

Pole Placement Control Technique for Tracking Path Control of UAV by Longitudinal and Lateral Parameters Control

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Abstract—Unmanned Aerial Vehicle (UAV) is an autonomous flight and to obtain desired flight path and trajectory, it is necessary to control its various parameters. This paper presents a flight path control of fixed wing UAV by the control of Lateral and Longitudinal parameters using MATLAB platform. In this paper, simple mathematical model of 6 degrees of freedom (DOF) UAV having three linear and three rotational motions is presented. For simplicity and to obtain desired path and trajectory control, mathematical model of fixed wing 6 DOF UAV is divided into two subsystems. One subsystem is used to control Longitudinal Parameter such as vehicle speed and height without any change in direction of motion while the other sub system is used for the control of lateral parameters such as control of angular speed along x-axis, for yaw and roll control and control of angular speed along z-axis. Both sub-systems are Multi Input Multi Output (MIMO) in nature, the desired input output combinations are extracted for the effective control of UAV. In this paper open loop behaviour of these system are plotted and analysed. It has been observed that open loop systems are not able to follow the desired trajectory. Further, these sub-systems are controlled by Pole Placement technique so that the vehicle can follow the desired path. The implementation and simulation of pole placement controllers on UAV is done using MATLAB software.

Keywords—Unmanned Aerial Vehicle, Lateral Autopilot, Longitudinal Autopilot, Autonomous Aerial Vehicle, Flight Control, Pole Placement, MIMO, SISO

I. INTRODUCTION

Use of advance control systems is increasing day by day in every field of engineering and aeronautics is one out of them. It was always a desire of humans to develop intelligent systems which can obey them on ground, water and in the air. Unmanned aerial vehicles (UAVs) are one such development of aeronautical, instrumentation and control system technologies [1]. UAVs are available in different sizes and have wide range of civil and military applications. Remote sensing, Commercial aerial surveillance, Archaeology, Forest fire detection, Armed attacks, Scientific research, Oil, gas and mineral exploration and production, Commercial and Motion Picture Filmmaking, Search and rescue operations, Maritime patrol, Aerial target practice in training of human pilots etc. are the few out of many applications where these have proved to be an alternative and fill the gap where the risk of human piloted aircraft is not acceptable or impractical [2].

The automatic flight controller, also known as autopilot, the main building block of UAV, controls the UAV by generating control signals on the basis of desired flight path, target information and waypoints. The various sensors are used in UAVs to generate feedback signals for the controller on the basis of real time state of vehicle. The autopilot is controlled by a pilot on the ground or in another vehicle [3,4]. The traditional approach used for flight control system synthesis, implementation and validation is time consuming and resource intensive. Applying the same techniques for medium and small vehicles is not realistic. To make cost effective autopilots for these aerial vehicles computer technology plays an important role [5,6]. MATLAB is one such platform which can be used to simulate and test the performance of an autopilot [7]. Conventional Proportional Integral (PI) and Proportional Integral Derivative (PID), state feedback controllers and robust fuzzy logic controllers can be used to make autopilots to track the desired flight path. This paper presents the pole placement control technique to control the longitudinal and lateral

parameters of fixed wing UAV which improves its tracking path performance.

II. AERODYNAMICS AND MATHEMATICAL MODEL OF UAVS

A 6-DOF medium sized, fixed wing UAV's mathematical model is multivariable, time variant and non linear in nature [8,9]. Understanding and solving such a plant is very complex problem. So, its conversion into a linearized model is the primary requirement for autopilot designers to provide clear insight into the system dynamics [10].

The concept of mathematical model used in this paper is derived from a mathematical model used for medium sized unmanned aerial vehicle by Iftikhar H Makhdoom and Shi Yin Qin [11]. Its small perturbation linearized model is adapted to design autopilots to control UAV's Angular velocity along X-axis, Yaw, Roll and Angular velocity along Z-axis.

The nonlinear dynamic model is developed with the help of force and moment equations. An aircraft is six degrees of freedom (6 DOF) having three linear and three rotational motions. All calculations are done by taking parameter values with respect to centre of gravity of vehicle. Force and moment depend on the thrust applied by engine and engine speed is taken in rpm [12].

