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UAV Pitch Control System Analysis and Design

Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science. (BSc Honor)

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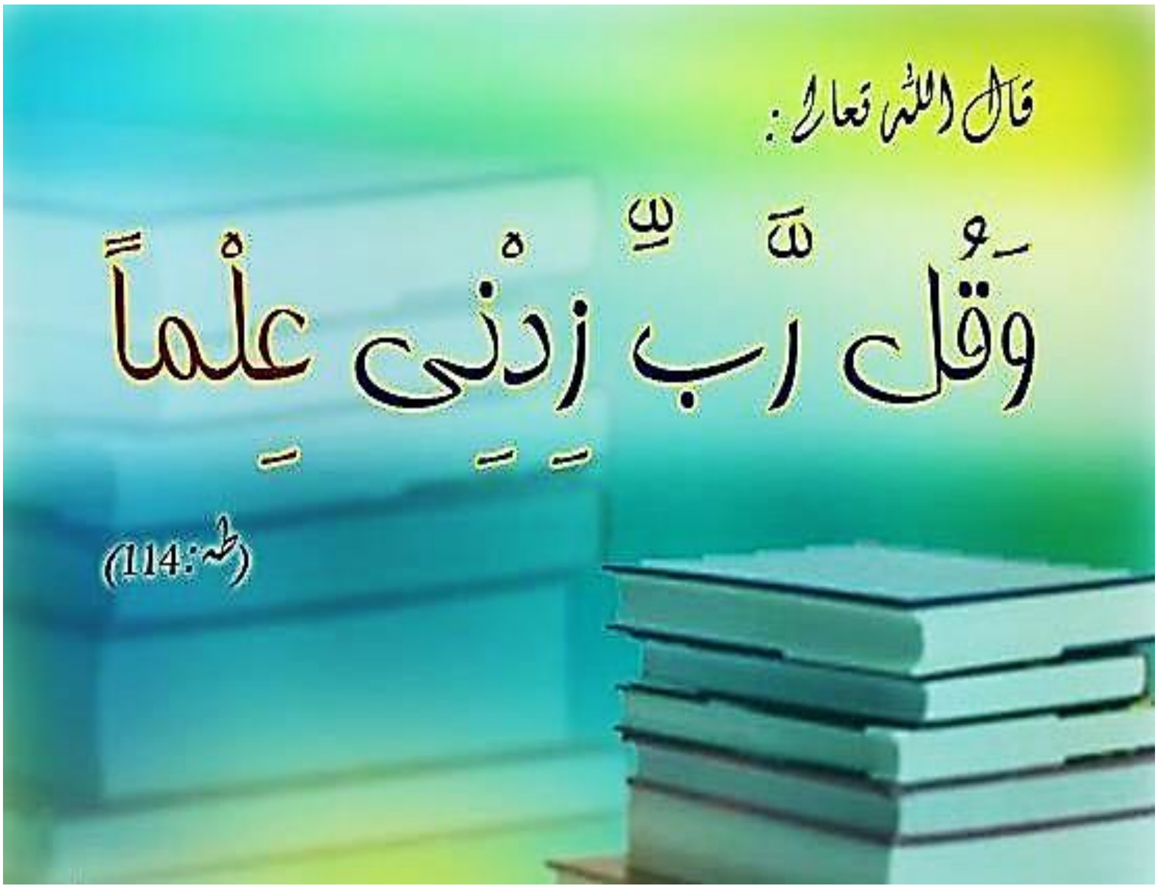
الآية



Abstract

The ability of UAV to do a certain task is mainly dependent on accuracy of its control system. The purpose of this project is to analyze and design pitch control system for the UAV model in short mode, Too long settling time is noted after the model whose aerodynamic data are available have been analyzed by Using Simulink. The main objective of this research is to Suggest and design one of the suitable controllers to Control the model. The result obtained when applying PID controller is not satisfactory. Good result is obtained by using state feedback controller to control pitch. And the system has been stable upon the step input.

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التجريد

تعتمد قدره الطائرة بدون طيار للقيام بمهمة معينة على دقة نظام التحكم . الغرض من هذا المشروع هو تحليل وتصميم نظام التحكم لزاوية الميلان الطوليه لنموذج طائرة بدون طيار. تم ملاحظة زمن استقرار طويل جدا بعد تحليل النموذج باستخدام Simulink. الهدف الاساسي لهذا البحث هو اقتراح وتصميم متحكم مناسب للتحكم بالطائرة ,لم يتم الحصول على النتائج المرغوبة عند تطبيق المتحكم التناسبي التكاملي التفاضلي .وقد ال تطبيق متحكم التغذية الراجعة لمتغيرات الحالة الى نتائج جيدة ونظام مستقر على دخل دالة الخطوة.

ACKNOWLEDGEMENT

First of all, all our gratitude is for Allah, for giving us the knowledge and lighting our way through, then our sincere appreciation for our supervisor T. Salma for her advice, support and guidance through the entire project. Special thanks to Dr. Ishraga azhari who shared with us the main principles of a successful preparation for a final project, and reviewing the context of this project with us.

DEDICATION

To those who helped us at reaching our target. To the University and Department that enlightened us through the years and for their deep concern and efforts. To the families, for always being there for us and encouraging us all the way.

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LIST OF FIGURES

List of ABBREVIATION

PID	Proportional Integral Derivative
UAV	Unmanned Aerial Vehicles
AP	auto pilot

LIST OF SYMBOLES

A	state matrix
B	Input Matrix
C_M	Pitching Moment coefficient
C_N	Yawing Moment coefficient
C_l	Rolling Moment coefficient
C_L	Lift coefficient
C_D	Drag coefficient
C_y	Side force coefficient
C_{tip}, C_r	$root$ Tip and root chords
$C_{L_{\alpha_v}}$	Vertical tails lift curve slope
F_y	Body axes aerodynamic force in Y directions
F_x	Body axes aerodynamic force in x directions
F_z	Body axes aerodynamic force in z directions
H	Angular Momentum Vector
$H_x, H_y H_z$	Angular Momentum x, y, z components
I	Inertia tensor
$I_{xx}, I_{yy} I_{zz}$	Moment of inertia about x-axis, y-axis, z-axis
$I_{xz}, I_{yy} I_{zz}$	Products of inertia
l_t	Tail arm
l_v	Vertical tail arm
M	Pitch moment
m	Mass
P	Linear momentum

q	Dynamic pressure or pitch Rate
S	Reference area, Wing plan area
S	Tail area
T	Thrust
i	Period
u	Velocity in X axes
uo	Control input vector
v	Velocity in Y axis
V	Velocity vector
V	Airspeed
V_H	Horizontal tail volume Ratio
w	Velocity in Z axis‘s
x	State vector

Greek letters

α	Angle of attack
β	Side slip angle (deg)
δ_a	Aileron deflection
δ_r	Rudder deflection
δ_e	Elevator deflection
Φ, φ	Roll attitude
Θ, θ	Pitch attitude
Ψ, ψ	Yaw attitude
λ	Taper Ratio, eigenvalue

η	Tail Efficiency
ρ	Air density
ζ_i	Damping ratio
W	natural frequency

CHAPTER ONE

INTRODUCTION

1.1 Overview

1.1.1 UAV control system

Unmanned Arial vehicle flight control systems provide enabling technology for the aerial vehicles to fulfill their Flight missions, especially when these missions are often planned to perform risky or tedious tasks under extreme flight conditions that are not suitable for piloted operation. Not surprisingly, UAV flight Control systems are often considered safety/mission critical, as a flight control system failure could result in loss of the UAV or an unsuccessful mission.

The flight control system is supplied with software designed the autopilot parameters adjustment, mission planning and flight data analysis, program operate with all types of raster terrain images (aerial photos, scanned maps)

The federal inventory of UAVs grew over 40 times in the last decade .Most UAVs in operation today are used for surveillance and reconnaissance (S&R) purposes, and in very few cases for payload delivery. In these cases a significant portion of the UAVs in operation Remain remotely piloted, with autonomous fight control restricted to attitude hold, non-agile Way-point fight, or loiter maneuvers. [1]

The model which has been used in this research has a long settling time and it needs a control system, there are two controllers that has been used first the PID controller was used but it didn’t achieve our design requirement because each term in the structure of PID controller decreases on one side and increases in another one of the characteristic of the step response so second the state feedback controller has been used because it allow us to full control over the closed loop poles.

1.2 Problem statement

The model (UAV WITH COAXIAL PROPELLER) which has been modeled have a long settling time after analysis and it actually lacks of control**.**

1.3 Problem solution

Design one of the suitable controller to Control the model.

1.4 Aims & objectives

1.4.1 Aim

Design autopilot for the UAV model

1.4.2 Objectives

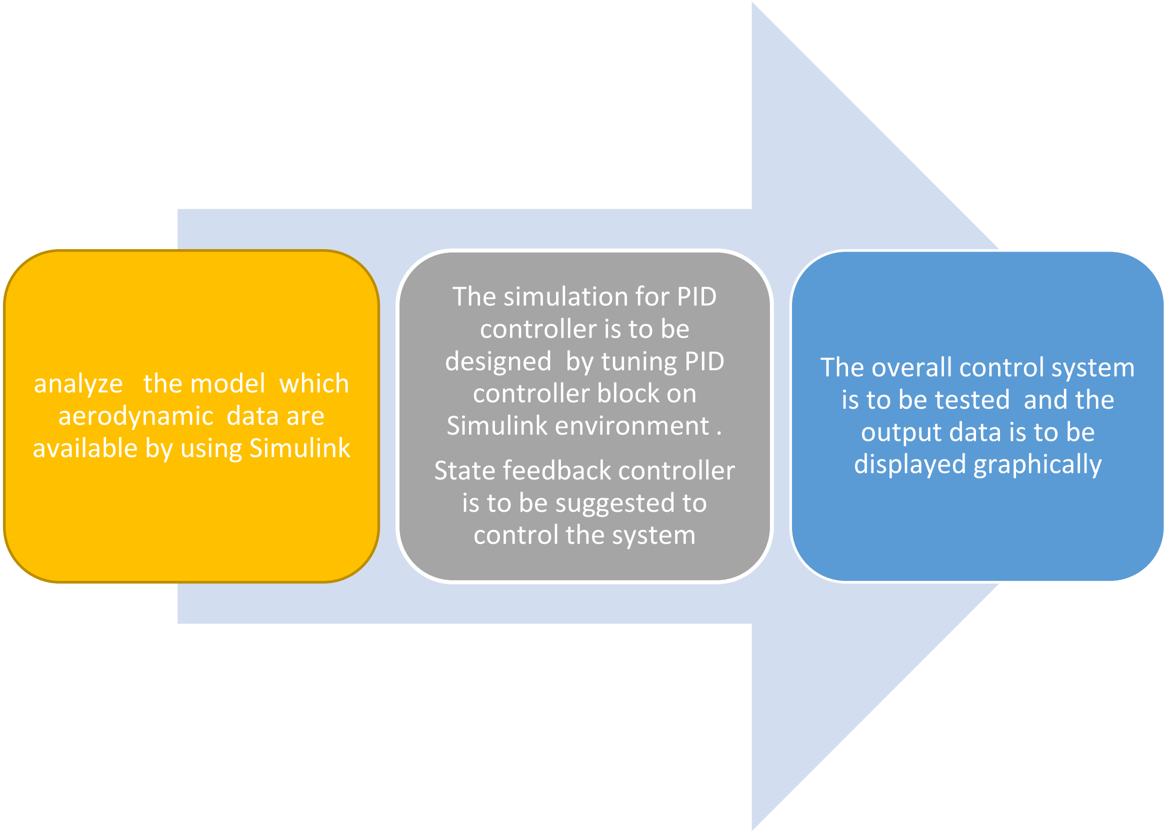
1-To analyze the behavior and check the stability of coaxial propeller UAV model by using MATLAB and SIMULINK

