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LAPORAN PROJEK SARJANA MUDA

MODELING OF A SMALL SCALE UAV QUADROTOR SYSTEM

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MAY 2014

I hereby declare that I have read through this report entitle “Modeling of a Small Scale UAV 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: ....

MODELING OF A SMALL SCALE UAV QUADROTOR SYSTEM

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

YEAR 2014

I declare that this report entitle “Modeling of a Small Scale UAV 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: ....

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ABSTRACT

Quadrotor is a flying robot that is highly nonlinear, multi variable and strongly coupled because it has 6 Degree Of Freedom of the system translational and rotational motions, which are $x, y, z, \phi, \theta, \psi$ with only four inputs from rotors. The inspection work at the gas, petroleum and specialty chemical plant side is very risky due to the height of chimneys. Currently the industries is using real helicopter to perform the inspection work, this method is high cost and require the plant side to shut down for a period of time which will cause lost to the company. To overcome this problem, quadrotor system is proposed and workers will able to collect information from more angles from high position more easily. The objective of this research is to derive and validates the mathematical modeling for autonomous quadrotor system. Based on the findings of other researcher, there are different types of derivation method for mathematical modeling and several tests need to be carried out to identify unknown parameter. The modeling is derived using Newtonian method, and several tests are conducted such as thrust factor and drag factor. The complementary filter is implemented in the on-board system of quadrotor to obtain more accurate reading from the sensors. In order to validate the modeling of quadrotor system, simulation test for the open loop system is performed using the Matlab Simulink. Then, real time implementation test is carried out as well. The data is recorded. The response of axes x, y, z, roll, pitch and yaw from an open loop system during real time implementation is recorded. Based on the analysis of the performance, the simulation generate similar pattern of signal as in real time.

ABSTRAK

Quadrotor adalah sebuah robot terbang yang *nonlinear*, pembolehubah berbilang dan kuat ditambah pula kerana ia mempunyai 6 darjah kebebasan, tetapi hanya ada empat *input* daripada rotor. Kerja-kerja pemeriksaan di cerobong-cerobong dalam kawasan kilang gas, petroleum dan loji kimia khusus adalah sangat berisiko kerana ketinggian cerobong sekurange-kurangnya 3 meter ke atas. Buat masa ini industri menggunakan helikopter sebenar untuk melaksanakan kerja pemeriksaan, kaedah ini melibatkan kos yang tinggi dan memerlukan kilang tersebut menghentikan operasi selama suatu tempoh masa yang akan menyebabkan syarikat tersebut mengalami kerugian. Untuk mengatasi masalah ini, quadrotor sistem adalah dicadangkan supaya pekerja akan dapat mengumpul maklumat dari lebih sudut dan kedudukan yang tinggi dengan lebih mudah. Objektif kajian ini adalah untuk mendapatkan dan mengesahkan model matematik bagi sistem quadrotor. Berdasarkan dapatan kajian penyelidik yang lain, terdapat berlainan jenis kaedah asal untuk pemodelan methamatikal dan beberapa ujian perlu dijalankan untuk mengenal pasti parameter yang tidak diketahui. Pemodelan dalam kajian menggunakan kaedah *Newton- Euler*, beberapa ujian dijalankan seperti faktor teras dan faktor seretan. Penapis pelengkap dilaksanakan di atas sistem quadrotor untuk mendapatkan bacaan yang lebih tepat dari sensor. Bagi mengesahkan pemodelan sistem quadrotor, ujian simulasi untuk sistem gelung terbuka dilakukan menggunakan Matlab Simulink. Kemudian, ujian pelaksanaan masa sebenar dijalankan juga dan data direkodkan. Hasil paksi *x, y, z, roll, pitch* dan *yaw* dari sistem gelung terbuka semasa pelaksanaan masa sebenar direkodkan. Berdasarkan analisis prestasi, simulasi menjana corak yang sama isyarat seperti dalam masa nyata.

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LIST OF ABBREVIATIONS

UAV	Unmanned Aerial Vehicle
VTOL	Vertical Take-off and Landing
IMU	Inertial Measurement Unit
DOF	Degree of Freedom
RRT	Rapidly-exploring Random Tree
GPS	Global Positioning Device
DGPS	Differential Global Positioning Device
OEM	Original Equipment Manufacturer
UART	Universal Asynchronous Receiver/ Transmitter
PIC	Peripheral Interface Controller
PID	Proportional Integral Derivative
COTS	Commercial Off the Shelf
FOV	Field of View
Gyro	Gyroscope
UKF	Unscented Kalman Filter
PI	Proportional Integral
PD	Proportional Derivative
ESC	Electronic Speed Controller

