotor system. The results of the experiments and the computed parameters form two state space representation. The analysis of each state space representation is done using MATLAB and tested as an open loop system. The physical modelling has a lower steady state error compared to computational modelling. These modelling are very important in order to produce an effective and accurate performance of the controller for Quadrotor system.

ABSTRAK

Kegiatan pengawasan adalah sangat penting untuk menjamin keselamatan negara. Kekurangan dari segi pengawasan akan menyebabkan pencerobohan pengganas yang telah berlaku di Lahad Datu, Sabah pada haribulan 12 Februari 2013. Eastern Sabah Security Command (ESSCOM) telah ditubuhkan oleh Jabatan Perdana Menteri untuk mengawasi Eastern Sabah Security Zone (ESSZONE). Pengawasan bagi sepuluh daerah ini dilakukan oleh pihak berkuasa. Walaubagaimanapun, keterbatasan manusia dari segi penglihatan dan kawasan di bawah pengawasan adalah sangat besar menyebabkan penurunan efisiensi dari segi kecekapan pengawasan. Oleh yang demikian, *Quadrotor* dicadangkan untuk menjalankan kegiatan pengawasan ini kerana ia adalah helikopter yang mempunyai empat pemutar yang mendatar dalam konfigurasi segi empat tepat persegi. Meskipun, *Quadrotor* merupakan sistem yang bukan linear dan mempunyai kesukaran untuk mencari sistem *Quadrotor* itu. Demi mengatasi masalah yang dihadapi, objektif kajian ini adalah untuk melakukan pemodelan secara komputasi and fizikal untuk sistem Quadrotor dan melakukan analisis prestasi pemodelan *Quadrotor* dari segi ralat keadaan mantap . Kaedah ini adalah untuk membandingkan kedua-dua model pengiraannya dan fizikal sistem Quadrotor. Lukisan *CAD* daripada *Quadrotor* itu ditukar kepada *SimMechanics Toolbox* menggunakan penambahan daripada *SimMechanics Link* untuk pemodelan pengiraannya manakala pemodelan fizikal dengan menjalankan eksperimen kesedaran fizikal. Sebanyak tiga eksperimen seperti pengukuran fizikal, ujian daya angkat dan ujian kelajuan, dan eksperimen bandul *bifilar* daripada *Quadrotor* dijalankan untuk mendapatkan parameter yang berkaitan untuk sistem *Quadrotor* itu. Keputusan eksperimen dan parameter digunakan untuk pengiraan dan membentuk dua perwakilan ruang keadaan. Analisis untuk setiap perwakilan ruang keadaan dilakukan dengan menggunakan *MATLAB* dan diuji sebagai sistem gelung terbuka. Pemodelan fizikal mempunyai ralat keadaan mantap yang lebih rendah berbanding dengan model pengkomputeran. Model ini adalah sangat penting untuk menghasilkan pengawal yang mempunyai prestasi yang berkesan dan tepat untuk sistem *Quadrotor*.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

In this modern era of globalisation, there are many kinds of technologies have been invented to ease the daily routine of humans. There are technologies which are able to fly by its own using four rotors. These type of vehicle is called as Quadrotor. Quadrotor are known as Quadcopter which is a helicopter that consists of multi-rotor. Typically, it is lifted and propelled by four rotors. There are many functions of this Quadrotor that are used by a lot of people such as the army, the police and other related person. This vehicle can be used for surveillance, search and rescue operation and many more. This is due to the size of the Quadrotor is small and easily controlled. It is normally has a camera fixed on it so that the person in charge able to see the surroundings of the Quadrotor. As in general, autopilot for Quadrotor is optimal. This vehicle is able to be used as load transportation from one place to another by just setting the location of destination. Developing a Quadrotor is not an easy task like creating a normal robot. Many things are taken into account such as the physical mathematical modelling of the Quadrotor, the parameter of the variables of the Quadrotor and even the configuration of the Quadrotor. The modelling of the Quadrotor is very important as the performance of the developed controller is depending on how well is the modelling [1].

