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Altitude Control for Small Fixed-Wing Aircraft Using H_∞ Loop-Shaping Method

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Abstract: Autopilot systems for UAVs without human pilots maintain the flight through an appropriate balance of aerodynamic forces autonomously. That is to say, they are used to make flight missions more reliable and efficient. Autopilot system design architecture conventionally contains two sections, inner and outer loops. Inner loop is the stabilizer and the outer loop can provide one of the additional motion controls (or all) such as speed, altitude, and heading hold. In this paper, $\boldsymbol{H_\infty}$ Loop-shaping method is used to provide the stabilizer mode and the PID controller is used to control the altitude.

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1. INTRODUCTION

UAVs can be controlled manually or autonomous to prevent any risk of human life. Due to their numerous advantages, control of UAVs and dynamically modelling them are important and essential issue. In addition, a UAV system is cheap enough to sacrifice and powerful enough to carry sensors, camera and communication systems (Efe, 2007). More importantly, a UAV can maintain the flight beyond the limits of a human pilot (Efe, 2007). UAVs play active roles in various fields (Kojima, Ogawara, Yoneda & Tomoigawa, 2008). To widen its appeal, it is necessary to improve the robustness of its navigation and control system (Kojima, Ogawara, Yoneda & Tomoigawa, 2008).

When autopilot systems are first generated, scientists consider comfort of the passengers. Such classifications terms, “Relief pilots”, “manoeuvring pilots”, “hard or soft pilots” etc., are used to automatically lead an aircraft (Young, Lynch & Boynton, 1944). Performance criteria came out when such terms are considered together.

Classical control methods are replaced by modern ones every day. Because modern control methods design concept takes cognizance of both performance and robustness (Akyurek, 2015).

Altitude control is needed to be included into the autopilot systems since elevation of the aircraft monotonous to comfort the passengers. Since the beginning of the 20th century autopilot systems matter grows in the field of research. In 1959 Litchford, Tatz, and Battle published a paper (Litchford, Tatz & Battle, 1959) about the future automatic landing systems. Current systems of instrument approach guidance, even with recent and forthcoming improvements, are shown to be inadequate for future operational needs (Litchford, Tatz & Battle, 1959). A broad look at future requirements, especially those posed by jet operations, leads to a specific set of desirable system characteristics (Litchford, Tatz & Battle, 1959). An approach system that is suitable to replace the interim improvements now being implemented must be provide a wide enough selection of flight paths to allow versatility in flight-control techniques; it must guide aircraft to actual landings; it must be fail-safe; and it must impose minimum burdens in terms of airborne equipment (Litchford, Tatz & Battle, 1959). There is increasing urgency in the need for a system to provide adequate guidance and control assistance to aircraft during final approach and landing (Litchford, Tatz & Battle, 1959).

During the flight aircraft’s manoeuvers need to be stable and smooth. That’s why researchers constantly develop algorithms for altitude control. In 1972, Blanchard’s research was about an algorithm for computing aircraft reference altitude. A recently developed algorithm which is being used to compute an aircraft reference altitude form air data inputs is accurate in a stationary column of air (Blachard, 1972). However, pressure gradients in the atmosphere can introduce significant errors (Blachard, 1972). An improvement which corrects for pressure gradient errors, has been developed which is based on the equilibrium equation for the motion of the air mass in the presence of pressure gradients (Blachard, 1972). When the aircraft reference altitude is computed entirely from parameters of the Earth’s atmosphere, errors are introduced due to variations or nonstandard conditions of the Earth’s atmosphere. Present state-of-the-art techniques permit corrections for variations in a column of air, i.e., in the vertical direction (Blachard, 1971).

As it is said before altitude hold autopilot systems grow attention in the field of research. Scientists develop various types of methods. Towards the end of the 20th century,

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modern control methods are commenced to be used as the approach to the systems. In 1994, Alvaro Olive's altitude hold autopilot design to work with an observer-based stability augmentation control law includes LQR optimal control method. A study about an altitude-hold autopilot design by optimal control method, LQR, has been carried out and the possibility of this design to work not only with the sensor based inner loop stability augmentation system has been evaluated. The possible simplifications in the autopilot design have been also studied (Oliva, 1994). The possible simplifications in the autopilot design have been also studied (Oliva, 1994). The main objective of the study is to show that the redundancy obtained for the inner loop flight control system can be extended to the autopilot system (Oliva, 1994). The altitude autopilot has been designed using the LQR method, with a PI controller structure, and in order to design the autopilot the altitude equation was included in the model (Oliva, 1994).

