Control And Tracking Of Fixed Wing UAV System

Najiya A , Laila Beebi M, Johnson Y

Abstract— This Paper presents the tracking and control of fixed wing UAV system.UAV(unmanned aerial vehicle)is a machine or also known as drone which functions either by means of remote control of a navigator or autonomously.It can fly autonomously and donot carry any human operator.Many applications of small and miniature UAVs requires that the vehicle traverse an inertially definite path.While we considering the effect of disturbance path tracking is not accurate.So it is necessary to control and track the path.Modelling of fixed wing UAV system by considering the longitudinal dynamics and the performance of UAV is analysed by using conventional PID controller and convenient result is obtained. To improve the performance and analysis,another controller named H-infinity controller was used and comparing the results with PID controllers.

Index Terms— Control,Elevator Actuator,Longitudinal Dynamics,Path tracking,PID,Robust H-infinity Controller,Unmanned Aerial Vehicle.

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1 INTRODUCTION

At present, the use of advanced control systems is increasing day by day in every field; aeronautics is one out of them. Unmanned Aerial Vehicles (UAVs) are one such development of aeronautical, instrumentation and control system technologies. UAVs have a wide range of civil and military applications and are of different sizes according to applications [1].

An Unmanned Aerial Vehicle (UAV) is an aircraft without a human pilot on board. Its flight is controlled either autonomously by computers onboard the vehicle, or remotely by a pilot on the ground, or by another vehicle [2]. In 1917, Peter Cooper and Elmer A. Sperry invented the first UAV, named Sperry Aerial Torpedo. Its size was equivalent to a normal size airplane. It took a payload of 300 pounds and flew 50 miles during its fight. There is a lot of interest recently in smaller UAVs also called Miniature Aerial Vehicles (MAVs). The development of technology, such as materials, electronics, sensors, and batteries has fueled the growth in the development of MAVs that are typically between 0.1 and 0.5 m in length and 0.1–0.5 kg in mass.

A fixed-wing aircraft is an aircraft, such as an aeroplane, which is capable of flight using wings that generate lift caused by the vehicle's forward airspeed and the shape of the wings.Fixed-wing aircraft are distinct from rotary-wing aircraft, in which the wings form a rotor mounted on a spinning shaft, and ornithopters, in which the wings flap in similar manner to a bird

This paper considers the longitudinal control of a system of two fixed wing UAVs along a predefined path. By considering two UAVs, one must follow the path of other.

2 PROBLEM STATEMENT

This paper presents the controller design for control and tracking of the longitudinal dynamics of forward and vertical velocities and pitch angle of two member UAVs system. The proposed controllers for the present study are Proportional-Integral-Derivative (PID) conventional controller and the H-infinity robust controller. A comparison is made based on their performance.

3 MODELLING OF UAV

From the Newton's second law for linear motion, the force is the product of mass and acceleration. In rotary motion, the product of moment of inertia and angular acceleration results in moment [4]. Consider a three dimensional axis system with the centre of gravity of a single UAV as the origin, the components of inertial velocities, accelerations etc. are computed based on fig.1[6]

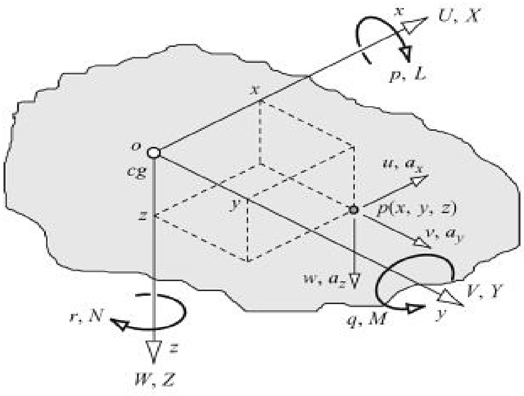

Fig.1: Resolving the inertial components from c.g. in a UAV.