2-To design a suitable controller to achieve the stability and desired response the pitch control

1.5 Motivation

UAV are the state of art in aeronautical engineering especially Avionics the control system of the UAV is very sophisticated system which have a strong relationship with autopilot & represent a challenge that needs to be met.

1.6 Methodology



analyze the model which aerodynamic data are available by using Simulink

The simulation for PID controller is to be designed by tuning PID controller block on Simulink environment .

State feedback controller is to be suggested to control the system

The overall control system is to be tested and the output data is to be displayed graphically

Fig. (1. 1) Methodology

1.7 Outlines:

- Chapter one gives an introduction to the problem definition, research objectives, methodology of this thesis including layout.
- Chapter two present a background and literature review to define UAV control system, its principles and methods of calculation.
- Chapter three describes items modeling and system analysis with simulation.
- Chapter four present simulation results and discussion for longitudinal control
- Chapter five gives conclusion and recommendations for further work

CHAPTER TWO

LITERATURE REVIEW

2.1 Brief History of Unmanned Aircraft:

Most aeronautical experimenters built models of their designs in order to discover if they would work. This practice is still used today. John String fellow and William Henson from England combined their talents in 1848 to build a steam powered propeller driven model aircraft with a 10 foot wingspan called the Aerial Steam Carriage shown in fig(2.1). This model successfully flew for a distance of approximately 60 yards. Another String fellow model was flown on a wire guide inside the Crystal Palace of London in 1868. Eyewitnesses reported that the steam powered tri-winged aero plane generated lift and only used the wire guide to keep from crashing into walls. The American experimenter Samuel Langley in 1896 successfully flew a steam powered model he called “Aerodrome Number 5” down the Potomac River for 3/4 of a mil. [1]

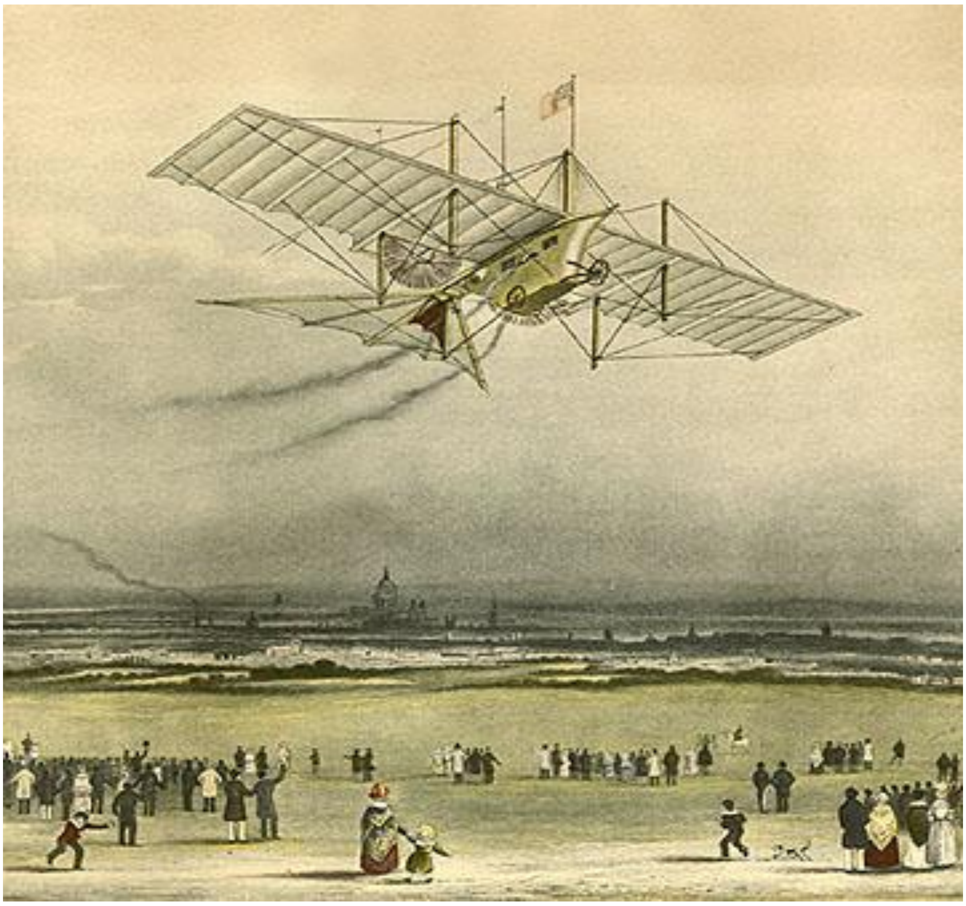


Fig. (2. 1) Aerial Steam Carriage [1]

Unmanned Aerial Vehicles (UAVs), UAVs can be classified into two major groups heavier-than-air and lighter-than-air. These two groups self-divide in many other that classify aircrafts according to motorization, type of liftoff and many other parameters. [1]

2.2 Auto pilot navigation control system with general information

UAVN's APs are complete APs; they include an Air Data System (ADS - static and dynamic pressure gauges) and a GPS, both connected to an Internal Measurement System that contains accelerometers, gyroscopes, magnetometers and an internal CPU as it shown in fig (2.2). These systems are connected to a flight control computer that implements aircraft control and communications with the GCS via a data link and payload control. The schematic of a typical UAVN AP is as follows. [2]

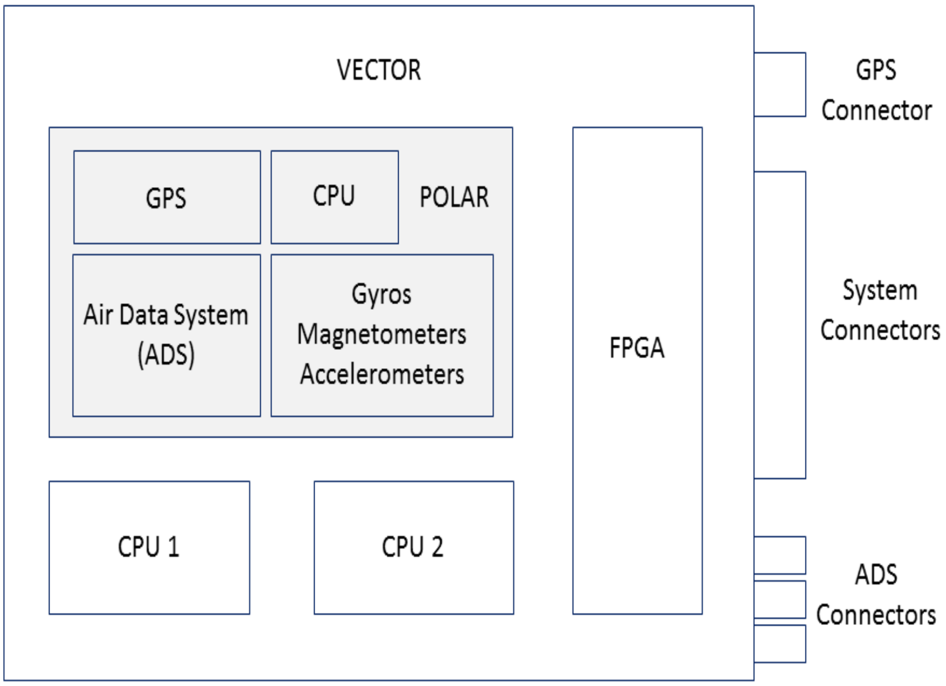


Fig. (2. 2) UAV autopilot system [2]

AP Navigation Control System Logic: the AP flies the aircraft in fully autonomous mode, from take-off to landing. Its Flight Plan Management (FPM) module will calculate the trajectory to guide the aircraft to the next waypoint (WP), and the FCS module will use the information provided by the Attitude and Heading Reference System (AHRS) to steer the aircraft in the desired trajectory. The fig (2.3) explains the logic circuit of autopilot system

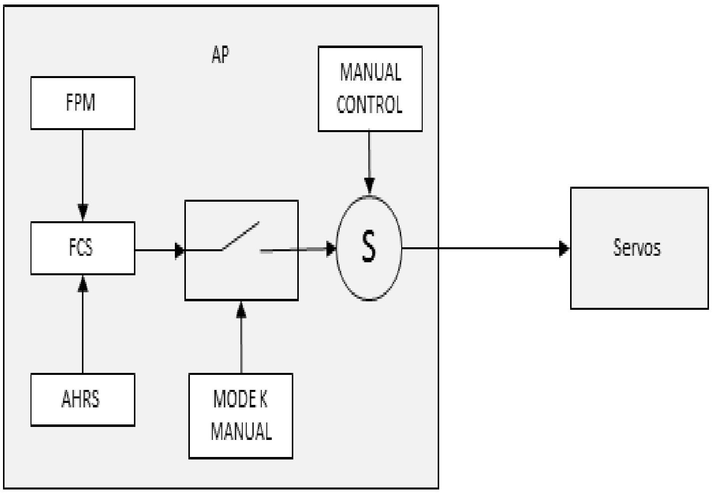


Fig. (2. 3) the navigation control system [2]

