

Design and Simulation of Stabilized Flight Controller for UAVs

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Abstract

This research paper is based on modeling and simulation of Unmanned Aerial Vehicles (UAVs) system using the equation of motion for stability and signal regulation. Two controllers have been used in sequence, Linear Quadratic Controller (LQR) and Proportional, Integral, Derivative (PID) for stability and signal regulation respectively. With the use of LQR, the system becomes more stable and less sensitive. This research work is divided into four parts i.e. mathematical modeling, design procedure of LQR and PID controllers, simulation and results. DATCOM files are imported by using datcom function. The results obtained from these simulations based on stability and signal regulation of UAV system.

I. Introduction and Background

Unmanned Aerial Vehicles (UAVs) are also recognized as RPVs (remotely piloted vehicle), drones, and pilotless aircraft. Mostly they are called UAVs, which are explained by the Department of Defense (DOD), aerial vehicles which does not depend on human operator i.e. can fly autonomously and can carry a lethal or nonlethal payload [1]. The abilities and roles of Unmanned Aerial Vehicles (UAVs) are developing, and for control new concepts are required. For example, today's UAVs usually operate through operators for each aircraft, but in future, UAVs will be autonomously and integrated into coordinated teams to attain high goals. A general control system architecture must be developed which can perform best coordination of vehicles and can evaluate system performance in actual time, and fastly reconfigure changes in the environment [2].

Unmanned Aerial Vehicles idea comes from Austrian used unmanned balloons load with explosives to attack itain city of Veince. It is designed for military actions, modelling and simlation of dynamic flight controllers in which the results are shown according to defines paramerters of flight control.

In first part unmanned aerial vehicle is stabalized by

linear quardatic regulator and performs their simulation results. Its stability must be robust or doesn't effect enviromental conditions. Second part is refernce signal regulaiton, this is performed by proportional, integral, derivative (PID) controller. PID controller controls their speed according to defined parameters and take a reference signal, a short range is mantained around it to control their speed. These function are performed on MATLAB Simulink so that results are shown for practical case. MATLAB Simulink is important for flight dynamics training system, MATLAB Simulink is composed of mathematical modelling and their related programs i-e flight dynamics modelling, modelling of navigation system and establishment and program of database are composed of mathematical phenomenon. In this research UAV stabalization and signal regulate through DATCOM files are imported into MATLAB and simulink results.

Aims and objective

The main objective of this research is to present a more vigorous controller representation. Designed controllers must possess the following technical requirements:

- Controller must achieve $\approx 150\text{m}$ stabilization of constant altitude virtually normal flying altitude.
- Airspeed of controller must be around $\approx 10\text{ m/s}$ as there is no wind gps.
- Reference signal regulation for altitude and airspeed must be provided by controller.
- In case a variation in center of gravity (CG) location of maximum 4 cm (2 cm forward, and 2 cm aft of the original CG location), controller must achieve stabilization.
- When the mass of UAV gets imbalance, controller must achieve stabilization.

Applications

Today Smart Planes specialized commercial UAV are accomplishing tasks of surveying, mapping, planning, mining, forestry, volume calculations, agriculture, wildlife protection, science, and much more.

- Security

- Search and Rescue
- Monitoring
- Disaster and crop Management
- Transportations

II. Methodology

The first step is to mathematical model the UAV physical structure which is then used for the stability and signal regulation of UAV system. Three reference frames used for aircraft modeling are defined: Body frame, Earth frame and Stability frame. We also define Euler Angles [3] (pitch (θ), roll (ϕ), and yaw (ψ)) provided by Heading Reference System (AHRS). They are transmitted to the ground control station at a specified rate. Euler-Lagrange method and Newton's approach are mostly used for derivations of equations of motion in vehicles. Dynamic modeling is done by using Newton's method.

