SIMULATION FOR HELICOPTER CONTROL SYSTEM USING LQR CONTROLLER

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UNIVERSTI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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Author : EN MOHD SHAKIR B. MD SAAT

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For you, my mom and dad

For your truly support and undivided love

For making me the person

Who I am today…

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ABSTRACT

This project will present detailed procedure on how to construct a basic mathematical model that represents general longitudinal helicopter flight dynamics. The establishment of global helicopter linear model is very precious and useful for the design of the linear control laws, since it is never afforded in the published literatures. In the first principle approach, the mathematical model was developed using basic helicopter theory accounting for particular characteristic of the miniature helicopter. The system presents a step by step development of linear model for small scale helicopter based on first-principle approach. The procedure will start from linearizing the translational and rotational dynamics and rotational kinematics equations of motion using the small perturbation theory. There are certain assumptions made for the sake of simplifications. The next step is to construct the fundamental linearized form for describing the stability and response of a small motion of a helicopter around a trim condition. Beyond the previous work, the calculation of the stability derivatives is presented in detail. A computer program is used to solve the equilibrium conditions and then calculate the change in aerodynamics forces and torque due to the change in each degree of freedom and control input. The detail derivation allows the comprehensive analysis of relative dominance of helicopter states and input variables to force and torque components. Hence it facilitates the development of minimum complexity small scale helicopter dynamics model.

ABSTRAK

Projek ini akan menjelaskan dengan terperinci langkah-langkah bagaimana untuk membina sebuah model asas matematik yang mewakili satah umum yang membujur untuk penerbangan helikopter yang dinamik. Penubuhan global model helikopter 'linear' sangat berharga dan berguna dalam reka bentuk undang-undang kawalan 'linear' sejak ia tidak mampu dibuktikan. Berdasarkan prinsip pertama, model matematik adalah dibangunkan dengan menggunakan teori asas helikopter yang dikira untuk ciri-ciri khusus helikopter miniatur. Sistem menunjukkan satu perkembangan selangkah demi selangkah model 'linear' untuk helikopter berskala kecil berdasarkan prinsip pertama. Langkah tersebut dimulakan dari persamaan peralihan gerakan 'linear', putaran gerakan dinamik dan putaran gerakan kinematik dengan menggunakan teori gangguan yang kecil. Terdapat andaian-andaian yang digunakan demi memudahkan proses pengiraan. Langkah seterusnya adalah untuk membina dasar 'linear' yang dibentuk untuk menggambarkan kestabilan dan tindakbalas satu pergerakan yang kecil sebuah helikopter pada satu keadaan yang teratur. Berdasarkan kerja-kerja terdahulu, pengiraan untuk kestabilan dilakukan dengan terperinci. Satu program komputer digunakan untuk menyelesaikan keadaan keseimbangan dan kemudian mengira perubahan dalam daya aerodinamik dan 'torque' disebabkan oleh perubahan dalam setiap darjah kebebasan dan masukan kawalan. Ketelitian membuatkan analisis menyeluruh berhubungkait dengan status helikopter dan pembolehubah masukan kepada komponen daya dan 'torque'. Oleh yang demikian ia memudahkan pembangunan yang rumit pada tahap minima untuk model berskala kecil helikopter dinamik.

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LIST OF ABBREVIATION

SISO	-	Single Input Single Output
MIMO	-	Multi Input Multi Output
PID	-	Proportional-Integral-Derivative
PD	-	Proportional-Derivative
LQR	-	Linear Quadratic Regulator
DOF	-	Degree of Freedom
M_a	-	Mass of helicopter (kg)
X,Y,Z	-	External aerodynamic forces in x,y,z body axes (N)
P,Q,R	-	Angular velocity around x,y,z body axes (rad)
L,M,N	-	External aerodynamic moment in x,y,z axes (Nm)
θ_0	-	Main rotor collective pitch angle (rad)
θ_{0T}	-	Tail rotor collective pitch angle (rad)
θ_{LS}	-	Longitudinal cyclic pitch (rad)
θ_{LC}	-	Lateral cyclic pitch (rad)
u,v,w	-	Translational velocity component of helicopter along fuselage (m/s)
p,q,r	-	Angular velocity component of helicopter (rad/s)
θ,ϕ,ψ	-	Euler angles defining the orientation of the aircraft relative to the Earth (rad)
Ω_a	-	Mass rotor angular velocity (rad/s)
UAV	-	Unmanned Aerial Vehicle
VR	-	Virtual Reality