. The principal flight control modes are: Take-off, auto, fly-to, land, hold (Fixed Wing) - hover (Rotary Wing), manual, safe [2]

2.3 Application of UAV

Unmanned aerial vehicles (UAVs) are widely used in:

1- Military and civilian applications. In recent years, several nonlinear control methods, such as back-stepping, the Lyapunov function and nonlinear dynamic inversion, have been applied in small UAV flight control. Back-stepping techniques can derive air speed and roll control commands from known heading and air speed control laws which explicitly account for the heading rate and air speed constraints of the UAV. [3]

2- A miniature fixed-wing 6-DOF UAV model is used to show the effectiveness in trajectory tracking control. Furthermore, three different approaches based on the state dependent Riccati equation, Sontag's formula and aggressive selection from a satisfying control set are proposed to design the heading and air speed control commands for this UAV .The design of the formation control laws for YF-22 include inner and outer loop design for two aircraft in the formation – the outer loop scheme is based on feedback linearization, while the inner loop scheme is based on a root locus-based approach – and experimental results validate the performance. The above methods improve the attitude and trajectory control performance of UAVs, however, the presented control methods are too complex to design and usually utilize a nonlinear model of a UAV.Emotions have a strong faculty for decision making. In past decades, modeling of emotion has attracted the attention of many researchers both in cognitive psychology and the design of artificial systems. [3]

3- A network model which simulates the brain emotional learning (BEL) mechanism of mammalians is designed by Moren and Balkenius [The BEL model is a computational model which mimics the amygdala, orbitofrontal cortex, thalamus, sensory input cortex and other parts of the brain.

From the BEL model being proposed, it was soon applied into control systems of real engineering fields, termed brain emotional learning based on an intelligent controller originally proposed by Lucas. In recent years, BEL controllers have proved to have good robustness and uncertainty handling properties when applied in many engineering systems, such as simo overhead travelling cranes, switched reluctance motors plant level systems, alarm systems, micro-heat exchangers, flight simulation servo systems and other uncertain nonlinear systems. [3]

The BEL intelligent control scheme has proved to be effective and robust in real systems from the above references. Therefore, in this paper, the BEL intelligent control is initially used to improve the attitude control performance of a small unmanned aerial vehicle (UAV). [3]

For the small UAV without the thrust deflection of an engine, the mathematical model is in the same form as a traditional UAV model, which includes dynamics equations and kinemics equations. The aerodynamic parameters of the small UAV are obtained by blowing experiments. [3]

2.4 Stability and control

An aircraft is stable if it returns to its initial equilibrium flight conditions when it is perturbed. There are two main types of aircraft instability, an aircraft with static instability uniformly departs from an equilibrium condition, an aircraft with dynamic instability oscillates about the equilibrium condition with increasing amplitude. There are two modes of aircraft control: one moves the aircraft between equilibrium states, the other takes the aircraft into a non-equilibrium (accelerating) state. [4]

2.4.1 Static stability

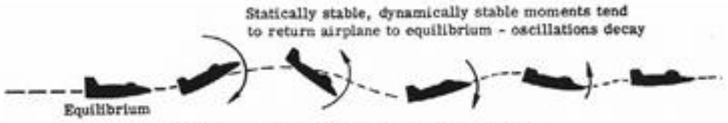
Static stability deal with the initial tendency of a vehicle to return to equilibrium after being disturbed .it says nothing about whether it ever reaches it equilibrium position, nor how it get there such matters the realm of dynamic stability as follows. There are three kinds of static stability:

1. Positive static stability: an aircraft tends to return to its original attitude when it's disturbed.
2. Negative static stability: an aircraft tends to continue moving away from its original attitude when it's disturbed.
3. Neural static stability: an aircraft tends to stay in its new attitude when it's disturbed. [4]

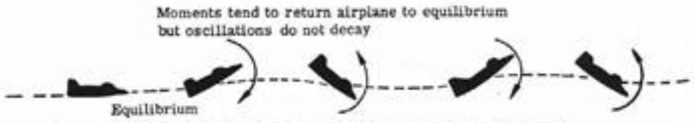
2.4.2 Dynamic stability

Dynamic stability deals with the time history of the vehicles motion after it initially responds [4].

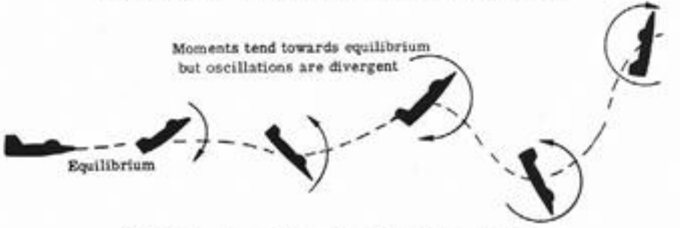
If an aircraft is statically stable, it may undergo three types of oscillatory motion during flight. When imbalance occurs the airplane attempts to retain its position, and it reaches the equilibrium position through a series of decaying oscillations, and the aircraft is said to be dynamically stable. If the aircraft continues the oscillatory motion without decay in the magnitude, then the aircraft is said to be on dynamically neutral. If the magnitude oscillatory motion increases and the aircraft orientation start to change rapidly, then the aircraft is said to be dynamically unstable as it shown in fig (2.4).



(a) Statically and dynamically stable.



(b) Statically stable; neutral dynamic stability.



(c) Statically stable; dynamically unstable.

Fig. (2.4) static and dynamic stability of aircraft [5]

An aircraft that is both statically and dynamically stable can be flown hands off, unless the pilot desires to change the equilibrium condition of the aircraft. [5]

2.5 Control System

Control system can be classified into two main categories:

2.5.1 Open Loop Control System

open loop control system input have no linkage with the output, practical Examples of Open Loop Control System are:

- Electric Hand Drier: the output which is the hot air comes out as long as you keep your hand under the machine, irrespective of how much your hand is dried.Automatic Washing Machine - This machine runs according to the pre-set time irrespective of washing is completed or not. Bread Toaster - This machine runs as per adjusted time irrespective of toasting is complete or not.

- Automatic Tea/Coffee Maker - These machines also function for pre adjusted time only.
- Timer Based Clothes Drier - This machine dries wet clothes for pre-adjusted time, it does not matter how much the clothes are dried.
- Light Switch - Lamps glow whenever light switch is on irrespective of light is required or not.
- Volume on Stereo System - Volume is adjusted manually irrespective of output volume level.

Advantages of Open Loop Control System:

- Simple in construction and design.
- Economical.
- Easy to maintain.
- Generally stable.
- Convenient to use as output is difficult to measure.

Disadvantages of Open Loop Control System:

- They are unreliable.
- They are inaccurate.

2.5.2 Close Loop Control System

Control system in which the output has an effect on the input quantity in such a manner that the input quantity will adjust itself based on the output generated is called closed loop control system, Practical Examples of Closed Loop Control System:

- Automatic Electric Iron - Heating elements are controlled by output temperature of the iron.
- Servo Voltage Stabilizer - Voltage controller operates depending upon output voltage of the system.
- Water Level Controller - Input water is controlled by water level of the reservoir.
- Missile Launched and Auto Tracked by Radar - The direction of missile is controlled by comparing the target and position of the missile.
- An Air Conditioner - An air conditioner functions depending upon the temperature of the room.
- Cooling System in Car - It operates depending upon the temperature which it controls.

Advantages of Closed Loop Control System:

The advantages of closed loop Control System are:

- Closed loop control systems are more accurate even in the presence of non-linearity.
- Highly accurate as any error arising is corrected due to presence of feedback signal.
- Bandwidth range is large.
- Facilitates automation.

The sensitivity of system may be made small to make system more stable.

This system is less affected by noise.

Disadvantages of Closed Loop Control System:

The disadvantages of closed loop control system are:

- They are costlier they are complicated to design.
- Required more maintenance.
- Feedback leads to oscillatory response.
- Overall gain is reduced due to presence of feedback.
- Stability is the major problem and more care is needed to design a stable closed loop system. [6]

2.6 Pitch Displacement autopilot

The basic components of a pitch control system are shown in Fig. (2.6). for this design the reference Pitch angle is compared with the actual angle measured by a gyro to produce an error signal to activate the control servo. In general, the error signal is Amplified and sent to the control surface actuator to deflect the control surface. Movement of the control surface causes the aircraft to achieve a new pitch Orientation, which is fed back to close the loop. Figure (2.5) shows the block diagram of pitch control system.

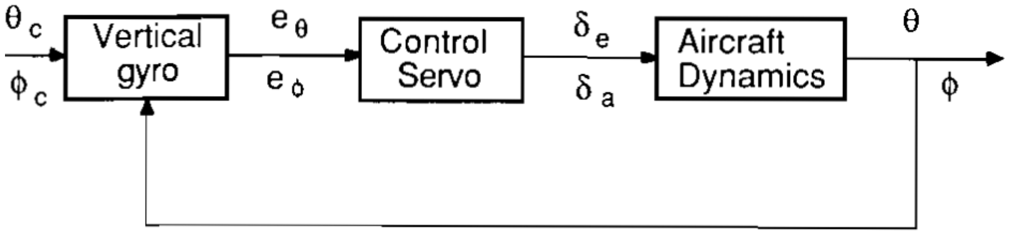


Fig. (2. 5) Block diagram of Block diagram of a roll or Pitch displacement autopilot [7]

Once we have decided upon a control concept, our next step must be to evaluate the performance of the control system. To accomplish this we must define the transfer functions for each of the elements in the block diagram describing the system. For the purposes of this discussion we will assume that the transfer functions of both the gyro and amplifier can be represented by simple gains. The elevator servo transfer function can be represented as a first-order system:

$$\frac{\delta_e}{v} = \frac{1}{\tau s + 1}$$

δ_eWhere υ, and τ: are the elevator deflection angle, input voltage, and servomotor time constant. Time constants for typical servomotors fall in a range 0.05-0.25 s [7].

Finally, we need to specify the transfer function for the airplane. To keep the description of this design as simple as possible, aircraft dynamics can be represented by using the short-period approximation.