Equation 1 defined the Euler angles that are compulsory for frame conversion. These equations represent relation between rate of change of Euler angles ($\dot{\phi}, \dot{\theta}, \dot{\psi}$) and angular velocities (p, q, r). By integrating the following equation Euler angles are obtained:

$$\begin{bmatrix} \dot{\phi} \\ \dot{\theta} \\ \dot{\psi} \end{bmatrix} = \begin{bmatrix} 1 & S_{\phi} \tan(\theta) & C_{\phi} \tan(\theta) \\ a_{21} & C_{\phi} & -S_{\phi} \\ a_{31} & S_{\phi} \sec(\theta) & C_{\phi} \sec(\theta) \end{bmatrix} \begin{bmatrix} p \\ q \\ r \end{bmatrix} \dots\dots(1)$$

Non-linear equations can be linearized by small distribution theory in non-linear control systems. To linearize the non- linear model a small distribution theory is established nearby a steady-state condition known as trimmed flight.

From linear equations, check the stability and signal regulation of UAV system by simulations. PID controllers are used for signal regulation, stability of system and reference for velocity, roll angle and height.

For stability, objective of UAV system is to obtain graphs of the following terms i.e. lift curve, pitching moment and drag polar.

- **Lift curve** is the graph between angle of attack and lift coefficient
- **Pitching moment** is the graph between pitching

moment coefficient and lift coefficient.

- **Drag polar** is the graph between dragging coefficient and lift coefficient.

Angle of attack (α) is the angle between chord line and velocity of wind (V_{air})[4].

$$\alpha = \tan^{-1} \left(\frac{w}{u} \right) \dots\dots(2)$$

$$V_{air} = \sqrt{u^2 + v^2 + w^2} \dots\dots(3)$$

For zero value of β (Side Slip angle, it relates to the rotation of the aircraft centerline from the relative wind.)[4], Side Force C_y is same for both axis systems. Equation 4 shows how one can find.

$$\beta = \tan^{-1} \left(\frac{V}{\sqrt{u^2 + w^2}} \right) \dots\dots(4)$$

Pitching moment is the torque or moment produced by the aerodynamic force applying on center of UAV aerodynamic foil. The Drag Polar is the connection between the lift on an aircraft and it's dragging force. Our focus is to import DATCOM file into MATLAB. Using datcomimport function, the MTALAB script written into the MATLAB to import DATCOM file. All DATCOM information in a MATLAB cell array stores. This array might cover various components which further cover information from numerous analysis of DATCOM. After importing file into MATLAB we meet predefined standards and obtain ranges of different parameters i.e. angle of attack, pitching moment, lift coefficient and drag polar as given in flow chart. If obtained ranges meet the predefined standard (mention in aims and objectives) then goes to the simulation but does not match then back to the file importing step. When obtained ranges meet the predefined standards then by using these values we design two controllers i.e. longitudinal and lateral controller. Longitudinal controller is designed to control the rolling moment and lateral controller is to control the pitching moment.

Simulation is done then comes to the analysis and after analysis we obtain the desired results.