To obtain dynamics of UAVs, Consider that it is heading along x axis, its right wing and z axis downward, passes through its center of gravity and perpendicular to both x and y axis. Suppose the state vectors are in north east down (NED) projection. By assuming flat earth model, the nonlinear dynamic state equations are [13]:

$$\dot{U} = RV - QW - g_D \sin \theta + (X_A + X_T)/M \quad (1)$$

$$\dot{V} = -RU + PW + g_D \sin \phi \cos \theta + (Y_A + Y_T)/M \quad (2)$$

$$\dot{W} = QU - PV + g_D \cos \phi \cos \theta + (Z_A + Z_T)/M \quad (3)$$

$$\dot{\phi} = P + \tan \theta (Q \sin \phi + R \cos \phi) \quad (4)$$

$$\dot{\theta} = Q \cos \phi - R \sin \phi \quad (5)$$

$$\dot{\psi} = (Q \sin \phi + R \cos \phi) / \cos \theta \quad (6)$$

$$\Gamma \dot{P} = J_{XZ} [J_X - J_Y + J_Z] PQ - [J_Z (J_Z - J_Y) + J_{XZ}^2] QR + J_Z \ell + J_{XZ} n \quad (7)$$

$$J_Y \dot{Q} = (J_Z - J_X) PR - J_{XZ} (P^2 - R^2) + m \quad (8)$$

$$\Gamma \dot{R} = [(J_X - J_Y) J_X - J_{XZ}^2] PQ - J_{XZ} [J_X - J_Y + J_Z] QR + J_{XZ} \ell + J_X n \quad (9)$$

$$\dot{p}_N = U c \theta c \psi + V (-c \phi \psi + s \phi s \theta c \psi) + W (s \phi s \psi + c \phi s \theta c \psi) \quad (10)$$

$$\dot{p}_E = U c \theta s \psi + V (c \phi c \psi + s \phi s \theta s \psi) + W (-s \phi c \psi + c \phi s \theta s \psi) \quad (11)$$

$$\dot{h} = U s \theta - V s \phi c \theta - W c \phi c \theta \quad (12)$$

Where

$X = [p_N \ p_E \ p_D \ \phi \ \theta \ \psi \ U \ V \ W \ P \ Q \ R]$, $[X_T, Y_A, Z_A]$ Are aerodynamic forces and $[\ell, m, n]$ are moments. The propulsive forces are represented by $[X_T, Y_T, Z_T]$.

$\Gamma = J_X J_Z - J_{XZ}^2$, where J represents the 3×3 inertia matrix θ, ϕ and ψ Are the Euler angles (roll, yaw and pitch angles). These aerodynamic forces and moments depends on elevator, throttle, aileron and rudder actuator control vectors $[\delta_e, \delta_t, \delta_a, \delta_r]$ and various other flight variables. and g_D is acceleration due to gravity in NED axis and $h = -p_D$ with vehicle weight M . $c\phi = \cos\phi$ and $s\phi = \sin\phi$ etc are the other notations used in above equations.

Decoupling of nonlinear equations is done by considering both bank angle and sideslip angle equal to zero which provide a normal flight condition and convert nonlinear set of equations into two sets for longitudinal and lateral motions of aircraft [14]. Conversion of nonlinear equations into linear equations uses small perturbation theory at normal non accelerated flight at constant speed. Linear model can be find out by using MATLAB commands around the trimmed conditions [15].

Linear model consist longitudinal and lateral model of system. To control height, speed and pitch of aircraft of vehicle we need longitudinal model of the aircraft having five states and two inputs Elevator and Throttle [16]. Elevator is used to control height, pitch and pitch rate of the aircraft while Throttle is used to control vehicle speed. To control angular speed along X-axis, Yaw and Roll of vehicle we need lateral model of the aircraft having five states and two inputs Aileron and Rudder [17]. Aileron is used to control angular speed along X axis, Yaw and Roll of the aircraft while Rudder is used to control vehicle angular speed along Z axis.

The performance of an aircraft can be described by assuming the aircraft is a point mass concentrated at the aircraft's center of gravity 'cg'. The flying qualities of an aircraft, on the other hand, cannot be described in such a simple manner. The flying qualities of an aircraft must, instead, be described analytically as motions of the aircraft's cg as well as motions of the airframe about the cg, both of which are caused by aerodynamics, thrust and other forces and moments [18]. Various forces and moments on 6 DOF UAVs [19] are shown in figure 1.

