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Stochastic Longitudinal Autopilot Tuning for Best Autonomous Flight Performance of a Morphing VTOL Drone

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Abstract: In this conference paper autonomous flight performance maximization of a morphing vertical take-off and landing (i.e., VTOL) drone is considered by using stochastic optimization approach. For flight control system a PID based hierarchical control system is applied. In this paper PID controller which is used for pitch angle is considered. In this research only longitudinal flight and longitudinal control system is evaluated during aircraft mode where the pitch motion is in primary interest and the used control surface is the elevator of VTOL drone. For optimization approach simultaneous perturbation stochastic approximation (i.e., SPSA) is chosen. It is fast and safe in stochastic optimization problems when it is not possible to evaluate gradient analytically. At the end of this paper a cost function consisting terms such that settling time, rise time and overshoot is minimized. A detailed graphical analysis is made in order to better evaluate effect of morphing on longitudinal flight of a morphing vertical take-off and landing drone flight. Moreover, the cost function consists of rise time, settling time, and overshoot during trajectory tracking.

Keywords: VTOL drone, Stochastic optimization, Morphing, Autonomous performance

Introduction

In recent years, Unmanned Aerial Vehicles (UAV) have been widely used for various purposes such as image acquisition, target determination, search and rescue. UAVs are also used in situations such as pesticides that may be dangerous for humans, working in chemical or radioactive areas, and working under enemy fire (Husain et al., 2022).

UAVs can be basically divided into fixed-wing and rotary-wing vehicles (Coban et al., 2020). Rotary wing vehicles have high manoeuvrability and do not need a runway during take-off and landing, but due to their aerodynamic structure, power efficiency is low (Alanezi et al., 2022). Fixed-wing vehicles, on the other hand, have a lower airtime due to their lower power consumption, and a longer range due to their higher speed (Falanga et al., 2019). However, the negative aspects of fixed-wing vehicles are that they need a runway or launch pad during take-off and landing, and they do not have the ability to hover. In such cases, while the available space for fixed-wing vehicles to take off and land is limited, rotary-wing vehicles do not have sufficient range and transport. Autonomous landings of fixed-wing vehicles are also relatively more difficult.

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Combining the superior features of fixed-wing and rotary-wing vehicles, vertical take-off and landing (VTOL) hybrid aircraft, UAVs, are created. Fixed-wing VTOL vehicles have the ability to take off and land vertically, hang in the air at a certain point, and fly horizontally, quickly and efficiently. In this way, they can reach the target point quickly, land and take off without the need for a runway, or perform their mission by hanging (Uzun et al., 2023).

VTOL vehicles have two different flight modes that have the characteristics of fixed-wing and rotary-wing vehicles. Fixed-wing VTOL vehicles can generally be divided into two categories: systems that have the ability to tilt partially or completely (tilt) and that do not lose the horizon plane during mode transitions and the mechanical equipment remains fixed (no-tilt) (Kocamer et al., 2022).

In this study, four rotary wing and fixed wing VTOLs were given a backward variable angle control to the fixed wings to improve roll control in horizontal flight. In this way, it has gained the ability to provide its lateral balance against atmospheric noise in different speed profiles. The best value will be obtained by using the backward angle value of the wings using the SPSA algorithm (Kose et al., 2021, 2022). SPSA, which is the algorithm where the angle of the wings can change the moment of inertia of the aircraft and the controller can respond to this situation the fastest, was preferred in this study (Kose et al., 2023).

Material and Method

Because the planes move around three axes, they have a wide range of motion. Airplanes can make horizontal and vertical turns, as well as movements that are a combination of both. A turning airplane (as opposed to automobiles) is in stable flight. This means that there is no lateral force pushing the pilot out of the turn, as in an automobile, in the aircraft making the turn. In some turns, the resultant of the forces acting on the banked plane acts towards the center of the turn. This type of rotation is called a balanced and coordinated rotation. Sometimes planes make a so-called horizon turn. This means turning at a fixed altitude.