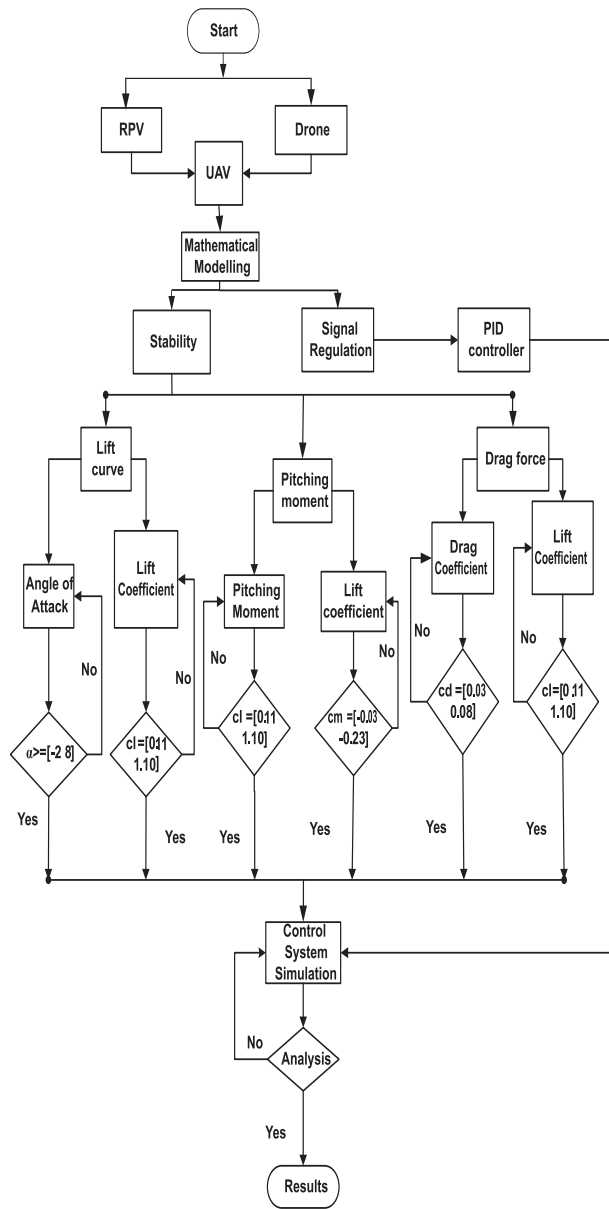


Figure1: Flow chart

III. Mathematical Modeling

For the derivation of equations of motion we used Dynamic model in this paper which is based on Newton's method [3]. Before the discussion of equations, some important points should be considered. In an aircraft, elasticity and compressibility effects with low speed range can be overlooked and this vehicle is considered like a rigid body through 6 DoF (Degree of Freedom). In this research, we use plane which is used as an electrical based driven engine and during flight planes mass will remain unchanged. With the help of above two assumptions equations can be simplified.

Equation of motion is derived by using Newton's Law of motion which explain relationships between forces in the body frame (F_x , F_y , F_z), moments (L , M , N) and aircraft linear (u , v , w) and angular (p , q , r) velocities.

$$F_x = m(u + qw - rv) \quad \text{.....(5)}$$

$$F_y = m(v + rv - pw) \quad \text{.....(6)}$$

$$F_z = m(w + pv - qw) \quad \text{.....(7)}$$

$$L = I_x p - I_{xz} r + qr(I_z - I_y) - I_{xz} pq \quad \text{.....(8)}$$

$$M = I_y q + rp(I_x - I_z) + I_{xz}(p^2 - r^2) \quad \text{.....(9)}$$

$$N = -I_{xz} p + I_x r + pq(I_y - I_x) - I_{xz} pq \quad \text{.....(10)}$$

Where m is the mass of UAV system, g is the gravitational acceleration.

Control system design

In this type of UAV system, there are two factors which can cause in modeling of controller i.e. inherent instability and non-linearity in flying wings. For the controller designing, model should be linearized which qualifies the engineer to take an advantage by using tools of system theory. As UAV profile is restricted to range of speed, weight and ceiling, so linear controller should be a sensible result. Therefore, we introduced a strategy which is linear controlled to switch lateral and longitudinal motion of the plane. For stability of system, a PID controller with LQR method used and give a reference following for different parameters i.e. velocity, height and roll angle. By proper locating poles of closed loop system, LQR stables the system as it is ideal state--=e\0dback controller. PID controller controls the system and also used to track reference input signals.

Static feedback gain matrix 'K' can be generating through Linear Quadratic Regulator (LQR) method.

$$x(t) = (A - BK)x(t) \quad \text{.....(11)}$$

LQR method is used to calculate feedback gain, also considered to be perfect for the yield performance for the minimization in energy.

Now comes to the longitudinal control model. Simulations of this controller is shown in fig-2. There are two input sets which is longitudinal states and input commands. Recall that the trim condition is the standard condition and longitudinal states are actually deviations from trim conditions. For axis of longitudinal controller model, Δ (linear velocity along aircraft X-axis),