In the early days of the history of flight, the configurations of a Quadrotor are seen as the solution to fix the persistent problems with vertical flight which means that the control of torque that being induced are being ignored by the counter-rotation and the comparatively short blades which could be constructed easily. The first Quadrotor has been invented on the year 1922 that is called as Oemichen No. 2 and follow by the De Bothezat Quadrotor which is built in 21st February 1923. Unfortunately, the first two Quadrotor are unable to lift off

due to its physical configuration. The first Quadrotor that manage to lift off and fly is the Convertawings Model A, built on 1955/1956. The first flight is on the March 1956.

Figure 1.1: Convertawings Model A. First Quadrotor that able to fly [2]

This Quadrotor is among the most successful Vertical Take Off and Landing (VTOL) vehicles. At first, like any other prototype, it had a poor performance and also requires more pilot work load. This has led to poor stability augmentation and also imperfect control authority. In comparison with other prototypes of these vehicles, this kind of Quadrotor has quite a huge weight difference which is including the weight of the pilot. The material used to build this prototype should be light in order to decrease the overall weight of the prototype so that the vehicle can easily lifted off vertically and also decreasing the stress on the rotor.

Quadrotor lies under the group of Unmanned Aerial Vehicle (UAV). This vehicle is an aircraft without a human pilot on-board and is usually controlled either autonomously by on-board computers or by a remote control of a pilot on somewhere else. Nowadays, there is a UAV that is quite popular and on demand which is the Quadrotor. It can be controlled either using an electronic control system or electronic sensor to stabilize the prototype from being crashed onto any obstacles which enables the Quadrotor to fly in indoor or outdoor places.

1.2 Motivation and Significance of Research

The terrorist intrusion in Lahad Datu, Sabah which is happened on 12 February 2013 has caused a big worrisome of Malaysian on their safety. The solution for this case is that the Eastern Sabah Security Command (ESSCOM) was established by the Department of Prime Minister. This department is a security enforcement agency whereby the Eastern Sabah Security Zone (ESSZONE) kept under surveillance of them in order to strengthen the protection and security in the east cost of the state. This ESSZONE covers 10 districts with a distance of 1733.7 km of the east coast of Sabah namely, Tawau, Semporna, Kunak, Lahad Datu, Kinabatangan, Sandakan, Pitas, BCS, Kota Marudu and Kudat.

Although the Police Headquarters has given order to strengthen their surveillance on the respective areas, they cannot be as efficient as expected due to human behaviours such as limited eyesight vision for the surveillance job. This is the limitation in surveillance techniques as it should cover wide area of east coast of Sabah [3].

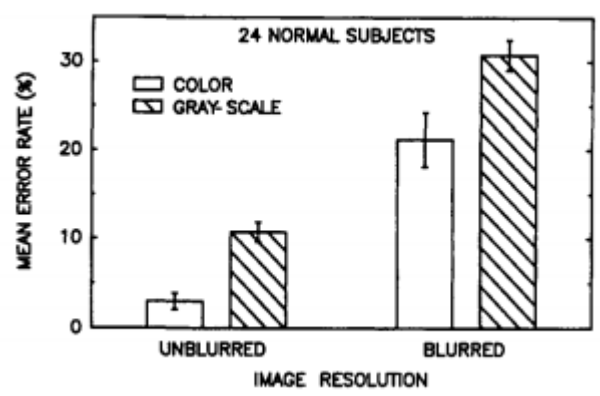

Figure 1.2: Percentage of images incorrectly identified for four stimulus conditions with standard error bars [3].

The Figure 1.2 shows the limitation of the vision of humans for four stimulus conditions that able to be relate to the surveillance on the east coast of Sabah. Since there is limitation of the vision of humans, this indicates the weakness of the current surveillance techniques.

