A NEW HYBRID CONTROL ALGORITHM DESIGN AND SIMULATED FOR LONGITUDE AND LATITUDE MOVEMENTS STABILIZATION OF NONLINEAR FIXED-WING UAV

by

FAIZAN AHMED WARSI
1330610955

A thesis is submitted in fulfillment of the requirements for the degree of Master of Science (Mechatronic)

School of Mechatronics Engineering
UNIVERSITI MALAYSIA PERLIS

2014

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name	:	Faizan Ahmed Warsi
Date of birth	:	28th, June, 1988.
Title	:	A new hybrid control algorithm design and simulated for Longitude and Latitude movements stabilization of nonlinear Fixed-wing UAV.
Academic Session	:	2013 – 2014

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

☐	**CONFIDENTIAL**	(Contains confidential information under the Official Secret Act 1972)*
☐	**RESTRICTED**	(Contains restricted information as specified by the organization where research was done)*
■	**OPEN ACCESS**	I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of 2015 years, if so requested above).

Certified by:

SIGNATURE | **SIGNATURE OF SUPERVISOR**

CQ6910721
(NEW IC NO. / PASSPORT NO.) | **NAME OF SUPERVISOR**

Date : 11th, May 2015 | Date : ________________

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentially or restriction.

ACKNOWLEDGMENT

I am deeply thankful and grateful to God on His blessings that this research activity is successful, and the writing of this thesis is completed. I would like to express my sincere and profound gratitude to the Vice Chancellor of University Malaysia Perlis, **Y. Bhg. Brigedier Jeneral Dato Prof. Dr. Kamarudin b. Hussin**for granting me permission to study in this university. I would like to express my thanks to the Dean of School of Mechatronic Engineering, University Malaysia Perlis, Associate Prof. Dr. **Abdul Hamid Adom** for providing support during my research work.

I would like to express my unlimited appreciation to **Prof. Madya Dr. HazryDesa** and **Dr. Syed Faiz Ahmed** for their valuable supervision and guidance in the research and preparation of this thesis. Their patience and positive attitude foster me in completing my research work. My sincere thanks to all the members of Center of Excellence for UAS (COEUAS), who have contributed directly and indirectly towards the completion of this research. Finally, I am grateful to my parents and also my siblings for their love, and special thanks to my wife Rohadiana dwi Nofianti warsi for continuous support and encouragement in completing this research work.

TABLE OF CONTENTS

CHAPTER 3 RESEARCH METHODOLOGY

CHAPTER 4 RESULTS & DISCUSSIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATION

UAV	Unmanned Aerial Vehicle
PID	Proportional, Integral and Derivative
LQG	Linear Quadratic Guassian
RC	Remote Control
GPS	Global Positioning System
EKF	Extended Kalman Filter
E-Frame	Earth Frame
B-Frame	Body Frame
H-Frame	Hybrid Frame

LIST OF SYMBOLS

$S(.)$	Skew-symmetric operator
R_{Θ}	Rotation matrix (roll-pitch-yaw)
m	Fixed-wing mass (kg)
J_{Θ}	Generalized matrix
X	Linear position along xe WRT E-frame (m)
$\dot{X}$	Linear velocity along xe WRT E-frame (m s^{-2})
$\ddot{X}$	Linear acceleration along xe WRT E-frame (m s^{-2})
O_B	Gyroscopic propeller matrix WRT B-frame
O_H	Gyroscopic propeller matrix WRT H-frame
T_{Θ}	Transfer matrix
U_1	Vertical thrust respect to the body frame (N)
U_2	Roll torque respect to the body frame (Nm)
U_3	Pitch torque respect to the body frame (Nm)
U_4	Yaw torque respect to the body frame (Nm)
Y	Linear position along ye WRT E-frame (m)
$\dot{Y}$	Linear velocity along ye WRT E-frame (m s^{-2})
$\ddot{Y}$	Linear acceleration along ye WRT E-frame (m s^{-2})
Z	Linear position along ze WRT E-frame (m)
$\dot{Z}$	Linear velocity along ze WRT E-frame (m s^{-2})

