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Information fusion based optimal control for large civil aircraft system

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ABSTRACT

Wind disturbance has a great influence on landing security of Large Civil Aircraft. Through simulation research and engineering experience, it can be found that PID control is not good enough to solve the problem of restraining the wind disturbance. This paper focuses on anti-wind attitude control for Large Civil Aircraft in landing phase. In order to improve the riding comfort and the flight security, an information fusion based optimal control strategy is presented to restrain the wind in landing phase for maintaining attitudes and airspeed. Data of Boeing707 is used to establish a nonlinear mode with total variables of Large Civil Aircraft, and then two linear models are obtained which are divided into longitudinal and lateral equations. Based on engineering experience, the longitudinal channel adopts PID control and C* inner control to keep longitudinal attitude constant, and applies autothrottle system for keeping airspeed constant, while an information fusion based optimal regulator in the lateral control channel is designed to achieve lateral attitude holding. According to information fusion estimation, by fusing hard constraint information of system dynamic equations and the soft constraint information of performance index function, optimal estimation of the control sequence is derived. Based on this, an information fusion state regulator is deduced for discrete time linear system with disturbance. The simulation results of nonlinear model of aircraft indicate that the information fusion optimal control is better than traditional PID control, LQR control and LQR control with integral action, in anti-wind disturbance performance in the landing phase.

1. Introduction

The automatic flight control systems of Large Civil Aircrafts play important roles in reducing the pilot's workload and achieving accurate attitude/trajectory control. As one of the key technologies of automatic flight control system, design of control laws directly determine the flight performance of Large Civil Aircraft. Control laws should be designed to meet all the requirements of performance index, and regard security, amenity and economical efficiency of flight as the major tasks of automatic flight control systems design.

There are several kinds of flight control methods presented for civil aircrafts. Nguyen (2009) uses robust optimal adaptive control to improve the tracking performance at a large adaptive gain, but the performance of restraining wind disturbance has not been tested [1]. Looye (2011) uses dynamic inversion and multi-objective optimization to design the attitude control system for civil aircraft, the controller is robustness to the parametric uncertainties, but performance index and flight quality have not been taken into account [2]. Gregory (2011) designs L1 adaptive control architecture to directly compensate for significant uncertain cross-coupling in nonlinear systems [3]. Shin (2007) uses a linear parameter-varying control synthesis method to design fault tolerant controllers for Boeing 747-100/200, and presents an application of robust gain-scheduled control methods [4]. References [5,6] study an adaptive control algorithm. Its advantages are the capability of improving the reliability and handling the aerodynamic parameter uncertainties. However, most references do not refer to concrete performance index, and do not test the control system's ability of anti-gust disturbance. Mohammad (2011) designs a closed-loop decision-making system to command the aircraft based on fuzzy logic controller for terrain following flight, which is important in approaching an airport with low or non-visibility for civil aircraft [7]. However, it only utilizes the system input–output data so that it is difficult to analyze and design the controllers, furthermore, theory basis of such intelligent methods is not perfect enough, and the computation costs of the intelligent methods generally become large.

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Development of Chinese Large Civil Aircraft is in the beginning stage, research on the automatic control law of the Large Civil Aircraft is not enough. Li (2010) uses LQG/LTR based method to design a longitudinal command augmentation system (CAS), this method is verified to enhance the stability, robustness and anti-jamming capacity, but the simulation is implemented based on linear system of civil aircraft [8]. Fan (2010) presents a modeling and control strategy for an advanced configured large civil aircraft with aeroservoelasticity via LQG method and control allocation [9].

