MODELLING AND PID CONTROL SYSTEM FOR FIXED-WING UNMANNED AERIAL VEHICLE

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Abstract - The paper focuses on the PID control techniques a for small UAV. In this research work, control derivatives were implemented for analytical method for longitudinal dynamics of a small fixed wing UAV. The simulation results of longitudinal stability derivatives have been proved for the UAV system with the help of MATLAB/SIMULINK model. These methods can be used to convert the unstable conditions that cause by pole locations to stable conditions. And then the PID controller can be used to adjust the desired set point for ARF 60 UAV.

Keywords – Modelling, Stability Analysis, Longitudinal Control, Fixed-wing UAV, MATLAB, SIMULINK model

I. INTRODUCTION

The increased interest in remote sensing applications and the advances in technology attract the researchers of aerospace engineering to design low cost satellites and UAVs for remote sensing and many other applications.

The increased interest in UAVs has resulted in a rapidly growing number of organizations, both military and civilian, and conducting researches to develop fully autonomous UAVs. SUAVs are of particular interest to many researchers around the scientific society, as they are relatively inexpensive, offer the ability to address a multitude of autonomous flight research applications that once seemed out of reach.

The more autonomous ability of UAV, the more complex its guidance and control system, advanced guidance algorithms development is essential and necessary for meeting new requirements with the increasing area of UAV applications and for defining future UAV concepts and associated critical technologies. SUAV control and stabilization is more difficult than larger one, due to several factors, including the low mass of the vehicle, lower Reynolds numbers, and light wing loading. These factors make it more difficult to design a flight control system. The complete state of the UAV comprises its position, airspeed, attitudes (roll (ϕ), angle-of-attack (θ), sideslip angle (ψ), and rotation (roll (p), pitch (q), and yaw (r)) rates. Position, airspeed, and heading attitude are also known as the navigation states. Control on these states provides full control on the vehicle movements with six degrees of freedom. [3].

II. STATE SPACE REPRESENTATION

The aerodynamic stability derivatives, mass, and inertia characteristics of the airplane have been made the coefficients in the differential equations. These equations can be written as a set of first-order differential equations. These first-order differential equations are called the state space or state variable equations.

The motion, or state, of any linear dynamic system may be described by a minimum set of variables. The number of state variables required to completely describe the motion of the system is dependent on the number of degrees of freedom the system has. Thus, the motion of the system is described in a multidimensional vector space called the state space, the number of state variables being equal to the number of dimensions. The longitudinal equations can be expressed in the following equations by the form of state space representation.

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{1}$$

$$y(t) = Cx(t) + Du(t) \tag{2}$$

where: x=state vector
u=input or control vector
A=state coefficient matrix
B=driving matrix
C=output matrix
D=feed-forward matrix

III.UAV PARAMETERS

The major dimensions of ARF 60 UAV are presented in Table I. There are other important parameters such as wing area (s) which is dependent on the shape of the wing. The wing span (**b**) which is defined as the distance between the wing tips of an aircraft. Aspect ratio (AR) which is important for low speed aircrafts since a high aspect ratio generates high lift at low speed. Aspect ratio determine the relation between wing span and wing area as in equation, AR=$\frac{b^2}{s}$.The dynamic pressure is also calculated by using $\frac{1}{2}\rho u^2$[11].

Notation	Values	Properties
b	1.87m	Wing span
s	0.6059 m^2	Wing area
m	3.5105 kg	Empty weight
ρ	1.225kg/m^3	Air pressure density
c	0.324m	Chord
I_{XX}	0.1996kg.m^2	Rolling moment of inertia
I_{YY}	0.24086kg.m^2	Pitching moment of inertia
I_{ZZ}	0.396kg.m^2	Yawing moment of inertia

TABLE I
ARF 60 UAV Specifications

The physical characteristics of the aircraft such as air foil data, geometric measurements, and relative positions of the aircraft components, mass and weight can be used to estimate the stability derivatives of the ARF60 UAV [11].