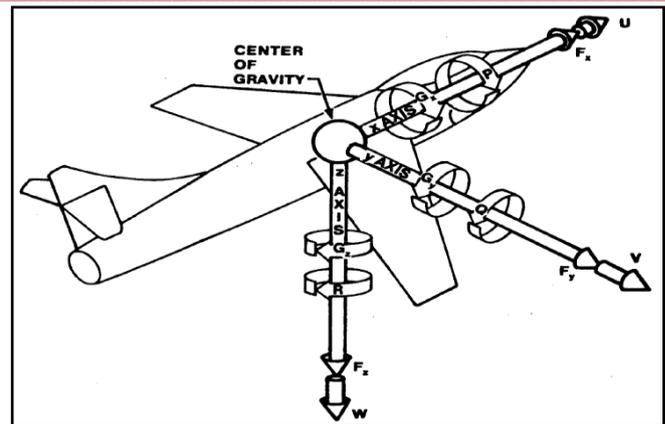


Figure1: Various Forces and Moments on a 6-DOF UAV [19]

The aircraft must be considered a three dimensional body and not a point mass. The applied forces and moments on the aircraft and the resulting response of the aircraft are traditionally described by a set of equations known as the aircraft equations of motion [20]. The equations that will be developed are not as rigorous and complicated as those used for design of modern aircraft, but the basic method is valid and will provide analysis techniques that are accurate enough to gain an insight into aircraft flying qualities [21]. With the aid of high speed computers the aircraft designers' more rigorous theoretical calculations, modified by data obtained from the wind tunnel, can often give results which closely predict aircraft flying qualities [22]. This is of substantial benefit in the development of new aircraft.

A 6 DOF UAV has six paths free to follow and it can move forward, sideways, and down; and it can rotate about its axes with yaw, pitch, and roll as shown in figure 2.

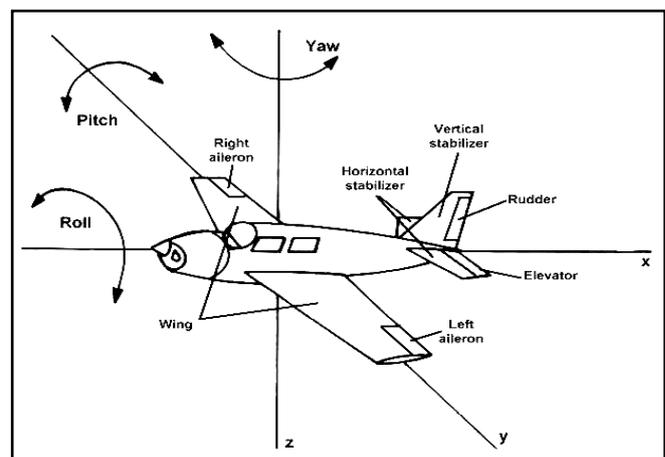


Figure2: Various Motions and Controlling Parameters of UAV

Various Rotational Motions and Euler angles of UAV are shown in figure 3.

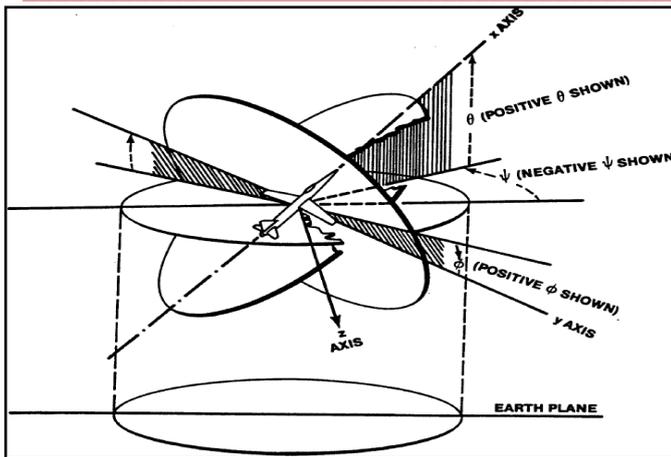


Figure3: Various Rotational Motions and Euler angles of UAV [19]

In order to describe the state of a system that has six degrees of freedom, values for six variables are necessary. To solve for these six unknowns, six simultaneous equations are required. For an aircraft, these are known as the aircraft equations of motion. The full aircraft equations of motion reflect a rather complicated relationship between the forces and moments on the aircraft, and the resulting aircraft motion.

III. STATESPACEEQUATIONSOF UAV

The nonlinear set of equations of aircraft dynamics can be linearized using MATLAB commands. This linearization is done around a flight condition called as trim conditions of dynamic model. The linear model and its conversion into state space leads to selection of desired MIMO systems for the control of UAVs. State equations of medium sized fixed wing UAV are given as:

$$\begin{aligned} \dot{U} &= -0.0844U + 0.4354W - 4.3589Q - 9.7483\theta - 0.0494\delta_e + 144.8262\delta_t \quad (13) \\ \dot{V} &= -0.1715V - 2.1808P - 45.91R + 9.7959\phi + 3.67\delta_r \quad (14) \\ \dot{W} &= -0.2920U - 1.8188W + 39.7431Q - 1.0682\theta - 3.2438\delta_e \quad (15) \\ \dot{P} &= -0.4943V - 7.3177P + 2.8589R + 23.711\delta_a - 0.3001\delta_r \quad (16) \\ \dot{Q} &= 0.8313U - 0.3089W - 2.3953Q + 0.0026\theta + 8.6497\delta_e - 7.2413\delta_t \quad (17) \\ \dot{R} &= 0.1782V - 0.982P - 0.4811R - 0.6447\delta_a - 5.413\delta_r \quad (18) \\ \dot{\theta} &= Q \quad (19) \\ \dot{\phi} &= P + 0.0468R \quad (20) \\ \dot{\psi} &= 1.0011R \quad (21) \\ \dot{h} &= 0.1090U - 0.9940W - 40.9624\theta \quad (22) \end{aligned}$$

State space model of any plant can be given as:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \quad (23) \end{aligned}$$

Where \dot{x} represent various states outputs and u inputs and A , B , C and D represent state matrices of the plant. It can be easily calculated from the state equations of the vehicle [23].

$A=$

$$\begin{bmatrix} -0.0844 & 0.4354 & -4.3589 & -9.7483 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -0.1715 & 2.1808 & -45.910 & 9.7959 & 0 \\ -0.2920 & -1.8188 & -39.7431 & -1.0682 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -0.4943 & -7.3177 & 2.8589 & 0 & 0 \\ 0.0313 & -0.3089 & -2.3089 & 2.3953 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.1782 & -0.9820 & -0.4811 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.0468 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1.0011 & 0 \\ 0.1090 & -0.9940 & 0 & 40.9624 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} -0.0494 & 144.8262 & 0 & 0 \\ 0 & 0 & 0 & 3.6700 \\ -3.2438 & 0 & 0 & 0 \\ 0 & 0 & 23.711 & -0.3001 \\ 8.6497 & -7.2413 & 0 & 0 \\ 0 & 0 & -0.6447 & -5.4130 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (25)$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (26)$$

$$D = [0]_{10 \times 4} \quad (27)$$

Where;

$$\dot{x} = [\dot{U} \ \dot{V} \ \dot{W} \ \dot{P} \ \dot{Q} \ \dot{R} \ \dot{\theta} \ \dot{\phi} \ \dot{\psi} \ \dot{h}]^T \quad (28)$$

$$x = [U \ V \ W \ P \ Q \ R \ \theta \ \phi \ \psi \ h]^T \quad (29)$$

$$u = [\delta_e \ \delta_{th} \ \delta_a \ \delta_r]^T \quad (30)$$

IV. SIMPLIFIED STATE MODELS

State space model of aerial vehicle contains Longitudinal and Lateral models. To control the system parameters using pole placement, we will divide these models on the basis of required pairs of input and output [24,25]. To do so we first convert state model of Longitudinal and Lateral into a set of transfer functions and choose the required transfer functions which are necessary to develop control strategy. Then we again convert the transfer functions into respective state models on the basis of input output relationship.

A. Simplified State Space Model Of Longitudinal Subsystem

Conversion of Longitudinal state model into two sub systems is done using MATLAB to make the problem simpler [26, 27]. It converts MIMO (Multiple Input Multiple Output) system into SISO (Single Input Single Output) and SIMO (Single Input Multiple Output) systems. First system is for Sideslip, Height and Pitch Control and second system is to control vehicle speed along x-axis. Pole placement operations can be easily applied on the resulting state models [28, 29]

1) State Space Model For Sideslip (Angular Velocity Along Y Axis), Height And Pitch Control:

$$A = \begin{bmatrix} -4.2980 & -17.25 & -1.778 & -1.42 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad (31)$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (32)$$

$$C = \begin{bmatrix} 8.65 & 17.46 & 2.461 & 0 & 0 \\ 0 & 8.65 & 17.46 & 2.461 & 0 \\ 0 & 3.219 & 16.3 & 684.5 & 59.86 \end{bmatrix} \quad (33)$$

$$D = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (34)$$

2) State Space Model For Speed (Linear Velocity Along X Axis) Control

$$A = \begin{bmatrix} -4.2980 & -17.25 & -1.778 & -1.42 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad (35)$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (36)$$

$$C = 1 \times 10^3 [0.1448 \quad 0.6419 \quad 2.411 \quad 0.0833 \quad 0] \quad (37)$$

$$D = [0] \quad (38)$$

B. Simplified State Space Model of Lateral Subsystem

As said above, the whole system is divided into two sub-systems, Longitudinal and Lateral. Conversion of Lateral state model into two sub systems is done using MATLAB to make the problem simpler. MI system are converted into SISO and SIMO (Single Input Multiple Output) systems according to the requirements. First system is for Yaw, Pitch and Forward Speed Control and second system is to control vehicle speed along z-axis. The state space model for first Lateral subsystem is given as:

1) State Space Model For Yaw, Roll And Angular Velocity Along X Axis Control:

$$A = \begin{bmatrix} -7.97 & -16.92 & -87.41 & 3.481 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad (39)$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (40)$$

$$C = \begin{bmatrix} 23.71 & 13.63 & 181 & -1.791 & 0 \\ 0 & 23.68 & 12.32 & 181.2 & 0 \\ 0 & -0.6454 & -28.14 & 3.7215 & 38.31 \end{bmatrix} \quad (41)$$

$$D = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \quad (42)$$

2) State Space Model For Angular Velocity Along Z Axis Control:

$$A = \begin{bmatrix} -7.97 & -16.92 & -87.41 & 3.481 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \quad (43)$$

$$B = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (44)$$

$$C = [-5.413 \quad -39.59 \quad -6.1275 \quad -26.73 \quad 0] \quad (45)$$

$$D = [0] \quad (46)$$

V. OPEN LOOP AND CLOSED LOOP RESPONSES OFS UAV

A. Open Loop Response

In this section open loop behaviour of 6 DOF UAV is shown. The various outputs of Longitudinal and Lateral parameters are unbounded and need a control mechanism for their stability.

1) Response Of Open Loop Longitudinal Subsystem:

Open loop response of UAV for longitudinal parameters such as sideslip q (angular velocity along Y axis), pitch θ and h (height) and open loop response of u (linear velocity along X axis) are shown in figures 4 and 5 respectively. Step signal is taken as input signals for Aileron and Rudder.

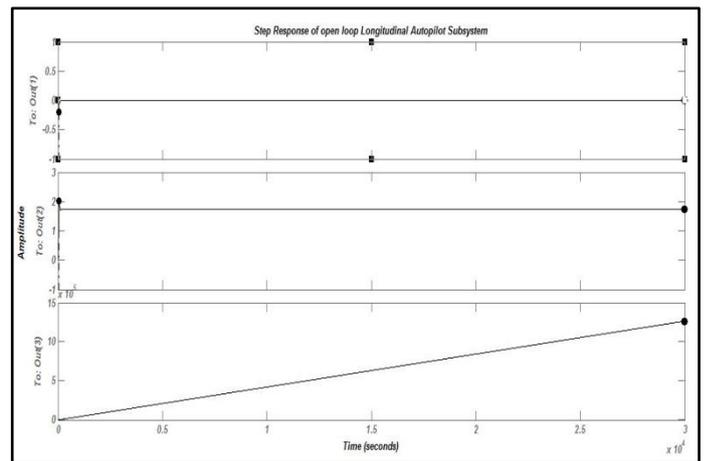


Figure4: Open loop response of sideslip q (angular velocity along Y axis), pitch θ and h (height)

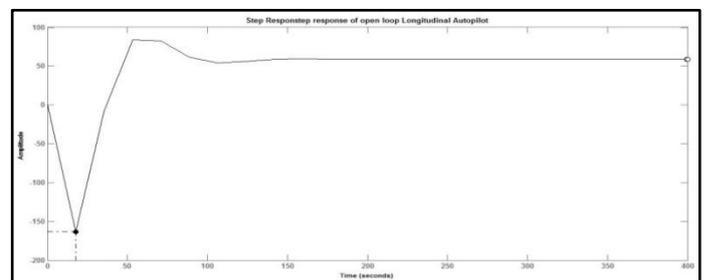


Figure5: Open loop response of u (linear velocity along X axis)

2) Response Of Open Loop Lateral Subsystem:

Open loop response of UAV for lateral parameters such as p (angular velocity along X-axis), ϕ (roll) and ψ (yaw) and open loop response of r (angular velocity along Z-axis) are shown in figures 6 and 7 respectively.