The velocity components at p(x, y, z) relative to 'o' are given by

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- Najiya A is currently pursuing masters degree program in industrial instrumentation and control in TKMCE in kerala University, India, PH-9497756859. E-mail: najiyaashraf92@gmail.com
- Laila Beebi M., Professor , industrial instrumentation and control, TKM college of engineering Kollam. Johnson Y,is currently working as Associate Professor, UKF CET, Parippally,India, PH-98475 90214. E-mail: j_yohannan2000@yahoo.com

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$$u = \dot{x} - ry + qz$$

$$v = \dot{y} - pz + rx$$

$$w = \dot{z} - qx + py \qquad (1)$$

Aircraft assumed to be rigid, then

$$\dot{x} = \dot{y} = \dot{z} = 0 \qquad (2)$$

Inertial velocity components (u', v', w') of the point p(x,y,,z)

$$u' = U + u = U - ry + qz$$

$$v' = V + v = V - pz + rx$$

$$w' = W + w = W - qz + py \qquad (3)$$

Similarly components of inertial acceleration

$$a'_x = \dot{u}' - rv' + qw'$$

$$a'_y = \dot{v}' - pw' + ru'$$

$$a'_z = \dot{w}' - qu' + pv' \qquad (4)$$

Total force acting on the rigid body and the resultant moment about the axes is given by

$$m(\dot{U} - rV + qW) = X$$
$$m(\dot{V} - pW + rU) = Y$$
$$m(\dot{W} - qU + pV) = Z \qquad (5)$$

$$\sum \delta m(ya'_z - za'_y) = L$$
$$\sum \delta m(za'_x - xa'_z) = M$$
$$\sum \delta m(xa'_y - ya'_x) = N \;\ldots\ldots\ldots\ldots(6)$$

By considering the aerodynamic coupling, the associated stability derivatives are negligibly small and thus aileron and rudder deflection does not have much effect in longitudinal dynamics. The longitudinal equations obtained after algebraic manipulations are

$$m\dot{u} - \overset{\circ}{X}_u u - \overset{\circ}{X}_w \dot{w} - \overset{\circ}{X}_w w - \overset{\circ}{X}_q q + mg\theta = \overset{\circ}{X}_\eta \eta + \overset{\circ}{X}_\tau \tau$$

$$-\overset{\circ}{Z}_u u + (m - \overset{\circ}{Z}_w)\dot{w} - \overset{\circ}{Z}_w w - (\overset{\circ}{Z}_q + mU_e)q = \overset{\circ}{Z}_\eta \eta + \overset{\circ}{Z}_\tau \tau$$

$$-\overset{\circ}{M}_u u - \overset{\circ}{M}_{\dot{w}} \dot{w} - \overset{\circ}{M}_w w + I_y \dot{q} - \overset{\circ}{M}_q q = \overset{\circ}{M}_\eta \eta + \overset{\circ}{M}_\tau \tau$$

The state space equation of Linear Time Invariant (LTI) system is given by

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

Convert the above longitudinal equations into state space format, then

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} x_u & x_w & x_q & x_\theta \\ z_u & z_w & z_q & z_\theta \\ m_u & m_w & m_q & m_\theta \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} x_\eta & x_\tau \\ z_\eta & z_\tau \\ m_\eta & m_\tau \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \eta \\ \tau \end{bmatrix}$$

The output equation may be obtained as

$$\text{y(t)=Cx(t) + Du(t)} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix}$$

'A' matrix corresponds to aerodynamic stability derivatives and 'B' matrix corresponds to aerodynamic control derivatives. 'C' matrix is I and D=0

Take the longitudinal response to elevator only about a trim state in which thrust is held constant. Then longitudinal state equation[7] become

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} x_u & x_w & x_q & x_\theta \\ z_u & z_w & z_q & z_\theta \\ m_u & m_w & m_q & m_\theta \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} x_\eta & x_\tau \\ z_\eta & z_\tau \\ m_\eta & m_\tau \\ 0 & 0 \end{bmatrix} [\eta]$$

4 CONTROL AND TRACKING

The variations in the longitudinal dynamics such as forward velocity, vertical velocity and pitch are controlled by using a suitable PID controller. PID is very popular for its damped response with negligible errors. So a detailed discussion about PID control technology is not mentioned here. The two UAVs are separately controlled by using these designed PID controllers.