Turning is not done using the rudder on the airplane. Because of as a result of such an application, lateral forces may occur and the aircraft may be thrown out of the control. For this reason, turning is done by using the aileron and elevator in coordination in high-speed aircraft. When making a turn in an airplane flying to the horizon, first of all, the plane is controlled by ailerons (winglets). After the plane has banked to a certain degree, the elevator is controlled to turn the plane.

The control surface that makes a turn to a banked aircraft is the elevator. The force that turns the plane is the lift force. The lift force of an airplane at rest is divided into two component vectors, vertical and horizontal. The horizontal component vector gives the aircraft acceleration towards the center of rotation. When the airplanes are moving at a fixed altitude, the wings are parallel to each other and the lift force is equal to the weight (lift = weight) (Fig.1).

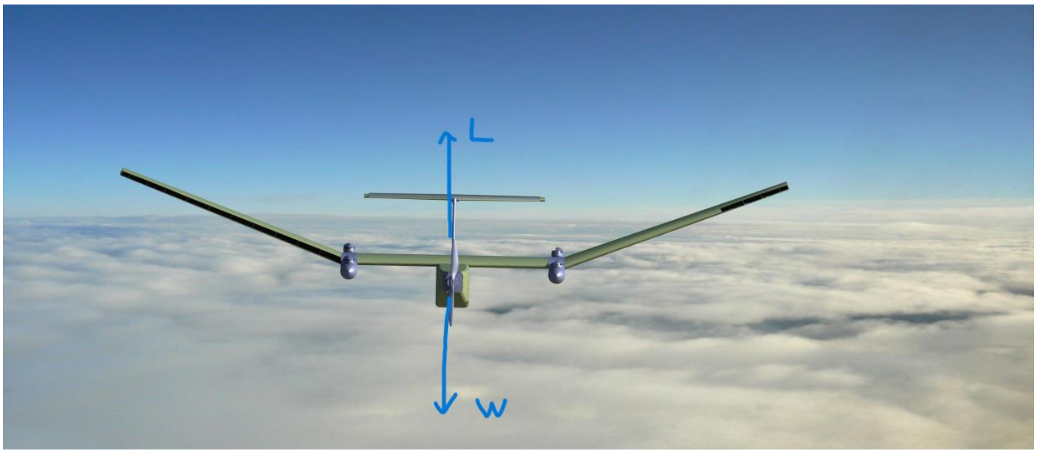


Figure 1. Fixed Altitude Flight

When the turn starts, the balance is disturbed. Sufficient acceleration must be gained in order to ensure the rotation. This creates a new force that helps to make a balanced and coordinated turn. This force on the horizontal axis is the centrifugal force. Fig.2 shows this force.

As with quadrotor, hexarotor and octorotor type UAVs, a mathematical model must be obtained for the decacopter type UAV. Newton's laws of motion and Euler's laws are used for the mathematical model of such UAVs (Mustapa, 2015). Accordingly, the mathematical position vectors (x, y and z) of the decacopter are shown in equations 1, 2 and 3 and the Euler angles (θ) are shown in equations 4, 5 and 6.