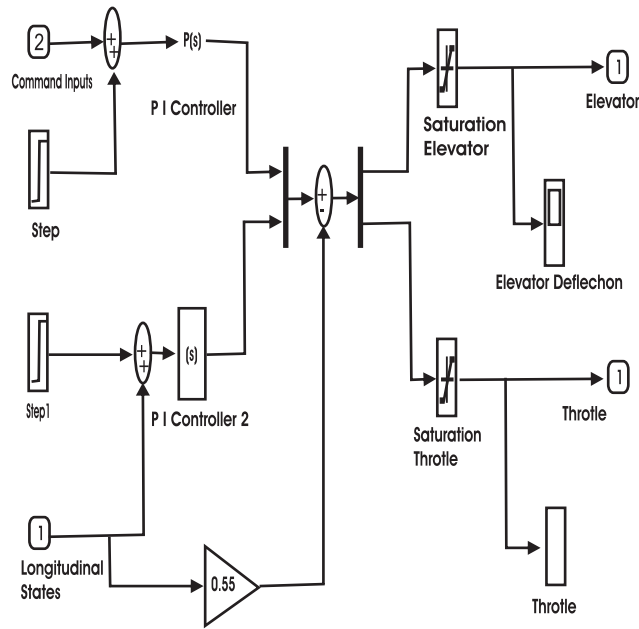


Figure 2: Longitudinal Control model

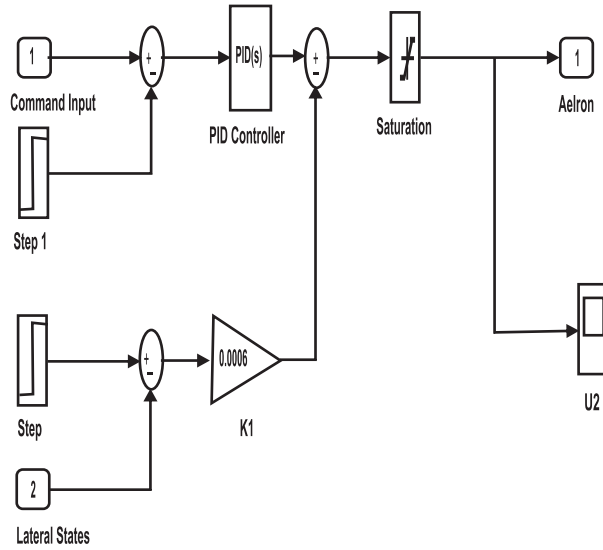


Figure 3: Lateral control model

Where ΔW is (linear velocity across Y-axis), Δq (angular velocity through Y-axis), $\Delta \theta$ (Pitch angle) and ΔV_{air} (air speed). Error signal is produced when highest command is deducted from the present altitude by PI controller, with gains. Same is done with integrator and airspeed command. Through LQR feedback, Output is subtracted from switch signals. This produces ultimate and mutual control signals which further approved over saturation

blocks which shows some limitations in aileron deflection angle ($-12^\circ < \delta e < 12^\circ$) and throttle opening ($\delta_T = 0$ to 1).

IV. MATLAB Simulation and DATCOM

Actual system is approximated by mathematical models. With certain level of uncertainty they are capable of presenting a physical platform. We need to know that the developed model accurately describes the actual system. By simulations and analysis of its behavior, with control system implementation it would be reasonable to minimize the risk associated [5]. To stimulate and analyze mathematical model and control systems MATLAB/Simulink provide a powerful tool for engineers in various discipline. Special set of blocks and functions are available as part of the 'MATLAB Aerospace Toolbox/Block set', 'MATLAB Control System Toolbox' [6]. To simulate aircraft dynamics and control MATLAB Control System is widely used. Longitudinal and lateral controller models have been developed [8].

The longitudinal controller gives the output of the throttle. Throttle is a device controlling the flow of fuel. Longitudinal controller controls the opening of the fuel. Output shows that throttle has a jerk in the start and then it becomes stable.

