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Control And Tracking Of Vertical Velocity Dynamics Of 2 Fixed Wing UAV System Based On Settling Time

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Abstract—
This paper presents the control of a fixed wing UAV (unmanned aerial vehicle). UAV functions either by means of remote control of a navigator or through autonomous means and it do not carry any human operator. Many applications of small UAVs require proper control for the vehicle to traverse an inertially definite path in disturbed conditions. A conventional PID controller and an H-infinity controller were used for the vertical velocity control and their performance are compared each other based on settling time.

Index terms: *Elevator, PID, Robust H-infinity Controller, Unmanned Aerial Vehicle.*

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I. INTRODUCTION

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 and have a wide range of civil and military applications [1]. The fig.1 shows the image of a UAV which is an aircraft without a human pilot on board and 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 fuelled 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.

Fig.1: A UAV in flight (ref: Google)

PROBLEM STATEMENT

Control and tracking of the longitudinal dynamics of forward and vertical velocities and pitch angle of two member UAVs system are considered. 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.

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 3D axes 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.2[6]

The Components of Inertial Acceleration

Consider the motion of a body referred to an orthogonal reference axis set oxyz [6]. Let u, v, w be the components of velocity and X, Y, Z represents the components of force. In similar way, p, q, r represents the components of angular velocity and L, M, N represents the moment components along x, y, z directions respectively [4].

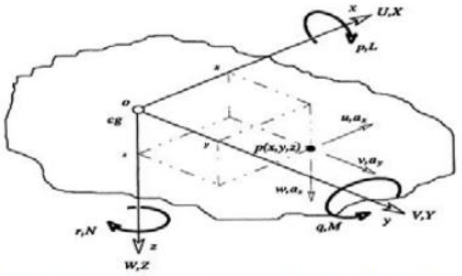

Fig.2.Motion referred to generalised body axis.

The velocity components at p (x, y, z) are given by,

$$\begin{aligned} u &= \dot{x} - \mathrm{ry} + \mathrm{qz} \\ \mathrm{v} &= \dot{y} - \mathrm{pz} + \mathrm{rx} \\ \mathrm{w} &= \dot{z} - \mathrm{qx} + \mathrm{py} \end{aligned} \tag{1}$$

Since the aircraft is assumed to be rigid, $\dot{x} = \dot{y} = \dot{z} = 0$. Then,

$$\begin{aligned} u &= -\mathrm{ry} + \mathrm{qz} \\ \mathrm{v} &= -\mathrm{pz} + \mathrm{rx} \\ \mathrm{w} &= -\mathrm{qx} + \mathrm{py} \end{aligned} \tag{2}$$

Corresponding components of acceleration are given by,

$$\begin{aligned} a_x &= \dot{u} - \mathrm{rv} + \mathrm{qw} \\ a_y &= \dot{v} - \mathrm{pw} + \mathrm{ru} \\ a_z &= \dot{w} - \mathrm{qu} + \mathrm{pv} \end{aligned} \tag{3}$$

The inertial velocity components are given by,

$$\begin{aligned} \dot{u} &= U + u = U - \mathrm{ry} + \mathrm{qz} \\ \dot{v} &= V + v = V - \mathrm{pz} + \mathrm{rx} \\ \dot{w} &= W + w = W - \mathrm{qx} + \mathrm{py} \end{aligned} \tag{4}$$

Similarly, the inertial acceleration components are

$$\begin{aligned} a'_x &= \dot{U} - \mathrm{rv} + \mathrm{qw} - \mathrm{x}(q^2 + r^2) + y(pq - \dot{r}) + z(pr + \dot{q}) \\ a'_y &= \dot{V} - \mathrm{pw} + \mathrm{ru} - \mathrm{x}(pq + \dot{r}) - y(p^2 + r^2) + z(qr + \dot{p}) \\ a'_z &= \dot{W} - \mathrm{qu} + \mathrm{pv} + \mathrm{x}(pr - \dot{q}) + y(qr + \dot{p}) - z(p^2 + q^2) \end{aligned} \tag{5}$$

CONTROL AND TRACKING

PID Controller

The variations in the longitudinal dynamics such as forward velocity, vertical velocity and pitch are to be controlled by using suitable PID controllers. 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.3 represents a system of two UAVs individually controlled and tracked one by another in MATLAB Simulink considering the vertical velocity longitudinal dynamics only.