The block diagram in Fig.2 represents a system of two UAVs individually controlled and tracked one by another in

MATLAB Simulink considering the longitudinal dynamics.

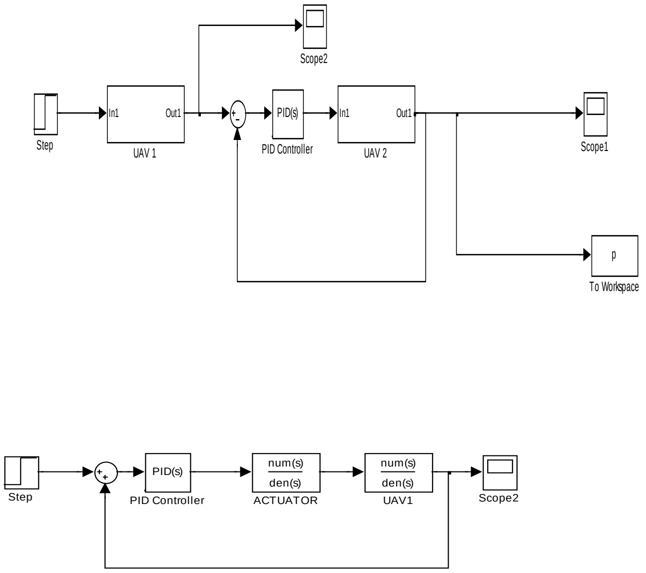

Fig.2: (A) The controlled and path tracked UAV system (top) (B) Block Diagram of PID controlled subsystem in fig.2(A).

Simulation is carried out for the control of fixed wing UAV system under longitudinal dynamics[5] by considering

1) longitudinal(forward) velocity
2) vertical velocity
3) pitch

An actuator block of first order transfer function, comprises of elevator servo gain and time constant of servomotor, is also incorporated along with the plant transfer function. The PID controllers are tuned using optimization techniques. They have achieved the required control and tracking performance as is clear from the results in section 6. But their settling times are of the order of thousands of seconds. But the required settling time will be in the order of a few seconds. So we have to switch over to another controller capable of controlling each state within seconds.

5 H-INFINITY CONTROLLER

Under perturbed condition the conventional controllers like PID may become a failure in proper control. To maintain stability in real perturbed conditions, the robust H-infinity controller[3] is taken for the given stability analysis. General Block diagram of H-infinity controller is shown in fig.3

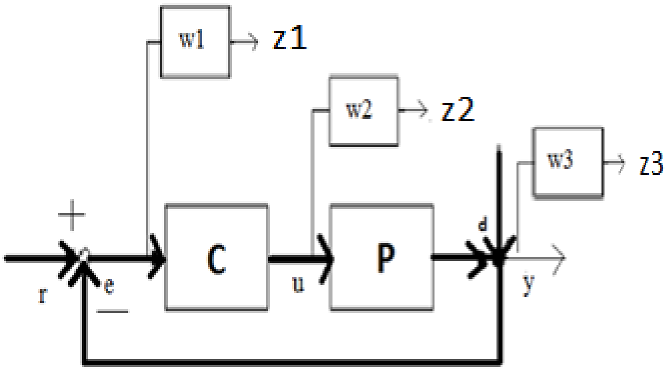

Fig.3:H-infinity Controller And Its Weights Along With The Plant

Where C=H-infinity Controller,P=plant,e=error,r=reference, u=input to the plant,y=actual output,and z1,z2,z3 aredesired error,desired input and desired output signals.Three weights W1,W2 and W3 are used to tune for getting performance and stability achievement.The performance(sensitivity) weight W1 is selected to achieve good disturbance rejection. For stability margin,the stability(complementary sensitivity) weight W3 is tuned.The control weight W2 is an empty weight for the present problem.