$\ddot{Z}$	Linear acceleration along ze WRT E-frame (m s^{-2})
ζ	Generalized velocity vector WRT H-frame
$\dot{\zeta}$	Generalized acceleration vector WRT H-frame
θ	Angular position around y1 WRT E-frame (rad)
$\dot{\theta}$	Angular velocity around y1 WRT E-frame (rad s^{-1})
$\ddot{\theta}$	Angular acceleration around y1 WRT E-frame (rad s^{-2})
ϕ	Angular position around x2 WRT E-frame (rad)
$\dot{\phi}$	Angular velocity around x2 WRT E-frame (rad s^{-1})
$\ddot{\phi}$	Angular acceleration around x2 WRT E-frame (rad s^{-2})
ψ	Angular position around ze WRT E-frame (rad)
$\dot{\psi}$	Angular velocity around ze WRT E-frame (rad s^{-1})
$\ddot{\psi}$	Angular acceleration around ze WRT E (rad s^{-2})
ξ	Generalized position vector WRTE-frame
$\dot{\xi}$	Generalized velocity vector WRT E-frame
ω^{B}	Angular velocity vector WRT B-frame (rad s^{-1})
$\dot{\omega}^{B}$	Angular acceleration vector WRT B-frame (rad s^{-2})
Γ^{E}	Linear position vector WRT E-frame (m)
τ^{B}	Torques vector WRT B-frame (Nm)
ν	Generalized velocity vector WRT B-frame

A hibrid reka bentuk algoritma kawalan baru dan simulasi untuk longitud dan latitud pergerakan penstabilan tak linear sayap tetap UAV

ABSTRAK

UAV (tanpa pemandu Kenderaan Aerial) telah membolehkan beberapa keupayaan misi baru dan sering digunakan dalam pelbagai aplikasi. Terdapat beberapa jenis konfigurasi UAV yang terdapat di pasaran, tetapi menetapkan sayap UAV adalah yang paling popular di kalangan mereka. Ia kebanyakannya digunakan dalam pengawasan dan menyelamat jenis permohonan oleh tentera dan juga organisasi perniagaan .This membuat reka bentuk dan mengawal UAV sebagai salah satu subjek yang paling berdesir untuk penyelidik. Aku janji menyusahkan untuk para saintis dalam reka bentuk UAV adalah untuk membangunkan algoritma kawalan yang cekap yang menjadikan keliling penerbangan UAV di bawah keadaan biasa dan tidak stabil atau jengkel.

Seperti UAV lain, UAV menetapkan sayap juga linear bukan dalam alam dan penstabilan semasa penerbangan adalah tugas yang menyusahkan. Ia mempunyai dua mazhab utama yang, pergerakan membujur dan sisi, yang mesti menjadi kawalan secara sah untuk membuat Fix Wing UAV penerbangan stabil. Terdapat beberapa teknik kawalan yang sedia yang digunakan untuk mengawal pergerakan penerbangannya. Teknik-teknik kawalan diakses mempunyai beberapa pro dan kontra, dan mempunyai halangan kerja mereka sendiri. Ini tawaran penerokaan penyelidikan dengan mereka bentuk sistem kawalan untuk saiz kecil sayap tetap UAV untuk meningkatkan prestasi penerbangan di bawah keadaan ketidaktentuan. Secara umumnya UAV ini wajah masalah unpredicted semasa penerbangan seperti tiupan angin berat, mengubah dalam perjalanan semasa angin, sensor kekecohan atau sensor bunyi. Ini kesan boleh terapung UAV daripadanya dicari arahan dan menjadikannya tidak stabil. Teknik-teknik kawalan tradisional didapati tidak cukup mantap untuk mengendalikan keadaan resah. Dalam tesis ini algoritma kawalan hibrid baru dibentangkan untuk pergerakan membujur dan sisi pengawalan kecil sayap tetap UAV. Teknik kawalan yang dicadangkan dibangunkan dengan menyertai algoritma PID dengan algoritma PD-LQG untuk menstabilkan sayap tetap penerbangan UAV yang kecil di bawah sensor keadaan bising dan keadaan gangguan luar. Untuk mengesahkan pelaksanaan strategi kawalan yang dicadangkan adalah simulasi pada 'kayu pengukur' jenis kecil UAV sayap tetap. Simulasi yang dilakukan dan dianalisis keadaan yang berangin dan bising berbeza. MATLAB Simulink dengan set blok Aerosim yang digunakan untuk melaksanakan semua penyelakuan. Keputusan simulasi menunjukkan bahawa teknik kawalan yang dicadangkan menunjukkan prestasi yang baik dalam keadaan yang risau dan prestasinya adalah lebih baik daripada algoritma tradisional boleh didapati di bawah syarat-syarat yang tidak menentu.