Longitudinal coefficients	Values	Longitudinal Derivatives	Numeric values
C_{M0}	0	X_u	-0.2289
C_{D0}	0.0500	X_w	0.3712
C_{L0}	0.4100	X_{δ_e}	0
$C_{M\alpha}$	0	X_{δ_T}	51.5
$C_{D\alpha}$	0	X_q	0
$C_{L\alpha}$	4.3842	Z_u	-1.8772
$C_{M\delta e}$	-0.7741	Z_w	-10.1512
$C_{D\delta e}$	0	Z_{δ_e}	-14.0042
$C_{L\delta e}$	0.3059	M_u	0.9219
C_{Mq}	-10.0467	M_w	-7.0403
C_{Dq}	0	M_{δ_e}	-147.6913
C_{Lq}	0	M_q	-26.072

TABLE II
Stability and Control Derivatives

IV. MODELLING FOR FIXED WING UAV

Mathematical modelling of a fixed wing UAV is a challenging task because of its nonlinear behaviour. During nonlinear manoeuvres of aircraft the longitudinal and lateral modes are strongly coupled so their modelling becomes complex. The simple and commonly followed approach is linearization of the nonlinear equations of motion followed by decoupling of longitudinal dynamics.

A. Equation of Motion

The standard 6-DOF equations of motion for a conventional aircraft are used for modelling and simulation of a small UAV. Flat Earth approximation provides a reasonable modelling assumption when the vehicle operates over a small area. The body –axes equations are as follows [5]:

(a) Force equations:

$$\dot{U} = rV - qW - g\sin\theta + \frac{(X_A + X_T)}{m} \qquad (3)$$

$$\dot{V} = -rU + pW + g\sin\phi\cos\theta + \frac{(Y_A + Y_T)}{m} \qquad (4)$$

$$\dot{W} = qU - pV + g\cos\phi\sin\theta + \frac{(Y_A + Y_T)}{m} \qquad (5)$$

(b) Moment equations:

$$\dot{L} = J_x\dot{p} - J_{xz}(\dot{r} + pq) + (J_x - J_y)qr \qquad (6)$$

$$\dot{M} = J_y\dot{q} + (J_x - J_z)pr + J_{xz}(p^2 - r^2) \qquad (7)$$

$$\dot{N} = J_x\dot{r} - J_{xz}(\dot{p} - qr) + (J_y - J_x)pq \qquad (8)$$

(c) Kinematic equations:

$$\dot{\phi} = p + \tan\theta\,(q\sin\phi + r\cos\phi) \qquad (9)$$

$$\dot{\theta} = q\cos\phi - r\sin\phi) \qquad (10)$$

$$\dot{\psi} = \frac{(q\sin\phi + r\cos\phi)}{\cos\theta} \qquad (11)$$

(d) Navigation equations:

$$\dot{p}^N = Uc\theta c\psi + V(-c\phi s\psi + s\phi s\theta c\psi) + W(s\phi s\psi + c\phi s\theta c\psi) \qquad (12)$$

$$\dot{p}^E = Uc\theta s\psi + V(c\phi c\psi + s\phi s\theta s\psi) + W(-s\phi c\psi + c\phi s\theta s\psi) \qquad (13)$$

$$\dot{p}^N = -Us\theta + Vs\phi c\theta + Wc\phi c\theta \qquad (14)$$

Where, c=cos and s=sin.

B. State Space Model for Longitudinal System

In this study, the longitudinal motion of the Smart ARF 60 UAV is investigated. The primary control surfaces in the longitudinal dynamic model are elevator deflection angle and throttle angle. We must define the positive elevator deflection angle to obtain the transfer function of the aircraft. For this study, the state space model of small UAV pitch model was obtained by using the analytical modelling.