1.3 Problem Statement

Based on the motivation, flying vehicle is proposed in order to overcome the limitation faced. Normally, flying vehicle used is the helicopter but there are limitations of the usage of the helicopter. The helicopter requires mechanical linkages to differ the rotor blade pitch angle as they rotates. The propeller of the helicopter is large in diameter which increases the work load for each rotor and experiences more stress. Due to the limitations of the helicopter, Quadrotor is proposed to overcome the limitations faced by the helicopter and the limitation in surveillance technique. The Quadrotor is a highly nonlinear system where the system does not produce an output that is not directly proportional to the given input. In other words, it contains a system that requires a crucial modelling so that it can controlled robustly. The problem faced when developing a plant which is finding a suitable state space representation that suits the system of the Quadrotor. Many variables of the Quadrotor such as the configuration of the Quadrotor should be taken into account on developing the mathematical modelling. For example, the configuration of the Quadrotor is the configuration of the body frame, the desired movement of the Quadrotor, the size of every each rotor, the overall weight of the Quadrotor and other variables. Besides, there some of the variables that are unable to be calculated easily. In fact, developing a mathematical modelling is important as the performance of the controller to be developed depends on how well is the mathematical model being developed. Furthermore, there are problems with the IMU such as the accelerometers and the gyroscopes. The accelerometer measures all forces that are working on the object. It also measures a lot more than just measuring the gravity vector. Any small vibration acting on the object will disturb the measurement completely. On the other hand, the gyroscopes has the measurement that has high tendency to drift which does not return to zero when the system is back to its original position. Thus, the more variables of the Quadrotor are taken into account, it is expected to produce a better and efficient transfer function that represents the modelling of the prototype [1].

1.4 Objective

This objectives of this research are:-

1.4.1 To computationally model the Quadrotor system using SimMechanics Toolbox and Solidworks.

1.4.2 To physically model the Quadrotor system using physical realisation experiments.

1.4.3 To analyse the performance of modelling of Quadrotor in terms of steady state error.

1.5 Scope

The scopes of this research are:-

- The testbed of this Quadrotor is developed by previous student, Ahmad Mahadi bin Razali.
- Newton-Euler formulation is used to derive the mathematical modelling of the Quadrotor system.
- The MATLAB Simulink environment is used to develop the modelling using functional blocks and it is developed using SimMechanics and Simulink functional blocks only but not using blocks from other toolboxes.
- The development of the modelling of the Quadrotor will be assumed to be at closed and indoor area which is in the laboratory whereby the weather of the surrounding will be ignored.
- The physical realisation experiments conducted consist of four experiments only which are the physical measurement, force-lift and speed test, and bifilar pendulum experiment.
- The analysis of performance of modelling of Quadrotor system is tested for the steady state error only. The transient response is not tested in this research.

1.6 Report Outline

This project report consists of five main chapters excluding the references part. It begins with introduction, followed by literature review, then research methodology, and preliminary result and lastly the conclusion for the overall project.

In Chapter 1, the introduction starts with the research background which includes the motivation and the significance of the project, the problem statement to be solved during this project, the objectives of doing this project and the expected project outcome. The first part is the explanation of what is the title of the project and the understanding of the hardware. This part is need to blend in together with the motivation and the significance of the research. For the next part, the problem statement is the part where problems occurred will be stated out and some expected methodology to solve the problem which also includes some of the expected result. The objectives is to state out what should be done throughout the whole project. Finally is the expected project outcome which is also known as the expected result for this project.

In chapter 2, the literature review is divided into three parts which is the theory and basic principles, the review of the previous related works and ended up with the summary and discussion of the whole review. The first part is the understanding and the explanation of the used theories and basic principles throughout the project. It is followed by the review of the previous related works whereby this part is to review back some journals which is related to the project title and give some summary on the journals. Lastly, the summary part is to conclude and compare all the reviewed journals and come out with a final conclusion.