A new hybrid control algorithm design and simulated for longitude and latitude movements stabilization of nonlinear fixed-wing UAV

ABSTRACT

UAVs (Unmanned Aerial Vehicles) have enabled a number of new mission capabilities and are frequently used in many applications. There are a few sorts of UAVs configuration available in the market, but fix-wing UAVs is the most popular among them. It is mostly used in surveillance and rescue type applications by militaries as well as business organizations .This makes UAV design and controlling as one of the most sizzling subject for the researchers. The troublesome undertaking for the scientists in UAVs design is to develop its efficient control algorithm which makes UAV flight settle under typical and instability or irritated conditions.

Like other UAVs, fix-wing UAVs are also non linear in nature and its stabilization during flight is troublesome task. It has two major movements that are, longitudinal and lateral movement, which must be control legitimately to make Fix Wing UAV flight stable. There are several control techniques available that are used to control its flight movements. These accessible control techniques have a few pros and cons, and have their own working impediments. This research exploration deals with the designing of control system for small size fixed-wing UAV to enhance the flight performance under uncertainties condition. Generally these UAV countenances unpredicted problems during flight such as, heavy wind gust, alter in wind current course, sensors commotions or sensors noises. These impacts may float the UAV from it sought direction and makes it unstable. The available traditional control techniques are not robust enough to handle these perturbed circumstances. In this thesis a new hybrid control algorithm is presented for longitudinal and lateral movements controlling of small fixed-wing UAV. The proposed control technique is developed by joining the PID algorithm with PD-LQG algorithm to stabilize the small fixed-wing UAV flight under sensor noisy conditions and external disturbance circumstance. For verifying the performance of proposed control strategy it is simulated on ‘Yardstick’ type small fixed wing UAV. The simulation are performed and analyzed under different windy and noisy conditions. MATLAB Simulink with its Aerosim block set is used to execute all the simulation. The simulation results demonstrates that the proposed control technique performed exceptionally well under perturbed conditions and its performance is much better than available traditional algorithms under uncertainty conditions.

CHAPTER 1

INTRODUCTION

1.1 Overview

Fixed Wing Unmanned Aerial Vehicles (UAVs) are considered as replacement of manned aircrafts for decades during military mission. Normally a general mission of UAVs are characterized by the pre-programming of navigation requirment for close observation of targeted mission. UAVs have recently been used with great success for military intelligence by providing a viable alternative to manned aircraft due to their smaller size, reduced risk to life and reduced cost (Sun, Y. P. 2013). Armed Forces use UAVs in applications such as border patrolling, security intelligence, surveillance and target acquisition mission (Haddal, C. C. 2010). Besides military applications of UAVs, it can also be used in many civil applications such as search & rescue missions, explorations, security & surveying of exposed pipe lines, fire forests, agricultural applications and power & nuclear plants inspection (Briant, C. L. 2013). There are many types of UAV including single rotor, quad rotor, fixed wing and hybrid types. However, fixed-wing UAV is more popular because of its simple shape and dynamics and its similarity with general airplane (Hefler, C. 2013). Fixed-wing UAV is preferable choice as compared to others because it requires less power and most of them use only single thruster for flying purpose. (Smit, S. J. A. 2013).

