CERTIFICATION OF APPROVAL

Stability Analysis of Micro Unmanned Aerial Vehicle during Vertical Take-Off and Landing

By

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

Micro aerial vehicle refers to a class of unmanned air vehicle UAV that is restricted by size and may have various levels of autonomy. Unmanned Aerial Vehicle (UAV) is new technology that its potential is not fully discover in our country. In the developed country, the Unmanned Aerial Vehicles (UAV) market is developing rapidly and presents a growing number of opportunities. The public is increasingly adverse to the risk of causalities and prefers to substitute technology for lives. So it is important to have a research project on this to as an initial step for future development.

The purpose of this project is to analyze the stability of Micro Unmanned Aerial Vehicle (MUAV) during vertical-take off and Landing (VTOL) operation. In order for successful operation of VTOL of UAV, the stability of the body should be maintained. One of the factors that can affect the stability of MUAV is unbalanced power caused by different propulsion output by the engine. The working prototype is not the objective that must be achieved within the allocated time for this project. The scope of study of this project is mainly on stability analysis of MUAV involving dynamic motion in x, y, z, roll, pitch, yaw axes, control system concept and simulation of the VTOL mechanism. Control system will deal with state feedback concept and state feedback controller. The dynamic and mathematical model was developed in order to simulate with Matlab7.1 software. The expected result of simulation analysis will be operational strategy during VTOL operation. The angle of MUAV body should be zero for the system to be stabile. Thus, it meets the objective of the project.

ACKNOWLEDGEMENT

With the name of ALLAH S.W.T, the most merciful, I would like to express my highly gratitude to my supervisor, Ir Idris Ibrahim for giving me the opportunity and trust given in assigning me to this project and gave a lot of guidance in this project. This project would not have been successfully completed if not for his knowledge, support, attention and constant encouragement. I would like also to thank my Final Year Coordinator, Dr. Saravanan for his kind effort in providing me with all the guidelines and technical expertise to ensure the successful of this project.

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Last but not least, I would like to thank everyone who helps me directly and indirectly in completing Final Year Project.

LIST OF FIGURE

LIST OF TABLE

LIST OF ABBREVIATIONS

MUAV	Micro Unmanned Aerial Vehicle
UAV	Unmanned Aerial Vehicle
VTOL	Vertical Take-off and Landing
QRT	Quad Rotor Type

TABLE OF CONTENT

CHAPTER 1

INTRODUCTION

1.1 Background of study

An unmanned aerial vehicle (UAV; also known as a remotely operated aircraft) is an aircraft that flies without a human crew. Their largest uses are in military applications. To distinguish UAVs from missiles, a UAV is defined as a reusable, uncrewed vehicle capable of controlled, sustained, level flight and powered by a jet or reciprocating engine. Therefore, cruise missiles are not considered UAVs, because, like many other guided missiles, the vehicle itself is a weapon that is not reused, even though it is also unmanned and in some cases remotely guided (Wikipedia 2009). UAV may come in wide variety in term of shapes, sizes, configurations, and characteristics. The earliest UAV was A.M. Low's "Aerial Target of 1916. A number of remote-controlled airplane advances followed, including the Hewitt-Sperry Automatic Airplane, during and after World War I, including the first scale RPV (Remote Piloted Vehicle) in 1935. Jet engines were applied after WW2,in such types as the Teledyne Ryan Firebee I of United States Navy in 1955 (Taylor et al 2009). Vertical takeoff and landing (VTOL) capability brings many operational benefits to an aircraft. Whereas conventional transportation depends on airports and long, paved runways, VTOL can be performed in a quite compact area. VTOL aircraft offers a compromise between helicopter like vertical flight and efficient wing-borne cruise. Building a UAV demands a vast knowledge of base vehicle platforms, flight dynamics, control theory, and real time software in a network environment. The flight system enables the aircraft platform to serve as autonomous agent. It requires sophisticated navigation sensors and integration methodologies for accurate and reliable autonomous operation (Al Quttub 2006).

1.2 Problem statement

The take-off and landing is very critical in the micro unmanned Ariel vehicle operation. Unbalanced power caused by different propulsion output by the engine may result in the crash of the vehicle. The requirement of the operation is to have stable take-off and landing operation. Thus, it is important to analyze the stability of the system especially during take-off and landing operation and hence, the formulation of the operational strategy can be developed.

1.3 Objectives

1. Analyze the stability of micro unmanned Aerial Vehicle (MUAV) especially during vertical take off and landing operation.
2. Design stability control system for VTOL operation of MUAV.
3. Modeling and simulation of the design.

1.4 Scope of Study

This project is aimed to analyze the stability of the micro unmanned Aerial Vehicle during take-off and landing operation. The scope of study also includes designing the control system for VTOL mechanism of MUAV. Hence, perform the dynamic modeling and simulation using Matlab 7.1. The expected output would be the operational strategy during take-off and landing of MUAV. The working prototype is not the objective that must be achieved at the end of allocated time of this project.

CHAPTER 2

Literature Review

2.1 Flight Dynamic

In flight dynamics, pitch, roll and yaw angles measure both the absolute attitude angles (relative to the horizon/North) and *changes* in attitude angles, relative to the equilibrium orientation of the vehicle. These are defined as (Stengel 2004). In this project the yaw, pitch, and roll is used to predict the possible motion that can affect the stability of body of MUAV. Hence this three reference axes need to be considered in designing the stability control system of MUAV during a VTOL operation.

- Pitch - Angle of X Body Axis (nose) relative to horizon. Also a positive (nose up) rotation about Y Body Axis
- Roll - Angle of Y Body Axis (wing) relative to horizon. Also a positive (right wing down) rotation about X Body Axis
- Yaw - Angle of X Body Axis (nose) relative to North. Also a positive (nose right) rotation about Z Body axis

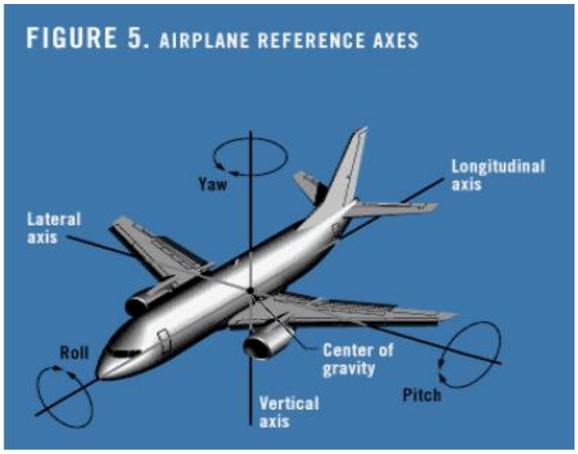

Figure 2.1: airplane reference axes (Stengel 2004

2.2 Rotorcraft

A rotorcraft or rotary wing aircraft can be defined as a heavier-than-air flying machine that uses lift generated by wings, called rotor blades that revolve around a mast. Several rotor blades mounted to a single mast are referred to as a rotor. There are several configurations available for the rotorcraft system with multiple rotors embedded into the structure; single rotor, twin rotor and multiple rotors (Wikipedia 2010). Rotorcraft has been chosen due to their compact configurations that give high thrust to weight ratio. For the MUAV, we choose quad rotor type fan (Hidayah 2009).

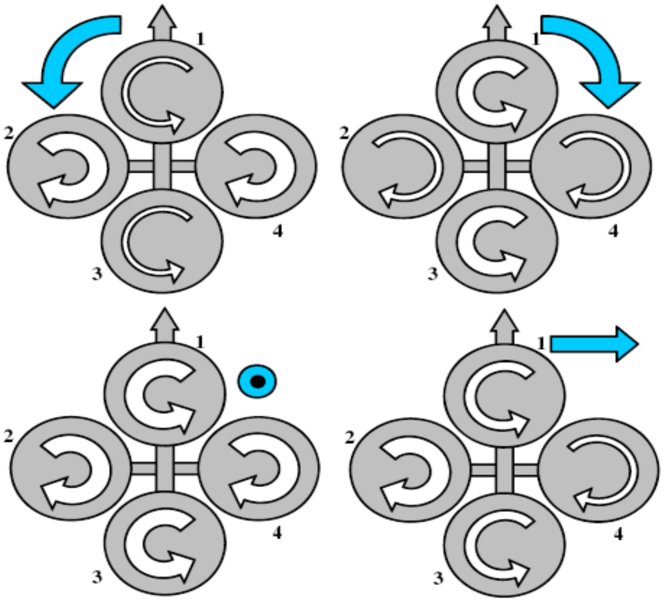

Figure 2.2: Quad Rotor Type (QRT) Motion principle (Springer Science 2009)

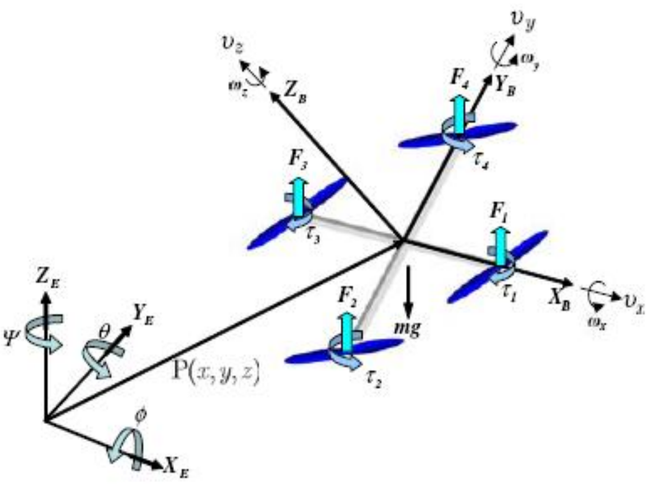

Figure 2.3: Coordinate system of MUAV rotorcraft (Springer Science 2009)

2.2.1 Quad Rotor

By varying each rotor speed, the quad rotor can change the lift force and create motion. Thus increasing or decreasing the four propeller speeds alone generates vertical motion for VTOL (Hidayah 2009). The quad rotors target are thus related to the four basic movements which allow the helicopter to reach a certain height and attitude which is throttling or vertical motion, roll, pitch and yaw (Boabdallah et al 2004).