LIST OF APPENDIXES

CHAPTER 1

INTRODUCTION

The first successful flight of an airplane on December 17, 1903 by the Wright brothers and the advent of the helicopter on November 13, 1907 by Paul Cornu (Helicopter History Site), man began exploring the skies. Both of these craft offer extraordinary ways to soar through the skies, yet each has its own limitations. While, the airplane can fly up to 120,000 feet and can do so flying three times faster than the speed of sound. It needs a runway about a mile long to take off and land and must maintain a forward velocity to produce lift. While the helicopter can take off without and runway and can remain stationary in a hover, it cannot fly much faster than 400 miles per hour and cannot fly much higher than 30,000 feet but can reach to the difficult area that airplane can reach. The helicopter was known to be inherently unstable, complicated and nonlinear dynamics under the significant influence of disturbances and parameter perturbations. The system has to be stabilized by using a feedback controller. The stabilizing controller may be designed by the model-based mathematical approach or by heuristic control algorithms. Due to the complexity of the helicopter dynamics, there have been efforts to apply non-model-based approaches such as fuzzy-logic control, neural network control, or linear quadratic regulator (LQR) controller [1].

1.1 OBJECTIVES

The objectives for this project are:

i. To develop the mathematical model of this system.
ii. To understand each of DRA Puma helicopter parameter that can be implant to helicopter model.
iii. To understand and calculate the EoM (equation of movement) in helicopter model and apply the EoM in state-space representation.
iv. To design the upward flight and forward flight control then design the stable control system for this model using LQR.
v. To demonstrate design and analysis techniques by using MATLAB software through graph and animation of the system.

1.2 PROBLEM STATEMENT

The control for a small scale helicopter has been designed using various methods. During the period of 1990s, the classical control systems such as single-input-single-output SISO proportional-derivative (PD) feedback control systems have been used extensively. Their controller parameters were usually tuned empirically [4]. This trial-and error approach to design an "acceptable" control system however is not agreeable with complex multi-input multi-output MIMO systems with sophisticated performance criteria. For more advanced multivariable controller synthesis approaches, an accurate model of the dynamics is required. To control a model helicopter as a complex MIMO system, an approach that can synthesize a control algorithm to make the helicopter meet performance criteria while satisfying some physical constraints is required. More recent development in this area include the use of optimal control (Linear Quadratic Regulator) implemented on a helicopter.

1.3 SCOPE OF PROJECT

The scope of this project involve of:

i. Develop the mathematical model of hybrid control system.
ii. Design upward flight and forward flight control system in simulation.
iii. Apply the LQR controller to stabilize the system.
iv. Produce the performance through graph by using MATLAB software.

1.4 PROJECT METHODOLOGY

Methodology is important part of the whole project because it shows out how the project's activity develops. For this project, there are some procedures and methods which be used to produce a set of simulation system of linear helicopter. The detail explanations about the methodology are discussed in Chapter III. The project workflow is shown in Figure 1.1