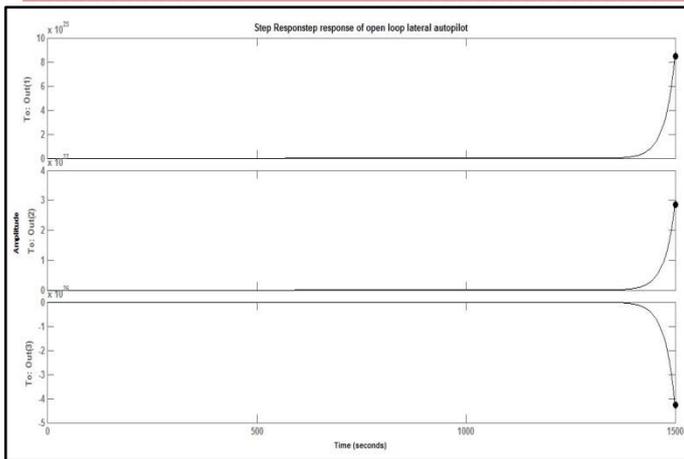


Figure6: Open loop response of p (angular velocity along X-axis), ϕ (roll) and ψ (yaw)

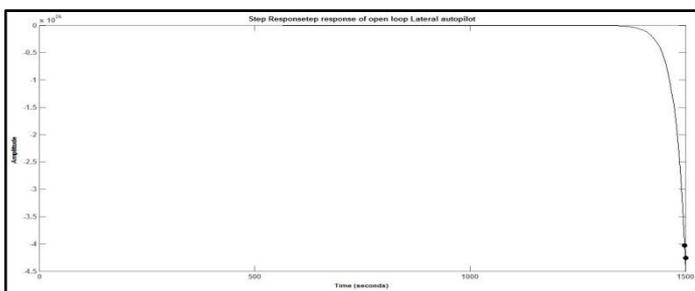


Figure7: Open loop response of r (angular velocity along Z-axis)

B. Closed Loop Response

Open loop system outputs were not following the desired set points, so to make them stable pole placement technique is used and stable outputs are achieved at some specific locations of closed loop poles in S-plane [30,31]. Controlled outputs of Longitudinal and Lateral subsystems are shown by plots which are achieved by MATLAB.

1) Response Of Closed Loop Longitudinal Subsystem:

In this paper, longitudinal and lateral parameters of UAV are controlled by using pole placement controller. The major task for lateral parameter control of UAV is the control of Aileron deflection for height control and the control of Rudder for speed control. The guidance block of the vehicle generates commands based on the required trajectory for lateral parameters. Control of yaw and roll is done by applying multiple feedback loops and control of angular speed along x-axis and z-axis is done by individual feedback loops [28,29]. The Closed loop response of longitudinal subsystem for sideslip q (angular velocity along Y axis), closed loop response for h(height) and Closed loop response for u(Linear velocity along X axis) using pole placement controllers are shown in figure 8, 9 and 10 respectively.

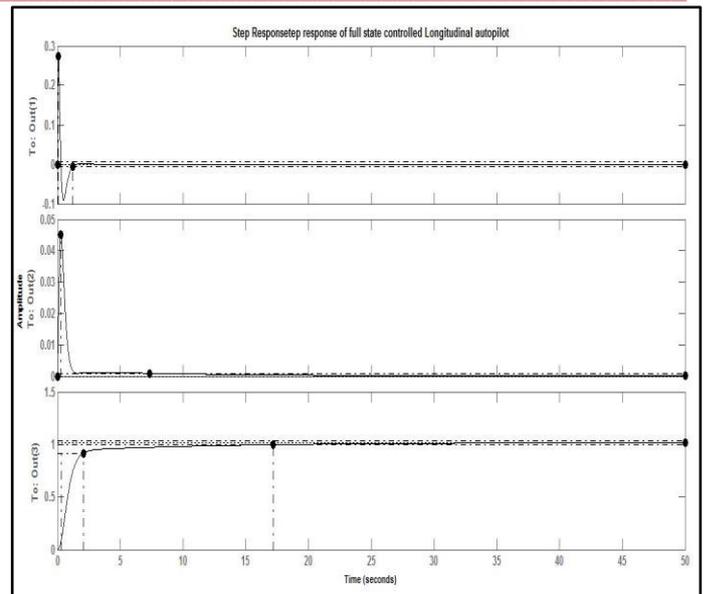


Figure8: Closed loop response of Longitudinal Subsystem for sideslip (q- angular velocity along Y axis) Control