To test the autopilot systems before embedding them into the actual aircraft is crucial. By doing that any fail or loss could be prevented. Automatic pilot systems can be tested in model aircrafts. In 2003, Dzul, Lozano and Castillo mentioned adaptive altitude control for a small helicopter. The research was focused on the design and implementation of a controller for a two degree-of-freedom system (Dzul, Lozano & Castillo, 2003). This system is composed of a small-scale helicopter which is mounted on a vertical platform. The model is based on Lagrangian formulation and controller is obtained by classical pole-placement techniques for the yaw dynamics and adaptive pole-placement for the altitude dynamics (Dzul, Lozano & Castillo, 2003). The method used in the paper was Lyapunov analysis to prove that all variables remain bounded and the altitude and yaw converge to their desired values (Dzul, Lozano & Castillo, 2003).

As it is mentioned earlier, altitude control is the outer loop of the system; the inner loop is the stabilizer mode. For SISO systems the integrated altitude is the composite control system of the open-loop control and the close-loop control (Zhen, Jialin & Huiping, 2004). This technique is addressed in 2004 by Zhen, Jialin and Huiping. The principle is using two independent altitude measure systems to measure the same altitude, comparing the result of the two, and from the feedback compensation (Zhen, Jialin & Huiping, 2004).

Couple of modern control procedures, such H_2, H_∞, take performance and robustness into account. This approach is nearly new to the world of science. For missile altitude control system H_2 guaranteed cost fuzzy output feedback control problem is explained by Yuan, Ren, He and Sun, in 2004 (Yuan, Ren, He & Sun, 2004). Robust control method in the framework of μ-synthesis is employed to design autopilots (Yuan, Ren, He & Sun, 2004). H_2 guaranteed cost control for uncertain linear systems has been extensively studied in the past years (Yuan, Ren, He & Sun, 2004). The objective is to design system that not only keeps robust stable but also guarantees an upper bound of quadratic performance for all admissible parameter uncertainties (Yuan, Ren, He & Sun, 2004).

Control systems are generally based on feedback principle. The signal to be controlled is compared to a desired reference signal and the discrepancy used to compute corrective control action (Doyle, Francis & Tannenbaum, 1990). Feedback control techniques have been applied to automatic flight control problems to produce a new type of automatic pilot (Hanna, Oplinger & Douglas, 1954). Generally speaking, the objective in a control system is to make some output, say y, behave in a desired way by manipulating some input, say u (Doyle, Francis & Tannenbaum, 1990). The simplest objective might be to keep y small (or close to some equilibrium point)—a regulator problem—or to keep y − r small for r, a reference or command signal, in some set—a servomechanism or servo problem (Doyle, Francis & Tannenbaum, 1990). For example, on a commercial airplane the vertical acceleration should be less than a certain value for passenger comfort (Doyle, Francis & Tannenbaum, 1990).

From the beginning 20th century through now, aircraft control is very broad and took heed of subject. All the methods and approaches mentioned above lead to combine both dynamics and control.

In this paper, to design a flight controller which ensures good performance and robustness, aircraft dynamic equations being calculated, system modelling and controller designing, H_∞ loop-shaping is explained in order. After these sections are clarified results of the technique will be described in the conclusion section.

2. AIRCRAFT DYNAMICS

In this paper, before any autopilot's function is mentioned, flight dynamics used in the autopilot system model should be discussed. After flight stabilizing mode, the inner loop of the system, is accomplished, altitude hold section is added into the system.

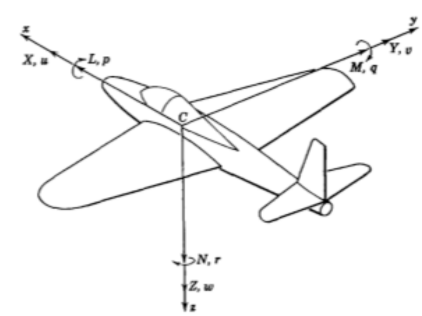

Fig. 1. Notation for body axes.

Convention for body axes is shown in Figure 1 (Etkin & Reid, 1996). L is rolling moment, M is pitching moment, N is yawing moment, p is rate of roll, q is rate of pitch, r is rate of yaw (Etkin & Reid, 1996). Components of resultant aerodynamic forces are X, Y, Z, and components of velocity of C relative to atmosphere are u,v,w (Etkin & Reid, 1996).

Table 1. Longitudinal stability derivatives

$M_u = C_{m_u} \frac{QSc}{u_0 I_y}$	$X_w = -\frac{(C_{D_\alpha} - C_{L_0})QS}{m u_0}$

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