Figure 2.4: Quad Rotor Fan (www.rcgroups.com)

2.3 Control System

Control theory addresses the automation of physical system, i.e. making system a given system behave in desired manner by using appropriate mathematical control theory (Bernardi 2010). The stability control system of MUAV was modeled using a block diagram. Each block diagram in that system represents the element of MUAV during a VTOL operation. There is two basic form of control system (Bolton 2003).

1. Open loop

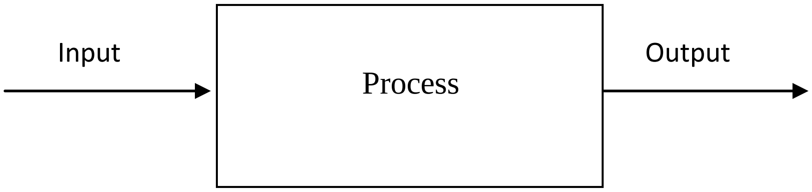

Figure 2.5: Open loop system

2. Closed loop

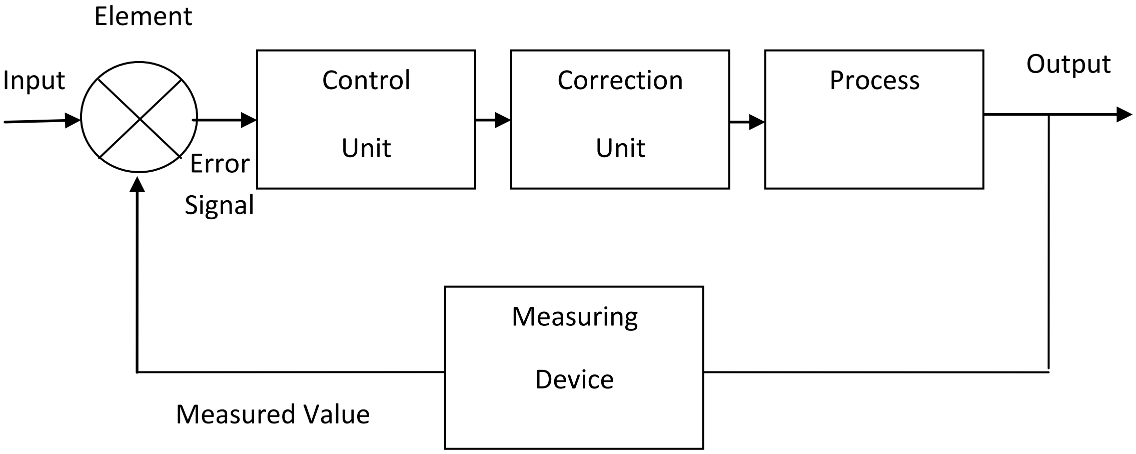

Figure 2.6: Closed loop system

In a closed loop control system, the output does have an effect on the input signal, modifying it to maintain an output signal at the required value. Closed loop systems have the advantages of being relatively accurate in matching the actual to the required values (Bolton 2003).

2.4 State-feedback Controller

The main design approach for systems described in state-space form is the use of state feedback. One selects pole locations to achieve a satisfactory dynamic response and develops the control law for the closed-loop system that corresponds to satisfactory dynamic response. The design of state- variable feedback for closed loop pole placement consists of equating the characteristic equation of a closed loop system to a desired characteristic equation and then finding the values of the feedback gains, K_i (Nise 2004).

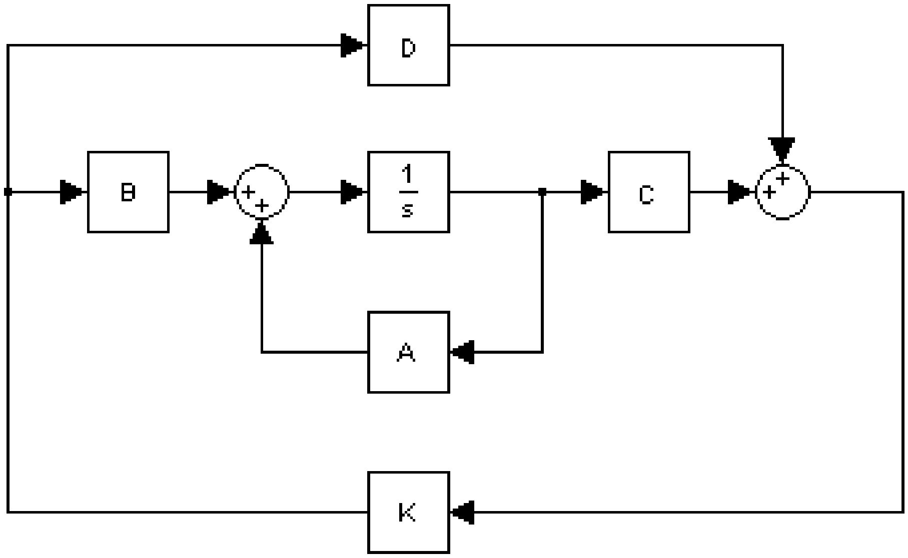

Figure 2.7: State space model with feedback (Wikipedia 2010)

The state equations for the closed loop system can be written by inspection as (Nise 2004):

$\dot{x} = Ax + B(-Kx + r) = (A - BK)x + Br$ (Equation 1a)

$y = Cx$ (Equation 1b)

According to Nise 2004, to apply pole placement methodology to plants represented in phase-variable form. We take following steps:

1. Represent the phase-variable form
2. Feed back each phase variable to the input of the plant through a gain K_i.
3. Find the characteristic equation for the closed loop system represented in step 2
4. Decide upon all closed loop pole locations and determine an equivalent characteristic equation.
5. Equate like coefficient of the characteristic equations from steps 3 and 4 and solve for K_i.

Following this steps, the phase variable representation of the plant is given by

$$A = \begin{pmatrix} 0 & 1 & 0 \; \dots & 1 \\ \vdots & & \ddots & \vdots \\ -a0 & -a1 & -a2 \cdots & -an-1 \end{pmatrix} \qquad \text{(Equation 2a)}$$

$$B = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 1 \end{bmatrix} \qquad \text{(Equation 2b)}$$

$$C = (c1\; c2\; \dots cn) \qquad \text{(Equation 2c)}$$

The characteristic equation plant is thus

$$S^n + a_{n-1} S^{n-1} + \dots + a_1 s + a_0 \qquad \text{(Equation 3)}$$

Now form the closed loop system by feeding back each state variable to u forming

$$u = -Kx \qquad \text{(Equation 4)}$$

$$A - BK = \begin{pmatrix} 0 & 1 & 0 & \cdots & 0 \\ \vdots & & \ddots & & \vdots \\ -(a0 + k1) & -(a1 + k2) & -(a2 + k3) & \cdots & -(an - 1 + kn) \end{pmatrix} \quad \text{(Eq5)}$$

The characteristic equation of the closed loop system can be written by inspection as

$$\det(sI - (A - BK)) = s^n + (a_{n-1} + k_n)s^{n-1} + \ldots + (a_1 + k_2) + (a_0 + k_1) = 0 \quad \text{(Equation 6)}$$

Eigen values Placement theorem:

The feed back matrix gain K is determined by the condition.

$$\lfloor \lambda - A + BK \rfloor \quad \text{(Equation 7)}$$

λ is desired Eigen values. Constant feedback gain K is only exists if the open loop system is controllable.

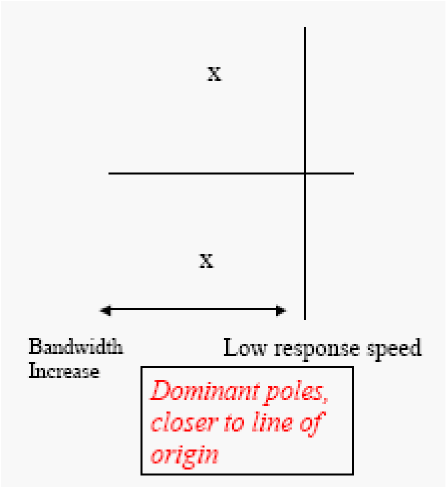

Figure 2.8: continuous time LH-s plane

If an input to a system can be found that every state variable from a desired initial state to a desired final state, the system is said to be controllable: otherwise, the system is uncontrollable. In order to be able to determine controllability or alternatively, to design state feedback for a plant under any representation or choice of state variables, a matrix can be derived that must have a particular property if all state variables are to be controlled by the plant input, u. we now know state the requirement for controllability, including the form, property, and name of this matrix. An *n*th-order plant whose state equation is

$$\dot{x} = Ax + Bu \qquad \text{(Equation 8)}$$

Is completely controllable if the matrix:

$$C_M = [B\ AB\ A^2B\ \ldots\ldots.A^{n-1}\ B] \qquad \text{(Equation 9)}$$

2.5 DC Servomotors

DC motors are powered by constant current or voltage. DC motors are used because of its convenience of using direct current as the power source. For the example, the small electric motors in MUAV are DC because the batteries are supplied direct current. Compared to AC motors, the torque speed relationships between are more attractive in many applications. The term servomotor simply means that a feedback loop is used to achieve speed control.