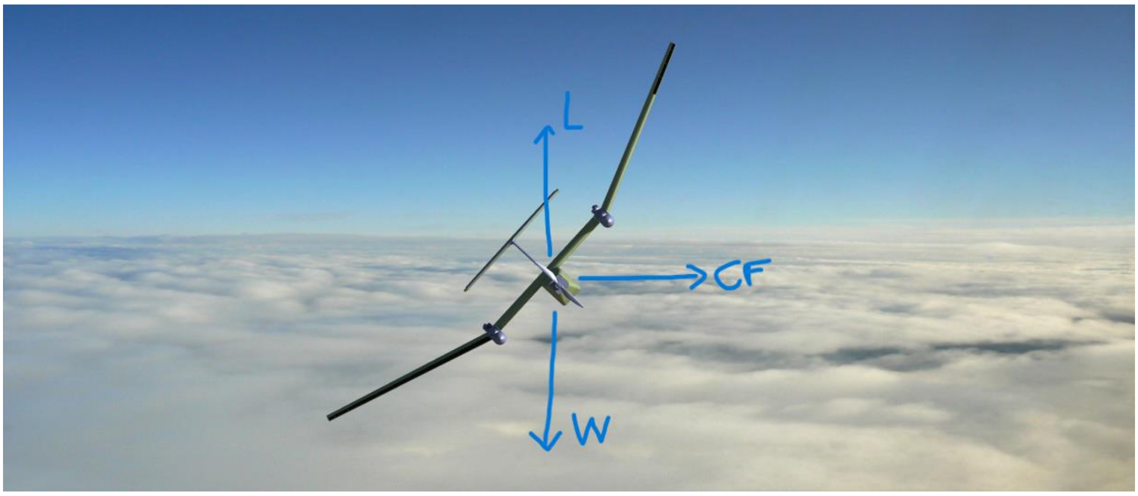


Figure 2. Formation of centrifugal force

In order to maintain the altitude during the turn, the lifting force during the turn must be equal to the resultant force (resultant force) created by the centrifugal force and the weight.

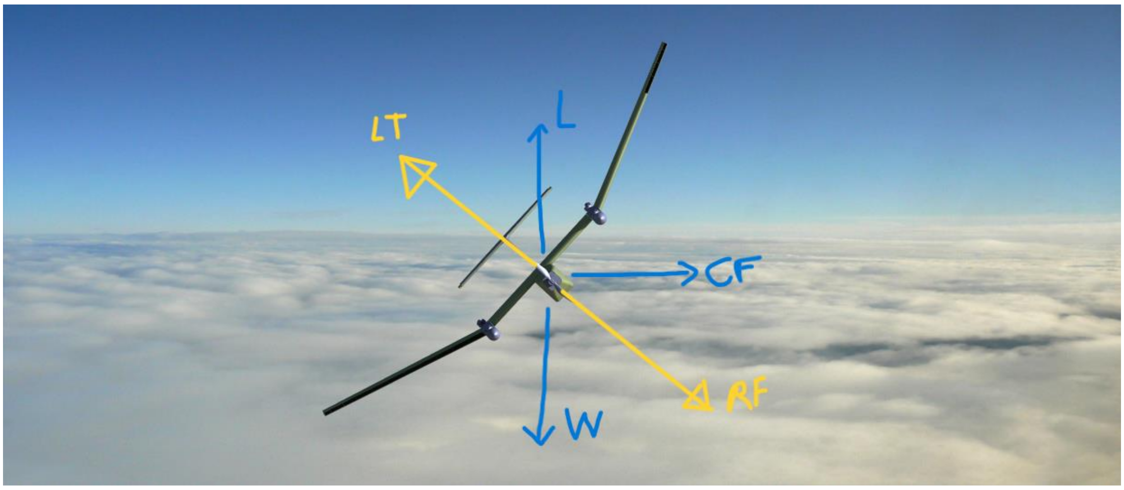


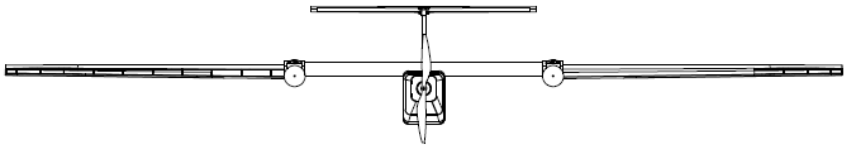
Figure 3. Formation of the resultant force and Lift in Turn.

As can be seen from the equation, either the lift coefficient (CL) or the velocity (V) must be increased in order to increase the lift force. If the aircraft is in cruise flight, the lift coefficient is increased. If it is flying at low speeds, the CL value is not changed because it is close to its maximum value, and the turn is made by increasing the speed.