2.7 PID controller

Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineers to operate them in a simple, straightforward manner.

The basic idea behind a PID controller is to read a sensor, then compute the desired actuator output by calculating proportional, integral, and derivative responses and summing those three components to compute the output. Before we start to define the parameters of a PID controller, we shall see what a closed loop system is and some of the terminologies associated with it.

As an example of a typical close loop control system, the process variable is the system parameter that needs to be controlled, such as temperature (ºC), pressure (psi), or flow rate (liters/minute). A sensor is used to measure the process variable and provide feedback to the control system. The set point is the desired or command value for the process variable, such as 100 degrees Celsius in the case of a temperature control system. At any given moment, the difference between the process variable and the set point is used by the control system algorithm (compensator), to determine the desired actuator output to drive the system (plant).

For instance, if the measured temperature process variable is 100 ºC and the desired temperature set point is 120 ºC, then the actuator output specified by the control algorithm might be to drive a heater. Driving an actuator to turn on a heater causes the system to become warmer, and results in an increase in the temperature process variable. This is called a closed loop control system, because the process of reading sensors to provide constant feedback and calculating the desired actuator output is repeated continuously and at a fixed loop rate as illustrated in figure (2.6).[8]

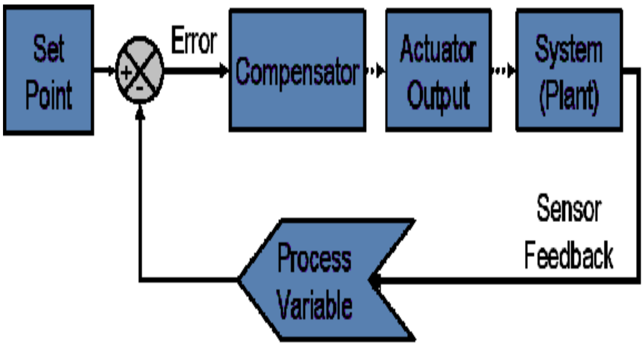


Fig. (2. 6) closed loop control system [8]

The control design process begins by defining the performance requirements. Control system performance is often measured by applying a step function as the set point command variable, and then measuring the response of the process variable. Commonly, the response is quantified by measuring defined waveform characteristics. Rise Time is the amount of time the system takes to go from 10% to 90% of the steady-state, or final, value. Percent Overshoot is the amount that the process variable overshoots the final value, expressed as a percentage of the final value. Settling time is the time required for the process variable to settle to within a certain percentage (commonly 5%) of the final value. Steady-State Error is the final difference between the process variable and set point as it shown in fig (2.7). Note that the exact definition of these quantities will vary in industry and academia.

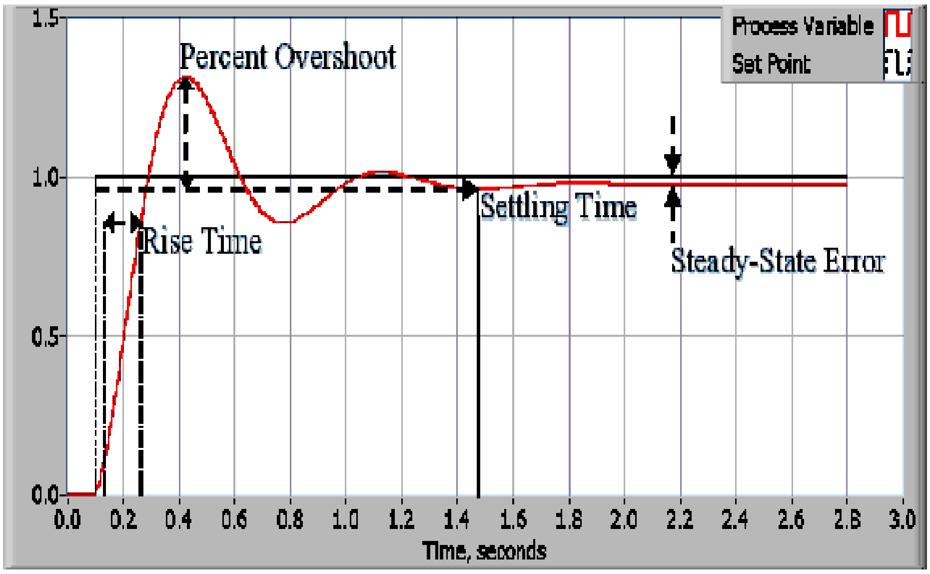


Fig. (2. 7) Response of a typical PID closed loop system

After using one or all of these quantities to define the performance requirements for a control system, it is useful to define the worst case conditions in which the control system will be expected to meet these design requirements. Often times, there is a disturbance in the system that affects the process variable or the measurement of the process variable. It is important to design a control system that performs satisfactorily during worst case conditions. The measure of how well the control system is able to overcome the effects of disturbances is referred to as the disturbance rejection of the control system. In some cases, the response of the system to a given control output may change over time or in relation to some variable. A nonlinear system is a system in which the control parameters that produce a desired response at one operating point might not produce a satisfactory response at another operating point. For instance, a chamber partially filled with fluid will exhibit a much faster response to heater output when nearly empty than it will when nearly full of fluid. The measure of how well the control system will tolerate disturbances and nonlinearities is referred to as the robustness of the control system.

Some systems exhibit an undesirable behavior called dead time. Dead time is a delay between when a process variable changes, and when that change can be observed. For instance, if a temperature sensor is placed far away from a cold water fluid inlet valve, it will not measure a change in temperature immediately if the valve is opened or closed. Dead time can also be caused by a system or output actuator that is slow to respond to the control command as it shown in fig (2.8), for instance, a valve that is slow to open or close. A common source of dead time in chemical plants is the delay caused by the flow of fluid through pipes. Loop cycle is also an important parameter of a closed loop system. The interval of time between calls to a control algorithm is the loop cycle time. Systems that change quickly or have complex behavior require faster control loop rates.[8]

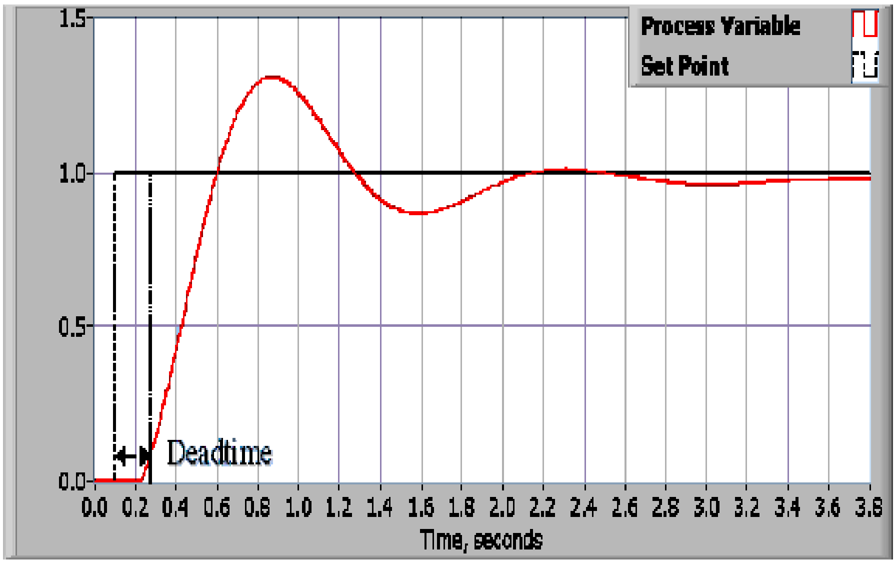


Fig. (2. 8) Response of a closed loop system with dead time [8]

Once the performance requirements have been specified, it is time to examine the system and select an appropriate control scheme. In the vast majority of applications, a PID control will provide the required results. The PID theory is the proportional component depends only on the difference between the set point and the process variable. This difference is referred to as the Error term. The proportional gain (Kc) determines the ratio of output response to the error signal. For instance, if the error term has a magnitude of 10, a proportional gain of 5 would produce a proportional response of 50. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process variable will begin to oscillate.

If Kc is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control as it shown in fig (2.9). [8]