In a Dc servomotor, the stator typically consists of two permanent magnets on opposite sites of the rotor. The rotor, called the armature in DC motor. The magnitude of rotor torque is a function of the current passing through windings (Groover 2008).

$$T = Kt\ Ia \qquad \text{(Equation 10)}$$

Rotating the armature in the magnetic field of the stator produces voltages across the armature terminal called the back e.m.f. In effect, the motor acts like a generator and the back e.m.f. increases with rotational speed as follow

$$Eb = Kv \qquad \text{(Equation 11)}$$

The mechanical power delivered by the motor is the product of torque and velocity

$$P = T\omega \qquad \text{(Equation 12)}$$

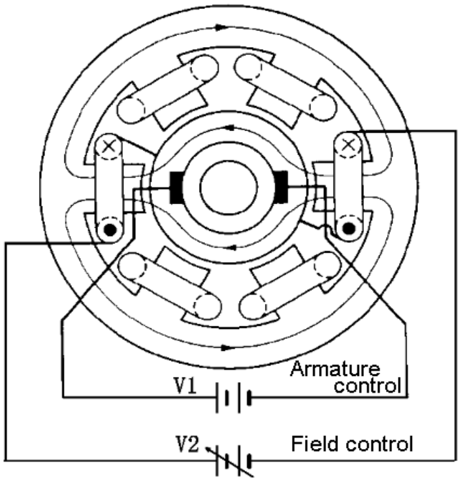

Figure 2.9: Separately excited DC Motor (ewh.ieee.org)

2.6 Sensor (Mechanical Absolute Encoder)

The term sensor is used for an element which produces a signal relating to the quantity being measured. An encoder is a device that provides a digital output as a result of a linear or angular displacement. Encoder can be grouped into two categories which are incremental encoders and absolute encoders (Bolton 2003). In MUAV application, the feedback device (encoder) plays a vital role in ensuring that the equipment operates properly. Absolute digital type produces a unique digital code for each distinct angle of the shaft. They come in two basic types: optical and mechanical (Wikipedia 2010).

A metal disc containing a set of concentric rings of openings is fixed to an insulating disc, which is rigidly fixed to the shaft. A row of sliding contacts is fixed to a stationary object so that each contact wipes against the metal disc at a different distance from the shaft. As the disc rotates with the shaft, some of the contacts touch metal, while others fall in the gaps where the metal has been cut out. The metal sheet is connected to a source of electric current, and each contact is connected to a separate electrical sensor. The metal pattern is designed so that each possible position of the axle creates a unique binary code in which some of the contacts are connected to the current source (i.e. switched on) and others are not (i.e. switched off).

Figure 2.10: Absolute Rotary Encoder (Wikipedia 2010)

2.7 State Space Representation

State space defined as a vector whose state elements are the state variables. While the state space is the n-dimensional space whose axes are the state variable (Nise 2004).

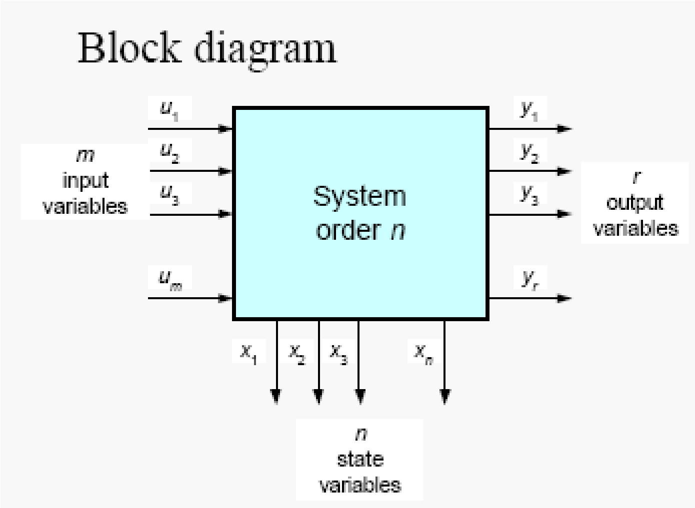

Figure 2.11: State representation

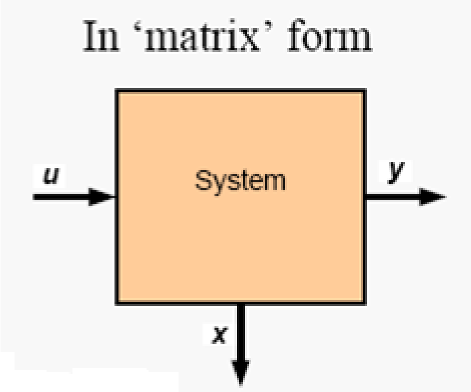

Figure 2.12: State Space Representation

A system is represented in state space by the following equations:

$$\dot{x} = Ax + Bu \qquad \text{(Equation 13)}$$

$$y = Cx + Du \qquad \text{(Equation 14)}$$

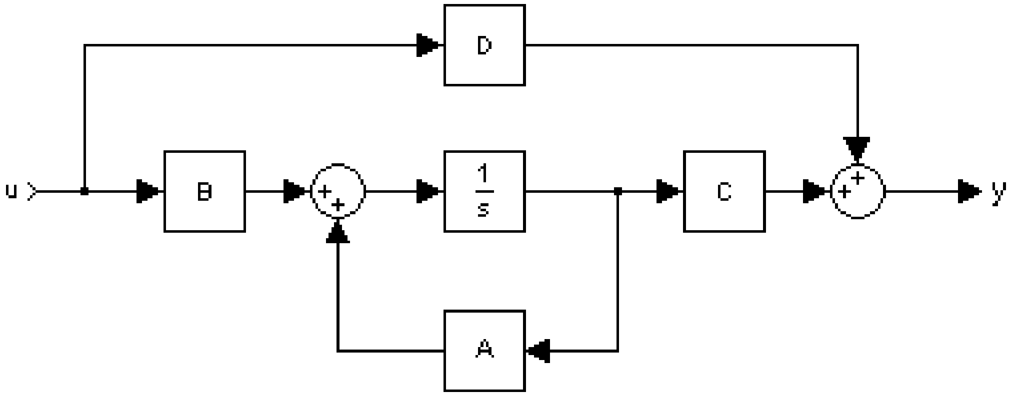

Figure 2.13: State Space block model (Wikipedia 2010)

According to Nise 2004, the first step in representing a system is to select the state vector, which must be chosen according to following consideration.

- A minimum number of state variables must be selected as components of the state vector. This minimum number of state variables is sufficient to describe completely the state of the system.
- The component of the state vector (that is, this minimum number of state variables) must be linearly independent.

CHAPTER 3

METHODOLOGY

3.1 Project Planning

The project is about the construction of the stability control system and simulation work. In order to construct the stability control system, a lot of research needs to be done giving the challenge to this project. The Gantt chart is attached in appendix A and research approaches is shown in the figure below.

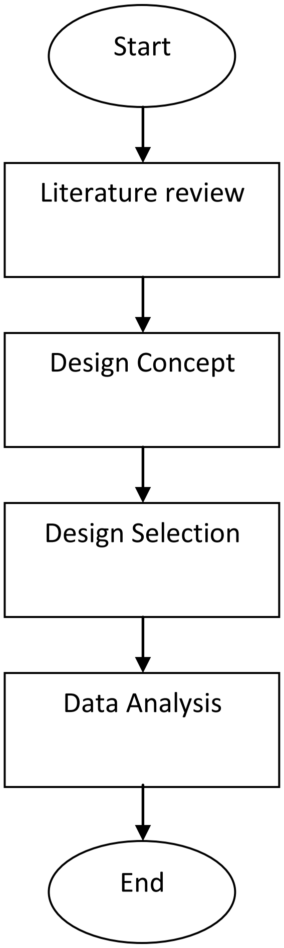

Figure 3.1: Research Methodology

3.1.1 Literature Review

The studies of stability of MUAV during vertical take-off and landing must be done before designing the control system. The stability requirement and function of the control system part is studies through. The existing control system is also studied and compared to the theory taught. The data collection and ideal assumption also studied through to determine closest possible result to the actual system.

3.1.2 Design Concept

The concept related with the stability analysis of MUAV and control system is first determined before proceed to the analysis. Among the important concept that has studied through are QRT rotorcraft, system modeling in state space, state feedback controller and encoders sensor.

3.1.3 Design Selection

The detail on model parameters: structure, equipment, material are among important part to be analyzed and considered. Each part will be analyzed through details of the requirement. The calculation is formed to justify the theory and choose the good design.

3.1.4 Data Analysis

A proposed design is done and analyzed throughout. Simulations were done through Matlab 7.1 software. Based on the analysis, we can determine the error occur in the system and suggest for improvement for the system. The system proposed can be modified to achieve the objectives of the project.

3.2 Tools and Software Used

3.2.1 Software used

Here is the list of software needed in order to develop the model

Table 3.1: software used

Software	Minimum requirement
Operating system	Window XP Service Pack 3
Supporting software	-Matlab7.1 -Autocad2004

3.2.2 Hardware Used

This is the minimum hardware specification of the application which it will be developed

Table 3.2: hardware used

Hardware	Model	Reason of usage
Phantom Force Feedback device		Compatible and stable
Central Processor Unit (CPU)	Intel ® Pentium Dual-Core @ 1.66 GHz	Compatible and stable
Main Memory	512 Megabytes(MB)	To support the Operating System and to improve machine's performance
Hard Disk	80 Gigabytes (GB)	To support the operating system, server, database and other related documentation or storage.