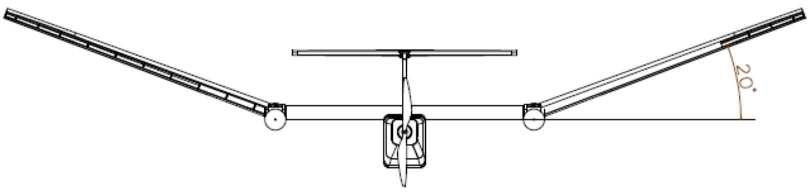
$$L = \frac{1}{2}\rho V^2 C_L S \tag{1}$$

Smaller angles can be turned at low speeds, and larger angles can be turned at higher speeds. While all these calculations are being made, it is necessary that the airplane does not enter a stall. The following formula can be used for this:

$$\frac{V_{turn}}{V_{level}} = \sqrt{n} \tag{2}$$



a)
Front view
Scale: 1:5



b)
Front view
Scale: 1:5

Figure 4. a) Non-morphing, b) morphing

Vturn: Stall speed during turn, Vlevel: Stall speed in level flight, n: Load factor.

VTOL aircraft can change shape during flight. It does this by changing the dihedral angle. The dihedral angle affects the lateral stability of the aircraft. Bank motion command or atmospheric disturbance can affect aircraft attitude. The measure of the aircraft's wing dihedral angle will affect stability and enable the aircraft to return to its course and continue flying. The condition before and after the shape change is shown in Fig. 4.

Conclusion

In order for an airplane to fly, not only lift equal to weight is required, sometimes more and sometimes less lift than weight is needed. If an airplane is turning at a fixed altitude, it creates a centrifugal force in addition to the weight if it comes out of the dive. The moment the aircraft exits the dive and moves into full straight (horizontal) flight, the lift force becomes equal to the vectorial sum of the lift force and the centrifugal force. Therefore, the buoyant force required is greater than the weight. The ratio of the resultant force to weight generated by the center force and weight generated by the aircraft rotating at an angle of 20° to 40° is called the load factor, denoted by ’n'. It is also called the g(ci) charge (gload). As the rotation angle increases, the value of the load factor also increases. During lateral movement, the wing in the direction of lying down will produce more lifting force depending on the amount of lateral angle. Aerodynamic force; allows the control surfaces of the aircraft to land without moving. In this study, the variable dihedral amount, PID coefficients and optimum values were obtained by using innovative approach methods. The SPSA algorithm was added to the controller design and the dihedral angle, PID coefficients were calculated. These values; fig. 5,6,7,8,9,10 and 11 were also given. These values were obtained from the simulation study.

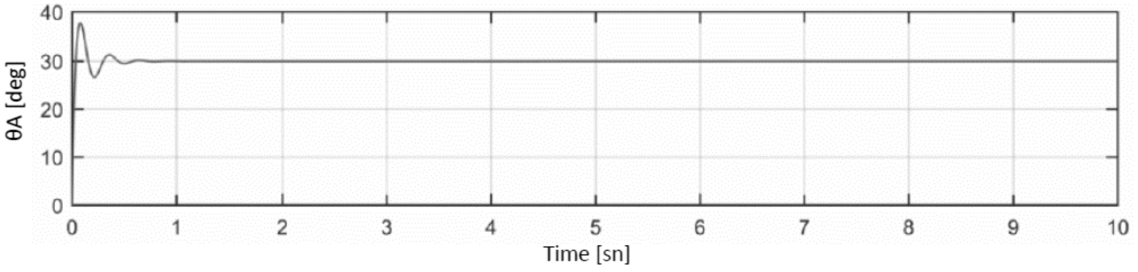


Figure 5. Longitudinal closed-loop responses (pure turbulence is ready) of the UAV with morphing wingtip

