



Ain shams university

Electronics and communication engineering department

Design and implementation of control for unmanned air vehicle

This thesis is submitted in partial fulfillment of the requirements for the degree of Master of
Science in Electrical Engineering

(Electronics and communication engineering)

By

Eng. Eslam Nabil Mobarez Hussein

Faculty of engineer .Ain shams university

Under Supervision of

Prof. Dr. Abdelhalim abdelnabi Zekry

Ain shams university

Dr. Ahmed Nasr Ouda

Military Technical College

Date of Discussion December 2016

Cairo 2016

Approval sheet

For thesis with title

Design and implementation of control for unmanned air vehicle

Presented by

Eng.eslam nabil mobarez hussien

This thesis is submitted in partial fulfillment of the requirements for the degree of
master of science in the electrical engineering
(Electronic and communication engineering)

Supervision committee

Name

signature

1- prof.DR .abdelhalim abdelnaby zekry
electronic and communication engineering
faculty of engineering,ainshams university

2- Dr.ahmed naser ouda
Military technical college

Approval sheet

For thesis with title

Design and implementation of control for unmanned air vehicle

Presented by

Eng.eslam nabil mobarez hussien

This thesis is submitted in partial fulfillment of the requirements for the degree of
master of science in the electrical engineering
(Electronic and communication engineering)

Approved by

Name

signature

1- prof.DR.Abdel-hakim abdel el-rahman el-manhawey
Military technical college

2- prof.DR .abdelhalim abdelnaby zekry
electronic and communication engineering
faculty of engineering,ainshams university

3- prof.DR.ismail Mohamed hafez
electronic and communication engineering
faculty of engineering,ainshams university

Acknowledgement

Thanks for Allah

I would like to express and present my faithful thanks and deepest gratitude to my supervisors **Prof. Dr./ Abdelhalim abdelnaby Zekry** and **Dr. Ahmed Nasr Ouda** for their inestimable guidance, humongous support, admirable advising, and ceaseless encouragement.

I would like to acknowledge my depth feeling to all members of electronics and communication department for their support and help.

My special thanks go to my family members; my Parents, my dear brother, for their valuable prayers, always been by my side, continuous support and encouragement thorough my life, and strong patience during all stages of my life.

I would like to thank my **Wife** for her assistance and carefree; this work would not have been possible without support of all whom I love.

Eslam Nabil Mobarez Hussien

Cairo, 2016

Abstract

Extensive researches have been conducted in advanced guidance, navigation, and control to exploit the full potential of autonomous Unmanned Aerial Vehicles (UAV). The uses of autonomous vehicles, for a wide variety of applications, have been increasing during the latest decades due to their great potential in numerous military and civil implementations. This motivated ever-increasing attraction of designing UAV flight control systems to achieve robust stability and acceptable performance across specified flight envelopes.

The research in this thesis concerns the UAV, via three major constituents; the first includes development of a physical, inertial, and aerodynamic model representing the Ultrastick-25e UAV. The second is the development and implementation of a non-linear, six degree of freedom simulation, employing the developed model integrated with sensors and actuators constructed in Matlab/SIMULINK. The simulation enables control system design and pre-flight analysis throughout the entire flight envelope. Detailed post-flight analysis is also performed in Matlab/SIMULINK. The third constituent of the research includes the flight control system design.

Developing an autonomous UAV control system is a challenge for several reasons; first, UAVs are highly sensitive to control inputs and require high frequency feedback with minimum delay for stability. Second, UAV dynamics are unstable, multivariable, highly coupled, and vary across the flight envelope. Third, UAVs have limited on-board power and payload capacity, due to which flight control systems must be compact, efficient, and light weight for effective on-board integration. The goal of this dissertation is to build an UAV mathematical simulation model and to design a control system that should be able to stabilize and control the underlying UAV.

Simulation results are given to demonstrate that this nonlinear model behaves like the real UAV dynamic system. Trimming the nonlinear model for steady-state flight and extracting the linearized model for the UAV are performed using Matlab functions. The flight control system is designed using two different

techniques; the classical PID and the fuzzy logic control, and a comparison is performed between their performances. Simulation results showed that the PID controller handled the disturbances in a satisfactory manner but with some shortcomings. Therefore, it was desired to design a more advanced control strategy able to neutralize the shortcomings of the PID controller and to enhance its performance. Hardware implementation environment with experimental test results, when the aircraft disturbed by external force the autopilot reject it by position control on the elevator control surface, and from the analysis we have two result that determine the comparison between the attitudes with and without filtering pitch estimation comparison and roll estimation comparison.