3.3 System Modeling

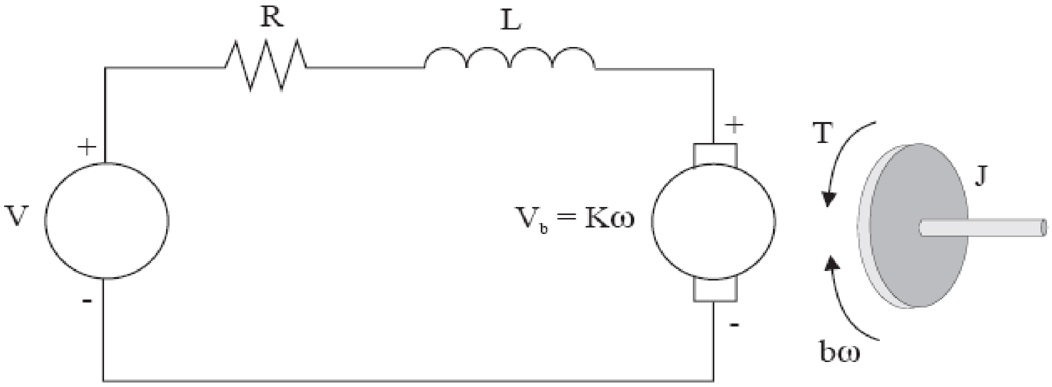

Figure 3.2: Schematic representation of DC motor

In particular, under ideal circumstances the torque produced at the shaft of a motor is proportional to the input current to the motor: the induced e.m.f v. The input is armature voltage, V in Volts and driven by voltage source. Measure variables are angular velocity in radians per second and angle in radians.

3.3.1 System equation

The motor torque, T is related to the armature current I, by a constant factor K

$$T = Ki \qquad \text{(Equation 15)}$$

The back electromotive force (emf) V is related to the angular velocity by:

$$Vb = K\omega \ = K\frac{d\theta}{dt} \qquad \text{(Equation 16)}$$

The electrical power P_e input to the motor is the product of the current and the induced e.m.f:

$$Pe = vi = \frac{K2}{K1}\tau\frac{d\theta}{dt} \qquad \text{(Equation 17)}$$

Based on Newton's law and Kirchhoff's law, we can write:

$$J\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} = Ki \qquad \text{(Equation 18)}$$

$$L\frac{di}{dt} + Ri = V - K\frac{d\theta}{dt} \qquad \text{(Equation 19)}$$

3.3.2 Transfer Function

Using Laplace Transform, the above equations can be expressed in terms of s:

$$Js^2\theta(s) + bs\theta(s) = KI \qquad \text{(Equation 20)}$$

$$LsI(s) + RI(s) = V(s) - Ks\theta(s) \qquad \text{(Equation 21)}$$

By solving above equation, the transfer function from the input voltage, V(s) to the output angle θ:

$$G(s) = \frac{\theta(s)}{V(s)} = \frac{K}{s[(R + Ls)(Js + b) + K^2]}$$

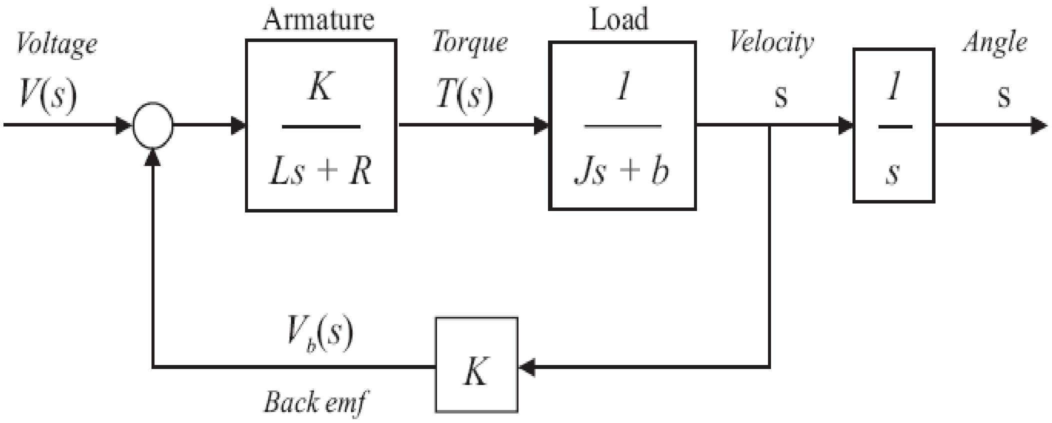

Figure 3.3: block diagram of DC motor

3.3.3 State space

These equations can also be represented in state-space form. Choose motor position and motor speed as our as state variable for the system. Based on Ohm law the behavior of the system;

$$E - V = Ri \qquad \text{(Equation 22)}$$

Where e is the input voltage and R is the electrical resistance of the motor armature, and where J is the moment of inertia of the load:

$$\tau = J\frac{d^2\theta}{dt^2} \qquad \text{(Equation 23)}$$

$$J\frac{d^2\theta}{dt^2} = \frac{K1}{R}e - \frac{K1K2}{R}\frac{d\theta}{dt} \qquad \text{(Equation 24)}$$

The equation is a second order equation and set $\frac{d\theta}{dt} = w$ to measure angle of shaft θ

$$\begin{bmatrix} \dot{\theta} \\ W \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 1 & \frac{-K1K2}{JR} \end{bmatrix} \begin{pmatrix} \theta \\ W \end{pmatrix} + \begin{bmatrix} O \\ \frac{K1}{JR} \end{bmatrix} \mathrm{e}$$

$$y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{pmatrix} \theta \\ W \end{pmatrix}$$

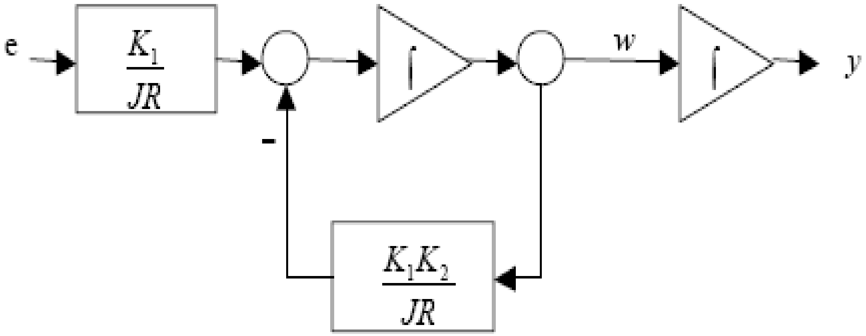

Figure 3.4: UAV state space model

CHAPTER 4

RESULT AND DISCUSSION

4. 1 Result Analysis

4.1.1 Model Description

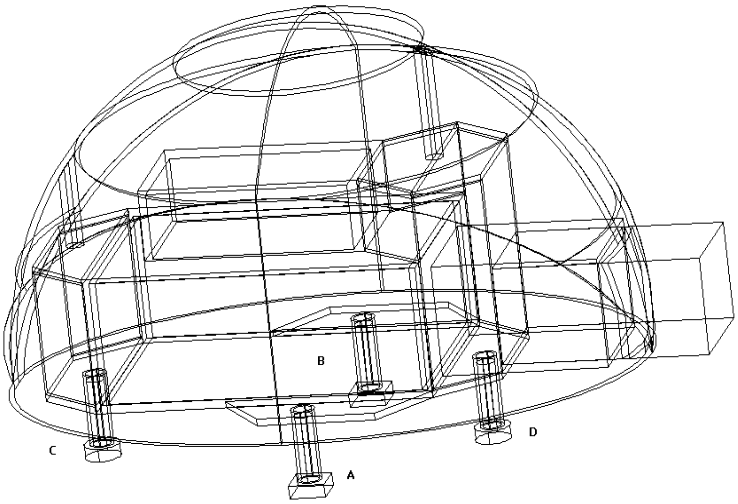

Figure 4.1: Micro Unmanned Aerial Vehicle (MUAV) model

MUAV Specification

Estimate size : 3 x 5 inches
Estimate weight : 200g
Operation : Indoor environment
Capability : Vertical take-off and landing
Equip with : Level sensor (encoder), 4 motor, Quad Rotor type ducted fan