W1=(s/M+w0)/(s+w0*A)

W2=0(empty control weight)

W3=(s+w0/M)/(A*s+w0)

Where

w0-desired closed-loop bandwidth

A-desired disturbance attenuation inside bandwidth

M- desired bound on hinf norm(S) and hinf norm(T)

The necessary condition to satisfy the required design is the value of the infinity norm of the product of weights assigned and the sensitivity(S)/complementary sensitivity (T) should be less than or equal to one. The SV (Singular Value) plots in fig. verified the application eligibility of H-infinity controllers in the present problem.

6 RESULTS

The open loop response of forward velocity, vertical velocity and pitch dynamics are given in figures 4 to 7. The PID controlled closed loop controlled and tracking responses of forward velocity, vertical velocity and pitch of the given UAVs are given in figures 8 to 10. The H-infinity controlled response in figures 11 to 13 are having settling time less than that we used with PID and satisfying the required criteria.

a) Open Loop Response

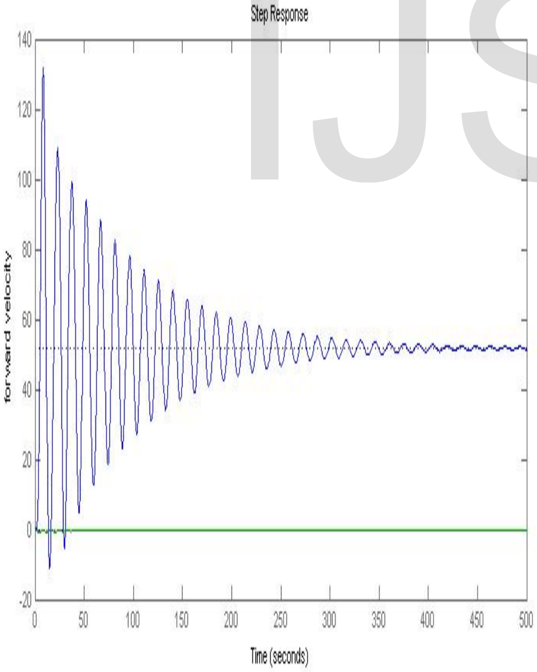

Fig.4: Open loop response of forward velocity path tracking of UAV system

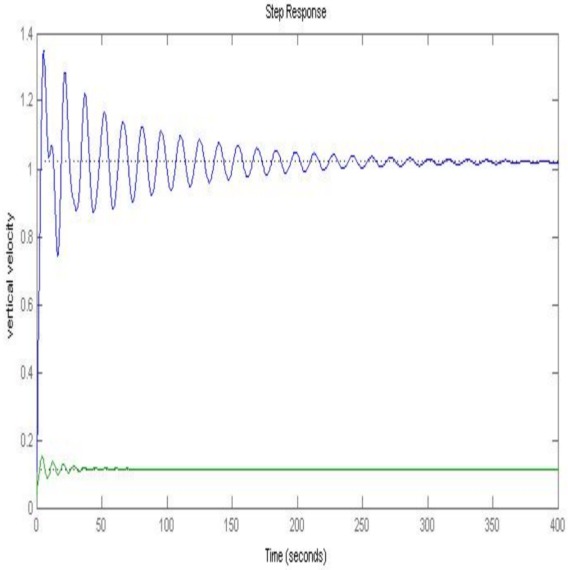

Fig.5: Open loop response of vertical velocity path tracking of UAV system

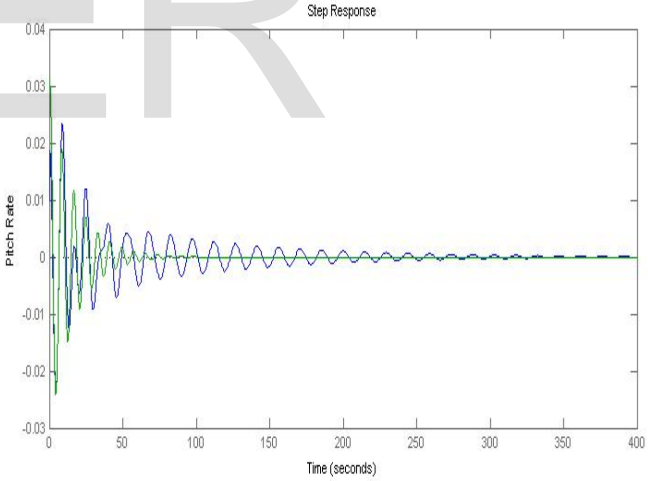

Fig.6: Open loop response of pitch rate path tracking of UAV system

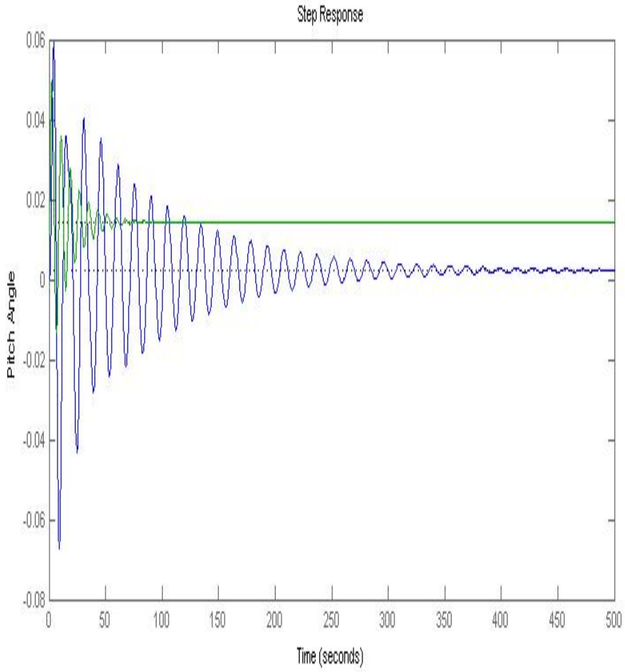