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CHAPTER 1

INTRODUCTION

Recently unmanned aerial vehicles (UAV's) have attracted considerable interest for a wide variety of different applications. Quadrotor is a certain kind of UAV. It is considered to be more preferable for surveillance, precise delivery and some other missions requiring agility and accuracy. It is a flying robot that is highly nonlinear due to it has 6-DOF with only four inputs. Compared to fixed-wing airplanes, quadrotor has several advantages such as it can easily move in any direction, able to hover, fly in low speeds, allows disposition in almost any ground, simple construction with made up of a light frame, four motors, speed controllers, batteries, a control board and/or a receiver. [1] [2]

1.1 History

In 1907, the Breguet Brothers built their first human carrying helicopter–they called it the Breguet-Richet Gyroplane No. 1, which is a quadrotor. The issue of stability is a consideration in the design, but the first requirement for the machine is simply to lift itself and a pilot off the ground under its own power. However, there is no means of control provided to the pilot other than a throttle for the engine to change the rotor speed, and the stability of the machine is found to be very poor. [3]

In year 1922, Etienne Oehmechen developed his quadrotor named as Oehmichen No.2 with six full-scale rotary-winged vehicles. The attitude and orientation of craft could not be control as only a single 120HP engine is used to power up all four rotor. four propellers are added to each rotor in order to change the speed of individual rotor and control the craft's attitude and orientation.

The prototype of quadrotor design by Marc Adam Kaplan in year 1956, Convertawings Model "A" quadrotor is the most successful rotorcraft early design as it is power up and control by varying thrust between rotors. It featured wings for additional lift in forward flight. This craft able to hover and maneuver using its two 90HP motors, each capable of driving all four rotors in backup mode. It is the first successful quadrotor that able to fly forward. [4] [5]

Quadrotor design is not competitive as the conventional aircraft performance specification in term of speed, range, payload and others at early stage. However, in recent decades, this design idea shows its great potential after the Stanford Testbed of Autonomous Rotorcraft for Multi Agent Control (STARMAC) project at Stanford University performed some of the initial work on making small-scale quadrotors autonomous. [4] [5]

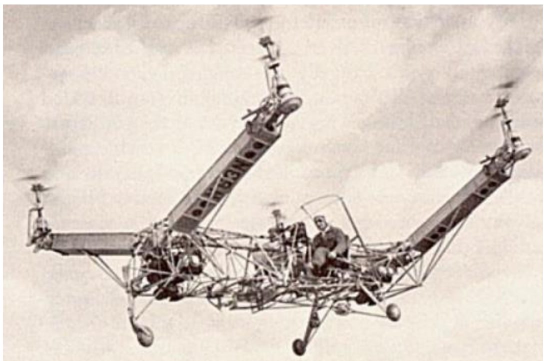

Figure 1.1: Convertawings Model A quad-rotor Design, 1956 [5]

1.2 Movement of Quadrotor

The frame structure of quadrotor is built in a cross intersection way, forming two diagonal square shapes and attached on a fixed body. Each end of the square has an individual rotor that is driven by a motor. The two rotors that in same diagonal will rotate in same direction, which means motor pair (1,3) rotates clockwise and the other pair (2,4) rotates counter-clockwise in order to balance the moments. The altitude and orientation of a quadrotor is affected by changing the speed of each rotor. Figure 1.2 shows the full throttle movement of quadrotor system.

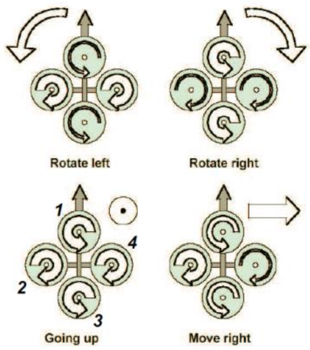

Figure 1.2: Full throttle movement of quadrotor [6]

When the motor's speed and motion is changed, quadrotor will generate 6-DOF movement. The changes in motion include translational motion along three coordinate axis (x,y and z) and rotational motion around three axis (roll, pitch and yaw). The vertical motion of z-axis in quadrotor is accomplished by increasing or decreasing speed of four motors at the same time and same amount. When the total of thrust of the quadrotor is same as its weight, it will become hoverable. The pitch angle is changed by a difference in thrust between the front and the back rotors to maintain the total thrust of the system, while the change of roll angle is a result from differences between the left and right rotor. Yaw rotation can achieved by the difference in the Counter-torque between each pair (1, 3 and 2, 4) of rotors, the total thrust remain unchanged to avoid the up-down motion. [6] [7]

1.3 Problem Statement

At the gas, petroleum and specialty chemical plant side, there are many chimneys used as ventilation structure to discharge the hot flue gases or smoke from a boiler, stove, furnace or fireplace in the factory to the outside atmosphere. The height of those chimneys are very tall, generally it should not less than 3 meters plus the building height. It is too risky to lift the worker with crane or fly them with helicopter to the top of chimney for every inspection work.

