A Review on Longitudinal Control Law Design for a Small Fixed-Wing UAV

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Abstract - *A longitudinal control strategy describes the altitude control in a cascade architecture, whose inner loop conveniently manoeuvres the pitch angle by acting on the symmetric flag deflection. Different technologies and theories are associated with developing the longitudinal control algorithm, such as Newton-Euler formulation, LQR technology, multi-model technique, root locus method, integral sliding mode control technique, etc. This paper describes the various techniques and the applications they have been used in. Thus, enabling one to analyse the effectiveness and robustness of the proposed control scheme.*

Key Words: Longitudinal; control; LQR; algorithm etc.

1.INTRODUCTION

The term UAV is an acronym for Unmanned Aerial Vehicle, i.e., flying vehicles that operate without a human pilot. The military and police commonly use UAVs in situations where the risk of artificial aircraft is unacceptable or where human-crewed aircraft is not possible. More advanced drones used radio technology to guide themselves, allowing them to perform missions and return. They are constantly being controlled by a human pilot and cannot fly independently. Modern drones are controlled by autonomous aircraft and human controllers at ground stations. This allows them to make long, unchallenging flights within their control and fly under the command of a human pilot during complex stages of the mission. Research and development of unmanned aerial vehicles have increased in Indonesia over the past decade. The application of UAVs has many advantages, which are aerial photography, surveillance and monitoring of disaster areas, and military purposes such as border patrol and targeted autonomous attack. Since then, Indonesia's military and civilian authorities have recognized the importance of research in this area. The tricky part of the UAV development process was designing and developing a flight control system to accomplish the mission and maintain flight stability during various periods of turbulence. The existence of any disturbance can reduce the stability of the flight. Flight performance decreases, and the mission becomes challenging to complete. Therefore, innovative control methods must be required to stabilize the drone under the pressure of different operating conditions, the kinetic and potential energy changes during landing. Drones are the most vulnerable and accident-prone devices. During a clean restore, they will face system failure and environmental interference. Therefore, it is necessary to design an ideal recovery point within a specific range and ensure a reasonable collision angle. Therefore, precise guiding devices and guiding law have essential research value and importance.

Currently, standard guide equipment includes special equipment and radio communications. Due to operational complexity, cost or other limitations, these technologies are unlikely to apply to small fixed-wing UAVs. The Sierra Nevada's joint tactical auto-landing and auto-recovery systems use external tracking radar and radio to obtain relative position information. But they are too expensive. The widespread applications of drones have raised concerns about reliability and range issues. While autonomously flying is now considered a mature technology, autonomous landing is much more difficult. It requires exact navigation and, above all, it involves switching flight stages, especially for fixed-wing drones. Due to the advantages of small volume, lightweight, flexibility, and low cost of unmanned aerial vehicles, UAVs are receiving more and more strong interest worldwide. The most significant difference between drones and manned aircraft is the unmanned aerial vehicle; The aircraft flies automatically under the influence of the flight control system. Therefore, the design of the control law of the flight control system is essential. The vertical motion controller of the fixed-wing UAV has been designed. The main functions of vertical motion are:

(1) Climb to the given pitch angle, keeping the altitude stable;

(2) Horizontal flight to a certain altitude, maintaining the flight altitude of the UAV.

The most widely used root locus method in engineering has been used; it is also a mature classical control theory design method. This method can select the appropriate system gain to produce a closed-loop system with acceptable flight quality and introduce poles and zeros, realize pole position, and improve performance. Nowadays, more and more attention is paid to the rapid development of Unmanned Aerial Vehicles (UAVs) worldwide due to their potential applications in military and civilian fields, such as surveillance, target acquisition and tracking, weapon delivery, mapping, traffic, search and rescue, etc.

In addition, the flight control system, which is the core of the UAV, determines the performance of the UAV to a large extent and thus attracts great interest in the academic field. The PID controller is widely used in traditional flight control systems and practical situations due to its simple structure and easy operation. However, the flight's poorer quality in terms of adaptability to the environment and the considerable difficulty of adjusting its parameters through test flight make it very difficult to achieve the desired flight quality. In recent years, advances in microelectronics have led to a wide range of UAV designs. From drones to multi-cruise aircraft, drones have evolved to take advantage of the higher computing power of today's microcontrollers to perform increasingly complex tasks on their own. The multirotor community mainly drives the commercially available development (COTS) of the open-source flight control computer (FCC). These computers became available to the general public at a relatively low cost. One of the most widely used open-source FCC COTS is Pixhawk. The project successfully used large-scale rotor processing quality specifications, modified to reflect small-scale dynamic differences, to optimize the inner-loop control law and Outer ring around static flight. This project serves as a breakthrough in the experimental discovery and determination of the processing qualities of a quadcopter. Traditional fixed-wing aircraft are still the design of choice when speed, range and endurance are essential tasks. This project aims to develop a comparable knowledge base for optimizing small-scale fixed-wing UAV control laws based on ADD's extensive research on large-scale fixed-wing aircraft. Since the flying-wing drone adopts wing-body mixing technology, the horizontal and vertical tail sections of the conventional configuration are cancelled, the aircraft looks like a raised surface.