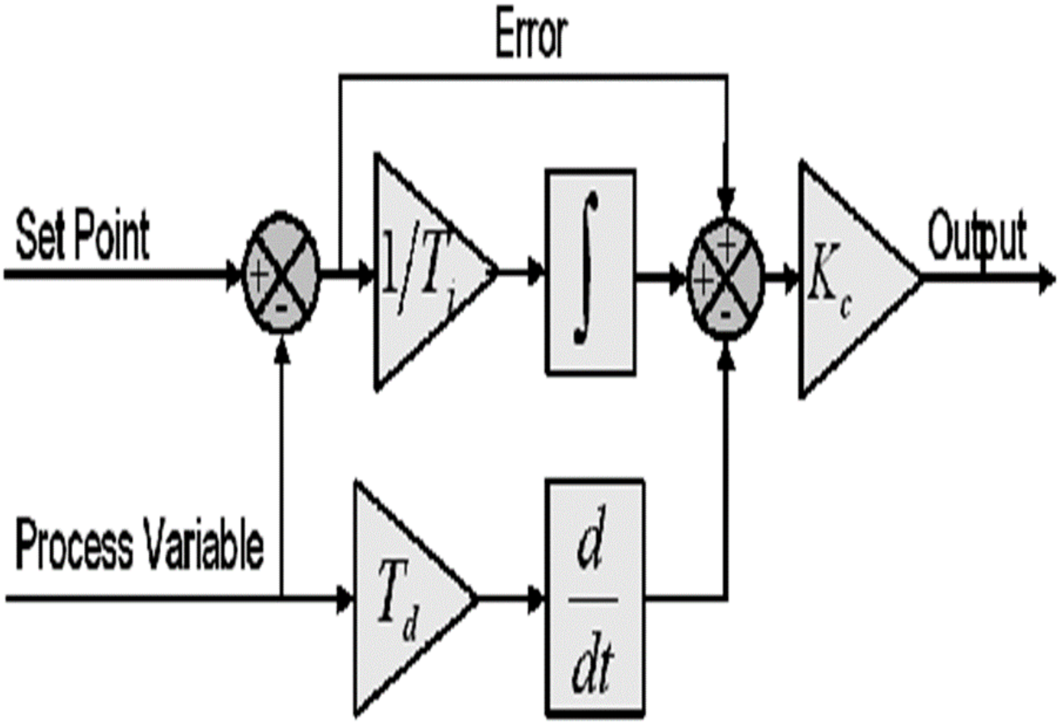


Fig. (2. 9) Block diagram of a basic PID control algorithm

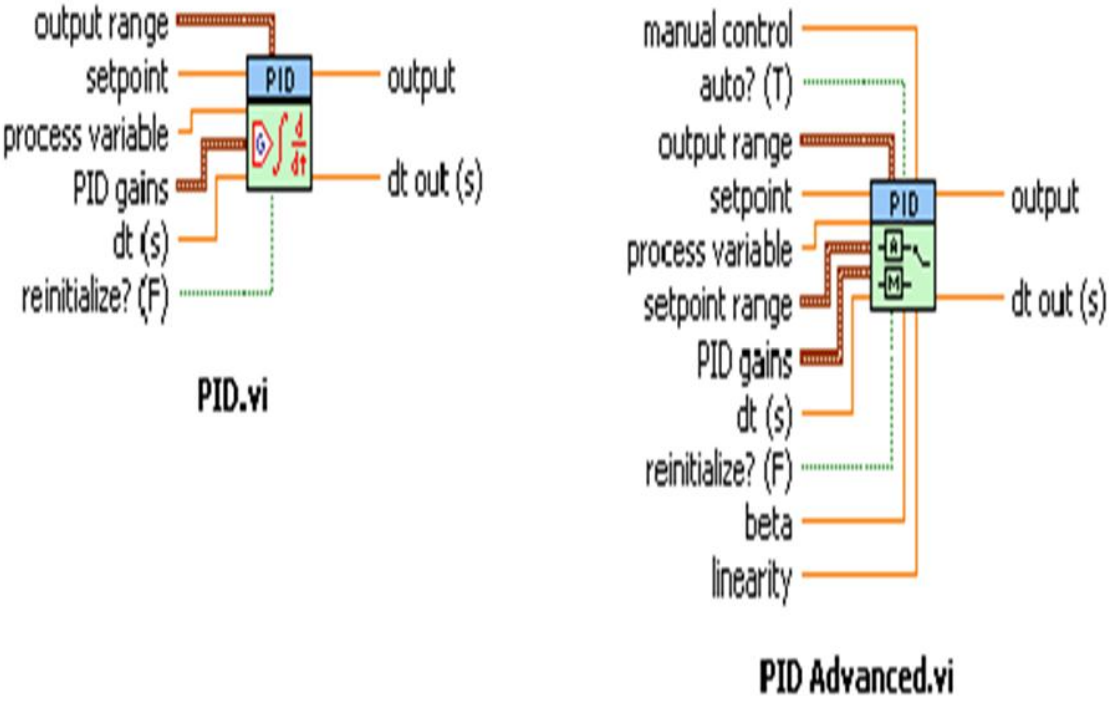


Fig. (2. 10) Block diagram of a basic PID control algorithm [8]

PID palette also features some advanced VIs like the PID Auto tuning VI and the PID Gain Schedule VI. The PID Auto tuning VI helps in refining the PID parameters of a control system. Once an educated guess about the values of P, I and D have been made, the PID Auto tuning VI helps in refining the PID parameters to obtain better response from the control system as it shown in fig. (2.10). [8]

2.8: State feedback controller

this controller is applied on the feedback control system which can be defined as:
A system in which the value of some output quantity is controlled by feeding back the value of the controlled quantity andusing it to manipulate an input quantity
so as to bring the value of the controlled quantity closer to a desired value. Also known as closed-loop control system. And feedback controller can be defined as:
A control system, comprising one or more feedback controls, that combines functions of the controlled signals withfunctions of the commands to maintain prescribed relationships between them. a particular system having dynamics:

$\dot{x}(t) = Ax(t) + Bu(t)$……………………………………………………………(2.1)

$y(t) = Cx(t) + Du(t)$…………………………………………………………… (2.2)

The open-loop system poles are given by eigenvalues of A. By assuming the form of linear state feedback with gain vector k.the input of the system u(t) can be illustrated from fig(2.11) as:

$u(t) = r(t) - Kx(t)$…………………………………...………………………(2.3)

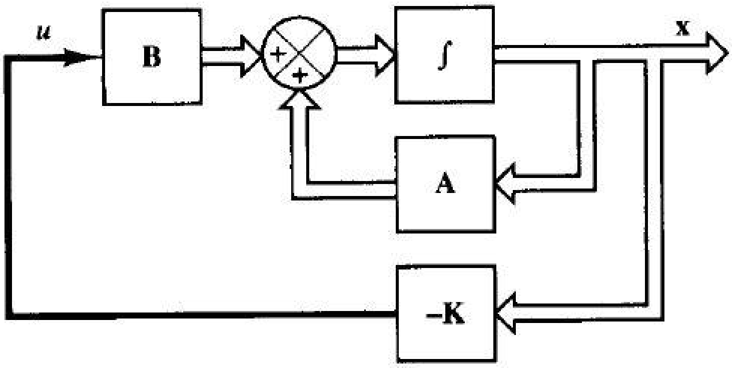


Fig. (2.11) block diagram of state feedback controller

By substitute:

$\dot{x}(t) = Ax(t) + B(r(t) - Kx(t))$………………………………………………..(2.4)

$\dot{x}(t) = (A - BK)x(t) + Br(t)$…………………………………………………(2.5)

$y(t) = Cx(t) + Du(t)$…………………………………………………………..(2.6)

Moreover, transfer function methods are applicable only for linear time invariant and initially relaxed systems. Consider the state-space model of a SISO system as follow:

$x(k+1) = Ax(k) + Bu(k)$…………………………………………………….(2.7)

$y(k) = Cx(k)$………………………………………………………………….(2.8)

Where, u (k) and y (k) are scalar. In state feedback design, the states are feedback to the input side to place the closed poles at desired locations.

Regulation Problem: When we want the states to approach zero starting from any arbitrary initial state, the design problem is known as regulation where the internal stability of the system, with desired transients, is achieved. Control input:

$u(k) = -Kx(k)$………………………………………………………………..(2.9)

Tracking Problem: When the output has to track a reference signal, the design problem is known as tracking problem. Control input:

$u(k) = -Kx(k) + Nr(k)$…………………………………………………....(2.10)

Where *r (k)* is the reference signal.

First we will discuss designing a state feedback control law using pole placement technique for regulation problem.

By substituting the control law (2) in the system state model (1), the closed loop system becomes

$x(k+1) = (A - BK)x(k)$……………………………………………………(2.11)

If K can be designed such that eigenvalues of A-BK are within the unit circle then the problem of regulation will be solved.

The control problem can thus be defined as: Design a state feedback gain matrix K such that the control law given by equation (2) places poles of the closed loop system [9]

$\mathrm{x(k+1) = (A - BK)x(k)}$……………………………………………………(2.12)

2.9: Controllability

Controllability and observability. A system is said to be controllable at a time t_0 if it is possible by means of a constrain control vector to transfer the system from any initial state x (t_0) to any other state infinite in travel in time.

A system is said to be observable at a time t_0 if the system in state x (t_0), it is possible to determine this state from the observation of the output over a finite time in travel. Of the concept controllability and observability where introduced by kalman. They play an important role in the design of control system in state space. In fact the condition of controllability and observability govern the existence of complete solution to the control system design problem. The solution to this problem may not exit if the system considered is not controllable. Although most physical system are controllable and observable corresponding mathematical model may not possess the property of controllability and observability .then it is necessary to know the condition under which a system is controllable and observable. [10]

2.10: Dominate pole

The slowest poles of a system (those closest to the imaginary axis in the s-plane) give rise to the longest lasting terms in the transient response of the system.

If a pole or set of poles are very slow compared to others in the transfer function, then they may dominate the transient response.

If we plot the transient response of the system without accounting for the transient response of the fastest poles, we may find little difference from the transient response of the original system. [10]

2.11: Prefix research

David Hyunchul Shim, Hyoun Jin Kirn and Shankar Sastry made a research “hierarchical control system synthesis for rotator craft-based unmanned aerial vehicle” which introduces the development of multiple Number of Unmanned Arial Vehicle (UAV) system as a part of BErkeley AeRobot (BEAR) project, highlighting the recent achievements in the design and implementation of rotorcraft-based UAV (RUAV) control system. Based on the experimental flight data, linear system model valid near hover Condition is found by applying time-domain numerical methods to experimental flight data. The Acquired linear model is used to design feedback controller consisting of inner-loop attitude feedback Control, mid-loop velocity feedback control and the outer-loop position control. The proposed vehicle level Controller is implemented and tested in Berkeley UAV, Ursa Magna 2, and shows superior Hovering performance. The vehicle level controller is integrated with higher-level control using a script Language framework to command UAV. [11]

Paula Raica made a research “Autonomous vehicle technologies for small fixed-wing UAV” which objective is to describe the design and implementation of a small semiautonomous fixed-wing unmanned air vehicle. In particular we describe the hardware and software architectures used in the design. We also describe a low weight, low cost autopilot developed at Brigham Young University and the algorithms associated with the autopilot Novel PDA and voice interfaces to the UAV are described. In addition, their approach is to real-time path planning, trajectory generation, and trajectory tracking. The research is augmented with movie files that demonstrate the functionality of the UAV and it control software. [12]

Mohammed Mahmoud et al designed an UAV “Designed and build UAV with Coaxial Propeller” in order to meet the specifications required for surveillance and reconnaissance mission. A project was undertaken to study & design Co-axial propeller for Small unmanned aerial vehicle UAV the Static and dynamic analysis for a stability model using the digital DATCOM had shown UAV is stable statically and dynamically. The mode needs a control system (autopilot) so it can be able to work efficiently and that what we hope to achieve.