LQ optimal control is a well-known fundamental theory in modern control theory. The LQ optimal control has received a great deal of attention from control theorists and engineers, since the resulting control law is linear with respect to the state and is therefore easy to compute [10,11]. There are many different approaches to the solution of LQ optimal control problems, such as the minimization method using Lagrange multipliers, dynamic programming, and Lyapunov function. Information fusion estimation (IFE) is the problem of how to best utilize useful information obtained from multiple sources or from a single source over a time period, for estimating an unknown parameter or process. The most important application area of IFE is track fusion or track-to-track fusion in target tracking system, which has been investigated for more than two decades [12]. Li (2003) establishes three estimation fusion architectures including centralized, distributed, and hybrid, moreover, he proposes an unified linear data model and two optimal fusion rules based on the best linear unbiased estimation (BLUE) and the weighted least squares (WLS) [13]. It is much more general and flexible than the previous approach of matching centralized and distributed fusion rules based on Kalman filters. Sun (2004) presents a new multi-sensor optimal information fusion criterion weighted by matrices in the linear minimum variance (LMV) sense which is equivalent to the maximum likelihood fusion criterion under the assumption of normal distribution [14]. Wang (2007) proposes a concept of the information weight which represents the contribution of the measurement on the estimated variable, and presents unified information fusion rules based on least square estimate criterion for linear and nonlinear measurements [15]. The information weight is essentially equal to the Fisher information matrix in case of Gaussian white noise. Information fusion is an ideological which universally exists in decision making problems. Both estimation problem and control problem belong to the decision making problem. In view of this, Zhen (2010) proposes a new optimal control method called information fusion control method for nonlinear systems [16,17]. It regards information of the desired trajectory, system dynamic equation and ideal control strategy as the measurement information of the control variable, and obtains an optimal estimate of the control variable by IFE, and then transfers the optimal control problem into the optimal estimation problem.

In summary, the previous references in designing the automatic control system of Large Civil Aircraft are few, in which the control strategies for anti-wind are especially little studied. Furthermore, previous research works always use linear models of Large Civil Aircraft in simulation, which is not accurate enough for real aircraft. Aiming to solve these problems, first, a nonlinear model with total variables is established for system simulation and natural analysis. Second, according to the aerial engineering experience, in landing phase with wind disturbance, the pitch attitude and flight speed can be well controlled by the traditional engineering methods, while the inclined attitude is difficult to be hold. Therefore, PID control and C* control are introduced to design the pitch attitude controller, an airspeed keeping autothrottle system is designed for flight speed control, and an optimal controller is designed for controlling inclined attitude. Third, in order to utilize the disturbance information to improve the control performance, this work originally propose an information fusion method to design the optimal regulator problem of discrete time linear system with disturbance.

The paper is organized as following: models of Large Civil Aircraft are established for natural analysis in Section 2, information fusion estimation and information fusion optimal regulator are shown in Section 3. Automatic flight control system which is composed of longitudinal channel and lateral channel and their control laws are designed in Section 4, simulations are carried out for comparing different control methods in Section 5, and finally the conclusions are shown in Section 6.

2. Modeling and property analyzing of large civil aircraft

According to the aerodynamic parameters of Boeing707 given in [18], we establish a nonlinear numerical model of Large Civil Aircraft, which is shown in Appendix A.1.

In order to study the natural properties of Large Civil Aircraft and design the control laws, firstly linear models need to be obtained. The selected trim point of landing phase is shown in Table 1.

By decoupling and linearization near the trim point, the linear longitudinal state equation of Large Civil Aircraft is expressed by

$$\dot{x}_{lon} = A_{lon} x_{lon} + B_{lon} u_{lon} \tag{1}$$

where $x_{lon} = [\Delta V \quad \Delta\alpha \quad \Delta q \quad \Delta\theta]^T$ is state vector, $u_{lon} = [\Delta\delta_e \quad \Delta\delta_T]^T$ is control input vector. System matrices A_{lon} and B_{lon} are given as follows.

$$A_{lon} = \begin{bmatrix} -0.0473 & 5.9918 & 0 & -9.7866 \\ -0.0030 & -0.5121 & 1.0000 & 0.0064 \\ 0.0006 & -0.7086 & -0.2730 & 0.0004 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad B_{lon} = \begin{bmatrix} 0.1156 & 6.4151 \\ -0.0299 & -0.0014 \\ -0.7558 & -0.1419 \\ 0 & 0 \end{bmatrix}$$

The lateral state equation is expressed by

$$\dot{x}_{lat} = A_{lat} x_{lat} + B_{lat} u_{lat} \tag{2}$$

Table 1
Trim state in landing phase.

State variable	Airspeed V_0	Altitude H	Angle of attack α	Track bank angle μ
Unit	m/s	m	deg	deg
Value	80	500	0.97	−3