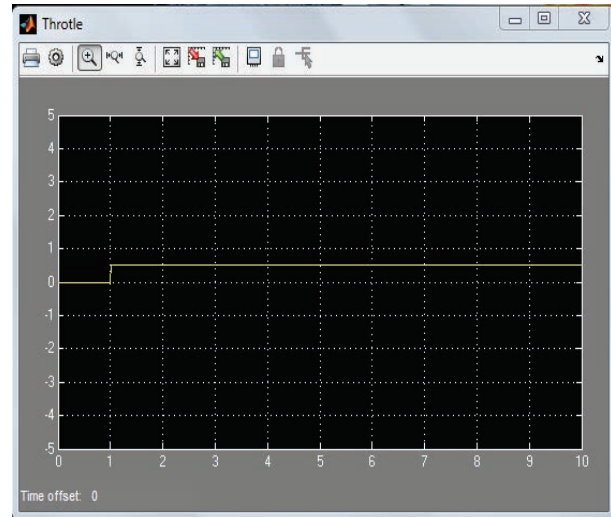


Figure 4: Output of throttle

The output of the longitudinal controller also controls the elevator deflection. The main objective of elevator deflection is to increase or decrease lift and hence pitching moment. The output shows that elevator deflection has a jerk in the start and then it becomes stable.

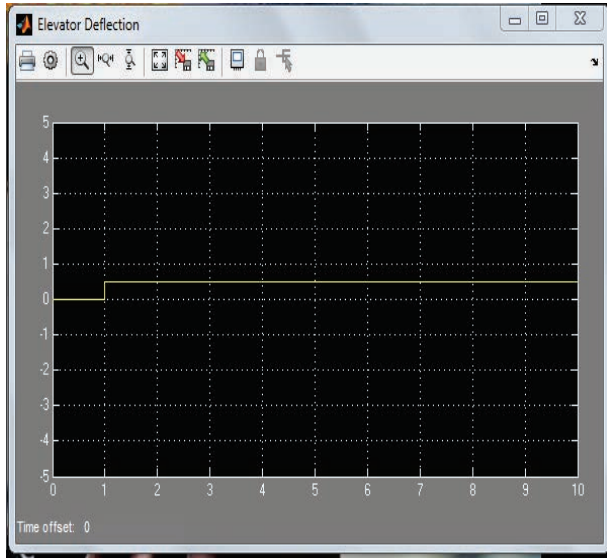


Figure 5: Output of Elevator Deflection

Lateral Controller block is shown in figure 3. Through the PID controller the error signal is subtraction of current state from lateral states which is standard state to generate control commanded $\delta\alpha$.

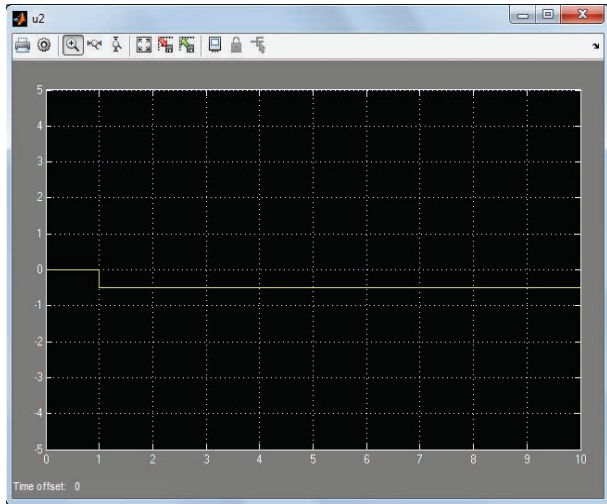


Figure 6: Output of vector of control signal

By using aerospace toolbox, introductory information of aircraft static, geometry and active stability features are required for aircraft modeling. For simulation of SmartFly, we import DATCOM output file into MATLAB. This Importing function obtain information from DATCOM and store it in a MATLAB in form of array which may consist of structure elements (only two). [7] The script extract suitable arrays from DATCOM and stocks these arrays into matrices and vectors in MATLAB workspace, for sake of easiness [9]. Sometimes we plot

some UAV aerodynamic features in MATLAB [10].

V. Results

These results show stability of UAV system, which is obtained by importing Datcom output file into MATLAB. For the stability of UAV, the relationship between lift coefficient and angle of attack (α) should be linear, which is shown in figure 7.