CHAPTER THREE

Analysis and Design

The UAV model With Coaxial Propeller fig (3.1)

Fig. (3. 1) the UAV model

In this chapter we will show our approach which is using MATLAB and MATLAB/SIMULINK for analysis and design a suitable controller to achieve our objectives to design a pitch control system for the UAV model

3.1: The coaxial propeller UAV model state variables

The longitudinal derivatives of the UAV model have been derived in prefix research and the model state variables matrixes are:

$$A = \begin{bmatrix} -0.0076 & 0.0052 & 0 & -32.2 \\ -0.0111 & -0.0023 & 154.2 & 0 \\ 0.0013 & -0.1317 & -3.7981 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -0.03365 \\ -0.002302 \\ -17.62 \\ 0 \end{bmatrix} \qquad c = [0 \quad 0 \quad 0 \quad 1] \qquad D = 0$$

3.2: The design requirement we want to achieve:

1- the overshoot required is to achieve less than 5%

2- the steady state error will be equal or less 0.1

3- the settling time will be one second

3.3: analysis components

1- MATLAB

Longitudinal stability of the model has been checked with the system state variables matrixes A, B,C, D which mentioned previously and the step response in obtained using MATLAB commands step(sys,t) , t=0:10:10000

Then the steady space of system found by the code blow.

This code has been used to minimize the scale and plot the step response of the system of the UAV model.

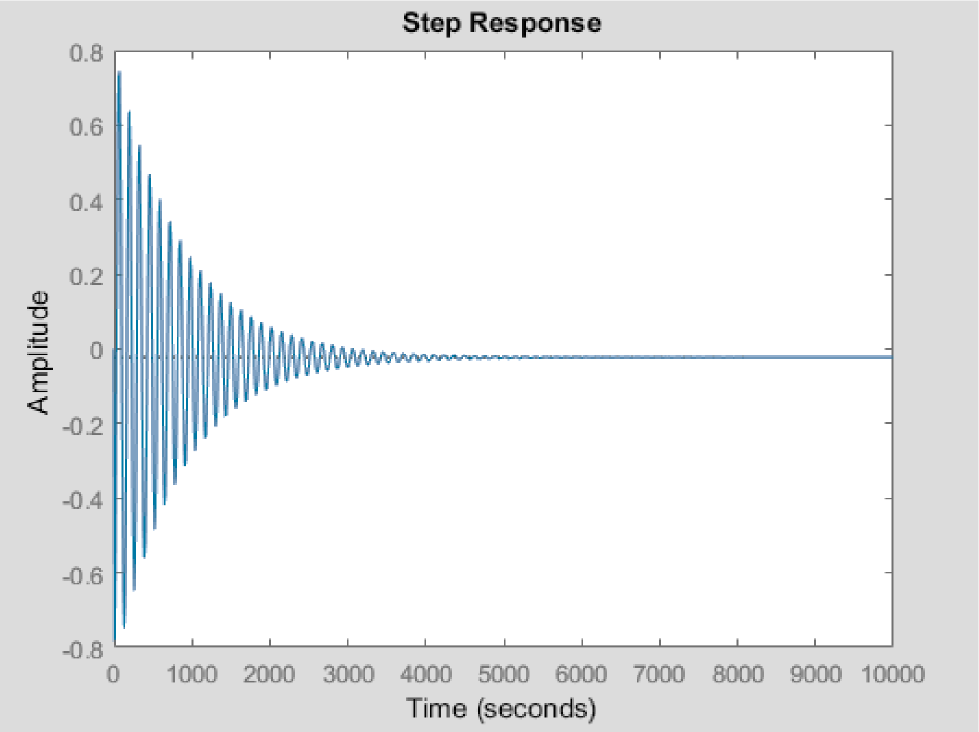


Fig. (3. 2) step response of pitch angle of the UAV model

From the figure the UAV reach to the damping point at 7000 seconds =116.6 MINUTS =1.94 hours which shows the system can’t be stable until after 2hr.

3.4: pitch control

The basic components of a pitch attitude control system are shown in the block diagram fig (3.3), the block is representation of a displacement autopilot with pitch rate feedback for improved damping, in the inner loop the pitch rate is measured by a rate gyro and fed back to be added with the error signal Generated by the difference in pitch attitude. [7]

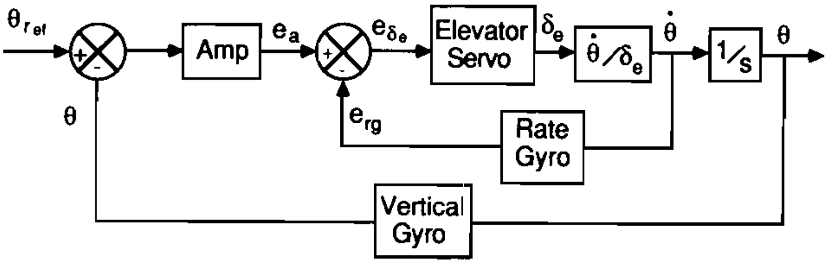


Fig. (3. 3) Block diagram of a pitch altitude control system employing pitch rate feedback

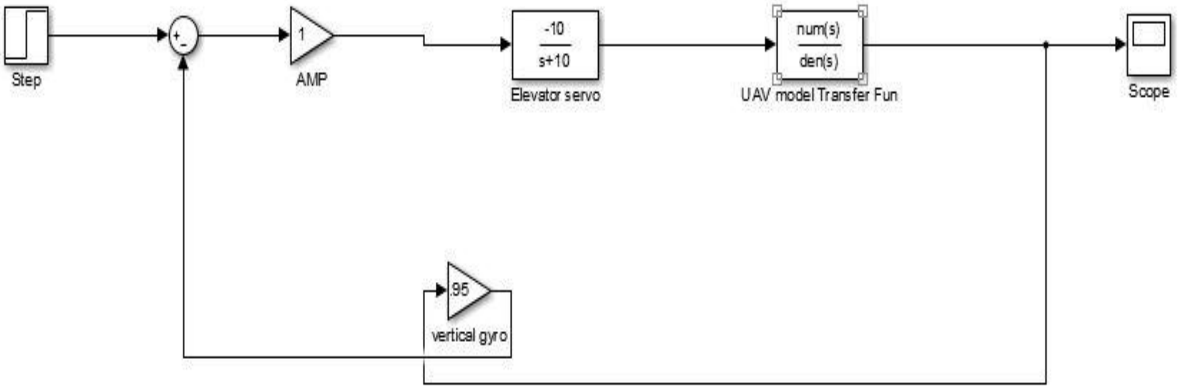


Fig. (3. 4) the implement of the pitch altitude control system in MATLAP/SIMULINK

1- **Amplifier:**

It amplify the input of the pitch angle it’s applied as gain in SUMLINK.

2- **Elevator servo:**

The elevator servo transfer function can be represented as a

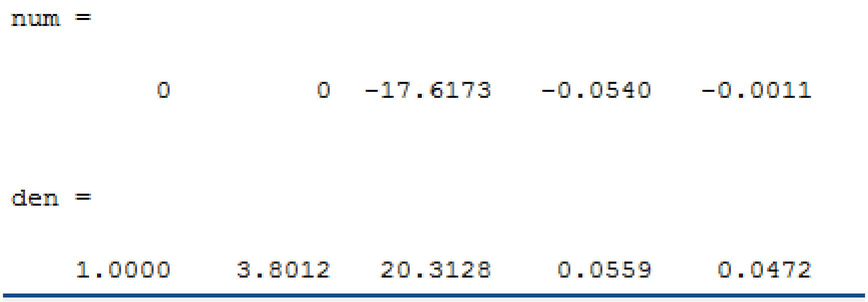
First-order system:

$$\frac{\delta_e}{v} = \frac{1}{\tau s + 1}$$

The basic value have been used which it’s
Num = [0 -10] & den= [1 10]

3-the transfer function of the system (pitch angle)

We found the system o/p by MATLAB code which shown in prefix mat work.



```
num =

         0         0  -17.6173   -0.0540   -0.0011


den =

    1.0000    3.8012   20.3128    0.0559    0.0472
```

4-vertical gyro:

The vertical gyro improve the stability of aircraft, vertical gyro have stander value of .95 [7]

As it shows in the block of implementing of the pitch control by ATLAB/SIMULINK the I/P added as unit step and the O/P appear by scope which gives the step response of the pitch control.

After adding PID controller:

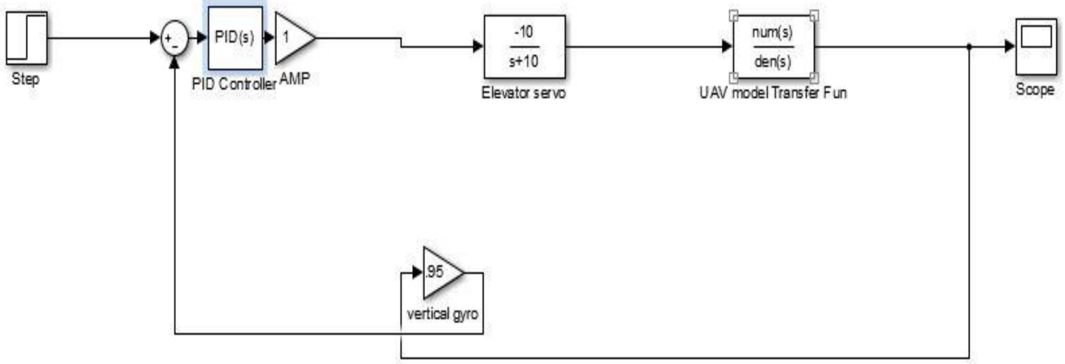


Fig. (3. 5) the implement of the pitch altitude control system in MATLAB/SMULINK with PID

3.5: State feedback controller

Dependent on the desired overshoot damping ratio can be computed by equation (3.1) the equation of feedback controller:

$$M_p = e^{-\pi\zeta/\sqrt{1-\zeta^2}} \qquad \text{………… ……………………………………………………} (3.1)$$

This Eq have been use to find the value of ζ_i (the damping ratio) to use it to come up with the desired transfer function which it's:

$\zeta_i = 0.69$

M_p = over shoot

$t_s = \frac{4}{\varsigma * \omega_n}$……………. …. ………………………………………………………(3.2)

this Eq have been use to find the value of ($ῴ_n$) to use it to come up with the desired transfer function which it's

$ῴ_n$ = 5.88

$\frac{k\, ῴ_n^2}{s^2 + 2 * \varsigma * ῴ_n * s + ῴ_n^2}$ ………….. ……………………………………………. (3.3)

After implementing the ῴn and ς and $k = 1$ in Eq (3.3)

$$\frac{33.6}{s^2+8s+33.6}$$

We use series gain in MATLAP code to convert it to:

$\frac{1128.9}{s^4+16s^3+131.2s^2+537.6s+1129}$ ……………. ………………………..………………(3.4)

to find the feedback controller value (k) we use the Eq:

$|SI - A + BK| = S^4 + 16S^3 + 131.2S^2 + 537.6S + 1129$ ……………………(3.5)

from Eq. (5) we find the value of k by using MATLAB code of (K=place(A, B, p))

CHAPTER FOUR

Results & Discussion

In the beginning the model was analysis using MATLAB and the result of longitudinal displacement show that the model has along settling time shown and need control system, firstly the PID controller was used to control the model but it didn't achieve the desired requirement, second we use the state feedback controller which gave us the desired response that we wanted.