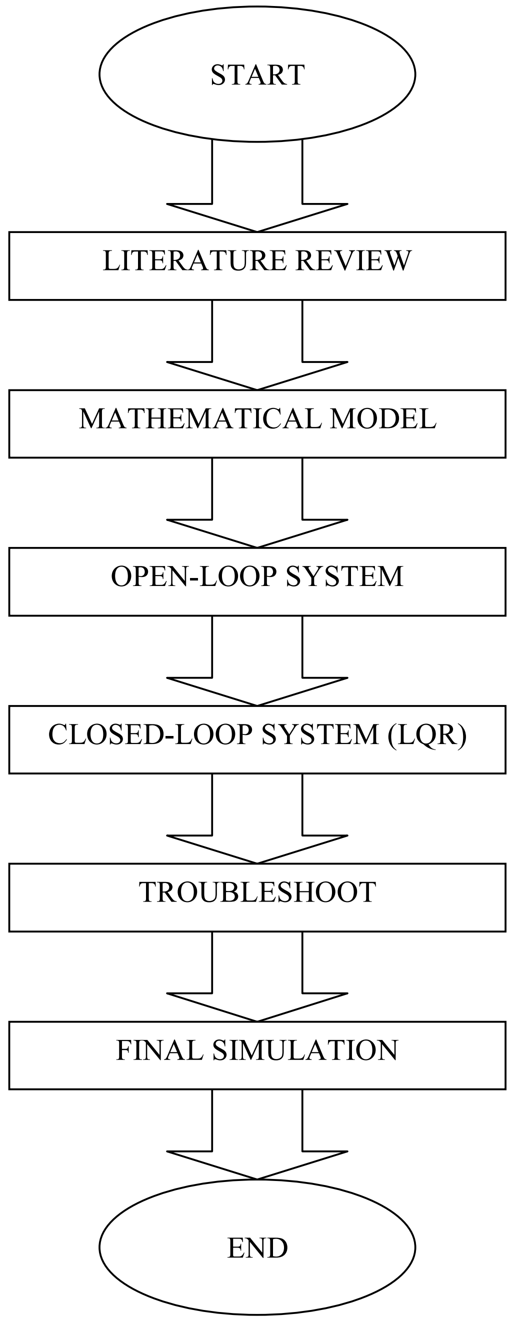

Figure 1.1 Project Workflow

1.6 REPORT ORGANIZATION

This report contains eight chapters that will be explaining the detail of this project. First six chapters are introduction, literature review, project methodology, mathematical model, LQR controller and virtual reality toolbox will briefly cover the main operation and understanding of the project. Seventh and the eighth chapter are on result and discussion that show finalize result that been achieved by the simulation in MATLAB. The observation and analysis will be describe detail to show the capability of the system performance.

The first chapter is about the introduction of the project. This chapter covers about the overview of this project, project objective, project problem statement, project scope and the project methodology.

The second chapter is about the literature review of the project. The literature reviews includes some research about the theory of controlling the real helicopter and remote control helicopter (RC). This chapter also explains about the sensors that use in the helicopter. Plus this chapter give information about atmosphere and standard air data measurement.

The third chapter is about the project methodology. In this chapter the explanation of the step of the project will be clarify. The general concepts will be shown and explain in detail. The process of the project is drawn in the flowchart of the project. All the process is elaborate completely in this chapter.

The fourth chapter mainly focuses on the mathematical model. Based on the three main axis than get the orientation of the helicopter. Using the basic equation from Newton's Law and Euler's Equation in term of coordinate system and derive to get 9 Equation of Motion (EoM) to use in the control system. This chapter also include the parameter used for the helicopter control system. The DRA Research PUMA will be the reference for this project.

The fifth chapter will show the derivation of the mathematical of LQR system based on Riccarti equation to stabilize the helicopter control system. The important variable needed to manipulate the system and give the optimize value for the controller.

The sixth chapter briefly show how to use the Virtual Reality Toolbox in MATLAB. Start from the introduction of VRML than to V-Realm Builder software and finally how to create the animation and communicate with the control system.

The seventh chapter contains the preliminary result of the project. In this chapter, the simulation for open-loop and closed-loop will be design. The output graph of open-loop system will show either the system is stable or unstable. The output graph of closed-loop system will show the difference performance compared to open-loop system. This chapter also show the UAV helicopter design through the graph analysis.