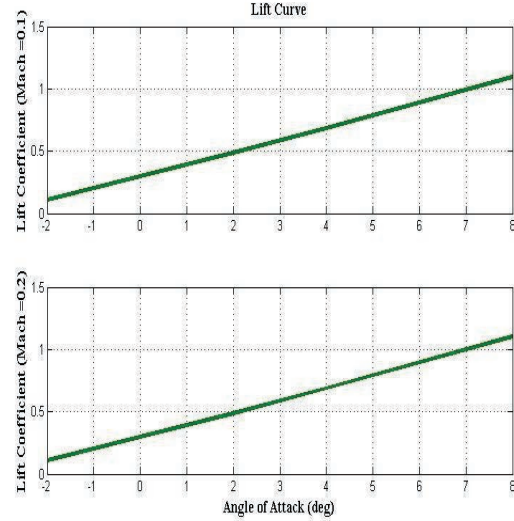


Figure 7: Lift coefficient CL due to change in α

Angle of attack is the angle between velocity of wind or air and chord line of an aircraft. Angle of attack and lift coefficient are directly proportional to each other.

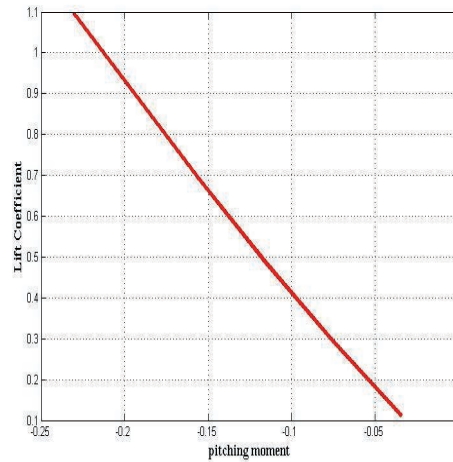


Figure 8: Pitching moment Vs Lift coefficient

Pitching moment on airfoil is the torque produced by the aerodynamic force at the aerodynamic center of the

airfoil.

So as the pitching moment increases the lift coefficient decreases as shown in figure 8.

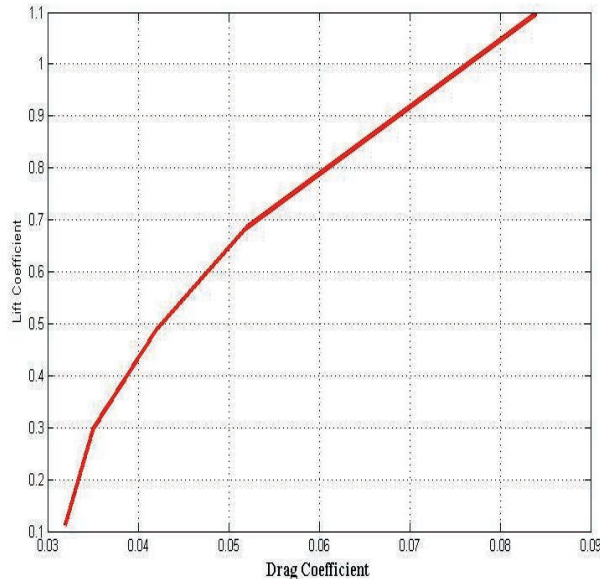


Figure 9: Lift coefficient Vs Drag coefficient

The Drag Polar is the liaison between the lift of the aircraft and its dragging force, articulated in the relation dependence on lift coefficient and the drag coefficient. So as the drag coefficient increases the lift coefficient decreases.

VI. Conclusion

We have discussed the technique for Flight Stabilizing Controller in Unmanned Aerial Vehicle. The lift coefficient, pitching coefficient and drag coefficient parameters have been used in mathematical model and simulation. The result is obtained by importing DATCOM output file into MATLAB which showed the stable UAV system. It also showed the controller architecture which provides both the system stability and signal regulation.

Furthermore, the developed lateral controller and longitudinal models have also stabilized the system.

VII. Future work

Using empirical data in simulation model would be an interesting recommendation for future work. With the use of "System Identification Toolbox" in MATLAB flight system parameter can be tracked. Also, by implementing developed switch loops on a definite platform might be really interesting. Future research could be: when we applied airspeed, the altitude tracking controller's response is slower.

IX. References

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