4.1: Result of the analysis of pitch angle for the UAV model without control system

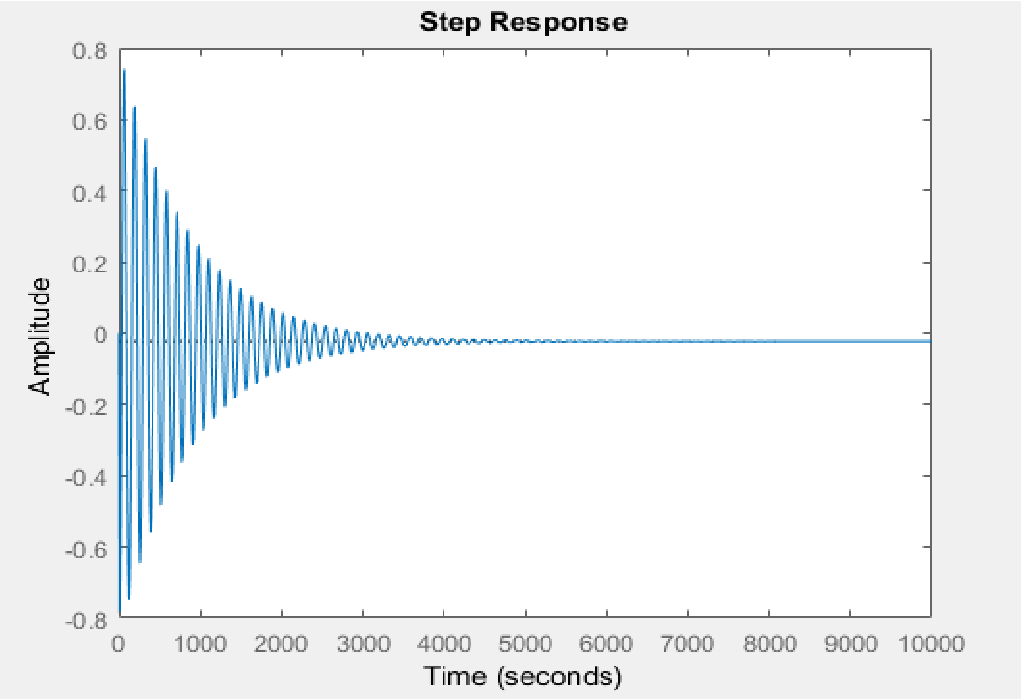


Fig. (4. 1) step response of pitch angle of the UAV model

We check the longitudinal stability of the model by using MATLAB and The response of the UAV model without control system show that the time settling of the model is 1.94 hour, that mean the UAV need 1.94 hour to fully damping if it distributed by external force and that mean it need control system

4.2: result of implement of the pitch altitude control system in (MATLAB/SIMULNK)

The pitch altitude control system has been implemented in MATLAB and the result of the block diagram shown in figure (4.2).

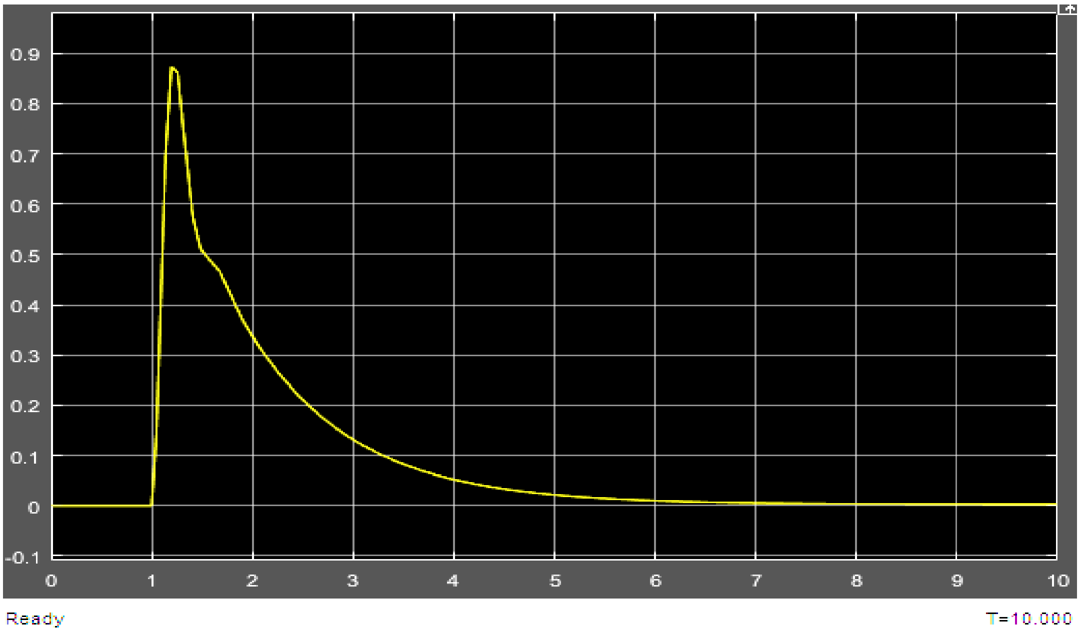
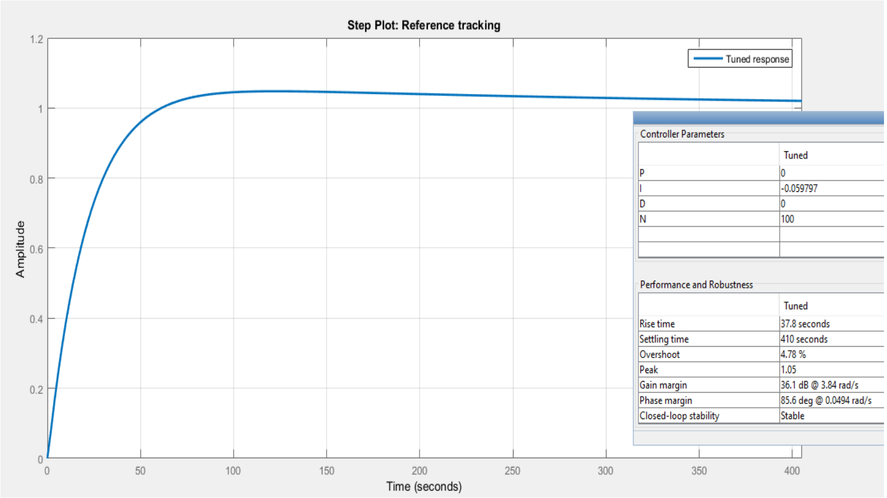


Fig. (4. 2) the response of pitch angle of the UAV without PID controller

As it shown the step response at zero level that’s mean there is no out put

4.3: result of implement of the pitch altitude control system in MATLAB/SIMULINK with PID

The PID controller have been insert to the system but we didn't get the desired response as it shown in figure (4.3)



Controller Parameters

	Tuned
P	0
I	-0.059797
D	0
N	100

Performance and Robustness

	Tuned
Rise time	37.8 seconds
Settling time	410 seconds
Overshoot	4.78 %
Peak	1.05
Gain margin	36.1 dB @ 3.84 rad/s
Phase margin	85.6 deg @ 0.0494 rad/s
Closed-loop stability	Stable

Fig. (4. 3) step response of the implement of the pitch altitude control system in MATLAP with a PID controller

The rise time was 37.8 sec, the settling time was 410 sec and the over shoot was 4.78% as it seem the PID result didn’t achieve the desired requirement we want

4.4: results of state feedback controller

4.4.1 Result of desired requirement of state feedback controller:

The response of the desired requirement of the state feedback controller have been found with MATLAB code from Eq (3.4) (return to appendix)

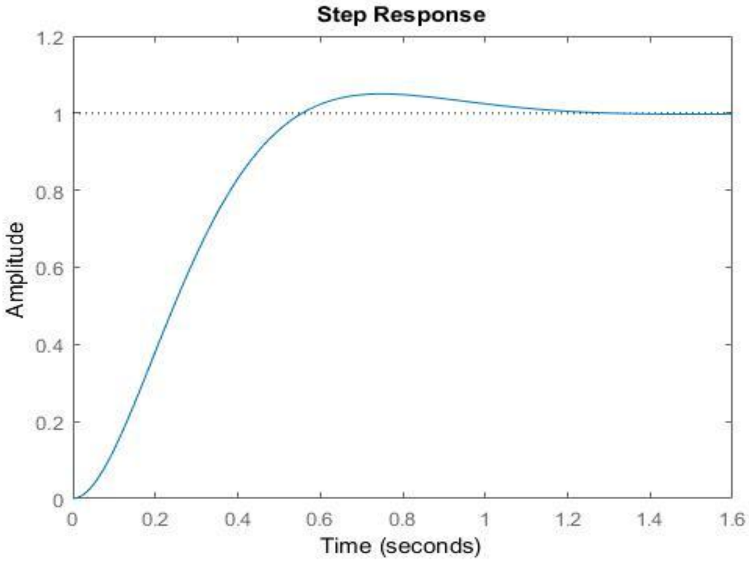


Fig. (4. 4) step response of pitch angle for the desired requirement of the state feedback controller

As shown in fig (4.4) the over shoot was 5%, the steady state error was 0.1 and the settling time was 1.21 second.