There are lots of military and general purposes UAVs available in the market like AeroSonde, Aladin, CyroWing, Luna, Luna NG etc. These UAVs are difficult to stabilize under uncertainty conditions; especially flight during heavy wind, external disturbance and sensor noise feedback. These uncertainties make them unstable and very difficult to control. The purpose of this research is to design a new PID and PD-LQG based hybrid control algorithm design that can work more efficiently in adverse environmental conditions.

The fixed-wing UAV is a six degree of freedom (DOF) system and its dynamics can be categorized into longitudinal and lateral dynamics (Lee, J., & Chung, J. 2013). The fixed-wing UAV is nonlinear in nature and it requires a rigid controller for stability during takeoff, landing and steady flight (Castañeda, H. 2014). This thesis focuses on the design and development of new hybrid algorithm for longitude and latitude stabilization by combining two famous control algorithms which are PID and LQG. The proposed hybrid controller, PID-PD-LQG, is implemented and simulated on small fixed-wing UAV under noisy and windy conditions. The simulation results show the performance of proposed algorithm and it shows very good response as compared to previous available algorithms.

1.2 Problem Statement

Fixed-Wing UAV structures are simple to design, but difficult to control due its non-linear nature. The longitude and latitude control of these fixed-wing UAV play a critical role in smooth flight. In real time applications these vehicles have to go through immensely harsh conditions. So, for smooth and stable flight of fixed-wing UAV, it is nessary to design an appropiate longitunal and latitudinal control. Most of the control techniques are closed loop system and uses sensors to get feedback of applied input response or system's output. It sould be noted that the control technique relies only on the sensors feedbacks and sensors are always noisy and the noise level depends on the environmental conditions. These noisy feedbacks can cause of error in the UAVs stability. The second major cause of error in UAVs stability is external disturbance. In UAVs the external disturbance is denoted as windy environment. Such winds can also destabilize the UAVs. To avoid or minimize the effect of noise and disturbance in the UAV, the control technique should be powerful and effective to make UAV system stable.

1.3 Significance of the study

The results and analysis of this research investigation will be used in improving the quality of fixed wing UAV flying and resolve the issues by incorporating fully autonomous fixed-wing UAV during its longitudinal and lateral motions under perturbed condition and false sensor measurements. Beside, these results would also be beneficial for other researchers who are working in the same field.

1.4 Research Objectives

The purpose of the research is to develop an efficient robust control design for longitudinal and latitudinal motion of fixed-wing under various uncertainties acting on the system. The researched technique used to develop control design can collectively react efficiently to uncertainties acting on the system. Following are the objectives of this research.

i. **To develop a mathematical model of fixed-wing UAV**

Developing a mathematical model of small fixed-wing UAV is a demanding task. In this research to develop a mathematical model a small fixed wing UAV is considered. There are several methods to develop the mathematical model of fixed-wing. This research works follows Newton Euler method to extract the fixed-wing equations of motion.

ii. **To implement and analyze PID, LQR and PD-LQR control algorithms on longitude and latitude stabilization of fixed-wing UAV**

The fixed-wing UAV experiences several challenges while flying, especially false sensor measurements can make fixed-wing UAV unstable. Air turbulence can affect the flight of fixed-wing UAV by suddenly drifting its position from its desire trajectory. The control algorithms such as PID, LQR and PD-LQR are implemented and to analyze the response of fixed-wing UAV under uncertainty conditions that can act on fixed-wing in real time.

iii. **To develop a new hybrid controller design for nonlinear fixed-wing UAV**

On the basis of these analytical results a new hybrid control technique i.e. PID-PD-LQR is developed for an efficient response of longitudinal and lateral-directional motion of fixed-wing UAV under air turbulence and false sensor data measurements.