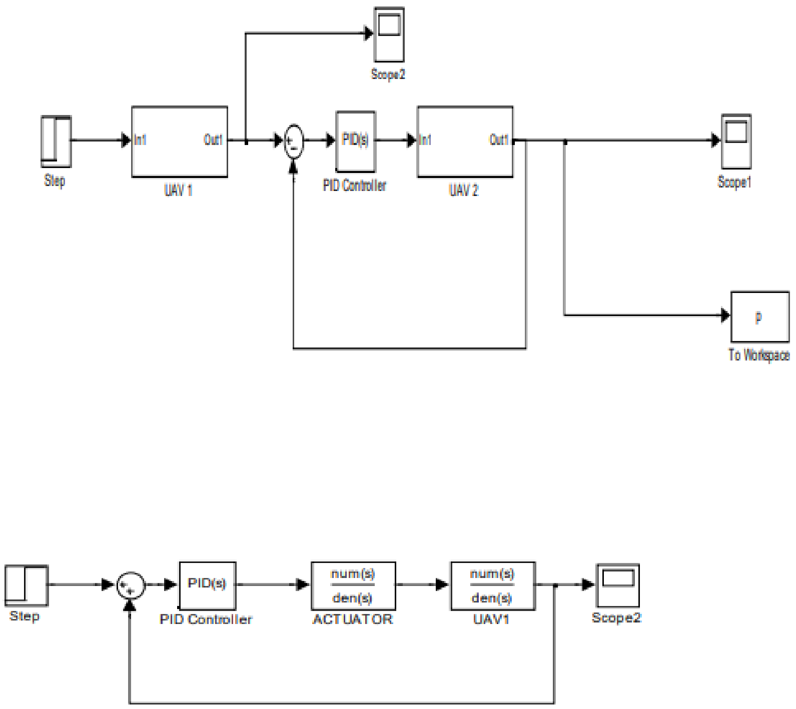

Fig.3: (A) (top)The closed loop controlled UAV2 based on UAV1 (B) (bottom) The closed loop controlled UAV1 based on an independent reference step trajectory.

Simulation is carried out for the control of fixed wing UAV vertical velocity longitudinal dynamics [5]. 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 in MATLAB. They have achieved the required control and tracking performance as is clear from the results in section-5. 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.

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.4.

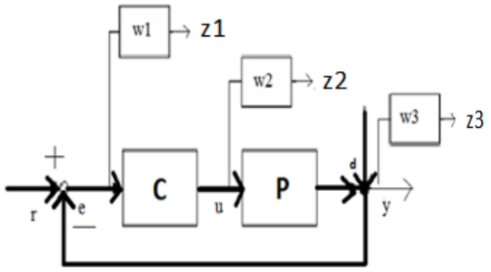

Fig.4: H-infinity Controller and its Weights along with the Plant

The notations used here are: C - H-infinity Controller, P - plant, e - error, r - reference, u - input to the plant, y - actual output and z1, z2 & z3 - desired 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) functions 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.

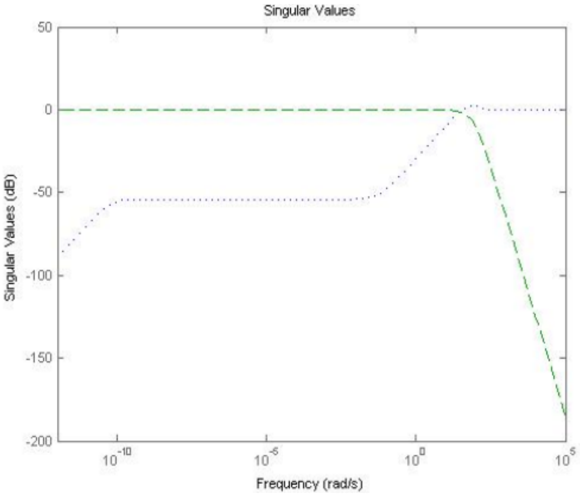

Fig.5: SV Plot

II. RESULTS

The open loop response of vertical velocity dynamics of the UAVs is given in fig.6. The closed loop PID controlled and tracked response of vertical velocity of the given UAVs is given in fig.7. The corresponding H-infinity controlled response is in fig.8.