2. LITERATURE SURVEY

[1] This article proposes a non-linear approach for guidance and longitudinal control of unmanned aerial vehicles (UAVs). The main task of the guidance algorithm is to minimize errors in the height and angle of the vehicle's flight path during flight. The guidance scheme should work well for large and small pitch errors without saturating the pitch angle of the vehicle acting as a control input. ISMC (Integral Slip Mode Control) is used for longitudinal control of the UAV. This is an improved slip control method. Initially, a linear sliding surface is used for longitudinal guidance. However, since it does not provide satisfactory performance in both large and small flight path altitude and angular errors, a non-linear sliding surface is proposed. Simulations are performed in MATLAB®/SIMULINK®. The simulation results show the efficiency and reliability of the proposed control method.

[2] This paper focuses on developing a stability control system for fixed-wing turboprop aircraft (UAV). The UAV model was created using DATCOM digital software to calculate aerodynamic derivatives. The longitudinal flight dynamics will sum up the control responses in the xb and zb planes. This search to increase stability uses the Linear Quadratic Regulator (LQR) approach. The flying stability of this drone comes from a solution to the Differential Riccati Equation (DRE) that provides optimal controller gain for tuning the states. The simulation results show that the proposed method can be considered to improve flight performance in the presence of turbulence.

[3] Easy and cheap replacement. This paper drafts a vertical guidance method based on visual guidance for network recovery of small fixed-wing unmanned aerial vehicles (UAVs). Based on openmv4, it employs an app tag detection algorithm to identify the target. This allows you to quickly calculate the pose and attitude of the target concerning the camera. A vertical lead tracking method has been proposed to compare tracking and proportional lead regulations. Considering the factors that affect the control performance of the angle switching time, we proposed a new vertical pseudo-tracking guidance law. The PID controller has been designed, and virtual recovery points have been set up for verification. Simulation results show that the designed guidance law is accurate and feasible.

[4] Unmanned aerial vehicles (UAVs) autonomy has long been a problem. One of the most important milestones is autonomous takeoff and landing capabilities. Several recovery/landing methods apply to UAVs, including Net recovery, parachute, etc. However, there are weight restrictions, structural reinforcements, and additional maintenance considerations for in-vehicle equipment in most cases. This paper presents some of the preliminary efforts of the National Cheng Kung University (NCKU) Remote Control Vehicle and Microsatellite Institute (RMRL) in Taiwan to develop a low-cost autonomous runway landing control system. The SWAN developed by RMRL in recent years is used as a UAV. The design process includes systematic identification of UAV dynamics using the Observer-Kalman identification (OKID) method, control system design using the PID design method for both descent and interception, and computer simulation control verification. It is included. These efforts should be the basis for realizing future autonomous landing control.

[5] Aircraft movement was decomposed into vertical and horizontal movements according to small linearized perturbations. We discussed the vertical control law design method using the root locus belonging to classical control theory. Simulation results for a 6-DOF non-linear model show that: The designed control parameters are reasonable, the simulation profile perfectly matches the adjustment profile, the control effect of the pitch and elevation loops is an indexing requirement, the procedure is mature and reliable, and engineering is easy.