$$\begin{bmatrix} \dot{u} \\ \dot{\omega} \\ \dot{q} \\ \dot{\theta} \\ \dot{h} \end{bmatrix} = \begin{bmatrix} X_u & X_\omega & X_q & -g\cos\theta & 0 \\ Z_u & Z_\omega & Z_q & -g\sin\theta & 0 \\ M_u & M_\omega & M_q & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & -\cos\theta & 0 & u\cos\theta + \omega\sin\theta & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \\ h \end{bmatrix} + \begin{bmatrix} X_{\delta_e} & X_{\delta_t} \\ Z_{\delta_e} & 0 \\ M_{\delta_e} & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{pmatrix} \delta_e \\ \delta_t \end{pmatrix} \qquad (15)=$$

$$\begin{bmatrix} -0.2289 & 0.3712 & 0 & -9.81 & 0 \\ -1.8772 & -10.1512 & 20 & 0 & 0 \\ 0.9219 & -7.0403 & -26.072 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & -1 & 0 & 20 & 0 \end{bmatrix} \begin{bmatrix} u \\ \omega \\ q \\ \theta \\ h \end{bmatrix} + \begin{bmatrix} 0 & 51.5 \\ -14.0042 & 0 \\ -147.6913 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \qquad (16)$$

Transfer functions for longitudinal are described as follows:

$$\frac{\overline{\Delta\omega}}{\overline{\Delta\delta}} = \frac{-14.0042s^3-2056.73s^2-120.22s-2846.43}{s^4+116.937s^3+372.55s^2+577.296s+571.930} \qquad (17)$$

$$\frac{\overline{\Delta\theta}}{\overline{\Delta\delta}} = \frac{49.072s^2-1058.069s-452.072}{s^4+116.937s^3+372.55s^2+577.296s+571.930} \qquad (18)$$

Poles values=-0.1152±j0.7299, -18.1110±j8.8071

V. IMPLEMENTATION

The input type is step input in this system because this input is easy to read and to adjust the desired set point for time domain in control system. The input command is step command and the output of the system response is described in Figure 3 and 5. We can implement the transfer functions of longitudinal control derivatives with the help of MATLAB/SIMULINK.

VI. PID CONTROLLER

The controller uses a sensor to measure the results and an actuator to affect the process. A proportional-integral-derivatives or PID controller perform the same function as a thermostat but with a more elaborate algorithm for determining its output. Tuning a PID controller is setting the Kp , Ki , Kd tuning constants so that the weighted sum of the proportional, integral, and derivative terms produces a controller output that steadily drives the process variable in the directional required to eliminate the error.

PID controller depends upon how the process responds to the controller's corrective efforts. Proportional control performs to reduce rise time and steady state error but increase the overshoot. If the integral tuning constant is too large, this subsequent error will be greater than the original. Integral control increases overshoot and settling time but reduces rise time. The advantage of this control is that it can eliminate the steady state error. The derivatives control can reduce overshoot and settling time.

VII. SIMULATION RESULTS

Assume the pitch rate transfer function can be neglected for small UAV. Forward velocity transfer function and pitch angle transfer function is applied to the altitude control for small UAV. The system is approached to unstable condition the fact that the right-hand pole in the s-plane gives the dynamically unstable with sinusoidal oscillations in the exponentially increasing components. So, PID controller is used for stability .

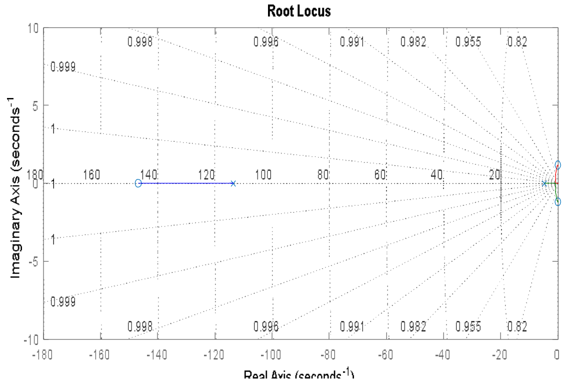

Figure .1 The root locus for forward velocity transfer function

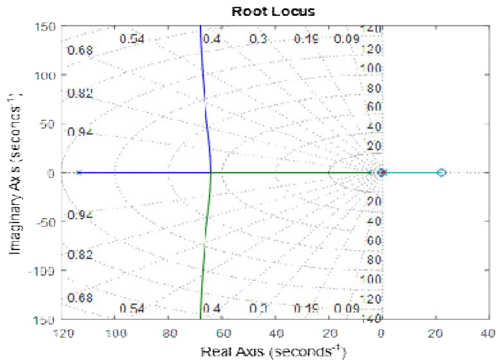

Figure 2 The root locus for Pitch angle transfer function.