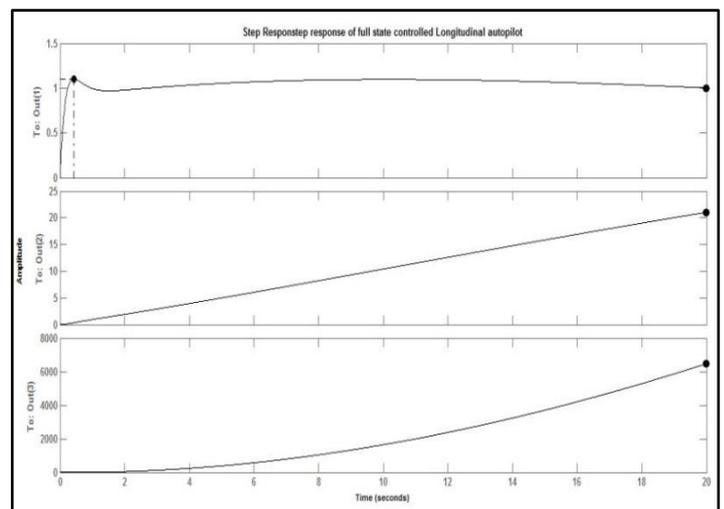


Figure9: Closed loop response of Longitudinal Subsystem for h (height) Control

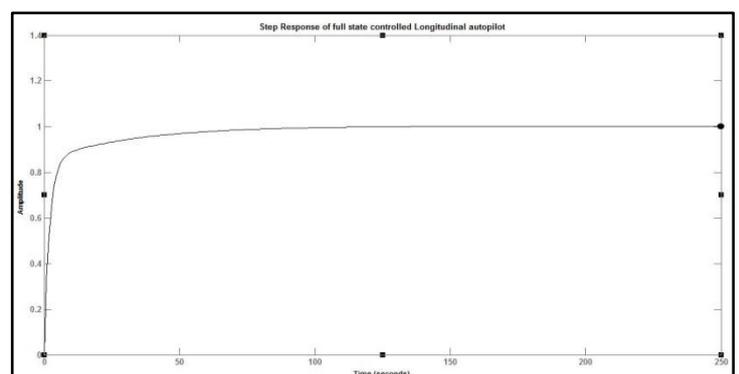


Figure10: Closed loop response of Longitudinal Subsystem u (Linear velocity along X axis) Control

2) Response Of Closed Loop Lateral Subsystem:

Closed loop response of p (angular velocity along x-axis), ϕ (Roll) and ψ (yaw), Closed loop response of p (angular

velocity along x-axis), ϕ (roll) and ψ (yaw), Closed loop response of r(angular velocity along z-axis) using pole placement controllers are shown in figure 11, 12 and 13 respectively.

closed loop poles for the stable output of system are shown in Table-1 and Table-2.

TABLE I. DESIRED LOCATION OF CLOSED LOOP POLES FOR LONGITUDINAL PARAMETERS POLE-PLACEMENT CONTROL

Parameter under control	Location of Closed-loop Poles	Corresponding Feedback Gains
Sideslip control	$P_1=-0.05+0.001j$ $P_2=-0.05-0.001j$ $P_3=0$ $P_4=-4.3$ $P_5=-4.2$	$K_1=4.3020$ $K_2=1.6625$ $K_3=0.0493$ $K_4=-1.3748$ $K_5=-0.0$
Height control	$P_1=-2.2512$ $P_2=-7.0107$ $P_3=-0.0811$ $P_4=-10.2$ $P_5=-4.5023$	$K_1=19.7472$ $K_2=182.5694$ $K_3=671.6383$ $K_4=776.6548$ $K_5=58.756$
Speed control	$P_1=-975$ $P_2=5.68$ $P_3=0.5$ $P_4=-0.3$ $P_5=0$	1×10^3 $K_1=0.9769$ $K_2=6.0405$ $K_3=2.9481$ $K_4=0.0816$ $K_5=0.0$

TABLE II. DESIRED LOCATION OF CLOSED LOOP POLES FOR LATERAL PARAMETERS POLE-PLACEMENT CONTROL

Parameter under control	Location of Closed-loop Poles	Corresponding Feedback Gains
P(Rotational Speed along x-axis) control	$P_1=-0.23+0.1j$ $P_2=-0.23-0.1j$ $P_3=0$ $P_4=-15.6$ $P_5=-15.61$	$K_1=23.7$ $K_2=241.0155$ $K_3=26.5705$ $K_4=18.7980$ $K_5=0.0$
Roll control loop	$P_1=-2.2512$ $P_2=-10.0107$ $P_3=-0.0811$ $P_4=-40.2$ $P_5=-0.4304$	1×10^3 $K_1=0.045$ $K_2=0.5254$ $K_3=1.0840$ $K_4=0.4848$ $K_5=0.0316$
R(Rotational Speed along z-axis) control loop	$P_1=-0.1-0.1j$ $P_2=-0.1+0.1j$ $P_3=-40$ $P_4=-32$	1×10^3 $K_1=0.0642$ $K_2=1.2775$ $K_3=0.17$ $K_4=0.0291$

This technique requires high level of expertise and understanding of control systems and their behavior to choose closed loop poles. A person with high expertise of the area can further improve the outputs of various parameters which lead to a better control system.