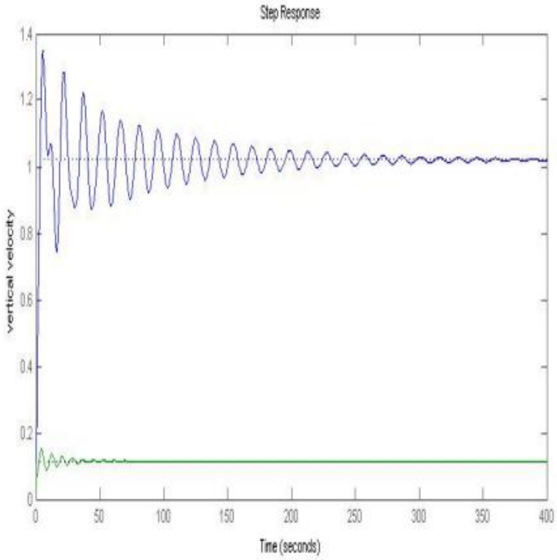

Fig.6: Open loop response of vertical velocity dynamics of UAVs

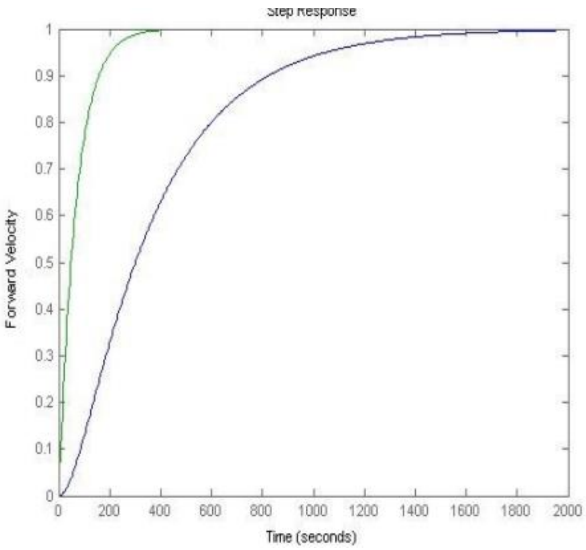

Fig.7: PID controlled vertical velocity dynamics of UAVs

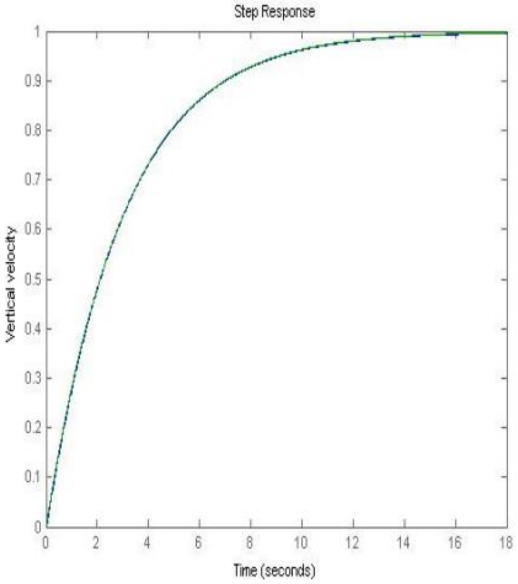

Fig.8: H-infinity controlled vertical velocity dynamics of UAVs

The h-infinity controlled and tracked response has the settling time of order 12 seconds which is very less than that we used with PID (400 sec for UAV1 and 1600 sec for UAV2). It is observed that the robust H-infinity controller achieved good performance when the required criteria (15 seconds) is considered.

III. CONCLUSION

The control and path tracking of two UAVs under vertical longitudinal dynamics are performed. This can be obtained by using PID controller. The longitudinal vertical velocity dynamics of 2 UAVs are controlled. By considering the H-infinity controller, improved the performance has obtained by reducing the settling time comparing with PID. Excellent path tracking is obtained with this controller.

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