In Chapter 3, the research methodology consists of four parts which is the principles of the methods or the techniques used in the previous work, some detailed discussion on the selected techniques and approach used such as the analytical or modelling and simulation, description of the work to be simulated. The first part is for discussion and analysing the principles of the techniques or methods used in the previous related works such as journals. Then, it is followed by some detailed discussion on the chosen techniques by using either analytical which is the statistics or by using modelling and simulation. Next, some of the set-

up of the experiment and data collection will be determined. Finally, project Gantt chart and key milestones are developed for making sure the path of this final year project is correct.

In Chapter 4, the preliminary results has two equally important subtopics which is the project achievement and the future work planning for the upcoming Final Year Project 2 (PSM2). This chapter started with the explanation on the achievement of the project itself by highlighting the initial results which have been achieved this far either can be the data collection, simulations of modelling and some simple analytical analysis on the performance.

Lastly, the last main chapter which is the overall conclusion for this final year project. This part is to conclude every each chapter previously on what has been done. Besides that, this chapter should also include some of every subtopics that have been discussed in details and clear.

CHAPTER 2

LITERATURE REVIEW

This part discusses the published information regarding the Quadrotor within a certain time period. It is just a simple summary of the sources related to the title. This part of report covers the explanations about the theories and the basic principles. Besides, this part also includes the review of previous related works which give a new ideas that is taken from a few different journals. This part is concluded up with the summary of the overall literature review and also the discussion of the review and the choice of the subsections to be used throughout this final year project.

2.1 Theories and Basic Principles

In this part of the theory and basic principles, the theory of Newton-Euler formulation is being discussed in details together with an example for a better understanding. Besides, the principle of the SimMechanics is briefly highlighting its usage and functions of every each functional block which is available in MATLAB Simulink environment.

2.1.1 Newton-Euler formulation method

This Newton-Euler formulation method is used to obtain a linear, angular accelerations and velocities for each link, free-body diagrams and Euler equations and Newton's Law. The motion of a rigid body can be disintegrated into translational motion with relative to an arbitrary point which is fixed to the respective rigid body and the same goes to the rotational motion is relative about that point.

According to Mark D. Ardema [5], the dynamic equation is represented with two equations where one describes the translational motion of the centroid, which can be said as the centre of mass, and the other one describes the rotational motion about the centroid. The author added that Newton-Euler method uses the propagation formulas for position or orientation of links and it consists outward iterations for velocities and accelerations.

Newton-Euler algorithm has computational complexity which means there are no any iteration or loops, the computation of the sets of equations are performed only once and the number of additions and multiplications is proportional to the number of links. It can be adapted for any serial manipulators with prismatic (P), rotary (R), or any other joints such as spherical and gimbal joints. Used for symbolic computation of equations of motion of a hardware. Typically, this method is used in development of robotics.

Based on Jerry Ginsberg [6], Newton-Euler method is the balance of forces or torques where its equations are written separately for each body. It represents the inverse dynamics in the real time where it is the best for synthesising of a model-based control schemes while the equations are assessed in recursive and numeric way. The closed-form dynamic equations which is identical to the Euler-Lagrange method can be done by eliminating the reaction force and the back-substitution of expressions.

2.1.2 SimMechanics

SimMechanics is a toolbox of Simulink environment which is used to model and simulate multi-body mechanical systems especially for 3D mechanical systems such as unmanned aerial vehicle, robots and many more. In this toolbox, model of the multi-body system can be developed easily using blocks to represents the bodies, joints, constraints and force elements. This toolbox will then formulates and solves the equation of motion for the developed mechanical model. Models from the CAD systems can be imported into SimMechanics including the mass, inertia, joint, constraint and 3D geometry of the models of CAD systems. The previous step can be done by using the add-on by using SimMechanics Link on the Solidwork software. 3D animation of the system dynamics will be automatically generated. The models can be parameterized using MATLAB variables and expressions. The