Keywords: unmanned air vehicle, ID control ,FUZZY control, equation of motion

Contents	Page
Abstract	I
Acknowledgment	III
Contents	IV
List of figures	VII
List of tables	X
Nomenclature	XI
Chapter 1: Introduction and Framework	1
1.1 Introduction	1
1.2 Historical background and applications	2
1.3 Ultrasick-25e UAV	3
1.4 problem formulation	6
1.5 Survey of controllers and autopilot	7
1.6 Thesis outline	8
Chapter 2: Ultrasick-25e UAV Modeling	9
2.1 Introduction	9
2.2 Mathematical representation	10
2.3 Reference Axes Frames	13
2.3.1 Earth Fixed Inertial Frame	13
2.3.2 Body Frame	14
2.3.3 North-East-Down Frame	15
2.3.4 Wind axis Frame	15
2.3.5 Stability Frame	15
2.4 The Ultrasick-25e UAV simulation model	16
2.4.1 The Atmosphere model	17
2.4.2 The Earth model	18
2.4.3 The Aerodynamic Model	19
2.4.4 Propulsion model	21
2.4.5 Inertia model	22
2.5 Sensor Modeling and Simulation	23
2.5.1 Gyroscopes	23
2.5.2 Accelerometer	25
2.5.3 Angle Of Attack Probe	26
2.5.4 Sideslip Vane	26
2.5.5 Velocity sensor	27
2.6 Actuators modeling and simulation	27

2.7	Conventional control response of Ultrastick-25e	28
2.8	Summary	30
Chapter 3:	Linearization of Uncontrolled Motion (nonlinear model)	31
3.1	Trim of the ultrastick-25e model	31
3.2	Model Linearization and State Space Representation	35
3.2.1	Solution of equations of motion	37
3.2.2	Decoupling of the equations of motion	38
3.2.3	Longitudinal Dynamic model	38
3.2.4	Lateral Dynamic model	41
3.3	Analytical linearization of the Ultrastick-25e equation of motion	44
3.4	validation of linearization of the aircraft model	46
3.5	nonlinear open-loop UAV model simulation	47
3.6	summary	50
Chapter 4:	Flight Control System Design	51
4.1	Introduction	51
4.2	Functions Of Automatic Flight Control Systems	52
4.2.1	Stability augmentation system	52
4.2.2	Control augmentation system	52
4.2.3	Autopilot	53
4.3	PID Controller	53
4.3.1	Tuning techniques	54
4.3.2	Optimization techniques	55
4.4	Fuzzy Logic Controller	57
4.4.1	Fuzzy-like PD Controller	58
4.4.2	Fuzzy like- PI Controller	58
4.4.3	Fuzzy like- PID Controller	59
4.4.4	Creating the membership values (fuzzifying)	60
4.4.5	Specifying the rule table	61
4.4.6	Defuzzifying the output	62
4.5	Flight Controller Design Specifications	62
4.6	Lateral Flight Controller	63
4.6.1	time domain analysis	65
4.6.2	comparative synthesis of PID and Fuzzy in linear model	65
4.6.3	comparative synthesis of PID and Fuzzy nonlinear model	68
4.7	Longitudinal Flight Controller	70
4.7.1	time domain analysis	73

4.7.2 Comparative Synthesis of PID and FLC in linear model	74
4.7.3 Comparative Synthesis of PID and FLC nonlinear model	77
4.8 Summary	79
Chapter 5: Hardware implementation environment with experimental test results	80
5.1 Introduction	80
5.2 Autopilot hardware block diagram	81
5.3 Selection of avionics and sensors	82
5.4 Flight computer	83
5.5 UAV sensors	84
5.5.1 inertia measurement unit	86
5.5.2 MPU 6050 IMU	87
5.6 Servo motor ES08A	90
5.7 Implementation Procedures of the Autopilot	92
5.8 Hardware Implementation.	94
5.9 summary	95
Chapter 6: Conclusion and Future Work	96
6.1 Conclusion	96
6.2 Future work	97
References	98

List of Figures

Fig. No.	Title	Page No.
1.1	UAV types and categories	6
2.1	Force and moments acting on the aircraft	11
2.2	Reference frames	13
2.3	Aircraft axes and angles	15
2.4	The Ultrastick-25e model structure	16
2.5	The Atmosphere simulink model	18
2.6	The Earth simulink model	19
2.7	Gyroscope simulink model	25
2.8	Accelerometer simulink model	26
2.9	sideslip angle vane	26
2.10	Actuator simulink model	27
2.11	Altitude control response for level climb at altitude 100 m	28
2.12	Pitch control response for + 5 doublet response	29
2.13	Heading control response for +5 deg multistep response	29
2.14	Roll control response for + 5 deg doublet response	30
3.1	Flight path of different flight condition	32
3.2	Trim algorithm	33
3.3	Flight envelope	33
3.4	Trim flight conditions points	34
3.5	An example of longitudinal roots on the real-imaginary axes	38
3.6	Phugoid motion	39
3.7	Short period motion	39
3.8	An example of lateral roots on a real-imaginary axis	42
3.9	Spiral motion	42
3.10	Dutch roll motion	43
3.11	Flowchart of aircraft modeling solution	43
3.12	Control surface pitch angle in double linear signal comparison technique by the application of the elevator deflection	46
3.13	Control surface in the double signal line by the use of a- pitch rate	46
3.14	Control surface roll angle in double linear signal comparison technique by the application of the aileron deflection (δ_a)	47
3.15	Control surface in the double signal line by the use of a- roll rate comparison technique (δ_a)	47
3.16	The open-loop simulink model	48