Fig.7: Open loop response of pitch angle path tracking of UAV system

a) Longitudinal Response

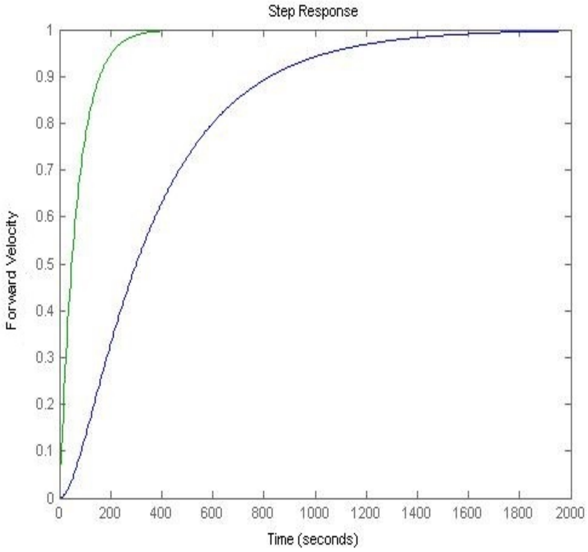

Fig.8: PID Controlled Forward-velocity Response of UAVs with Elevator Actuator

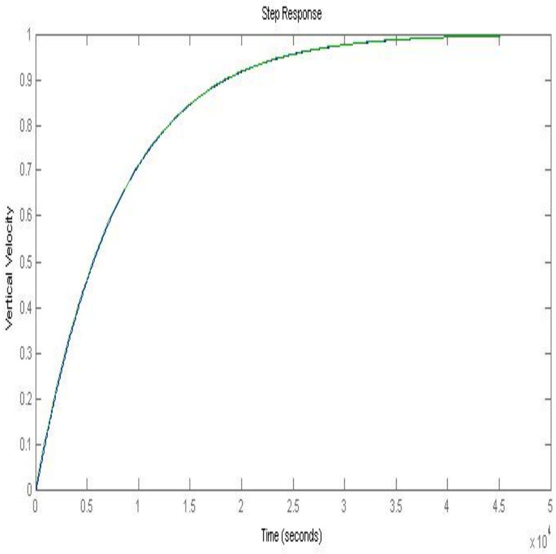

Fig.9: PID Controlled Vertical-velocity Response of UAVs with Elevator Actuator

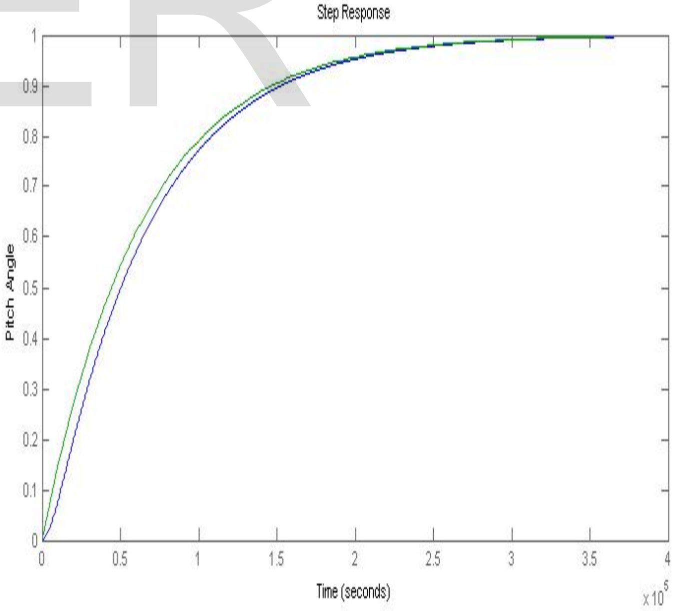

Fig.10: PID Controlled Pitch Response of UAVs with Elevator Actuator

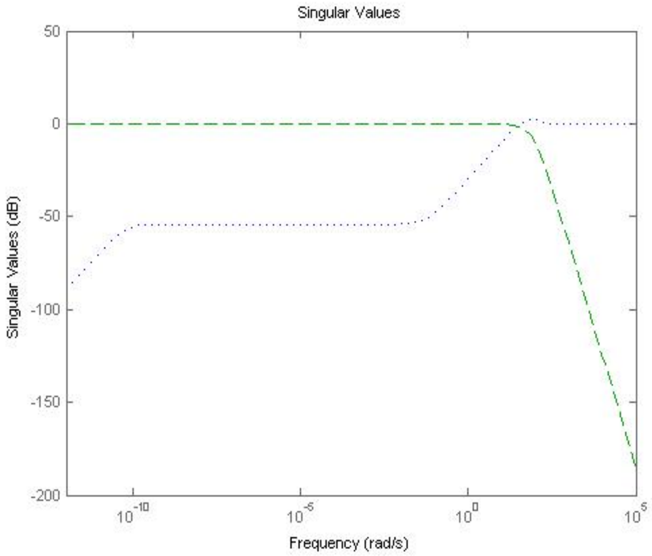

Fig.11: SV Plot

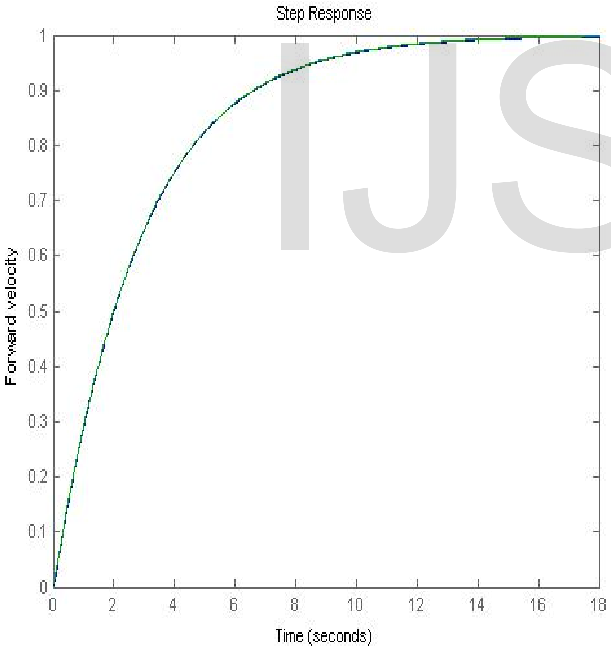

Fig.12: H-infinity controlled forward velocity response of UAVs with elevator actuator

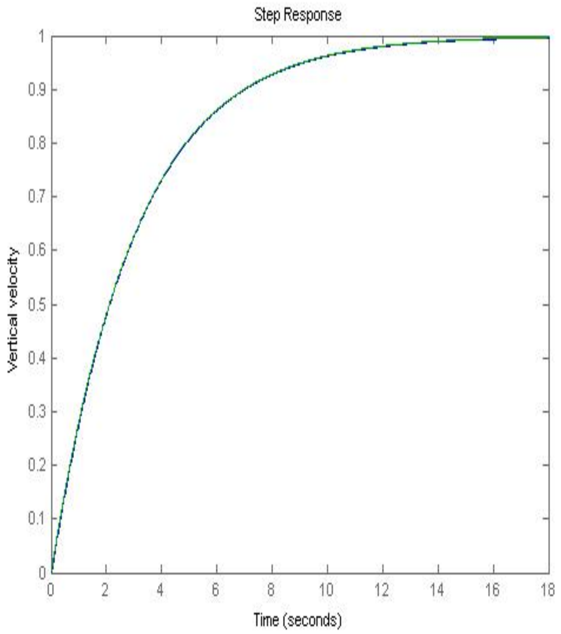