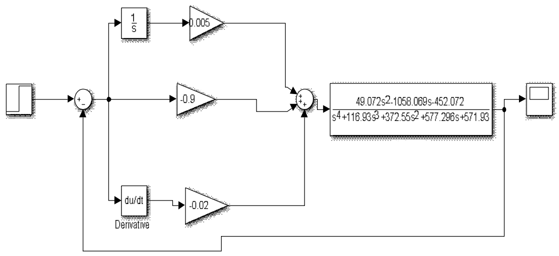

Figure.3. Simulink Model for Pitch angle control

In figure 3, the proportional gain is -0.9 and integral gain with 0.05 and derivative gain -0.02 is used. The scope result is presented in figure 4 with the step command.

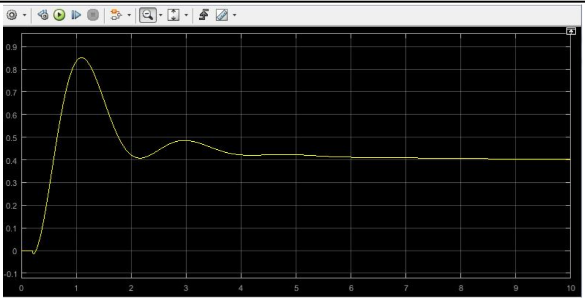

Figure.4. Stability Response for Pitch angle control

The system reaches the steady state condition after 4 seconds from initial condition. Moreover, the system has the oscillations between 0.2 to 4 seconds with pronounced overshot. But the system is maintained in stable condition.

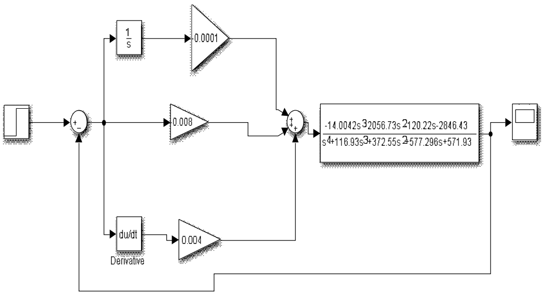

Figure.5. Simulink Model for forward velocity

In figure 5, the proportional gain is -0.001 and integral gain with -0.008 and derivative gain 0.004 is used. The scope result is presented in figure 6 with the step command. The system reaches the steady state condition after 5 seconds from initial condition. Moreover, the system has the oscillations between 0.2 to 4 seconds with pronounced overshot. But the system is maintained in stable condition.

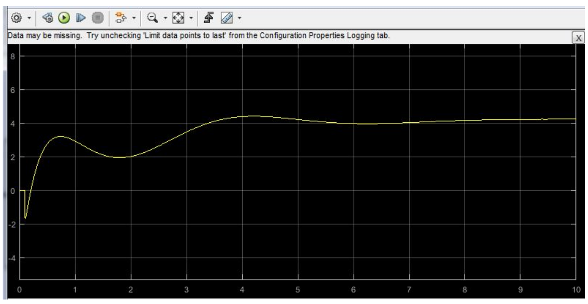

Figure.4. Stability Response for Forward velocity

CONCLUSIONS

The longitudinal dynamics response of ARF60 UAV met the performance specification for stability analysis. Furthermore, the nonlinear model of fixed wing UAV has many advantages to estimate flight dynamics for all condition of altitude that is important to build a controller that adapt to the UAV altitude. For pitch angle system, the damping is closer to critical damped like but rise time is longer than initial condition. As the technical advancement, the remote piloted vehicles have been developing to autonomous UAVs. During the level flight, it is necessary to test the various flight conditions at desired airspeeds and altitudes.

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