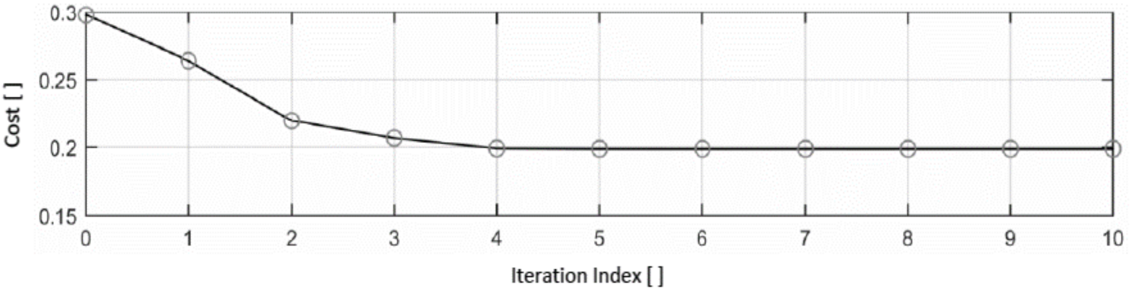


Figure 6. Cost improvement at each iteration

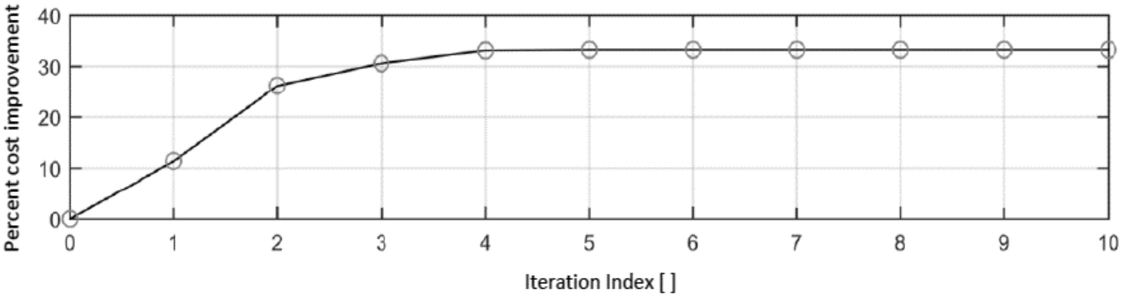


Figure 7. Optimization results of cost-index with varying number of iteration

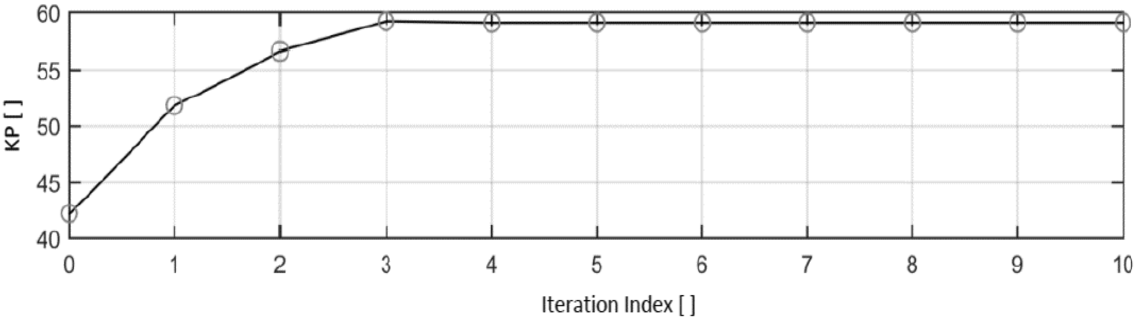


Figure 8. Optimization results of P coefficients with varying number of iteration