3. DIFFERENT THEORIES AND THEIR APPLICATION

S.No.	Approach	Platform Used	Application	Disadvantage
1	Model Predictive Control (MPC) and NMPC methods	MATLAB®/SIMULINK ®	Develop a high-level controller for small fixed-wing UAVs using NMPC and minimization of the proposed cost function that minimizes the cross-track error.	Computational and implementation complexity.
2	Integral sliding mode control	MATLAB®/SIMULINK ®	Minimize the errors in altitude and flight path angle.	High frequency switching in the control signal.
3	LQR technique	Digital DATCOM	Calculate state feedback controller gain K to minimize cost function thus the stability of the system can be guaranteed.	One big disadvantage of LQR is that for each turbulence, there exists an optimum value of Q and R at which best reductions in responses is obtained. Hence adjustment of Q and R is one such disadvantage.
4	Apriltags Recognition Algorithm based PID controller	Openmv4	To identify the target, which can quickly calculate the pose and attitude of the target relative to the camera.	A localization system may result in erroneous localization due to multiple factors.
5	PID design method based on Observer Kalman Identification Method (OKID)	MATLAB	To identify the SWAN UAV's linear model from the flight test data.	Drawbacks of this method include the need to invert an input matrix which necessarily becomes particularly large for lightly damped systems.
6	Nonlinear model simulation	MATLAB	Select reasonable control parameters.	They can be less flexible than competing linear models and that generally there is no analytical solution for estimating the parameters.
7	Root locus method	MATLAB	Method selects appropriate system gain, make closed-loop system with acceptable flying qualities, but also can introduce poles and zeros, implement pole placement, improve the dynamic performance of the system.	The limitations of root locus method for tuning PID controllers are: Not perform well on a nonlinear system. Loses significance at high frequencies or high degrees of damping. The designs are susceptible to noise.
8	Multi-model Technique	MATLAB	To describe different environments and to gain better dynamic properties, including making the controllers possess better performance in tracking speed, control precision and stability for complex systems.	Multi-model database systems are challenging to work with and complicated. The database model is still developing and has not matured properly. There is limited availability of different modeling techniques. Not suitable for simpler systems or projects.

Fig -1: Development of different theories and their application to the design of longitudinal control laws for a small fixed-wing drone

3.1 Integral sliding mode control

Integrated control in sliding mode with non-linear sliding surfaces is proposed to control the longitudinal guidance of the aircraft with parameters selectable to meet specified operating conditions. Then the non-linear guide law is derived. The stability of the proposed sliding surface is demonstrated using the corresponding Lyapunov function. Avoid saturation adjustments. In addition, the desired performance is achieved without saturation of the pitch angle control command by the vehicle control system. Simulations were performed in SIMULINK®, and simulation results obtained using ISMC were compared with those obtained using SMC. After that, you successfully gained maximum control. The results demonstrated the effectiveness of the proposed control scheme. [1]

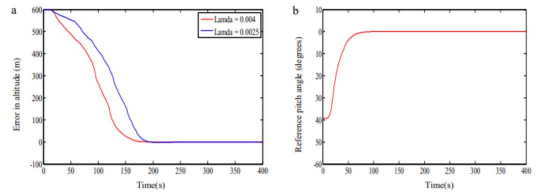

Fig -2: (a)Simulation results for error in altitude versus time for different values of λ ;(b) Simulation results for reference pitch angle with λ=0.004 [1]

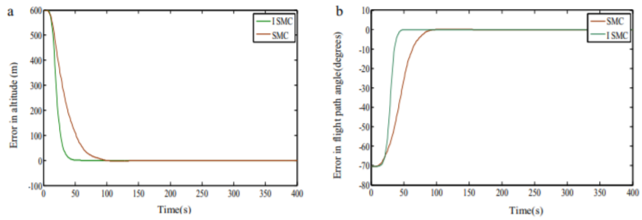

Fig -3: (a) Simulation plot of error in altitude versus time using ISMC and SMC; (b) Simulation plot of error in flight path angle versus time using SMC and ISMC [1]

3.2 LQR technique

The longitudinal stability gain control is developed based on the Linear Quadratic Regulator (LQR) approach. This proposed methodology can train the system to a stable flight by correcting the state system causing the deflection movements. In addition, this approach effectively restores the drone's stability when interference occurs. This advantage is obtained because the optimization process creates a feedback gain controller. As a result, the scope of order management is more comprehensive than that obtained with the classical approach. Therefore, this optimal control can provide a guarantee of flight stability. [2]

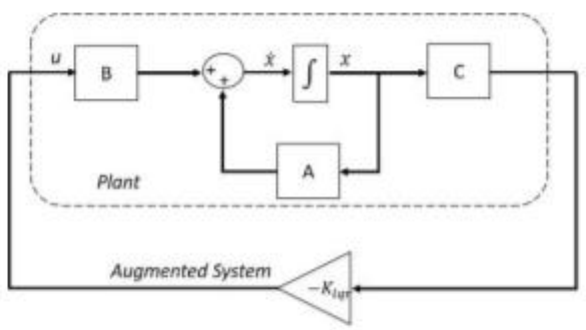

Fig -4: Diagram Blok of LQR as Stability Augmentation System [2]