4.1.2 Control System

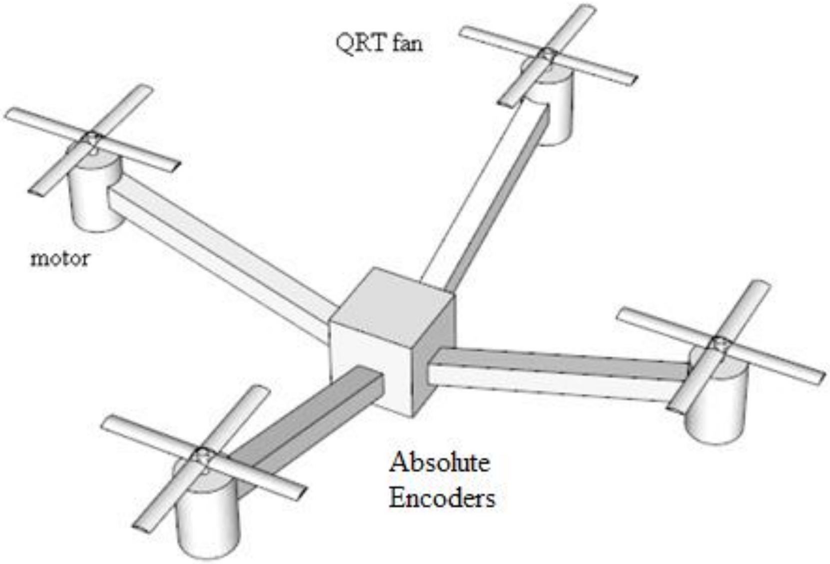

Figure 4.2: Control System Concept

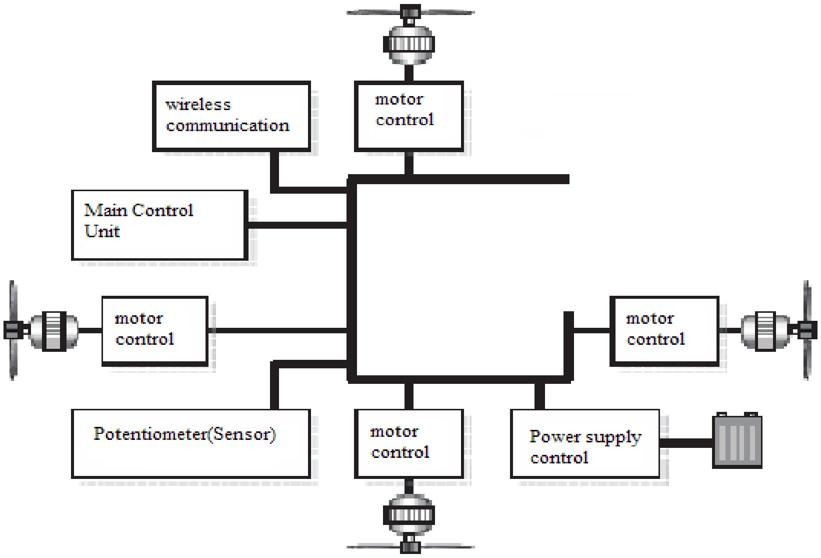

Figure 4.3: Control System Structure

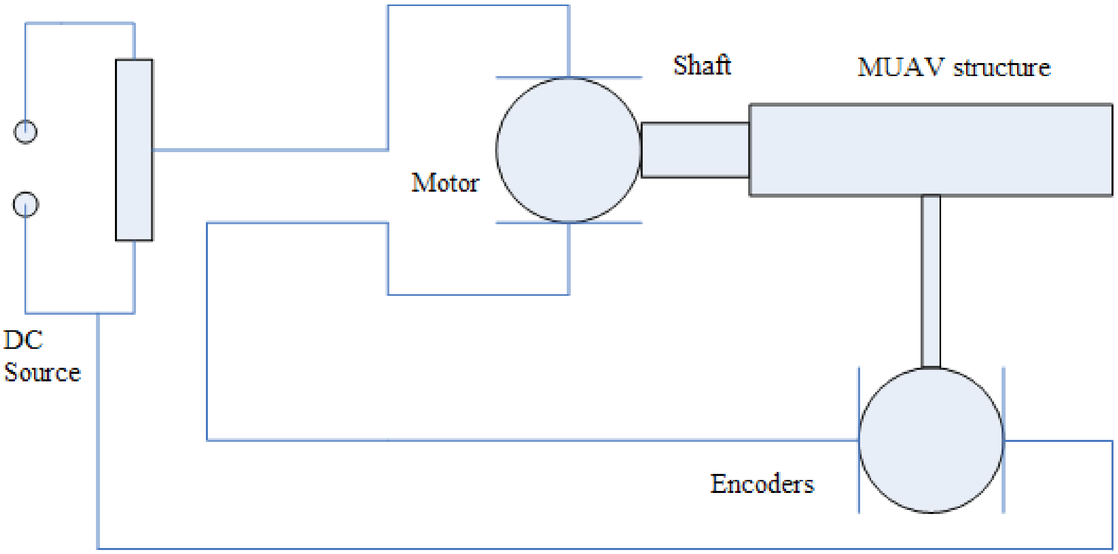

Figure 4.4: Schematic diagram of control system

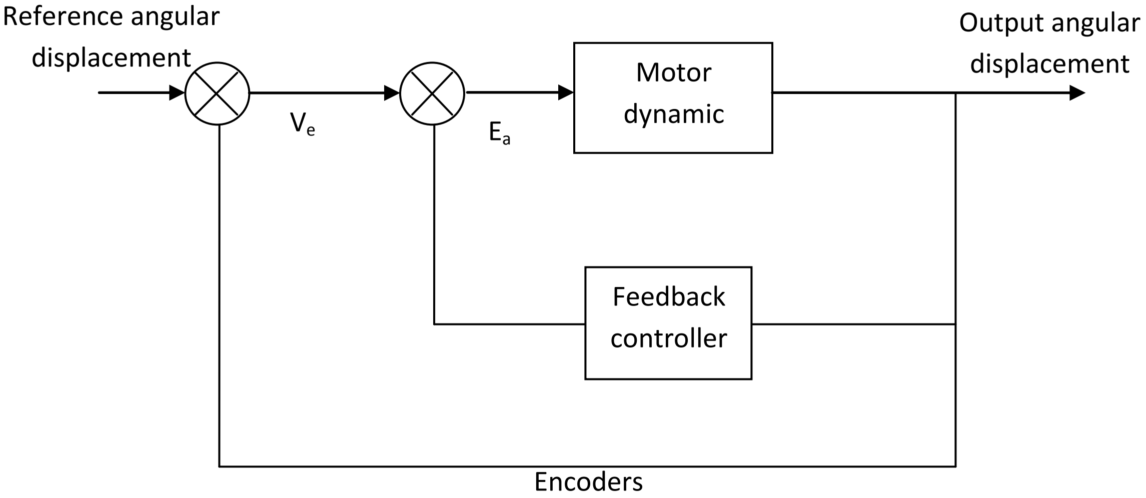

Figure 4.5: Functional Block diagram

4.1.3 Control Objective

Regulate the angular displacement of MUAV body frame by manipulating speed of quad rotor ducted fan. The purpose of this system to have the angular displacement output of motor follow the input angular displacement of absolute encoders. The input command of the system is angular displacement. The signal and power controller boost the difference between the input and output voltage. This amplified actuating signal drives the plant. The system normally operates to drive the error to zero. When the output and input match, the error is equal to zero and the motor turn at constant load. The greater the difference between the output and input, the larger motor the motor input voltage, and the motor will be driven harder. Hence the speeds of quad rotor fan turn faster.

The MUAV used in this work is an electric four motor rotorcraft with each motor attached to a rigid cross frame as shown in Fig 4.2. It is a vertical takeoff and landing vehicle (VTOL) able to move omnidirectionally with the ability to fly in a stationary way like the conventional helicopter. In this type of flying machine the front and rear rotors rotate counter-clockwise while the left and right rotors rotate clockwise canceling gyroscopic effects and aerodynamic torques in stationary trimmed flight. Vertical motion is controlled by the collective throttle input, i.e., the sum of the thrusts of each motor. Forward/backward motion is achieved by controlling the differential speed of the front and rear motors. This causes the quad-rotor to tilt around the y-axis generating a pitch angle. The left/right motion of the vehicle is achieved by controlling the differential speed of the right and left motors, tilting around the x-axis and producing a roll angle. Finally, yaw movement is obtained by taking advantage of having two sets of rotors rotating in opposite direction. Thus a yaw angular displacement is obtained by increasing or decreasing the speed of the front and rear motors while decreasing or increasing the speed of the lateral motors. This is done by keeping the total thrust constant so that the altitude remains unchanged.

4.1.4 Modeling and Simulation

4.1.4.1 DC Motor speed control

In armature voltage control method, the voltage applied to the armature circuit, V_a is varied without changing the voltage applied to the field of circuit of the motor. Therefore, the DC motor must be separately excited from two different DC power sources. When armature voltage, V_a increases, the no load speed of motor increases while the slope of torque-speed remains unchanged since the flux is kept constant.

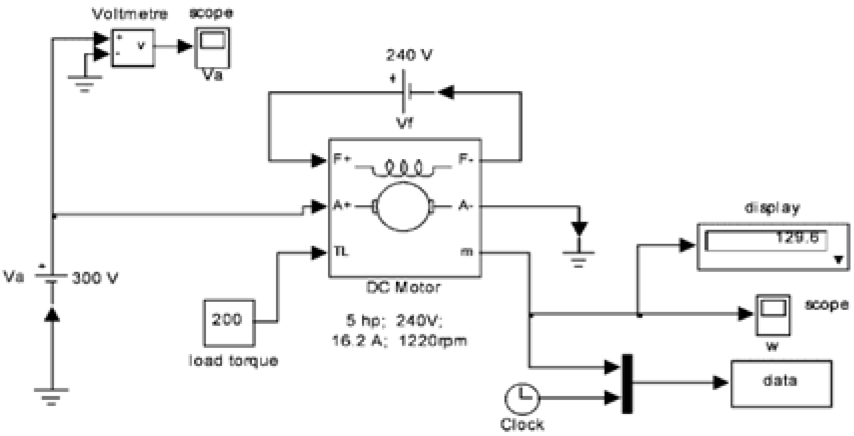

Figure 4.6: Simulink implementation of armature voltage current

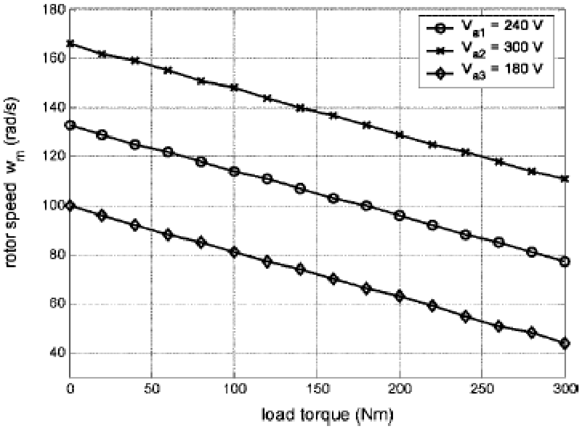

Figure 4.7: Torque speed characteristic for three: 180V, 240V, 300V armature voltage current

4.1.4.2 MUAV’s Stability Control System without controller

The efficiency of the motor is 100% then

$K1 = K2$

Hence set the value for

$K1 = K2 = J = R = 1$

$$A = \begin{bmatrix} 0 & 1 \\ 1 & -2 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