Fig.12: H-infinity controlled vertical velocity response of UAVs with elevator actuator

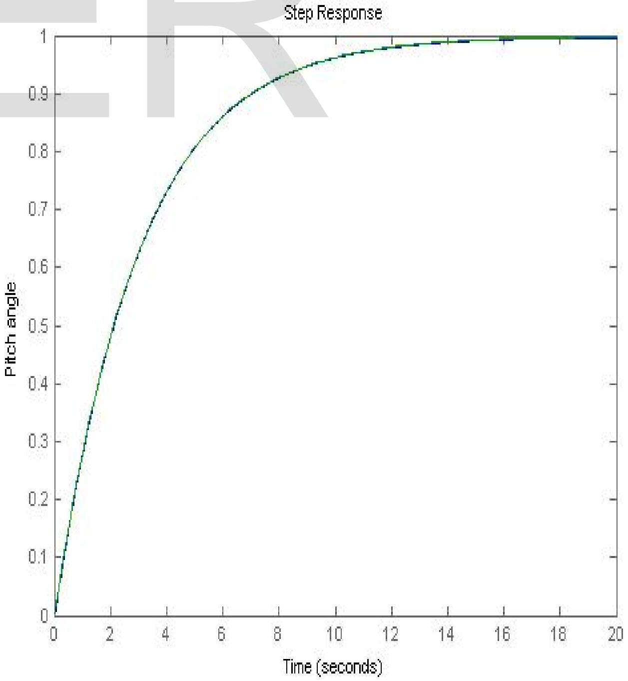

Fig.13: H-infinity controlled pitch angle response of UAVs with elevator actuator

7 CONCLUSION

The path control and tracking of two UAVs under longitudinal dynamics can be performed .This can be obtained by using PID controller. The longitudinal dynamics of forward velocity, vertical velocity, pitch of two UAVs are controlled. By considering the H-infinity controller, improved the performance by reducing the settling time comparing with PID. Excellent path tracking is obtained with this controller.

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