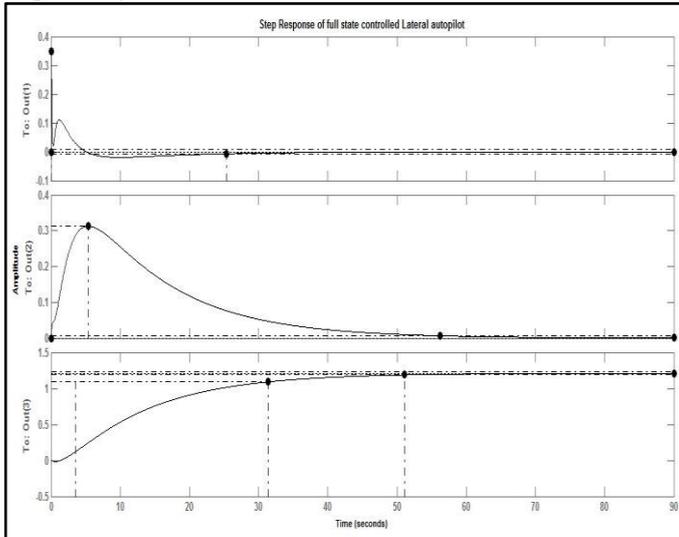


Figure 11: Closed loop response of lateral subsystem for p (angular velocity along x-axis) control

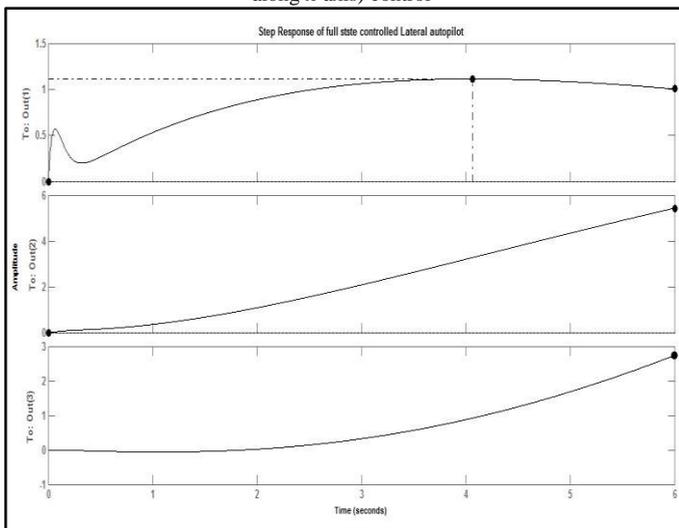


Figure 12: Closed loop response of lateral subsystem for ϕ (Roll) Control

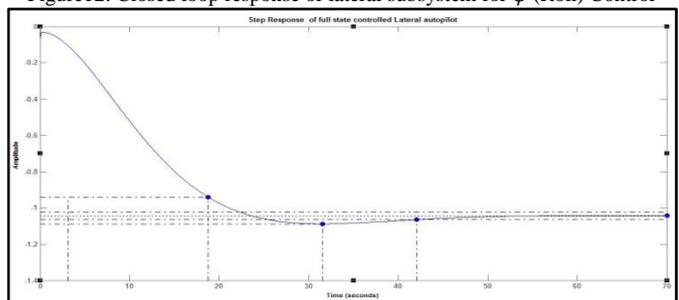


Figure 13: Closed loop response of Lateral Subsystem for r (angular velocity along z-axis) Control

VI. POLE LOCATIONS

Pole Placement technique is used efficiently to control Longitudinal and Lateral parameters of UAV. The construction of appropriate state-space models for various desired transfer functions leads to the implementation of this control technique. The various values of arbitrarily chosen

CONCLUSION

In this paper, a flight control design technique for the longitudinal and lateral parameter control of UAV is presented. This paper simplifies the non-linear model of UAV by linearization and then converts MIMO system into simple SISO systems using MATLAB environment. Autopilot is designed for a given flight conditions, this design technique can be repeated for a series of flight conditions. Keeping control objectives i.e minimum overshoots and steady state errors, in mind, multi-loop control technique and simple feedback control techniques are applied. Pole placement controller is used to achieve control objectives. As seen from the open loop response shown in figure 4, 5, 6 and 7 and closed loop pole placement controlled UAVs response shown by figure 8 to 13, a substantial improvement in the longitudinal and lateral parameters of UAVs has been achieved.

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