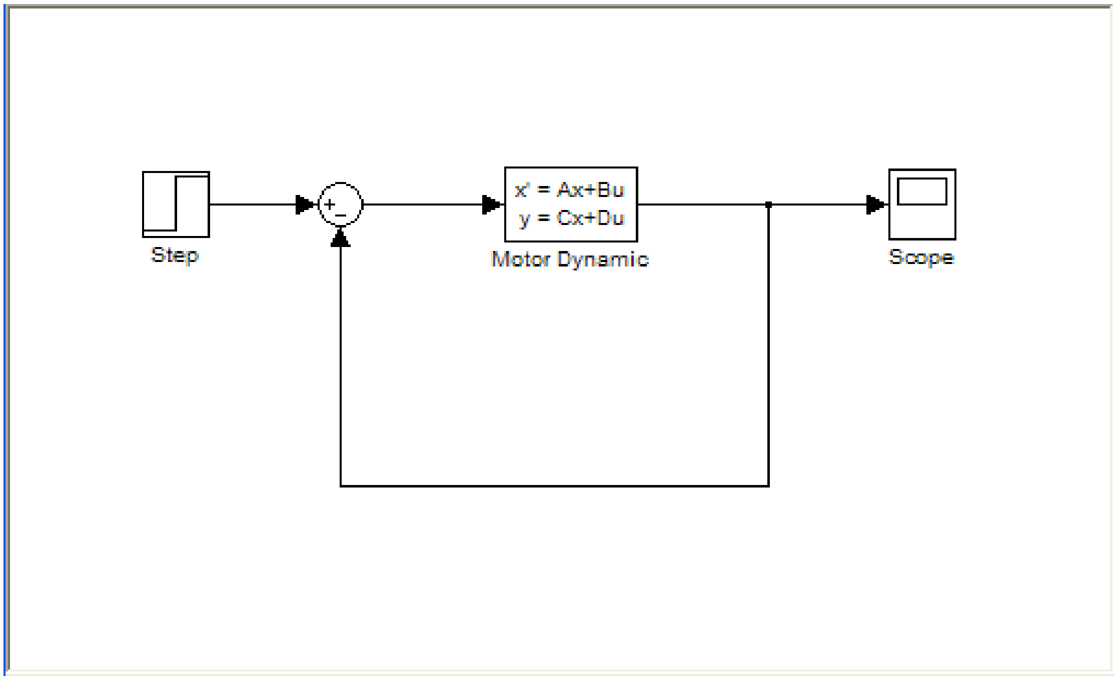

Figure 4.8: Block diagram of the system without the controller

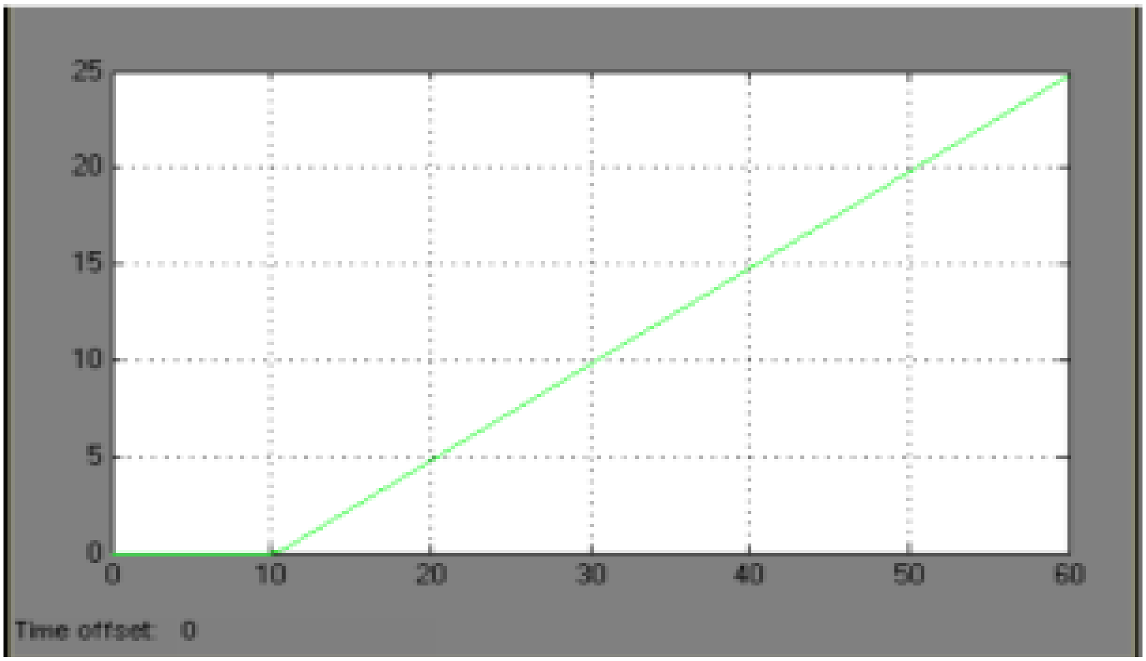

Figure 4.9: State response of angle versus time

Analysis

Based on figured 4.9, the settling time, T_s is unknown. Since the response keep increase with time. Output response of the system does not resemble the desired reference input. The system is not stabile. The system can be improved by adding the feedback controller to the system that will minimize the error. But first, check whether the system is controllable or not. To determine this, determine the rank and determinant of the matrix [B AB].

$$[B \quad AB] = \begin{bmatrix} 0 & \frac{K1}{JR} \\ \frac{K1}{JR} & \frac{-K1K2}{J^2R^2} \end{bmatrix}$$

$$[B \quad AB] = \begin{bmatrix} 0 & 1 \\ 1 & -2 \end{bmatrix}$$

$$det\begin{bmatrix} 0 & \frac{K1}{JR} \\ \frac{K1}{JR} & \frac{-K1K2}{J^2R^2} \end{bmatrix} = 0 - 1 \neq 0$$

The rank is equal to 2 for matrix [B AB] and the determinant is equal to 1 which is not equal to 0. Thus the system is controllable.

4.1.4.3 MUAV's Stability Control System for MUAV with feedback controller

The feedback gain, K with u(K)=Kx(K) gives a closed system, whose dynamics are governed by (**A-BK**):

$$(\text{A-BK}) = \begin{bmatrix} 0 & 1 \\ 0 & -2 \end{bmatrix} - \begin{bmatrix} 0 \\ 1 \end{bmatrix} \begin{bmatrix} K1 & K2 \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 \\ -k1 & -2-K2 \end{bmatrix}$$

Then, find the Eigen values of (A-BK) by solving equation below:

$$[\lambda I - (A - BK)] = \begin{pmatrix} \lambda & 0 \\ 0 & \lambda \end{pmatrix} - \begin{bmatrix} 0 & 1 \\ -k1 & -2-K2 \end{bmatrix}$$

$$= \begin{bmatrix} \lambda & -1 \\ k1 & \lambda+2+k2 \end{bmatrix}$$

We define k = [k_1 K_2], the characteristic equation obtain is:

$$\lambda(\lambda - 2 - K2) + K1 = 0$$

$$\lambda^2 + (2 + K2)\lambda + K1 = 0$$

Assume Eigen values = -9,-9

$$(\lambda + 9)(\lambda + 9) = 0$$

$$\lambda^2 + 18\lambda + 81 = 0$$

Compare equation (1) and (2) to obtain K_1, K_2

K_2 = 16

K_1 = 81

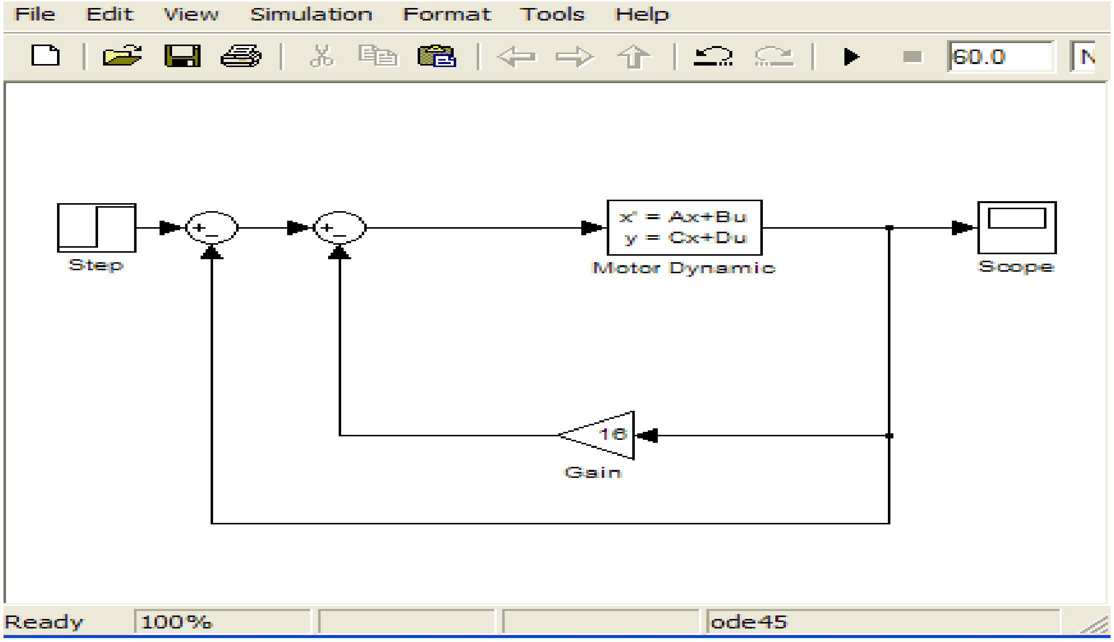

Figure 4.10: State feedback control design block diagram

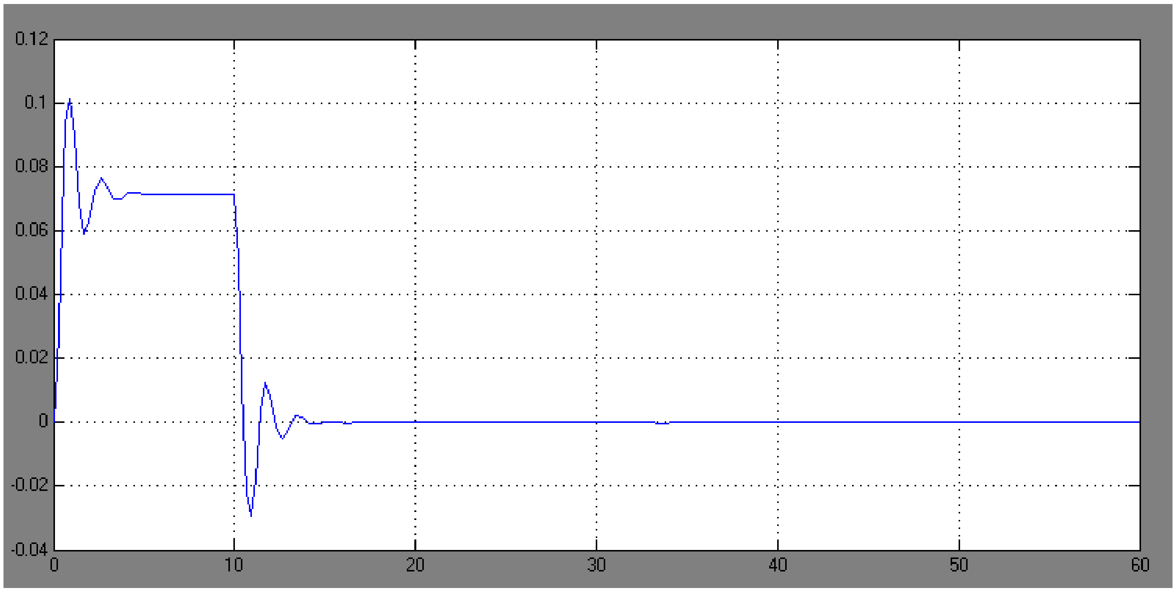

Figure 4.11: Output response: Angle vs Time for gain,K equal to 16

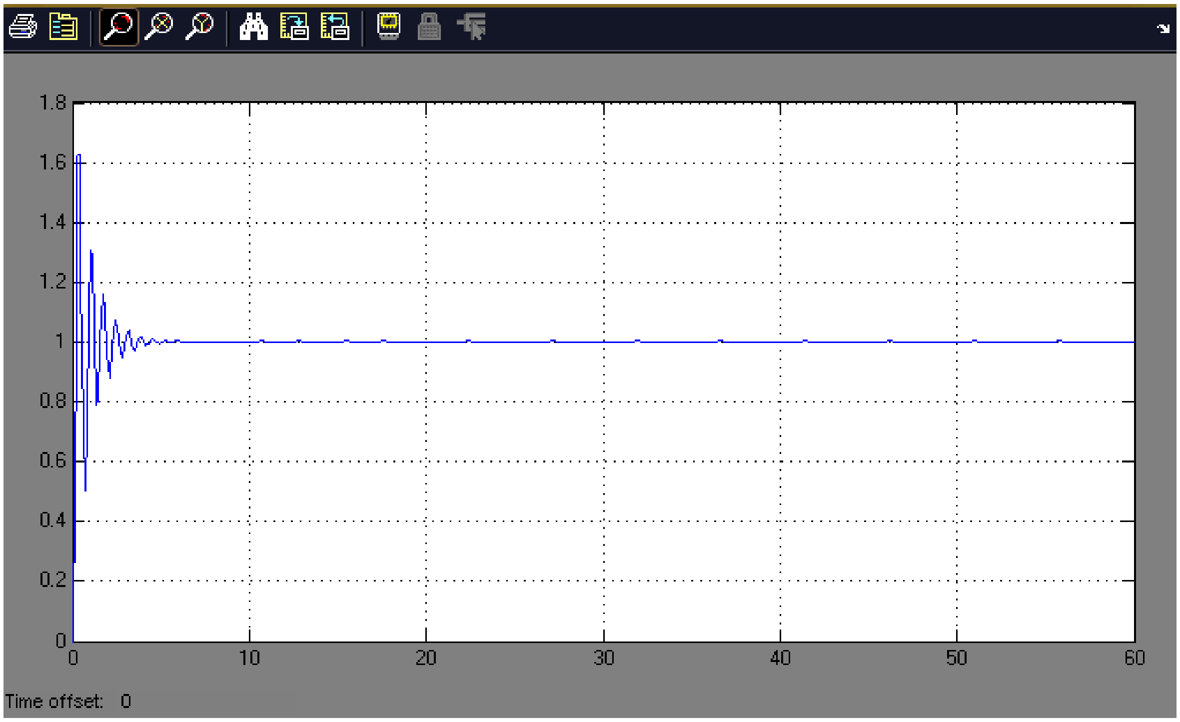

Figure 4.12: Output response: Angle vs. time for gain, K equal to 81

Analysis

Graph from figure 4.11 show the weak controllability compare with graph from figure 4.12. Hence, choose the system with gain equal to 81. Based on graph from figure 4.13, the peak time, T_P of the system is equal to 1 second. While the settling time, T_S is equal to 6 seconds. The system settles at angle equal to 1 degree. The desired output was 0 degree was not achieved. This means that the system has the offset value of 1. This offset value known as steady state error. The system can be further improved with addition of forward gain. The function of forward gain is to reduce or eliminate the steady state error from the system.

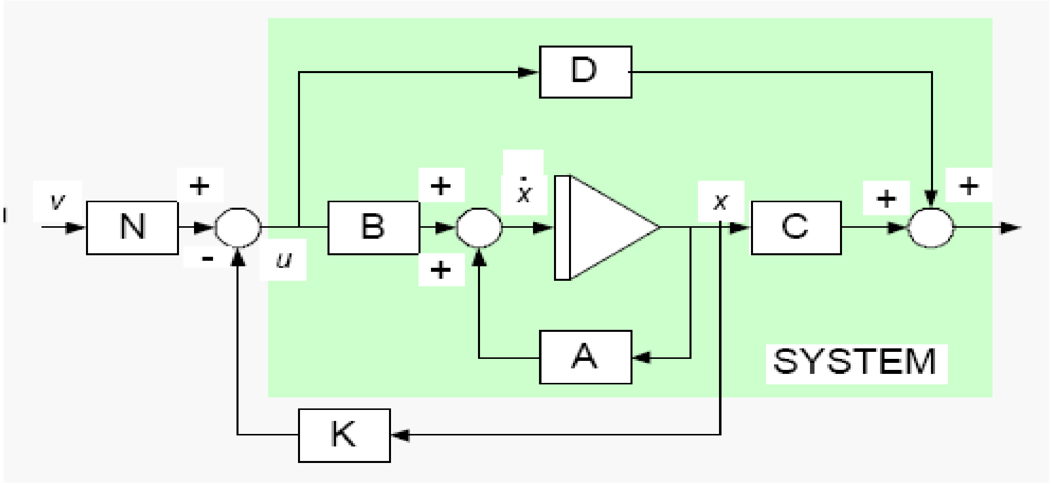

Figure 4.13: State feedback controller with forward gain

4.1.4.4 MUAV's Stability Control System for MUAV with feedback controller and forward gain

Determining N

$$N = Nu + KNx$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}\begin{pmatrix} Nx \\ Nu \end{pmatrix} = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

$$\begin{pmatrix} Nx \\ Nu \end{pmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}^{-1}\begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix}$$

$$\begin{pmatrix} Nx \\ Nu \end{pmatrix} = \begin{bmatrix} 0 & 1 & 1 \\ 0 & -2 & 0 \\ 1 & 0 & 0 \end{bmatrix}^{-1}\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$$

$$\begin{pmatrix} Nx \\ Nu \end{pmatrix} = \begin{bmatrix} 0 & 1 & 1 \\ 0 & \frac{-1}{2} & 0 \\ 1 & 0 & 0 \end{bmatrix}^{-1}\begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix}$$