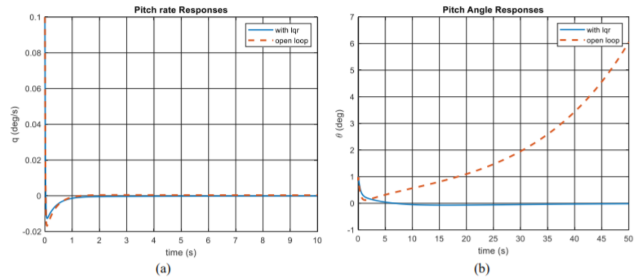

Fig -5: Feedback outputs due to deviation from original attitudes. (a). Pitch rate response, and (b). Pitch angle response. [2]

3.3 Apriltags Recognition Algorithm based PID controller

The Apriltags recognition algorithm based on openmv4 allows the system to convert the image signal into the required instruction signal, meeting the expected requirements for lightness, cheapness and anti-interference robustness. The designed vertical guiding law processes position solution information from the vision system and generate control signals. Simulation verifies the configuration of one and three virtual restore points. It is concluded that the actual situation matches the ideal situation. In addition, the vertical LOS angle responds quickly. These fully prove that the designed guidance law is accurate and feasible.

3.4 PID design method based on Observer Kalman Identification Method (OKID)

Attempts to determine the dynamics of the UAV using the Observer Kalman filter and the design of a vertical landing controller for the approach and flare phases. The controllers have been tested in computer simulation under ideal conditions. To perform these tasks, a new high-precision altimeter sensor, RFM, was also developed and used for data collection, especially for system identification. Its potential could be fully demonstrated in the next test flight. It monitors altitude with minor errors and a higher sampling rate than barometric and GPS altimeters. Analysis of the flight test landing data was performed. Several essential parameters for controller design and simulation have been identified from the studies. The comments provide a rough idea of the range and mean of the parameters. Discrete-time linear longitudinal models of the SWAN drone dynamics were obtained using OKID from the windless flight test data. OKID has proven to be a handy tool to identify systems in discrete time. The PI controllers for the approach and flare phases have been designed and tested in computer simulation under ideal conditions, with no noise and no wind. Both controllers work fine, and the simulated flight path matches the desired flight path. The controllers are designed to be a significant preliminary attempt to achieve an automatic landing runway.

3.5 Root locus method

Isolated all of the moments and strengths withinside the system: weight, aerodynamic forces and moments, thrust, drag sweep. Following Newton-Euler formulation, we've given you a non-linear version that has been linearised to use linear manipulate theory. A longitudinal balance version has been used to layout cascade shape comments manipulate loops. Frequency area strategies had been used to create PID kind controllers. An internal comments loop managed the pitch perspective via way of means of quite simply performing at the flap deflection. Then, an outer loop allowed monitoring of the preferred altitude. Achieving this managed version is the beginning of a manner for development and could allow us to create navigation structures that lay the principles of the latest paintings lines. Improving the version and its manipulation is step one to designing optimized manipulation techniques and exploring new opportunities withinside the field.

3.6 Nonlinear model simulation

Development of longitudinal control method and modelling method of fixed-wing UAV. For example, for some UAVs, we have discussed how to construct control laws for pitch angle contours and elevation contours. The accuracy of the control law was verified by modelling a nonlinear model with 6 degrees of freedom. This control method was simple in a technically easy form to implement.

3.7 Multi-model Technique

System identification in the 12 Cessna 182 UAV frequency domain was performed, and a state-space model was obtained from the flight data. A multi-target optimization-based flight control system was developed and flight-tested for longitudinal stability during surveillance missions. An explicit model based on the architecture used the attitude command response style to provide independent throttling and throttling feedback. The influence of the noise cancellation performance of the control system on the image stability of the down-facing camera was observed. The following findings were recorded:

1. Full-scale frequency-domain system identification methods work well for small-scale aircraft. This is because the flight control hardware and sensors can produce a high signal to noise ratio data suitable for identification.

2. The multi-objective optimization-based methodology developed for full-scale aircraft and rotorcraft has been shown to work well in designing flight controls for a fixed-wing UAV to meet specifications with minimum control usage. The specifications used to optimize the longitudinal control laws for the C182 UAV worked well and can serve as a baseline for future UAV control law optimization. Limiting the integrator's proportional gain to ≈ 1/5 of the cut-off frequency results in a good design with good noise rejection characteristics.