4.4.2: result of state feedback controller of the UAV model

After the state feedback controller have been used the desired response was obtained as shown in fig (4.5)

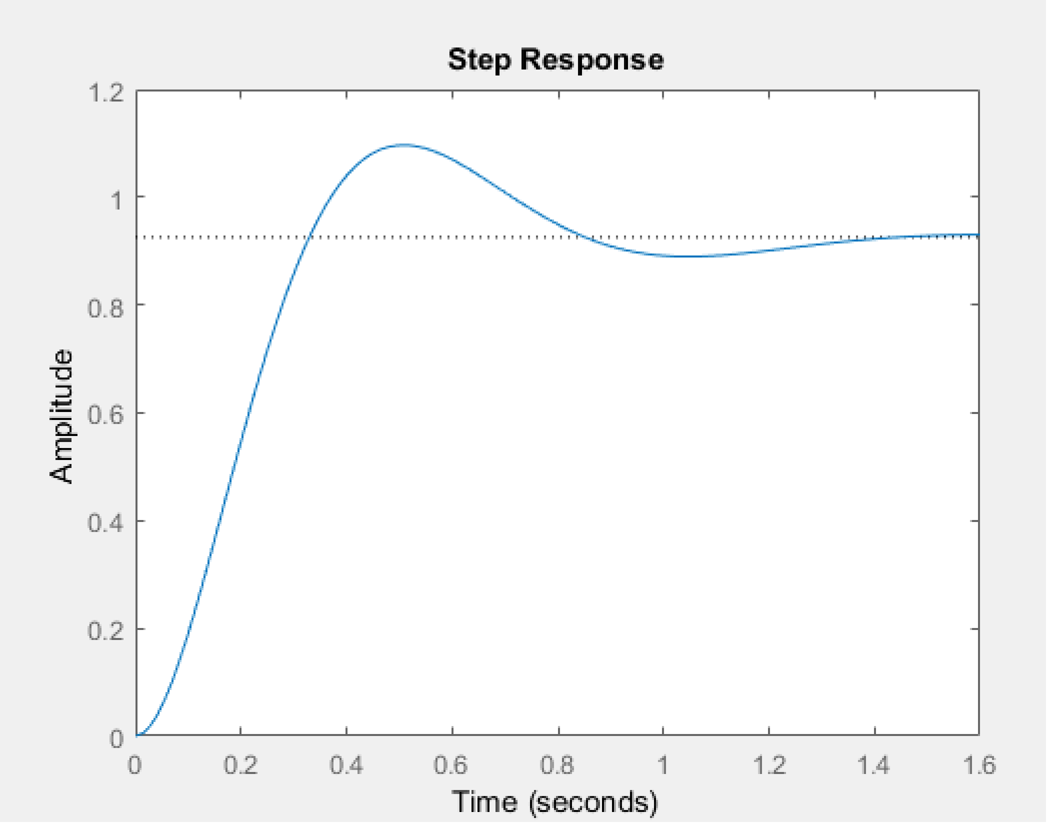


Fig. (4. 5) step response of pitch angle by state feedback controller

The result of the state feedback controller achieve the rate of the desired requirement of the pitch control of the UAV model as it shown in fig(4.5) it has been found that the overshot 8% , the steady state error was 0.1 and the settling time 1.3 second .

The values of gain of the feedback controller (k) evaluated from MATLAP is:

k1= 4.6021

k2= 4.0420

k3= 5.4998

k4= 0.0807

And the results of the Eigenvalues of the desired requirement of the state feedback control of the UAV model is:

-3.32 + 5.600i

-3.323 - 5.600i

-4.676 + 2.180i

-4.676 - 2.1801i

And the results of the Eigenvalue of the UAV model after been controlled by using the state feedback controller is :

-3.323 + 5.600i

-3.323 - 5.600i

-4.676 + 2.1801i

-4.676 - 2.1801i

As it shown the Eigenvalue of the desired requirement and the Eigenvalue of the UAV model after been controlled by using feedback controller is approximate the same.

CHAPTER FIVE

Conclusion, Recommendations and Future Work

5.1 Conclusion

After analysis by using MATLAB, the UAV model seemed to have a long settling time and the solution to this problem is to design one of the suitable controllers to Control the model, Firstly PID controller have been used but it didn’t achieve the desired requirement but after using state feedback controller it helped to achieve the desired requirement of the pitch control system for the UAV model.

5.2 Recommendations and Future Work

Check the lateral & directional stability of the UAV model and design one of the suitable controllers to Control the model laterally and directionally, and implement the theoretical design to an actual practical model controller to control the UAV model.

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APPENDICES

Appendix A: STATE SPACE CALCULATION

```
%calculations for long

Cydeltar =-0.0135192662398883;

Cndeltar =0.0567370474494455;

Cldeltar =-0.0

m = 167.653 ;%mass of uav

S = 14.80812952 ;%wing refrence area

AR = 11.3; % Aspect Ratio

e = 0.9 ;% Oswald efficiency factor

b = 12.9356818; %span

Cbar = 1.17691321; %mean areodynamic cord

U = 154.2 ;%design cruise speed

p = 0.002378 ;%air density

g = 32.2 ;%gravity constant

Cla =0.09436 ;%aircraft lift curve slope

Cmq =-31.1574 ;%change in pitching moment due to change in pitch rate

Clq =6.38275 ;%change in lift cofficient due to changein pitch rate

Cmu = 0.007047 ;%change in pitching moment due to changein forword speed

Clu = 0 ;%change in lift cofficient due to change inforward speed

Cdu =0; %Drag Change with forwardspeed

Cma = -0.7563 ;%pitching moment change with angle ofattack

Cl0 = 0.344 ;%wing zero lift

Cd0 = 0.024 ;%wing zero drag

Clat= 5.4981; %tail lift curve slop

Vh = 0.7 ;%volume of the horizontal tail

t = 1 ; %tail efficiency

down =0.156 ; %downwash

Lt = 5.8 ; %tail moment arm

Clai = 0.142381158 ;%change in lift force due toelevator deflection

Cmai = -0.656325446 ;
```

```
CDdeltae = 0.0135; %change in MOMENT due toelevator deflection
Iy= 18.32359572 ; %inertia
Q = 28.22405; %Dynamic pressure
% lateral inputs
Ix = 2.371494762;
Iz = 19.26043419;
Cybeta = -1.13319264334939;
Cnbeta = 0.401521483934691;
Clbeta = -0.1347;
Cyp = -0.000287755824147965;
Cnp = -0.0479796877158797;
Clp= -0.0105;
Cyr = 0.869496571048604;
Cnr = -0.3682;
Clr = 0.2118;
Cydeltaa = 0;
Cndeltaa = -0.00238399695629669;
Cl=135192662398883;
theata0 =0;
%calculations for long
Xu = - ( Cdu + 2 .* Cd0 ).* Q .* S ./( m .* U );
Xdeltae=-Q*S*CDdeltae/m;
XdeltaeP=Xdeltae;
Zu = - ( Clu + 2 .* Cl0) .* Q .* S ./( m .* U );
Zw = - ( Cla + 2 .* Cd0) .* Q .* S ./( m .* U );
Za = U .* Zw ;
Czq= -2 .* t .* Clat .* Vh ;
Zq = ( Czq .* Cbar .* Q .* S)./( 2 .* U .* m );
Mu = ( Cmu .* Q .* S .* Cbar )./( U .* Iy );
Mw = (Cma .* Q .* S .* Cbar )./( U .* Iy );
Ma = U .* Mw ;
Mq = ( Cmq .* Q .* S .* Cbar .* Cbar )/( 2 .* U .* Iy)
;
```

```
Xw = -( Cd0 - Cl0 ) .* Q .* S / ( m .* U );
Czaa = - 2 .* t .* Clat .* Vh .* down ;
Zww = ( Czaa .* Q .* S .* Cbar) /( 2 .* U .* m .* U );
Zalphadot = U .* Zww ;
Czai = - Clai ;
Zdeltae = Czai .* Q .* S ./ m ;
Cmaa = - 2 .* t .* Clat .* Vh .* Lt .* down ./ Cbar ;
Mww = Cmaa .* Cbar .* Q .* S .* Cbar ./( 2 .* U .* U .*Iy ) ;
Malphadot = U .* Mww ;
Mdeltae = Cmai .* Q .* S .* Cbar ./ Iy;
MdeltaeP=Mdeltae+Malphadot*Zdeltae/(U-Zalphadot);
ZdeltaeP=Zdeltae/(U-Zalphadot);
% calculate state space long.
Al = [ Xu Xw 0 -g ; Zu Zw U 0 ; (Mu + Mww * Zu) (Mw + Mww* Zw) (Mq + Mww * U ) 0 ; 0 0 1 0 ] ;
B = [XdeltaeP ZdeltaeP MdeltaeP 0];
b=eig(Al);
```

Appendix B: State feedback controller MATLAP CODE

```
num1=[0 0 -17.6173 -.054 -.0011 ]
den1=[1 3.8012 20.3128 .0559 .0472]
g1=tf(num1,den1)
num2=[0 -10]
den2=[1 10]
g2=tf(num2,den2)
k1=1
k2=.95
g3=series(g1,g2)
g5=series(g3,k1)
g4=feedback(g3,k2,-1)
num4=[176.2 .54 .011 ]
den4=[1 13.8 85.32 370.5 1.119 .4824]
numd=[1128.9]
dend=[1 16 131.2 573.6 1129]
[add,bdd,cdd,ddd]=tf2ss(numd,dend)
eiggd=eig(add)
gd=tf(numd,dend)
p=roots(den4)
syms s
y=(s+2.4541+5.969i)*(s+2.4541-5.969i)*(s+0.0014+0.0361i)*(s+0.0014-0.0361i)
n=[176.2 .54 .011]
t=p(2:5)
 kg=1/8.889
 [A,B,C,D]=zp2ss(n,t,kg)
 sys=ss(A,B,C,D)
 Co=ctrb(A,B)
 unco=length(A)-rank(Co)
a=canon(sys,'modal')
% v=s*eye(4)
 % f=v-A
```

```
 format long
 A
% syms k1 k2 k3 k4
% k=[k1 k2 k3 k4]
%L=B*k
%zom=[s+k1 k2-.4 k3 k4;-.4 s 0 0;-1 4881 s+4.9 6.5;0 0 -6.5 s]
% mazin=det(zom)
 Z=roots(dend)
 K=place(a.a,a.b,Z)
 Ad=a.a-a.b*K
 eigg=eig(Ad)
 %forword gain
 m=-((cdd*(add^-1)*bdd))^-1
 [numm,denn]=ss2tf(Ad,B,C,D)
 numm=numm*m/85
 desys=tf(numm,denn)
subplot(2,1,1)
step(gd)
subplot(2,1,2)
step(desys)
```