In last decades, one of the solutions to perform the inspection work is by using real helicopter. There are still limitation as the height of chimneys are very tall, the view is not clear for the person controlling the helicopter to continue monitor the direction of the helicopter when it reach certain level. Besides, issue of human component like capability has to be considered. [8] [9]

As a solution, quadrotor is proposed to overcome this problem. The mathematical modeling for quadrotor system is derived for developing the quadrotor system to work autonomously. With the development of on-board system of quadrotor and system estimation through implementation of filters, the system would able to get a more accurate state estimation and these can be features in quadrotor to vertical take-off and landing with hovering autonomously. By implementing a VTOL system into a quadrotor, it will become more functional for small area inspection purpose. The specialties of quadrotor are it can hover and control precisely, the design are more simple compare to the helicopter with mechanical linkage. This system will make the inspection work at plant side easier and also reduce the cost of renting the helicopter. The plant side maintenance team will able to collect information from more angles from high position.

1.4 Research Motivation

The purpose of this research is to model the quadrotor system. Nowadays, quadrotor is been widely used in many sector as it is a better choice compare to remotely-controlled helicopter. The inspection on the chimney is very dangerous due to the high temperature. From The energy newspaper, March 2013, Gary Livingstone, senior mechanical integrity engineer, said: “This was much harder because the flare tip – used to burn off waste gas – is in constant use. So usually the only way to inspect it manually is during a shutdown.” [10]

On the other side, the inspection environment is also being an issue for the workers. The bad weather will affect their vision and inspection works have to stop immediately to encounter the safety of worker. Malcolm Connolly, company founder and technical director, said: “The biggest challenges when working offshore are weather and working in a dangerous environment. We planned four days for this inspection but it took six, despite being able to continue when even a full-sized helicopter couldn’t get out to the platform because of bad weather.” [10]

Thus, it is stated that inspection work would cause an amount of lost to the company due to the entire shutdown. Besides that, inspection through the small scale quadrotor system can be carried out frequently compared to helicopter as the issues for example the cost of renting, impact of shutdown the entire station has to be considered.

1.5 Objective

The objectives of this research are:

1. To derive the mathematical modeling of quadrotor system through Newtonian derivation.
2. To perform system estimation through the implementation of complementary filter.
3. To validate the modeling of quadrotor via simulation and real time implementation and comparison on the signals generated.

1.6 Scope

This research is limited to several scopes:

1. The testbed used in this research is assembled and calibrated by Ahmad Mahadi bin Razali, who are working on another research topic, "Design and Development of a Small Scale UAV Quadcopter".
2. Control design for quadrotor system does not included in this research. The flight test is performed under an open-loop system.
3. The real time implementation testing is done under indoor environment; the testbed is tied with rope for safety purpose during testing.
4. Arduino board is used in this research for retrieve the result from sensor reading and to perform open loop test.

1.7 Report Outline

This report begins with Chapter 1, the introduction of this research, history background of quadrotor system, the construction and the movement of quadrotor, the problem faced by inspection work on plant side, the motivation of carry out this research, lastly the objective and scope of this research.

In Chapter 2, literature review on the quadrotor system is done and separated into several subtopics, which are the method used to derive the mathematical modeling of the system, sensors that other researcher used at the on-board system and its functions, type of filter used for system estimation.

Methodology to carry out the research in Chapter 3, it is divided into several part, which are the mathematical modeling of the quadrotor system, experiment procedure to carry out several tests to identify unknown parameter, includes speed test, force-lift test and bifilar pendulum test; implementation of filter for system estimation, design procedure for Mitlab Simulink block diagram for simulation test, open loop test and data analysis.

All the results and discussion comes under Chapter 4, the derivation of the mathematical modeling, includes the rotational matrix, force and torque equation, the kinematic movement of quadrotor, thrust force of all rotors, moment of inertia calculation, differential equation and finally state-space equation. To determine all the unknown parameters, physical measurement on quadrotor is carried out, speed test, force-lift test and bifilar pendulum test as well. Besides that, the estimated data from complementary filter result for open loop test from Matlab simulation and real time implementation is recorded and discussed. Lastly Chapter 5 will conclude this research and some recommendation are made.

Appendix includes Gantt chart of this research, the coding for single rotor to operate in speed test and force-lift test, coding for complementary filter implementation, the results of simulation and real time open loop test.

CHAPTER 2

LITERATURE REVIEW

The literature review is conducted to determine the information of quadrotor system overview that done by other researchers. The topics included in this chapter are method of mathematical modeling of quadrotor, implementation of filter for system estimation and sensors used at on-board system and its function.

2.1 Mathematical Modeling

Hui Bai *et al.* [11] presents a quadrotor platform and applies a path planning method for multi-UAVs. The path planning method implement in this platform is Rapidly-exploring Random Tree (RRT) method, which is to find a path to travel from a starting position to a goal position through a configuration space. The algorithm developed using the RRT Method was implemented in C language tested on an ARM9 platform run under embedded Linux system for real-time implementation.

The avionic system by Mustafa Ilarslan *et al.* [12] implements the non-linear control algorithms to have a degree of autonomous control. The integrated modular avionic architecture will enable the rapid realization and testing of these algorithms.