3. The excellent consistency between closed-loop, interrupt-loop and turbulence feedback coatings emphasizes the importance of an accurate vacuum model. The deterministic model of the C182 drone shows good agreement with the full-scale C182 Froude scale values.

4. Less aggressive designs with low DRB and DRP result in more stable video images for down-facing cameras. With higher DRB and DRP, more aggressive controller designs result in a more stable video for the front-facing camera.

5. The most significant improvement over the old controller is the Low DM design. Optimizing to minimal aggression resulted in a 77% improvement in attitude tracking with a 60% reduction in lift usage compared to the old controller. For the gain of the design margin, the attitude tracking progress is relatively little. At the same time, the use of elevators is increasing rapidly and approaching the legacy value of the most dynamic high DM design. Also, the optimization made the gain and phase margin almost twice the importance of the legacy controller, giving better certainty over the uncertainty.

6. C182 UAV noise rejection bandwidths and dimensionless specifications of gain margin, phase margin, auto-shutdown and peak noise rejection agree with the requirements being met at the full scale. Additionally, the C182's Froude-scale DRB is reasonably close to the full-scale DRB requirements for the UH60 rotor. This finding suggests that Froude scaling large-scale processing quality to a UAV scale can define UAV-specific processing quality requirements.

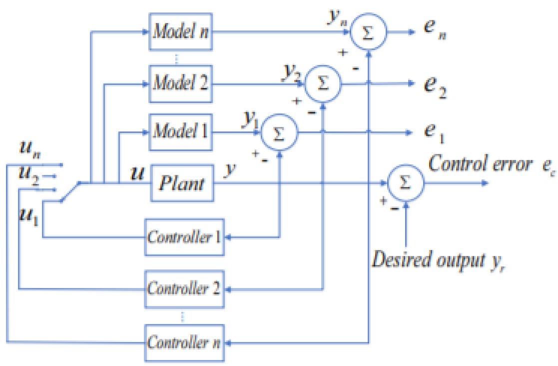

Fig -6: The global architecture of multi-model control

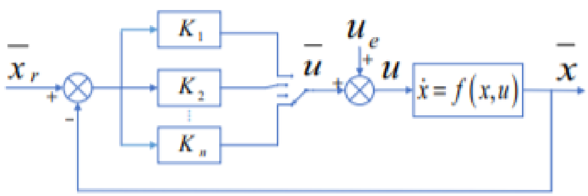

Fig -7: The inner loop for velocity and pitch angle

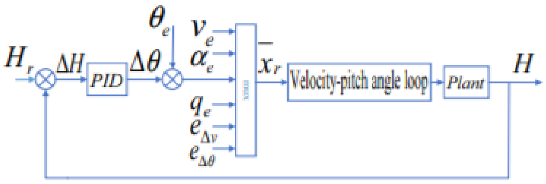

Fig -8: The altitude control loop

3.8 Model Predictive Control (MPC) and NMPC methods

Model Predictive Nonlinear Control (NMPC) is a variant of predictive model control characterized by the use of a nonlinear system model for prediction. NMPC, like linear MPC, requires an iterative solution to the optimal control problem over a finite prediction range.

4. CONCLUSIONS

The problem discussed in this paper is based on the guidance of an air vehicle from waypoint WP1 to waypoint WP2(as shown in Fig.1.(a))with minimum error in altitude and flight path angle in the presence of disturbances. The UAV control system consists of an outer guidance loop and inner control loop. Fig.1.(b) shows the structure of the overall longitudinal guidance and control system. The outer guidance block gets the current position and ground velocity vector inputs from the sensor and the waypoint information from the mission plan. Based on this information, the guidance block will generate a reference pitch angle (θr) for the inner control loop to follow. The internal control loop receives information about the current pitch angle and pitch rate from the sensor and generates the commands used to activate the elevator.

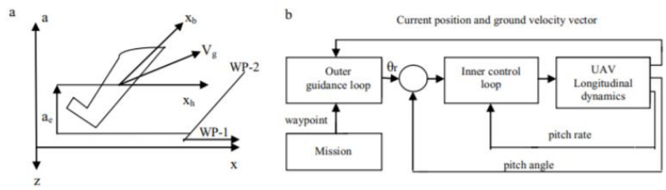

Fig -8: (a)Guidance problem definition; (b)Longitudinal Guidance and Control System [1]

The presented vertical control concept overcomes these difficulties by combining an adaptive controller based on a reference model with a set of dynamic feedforwards to form aircraft movement under all conditions and pilot tasks.

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