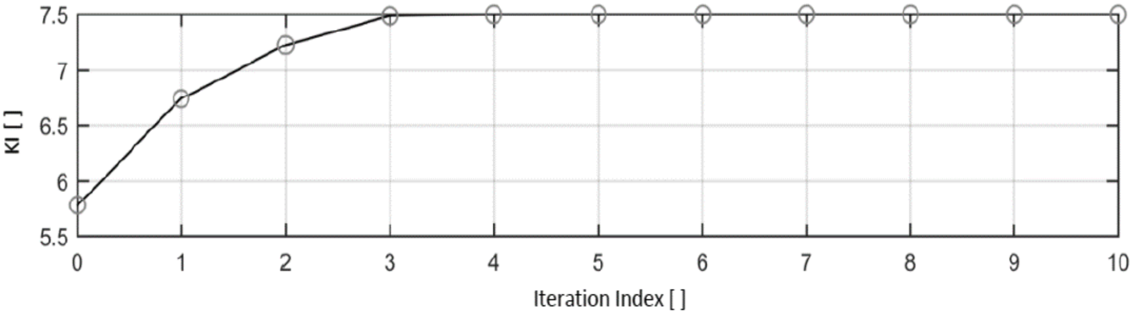


Figure 9. Optimization results of I coefficients with varying number of iteration

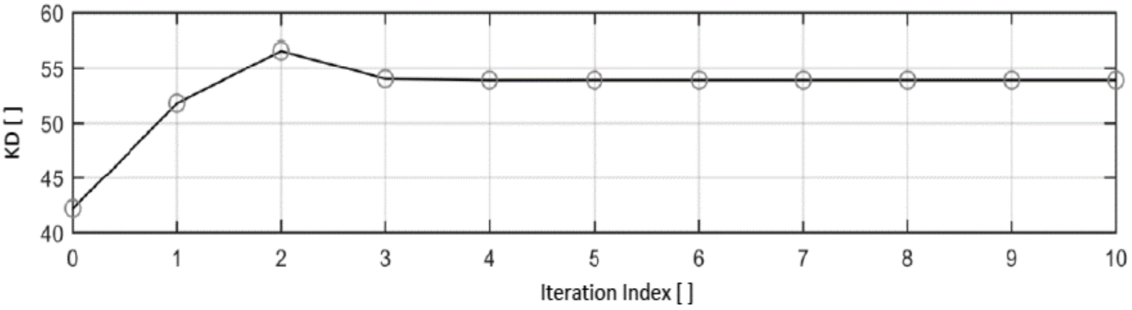


Figure 10. Optimization results of D coefficients with varying number of iteration

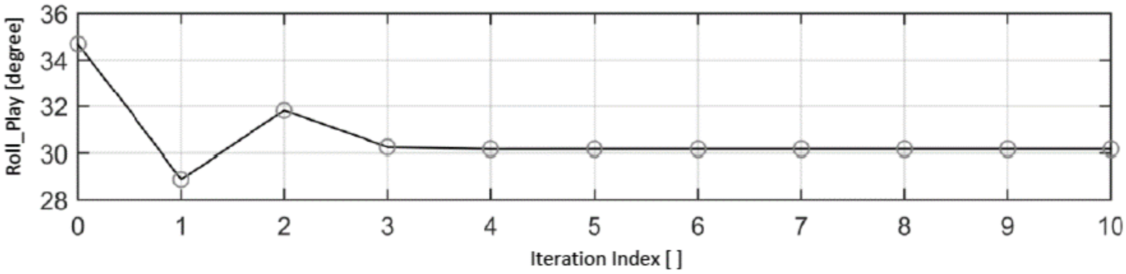


Figure 11. Roll play value of each ıteration ındex

In this study, a UAV is redesigned using an innovative conversion approach to improve the autonomous flight performance of VTOL. The wing tip can change the dihedral angle from 20 to 40 degrees. Simultaneously, movable wing tip design and control system design are considered together. The control system is implemented in a traditional hierarchical structure consisting of six PID controllers, these for 3 longitudinal and 3 lateral movements, and autonomous flight performance is defined as the sum of longitudinal trajectory tracking parameters. Longitudinal PID coefficients and wingtip dihedral angle are optimized within the constraints to improve performance using SPSA.

The concurrent design idea combined with SPSA optimization resulted in a significant 33.5% improvement in longitudinal cost to the initial state. The PID coefficients of the initial condition were developed and the basic wing design resulted in a design with a 30 degree wing tip dihedral angle. Satisfactory closed-loop responses were obtained without any catastrophic release.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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