3.17	Pitch angle	49
3.18	Bank angle	49
3.19	Heading angle	49
3.20	Altitude	49
3.21	Open loop flight path	50

Fig. No.	Title	Page No.
4.1	Integrated framework for flight control development	51
4.2	Automatic flight control system	52
4.3	Optimization techniques classification	56
4.4	Genetic algorithm process flowchart	57
4.5	Fuzzy-like PD controller	58
4.6	Fuzzy-like PI controller	59
4.7	Fuzzy-like PID controller using parallel structure	59
4.8	FLC flowchart	60
4.9	Membership functions	61
4.10	The rule base	62
4.11	Lateral PID controller	64
4.12	Lateral fuzzy controller	64
4.13	+5 degree doublet signal response for roll tracker linear model	66
4.14	Disturbance rejection of roll tracker	66
4.15	noise effect of the doublet signal response	67
4.16	Multistep signal response for heading tracker linear model	67
4.17	the noise effect of the multistep signal response	68
4.18	+5 degree doublet signal response for roll tracker nonlinear model	69
4.19	Multistep signal response for heading tracker nonlinear model	69
4.20	Climbing and turn trajectory of the aircraft	70
4.21	longitudinal PID controller	72
4.22	longitudinal fuzzy controller	72
4.23	+5 degree doublet signal response for pitch tracker linear model	74
4.24	the noise effect in the doublet signal response	75
4.25	the ability of pitch tracker to disturbance rejection	75
4.26	Level climbs scenario 100m altitude from pitch (linear model)	77
4.27	The noise effect of the altitude hold controller	77
4.28	+5 degree doublet signal response for pitch tracker nonlinear model	77
4.29	Level climbs scenario altitude from pitch nonlinear model	79
4.30	Climbing and level trajectory of the aircraft	79

Fig. No.	Title	Page No.
5.1	SUAV electronic components block diagram.	82
5.2	Open source development boards.	83
5.3	Functional block diagram of the Arduino UNO board.	84
5.4	Orientation of axes descriptions of the device and mathematical calculations.	90
5.5	MPU6050 pin configuration	90
5.6	servo motor with extension wire and its component	91
5.7	(IMU& Arduino UNO & Servo motor) connection	92
5.8	+40 degree pitch up disturbance act on the aircraft	93
5.9	-40 degree pitch down disturbance act on the aircraft	93
5.10	+17.5 deg Pitch angle comparison according to various state estimator techniques	94
5.11	+1 deg Pitch angle comparison according to various state estimator techniques	94
5.12	Roll angle comparison according to various state estimator techniques	95

List of Tables

Table No.	Title	Page No.
2.1	The Ultrastick-25e UAV specifications	16
2.2	WGS-84 coefficients	18
2.3	Propeller properties	22
2.4	Characteristics of UAV actuators	27
3.1	Parameters of Steady state flight conditions	32
3.2	Trim results for operating point straight and level	34
3.3	Trim results for operating point level and climb	34
3.4	Trim results for operating point level and turn	35
3.5	Trim results for operating climb& turn	35
3.6	Longitudinal motion parameter	40
4.1	PID controller characteristics	54
4.2	PID tuning characteristics	54
4.3	Rule table of the FLC	62
4.4	Lateral control's gains	64
4.5	Time analysis of phi tracker	65
4.6	Time analysis of psi tracker	65
4.7	Longitudinal control's gains	71
4.8	Time analysis of (pitch tracker) inner loop of longitudinal motion controllers	75
4.9	Time analysis of (altitude) outer loop of longitudinal motion controllers	75

Nomenclature

Symbols

A_{total}	Total acceleration
Alt	Altitude
AR	Aspect ratio
A_X	Acceleration in X-axis
A_Y	Acceleration in Y-axis
A_Z	Acceleration in Z-axis
$\tilde{a}_x$	The measurement provided by an accelerometer
b	Wing span
$\tilde{B}$	The measured magnetic field
c	Mean aerodynamic chord
C_D	Drag coefficient
C_L	Lift coefficient
C_l	Roll torque coefficient
C_m	Pitch torque coefficient
C_n	Yaw torque coefficient
C_P	Power coefficient
C_T	Thrust coefficient
C_Y	Side force coefficient
e	Quaternion parameter
$e(t)$	Error
F	Force
F_{aero}	Aerodynamic force
F_{prop}	Propulsion force
g	Gravity acceleration
g_{WGS0}	Gravity at equator
g_{WGS1}	Gravity formula constant
h	Altitude
H	The angular momentum of a rotating body
H_f	The stable filter transfer function
I	Moment of inertia