DYNAMIC MODELLING AND SWING CONTROL OF A QUADROTOR WITH A CABLE-SUSPENDED PAYLOAD

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechatronics and Automatic Control)

School of Electrical Engineering
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16 FEBRUARY 2021

DEDICATION

This thesis is dedicated to my father and mother who have been very supportive in ensuring that I come this far and continually encouraging me to aspire for more. It is also dedicated to all my siblings who were always there to encourage me when the going got tough and supported me through-out.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts. In particular, I wish to express my sincere appreciation to my main thesis supervisor, Professor Dr. Zaharuddin B Mohamed, for encouragement, guidance, critics and friendship, without whose continuous support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknologi Malaysia (UTM) for providing me with a conducive learning environment and the necessary facilities to successfully complete my work.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

ABSTRACT

A quadrotor is a highly nonlinear system due to the presence of aerodynamic factors such as Coriolis and gyroscopic effects when in flight. In meeting todays' demands, the applications of quadrotors have been extended to include transportation and therefore, the study of Quadrotor Suspended Load (QSL) systems has become equally as important. However, the presence of the suspended load further complicates the quadrotor system as there is strong coupling with the load and excessive load swinging. This is a problem which forms the basis for this work. This project begins by providing a mathematical description of the QSL system using Euler-Lagrange equations as they are much simplified, yet encompass the many factors present during quadrotor operation and subsequently control excessive payload swinging. The main strength of this work is that unlike other previous work, it covers 8 degrees of freedom (8 DOF) in representing the system dynamics. This presents a much more comprehensive and definitive way of describing the quadrotor and payload positions. Input shaping is used as the swing controller as it is more practical and has been used for swing control of other systems. Validation of the swing controller performance is done using MATLAB SIMULINK. Unlike other controllers that require sophisticated algorithms for their implementation, input shaping will be used as a swing controller as it is much simplified in handling excessive load swinging.

ABSTRAK

Quadrotor adalah sistem yang sangat nonlinier kerana adanya faktor aerodinamik seperti Coriolis dan kesan giroskopik ketika dalam penerbangan. Dalam memenuhi tuntutan hari ini, aplikasi quadrotor telah diperluas untuk mencakup pengangkutan dan oleh itu, kajian sistem Quadrotor Suspended Load (QSL) telah menjadi sama pentingnya. Walau bagaimanapun, kehadiran beban yang digantung lebih merumitkan sistem quadrotor kerana terdapat gandingan yang kuat dengan beban dan beban berayun yang berlebihan - masalah yang menjadi asas bagi kerja ini. Projek ini dimulakan dengan memberikan penerangan matematik sistem QSL menggunakan persamaan Euler-Lagrange kerana banyak disederhanakan, tetapi merangkumi banyak faktor yang terdapat semasa operasi quadrotor, setelah itu pengawal dirancang untuk mengawal ayunan muatan. Kekuatan utama karya ini adalah tidak seperti karya sebelumnya yang lain, ia merangkumi 8 darjah kebebasan (8 DOF) dalam mewakili dinamika sistem. Ini menunjukkan cara yang lebih komprehensif dan pasti untuk menerangkan kedudukan quadrotor dan muatan. Pembentukan input digunakan sebagai swing controller kerana lebih praktikal dan telah digunakan untuk swing swing sistem lain. Pengesahan prestasi swing swing dilakukan dengan menggunakan MATLAB SIMULINK. Tidak seperti pengawal lain yang memerlukan algoritma yang canggih untuk pelaksanaannya, diharapkan pembentuk input akan menjadi pengawal yang jauh lebih mudah dalam menangani ayunan beban yang berlebihan.

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LIST OF ABBREVIATIONS

AIAA	-	American Institute of Aeronautics and Astronautics
DOF	-	Degrees of Freedom
FL	-	Fuzzy Logic
iLQR	-	iterative Linear Quadratic Regulator
IDA-PBC	-	Interconnection and Damping Assignment Passivity Based Control
LQR	-	Linear Quadratic Regulator
MBPC	-	Model Based Predictive Control
MEMS	-	Micro Electromechanical Systems
NN	-	Neural Network
PID	-	Proportional-Integral-Derivative
QSL	-	Quadrotor Suspended Load
RL	-	Reinforcement Learning
STARMAC	-	Stanford Testbed for Autonomous Rotorcraft for Multi-Agent Control
SMC	-	Sliding Mode Control
T-S	-	Takagi-Sugeno
UAV	-	Unmanned Aerial Vehicle
ZV	-	Zero Vibration
ZVD	-	Zero Vibration and Derivative
ZVDD	-	Zero Vibration and double Derivative

CHAPTER 1

INTRODUCTION

1.1 Background

Over the past few years, Unmanned Aerial Vehicles (UAVs) have gained so much popularity mainly due to the nature of their simplicity and ease of manoeuvrability. UAVs have found several applications in rescue operations, surveillance, robotics, image and data acquisition, etc. [1]. Due to these wide range of applications, UAVs have drawn so much attention from several scholars around the globe as they are all trying to find better and innovative ways of being able to control, analyse and understand these UAVs in the best possible way [2]. Quadrotors are one such example and have enabled previously impossible tasks to now become a reality [3] as they are now able to perform tasks that would otherwise be too risky for human beings or impossible for human beings to perform due to remoteness of the area, risk factors, just to name a few.

A quadrotor consists of four rotors propelled by motors, control board and power source. By rotating, the four rotors generate a downwards thrust that in turn causes the UAV to be lifted upwards [4]. Manoeuvrability of the quadrotor is achieved by varying the motor speeds to each of the four rotors while the control board is responsible for all control actions and synchronisation of all components. Quadrotors are now being commonly used for rescue transportation and by extension, the study of Quadrotor Suspended Load (QSL) systems is just as important. However, the main challenge posed by QSL systems is excessive load swinging as it is undesirable.

In an effort to reduce this undesirable load swinging, several control methods such as Linear Quadratic Regulation (LQR), iterative LQR (iLQR), Interconnection and Damping Assignment Passivity-Based Control (IDA-PBC), have been proposed.

1.2 Problem Statement

Control and dynamic modelling of higher order and nonlinear systems continues to be a huge engineering challenge. A quadrotor is one such system as there are several aerodynamic properties at play during its operation.

When coupled with a suspended load, it becomes even much more complicated because it has higher degrees of freedom. Additionally, it has strong coupling with the payload and has significant payload oscillation.

1.3 Research Objectives

The objectives of the research are:

(a) To obtain an accurate non-linear mathematical description of the quadrotor with a cable suspended payload.

(b) To simulate the obtained mathematical model and to analyse their dynamic characteristics.

(c) To control the payload swing angle using input shaping control as a swing controller

1.4 Scope of the Work

This work is limited to the following factors:

(a) To obtain an accurate non-linear mathematical description of the quadrotor with a cable suspended payload

(b) To simulate the obtained mathematical model and to analyse their dynamic characteristics by using MATLAB/Simulink

(c) To control the payload swing angle using input shaping control as a swing controller.

(d) A QSL system with 8 DOF is considered.

1.5 Organization of this Report

The subsequent chapters are organized as follows; Chapter 2 reviews relevant literature in the field of QSL systems as well as some controllers that have been used. Chapter 3 then discusses the methodology used in achieving the project objectives and is followed by chapter 4 which discusses the mathematical modelling and simulation setup. Chapter 5 presents the results and lastly chapter 6 concludes the project and outlines the recommendations for future work.

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