$$N = Nu + KNx = 0 + [81\ 16]\begin{bmatrix} 1 \\ 0 \end{bmatrix} = 81$$

$$U = -[81\ \ 16]x + [81]r$$

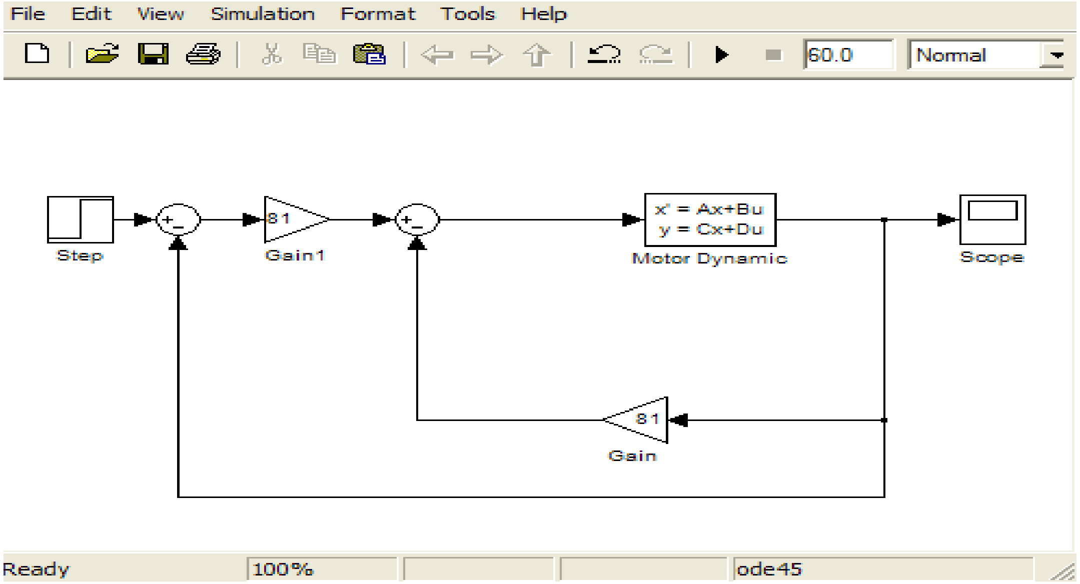

Figure 4.14: State feedback control diagram with forward gain

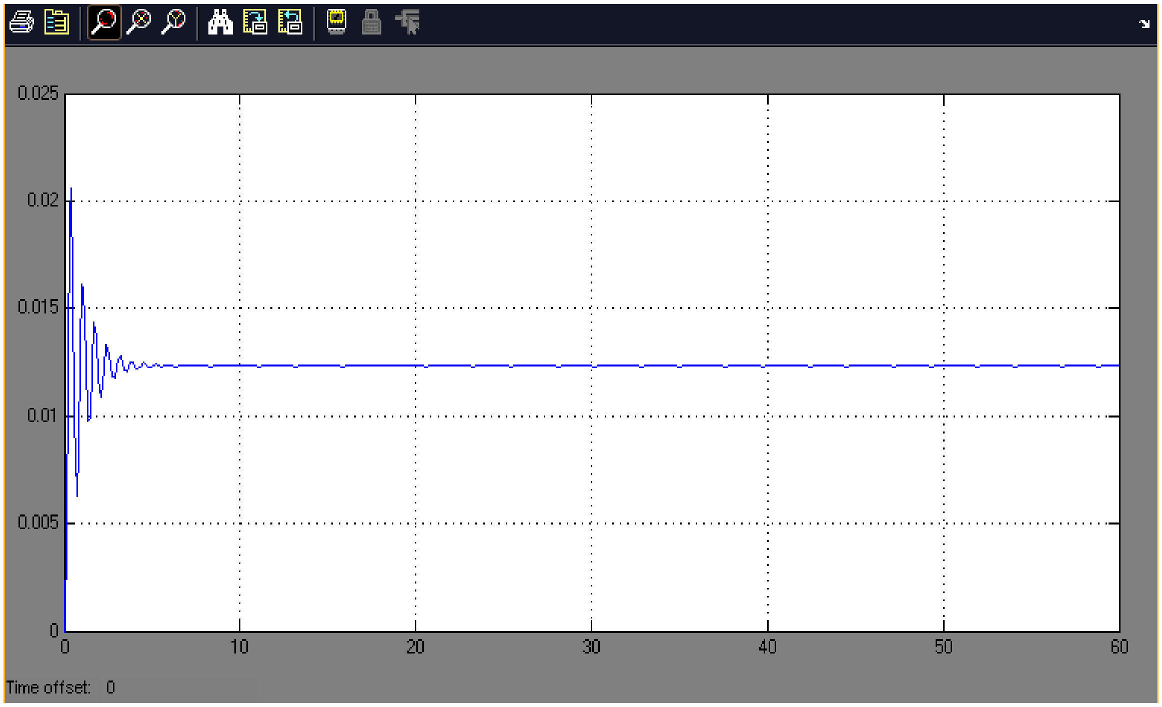

Figure 4.15: Output response: Angle vs. time

Analysis

From figure 4.15, the system settles at 0.012 degree. It is acceptable since its approaching zero. Thus, the steady state error has been reduced in the system. The peak time, T_P of the system is equal to the 1 second and the settling time, T_S is equal to 8 seconds. The figure below showed the improved schematic and functional diagram of the system.

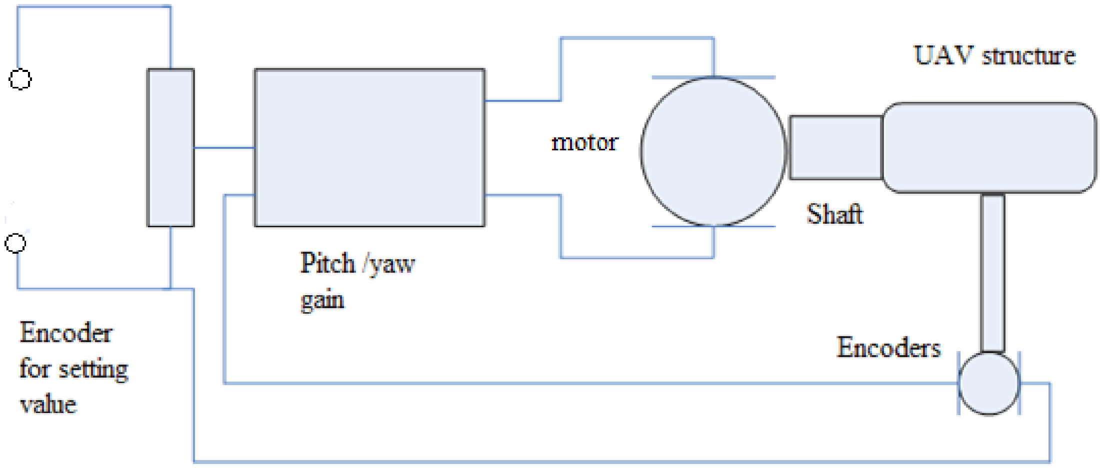

Figure 4.16: improved schematic diagram of the system

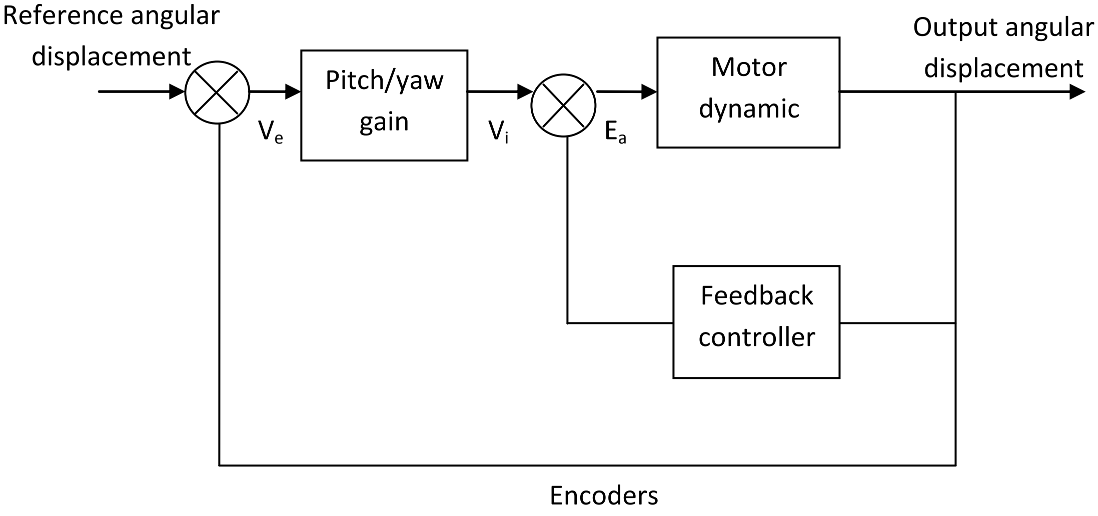

Figure 4.17: Improved functional block diagram

4.2 Discussion

Based on result on figure 4.9, the output response is not stabile. Its never reach desired output response for the system. The addition of feedback controller will improve system characteristic or transient responses such as rise time, settling time, overshoot. Before proceed to the controller design, first check whether the system is controllable or not. Controllability play important role in design of control system in state space. The conditions of controllability may govern the existence of a complete solution to the control system design problem. The solution to this problem may not exist if the system considered is not controllable.

The values that have chosen for desired poles are -9,-9 since it is the most common values used in the industry. The criteria to choose the values are it must far from the jω axis and must be on left half plane (LHP). From the output response which has the forward gain (figure 4.15), it experience overshoot and settle at approximately 0.012 degree. On other hand, the output response which does not has forward gain settled at 1 degree (figure 4.12). The addition of forward gain into the system has reduced the steady state error of the system. But at the same time, the settling time, T_S for system with forward gain a bit slower compare with control system with feedback controller only. The difference is 2 seconds. The feedback controller without forward gain settles faster but it has large value steady state error. Thus the system with forward gain has better overall performance. By having forward gain, the output should resemble the input signal. From the figures 4.15, the output does not resemble the input. It can be caused by the selection for value of poles. The selection of poles should be further away in LHP jω axis. But at the same time, disturbance and noise incur in the system. The bandwidth of the system increases as selected desired poles are further onto the left hand side of the plane. This causes the system to be more sensitive to noise and disturbance that is likely to alter the output response of the system.

CHAPTER 5

CONCLUSION AND RECCOMENDATIONS

5.1 Conclusion

Based on modeling procedure and simulation process, the control objective to maintain the MUAV's stability during VTOL operation is achieved. The controls ensure that output response of *x, y, roll, pitch, and yaw angles* are equal to 0^0 during VTOL operation. The analytical model is based on stability concept involves MUAV's movements in *x, y, z, roll, pitch and yaw axes* with respect to the body and also rotorcraft principle. The model is represented in state space with feedback controller. The state space representation provides a convenient and compact way to model and analyze systems with multiple inputs and outputs. To minimize the tracking errors, the feedback structure is augmented with a feed forward controller.

5.2 Recommendations

For the simulation part, the transient response needs to be carefully monitored since some undesired phenomena like high frequency phenomena like high-frequency oscillations, rapid changes and high magnitudes of the output may occur. It is recommended to add the observer system and optimal control to the existed state space model for the future work for optimum performance of the control system. The observer will track the original system. This type of feedback system is exponentially stable.

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APPENDICES

Appendix A:

Gantt Chart For FYPI & FYPII