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Simplified brain storm optimization approach to control parameter optimization in F/A-18 automatic carrier landing system

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ABSTRACT

The design of automatic carrier landing system is a crucial technique for carrier-based aircraft, since it facilitates landing of aircraft on carriers in various severe weather conditions, such as low visibility, heavy wind and rough sea conditions, which can hardly be achieved by manual control. In this paper, a novel method of optimizing the control parameters in the automatic carrier landing system of F/A-18A is developed, which is based on simplified Brain Storming Optimization (BSO) algorithm. The gains in the inner loop are optimized by fitting the frequency response curve of the closed-loop system with a desired frequency response curve. The control parameters in the autopilot and auto-throttle control module are optimized by minimizing a set of objective functions defined in the time domain. Comparative experiments are conducted to verify the effectiveness of our proposed method.
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1. Introduction

Carrier-based aircraft are important combat forces in modern navy. The ability to land safely on carriers in all weather conditions is a big challenge for all carrier-based aircraft. In manual landing operations, the pilots are under great pressure and accidents often occur if the weather condition is severe. Automatic Carrier Landing System (ACLS) is developed to relieve the pilot and help the aircraft achieve accurate sink rate and touchdown position in various conditions of sea state, visibility and air turbulence.

Usually, ACLS system consists of five components: flight control system, throttle control system, inertial navigation sensors, data link and the shipboard radar system [29]. The shipboard radar system tracks the position of the aircraft and computes the H-dot command or the pitch angle command. Afterwards, the command is transmitted to the aircraft by data link. The flight control system and throttle control system are used to manipulate the aircraft to follow the H-dot command or the pitch angle command to track the glide slope accurately. The control system is composed of the inner loop, the autopilot, and Approach Power Compensation System (APCS). The inner loop is similar to the conventional Control Augmentation System (CAS) used in other flight conditions, which increases the stability and the handling quality of the aircraft. The autopilot is used to follow the H-dot command or the pitch angle command, and create input signal for the inner loop. In the history of ACLS, two types of autopilot systems have been used. For instance, the ACLS of F-4J jet adopts the pitch angle command autopilot, while the ACLS of F/A-18A jet adopts H-dot command autopilot [13,20]. The H-dot command autopilot is proven to be more effective in alleviating the influence of air turbulence in automatic landings [30]. As a consequence, it is seen as a better option for advanced carrier-based aircraft. The APCS is used to maintain a constant velocity and angle of attack during the landing process [34]. The aircraft will rotate and cannot achieve an accurate flight path angle without a constant angle of attack. The study in Ref. [5] gave a detailed analysis of the APCS used in the US navy.

In additional to the traditional PID controller, the researchers have also investigated using more advanced controllers in ACLS. In Ref. [24], the authors designed a fuzz logic controller for the ACLS of F/A-18. The robust control design of ACLS was studied in Refs. [26] and [6]. A comparison of neural, fuzzy, evolutionary, and adaptive approaches for carrier landing control was given in Ref. [25].

After determining the structure of the control system, the designers have to adjust the parameters used in the control law to achieve the best control performance. However, the process of adjusting the control parameters is difficult and tedious even for designers with much experience. One major difficulty of the problem is that the number of the control parameters to be adjusted is relatively large, and an experienced designer often can only adjust one or two of the parameters at one time. Most of the time, the best control performance under the given control structure cannot

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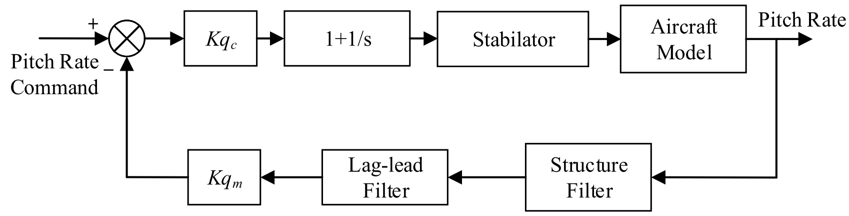

Fig. 1. The block diagram of the inner loop in ACLS.

be achieved. Aviation engineers have come up with many methods to optimize the parameters used in the flight control systems [17,16,19].

Recently, many researchers turn to bio-inspired optimization algorithms to solve the control parameter optimization problem [2,3,1,11,7]. Bio-inspired optimization algorithm is a flourishing field today. Some bio-inspired optimization methods like Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA) have been successfully applied to solve optimization problems in various fields [18,10,15,8]. The study in Ref. [14] used GA to optimize the feedback gains in two flight control systems. In Ref. [27], GA was applied to optimize the adaptive leading edge of an airfoil. In recent years, many new bio-inspired optimization algorithms were proposed. Among them, Brain Storming Optimization (BSO) is a promising method. BSO was proposed by Shi in 2011, which mimics the brainstorming process of a group of people working together to come up with new ideas to solve a difficult problem [22]. Intuitively, Shi thought the collective behavior of human beings should be superior to that of insects or animals, since human beings are the most intelligent creature on this planet. In Ref. [23], Shi proposed an improved model of BSO, and gave a detailed analysis of the algorithm. In Ref. [33], Zhou studied adapting the step-size of BSO according to the dynamic range of individuals on each dimension. The values of the parameters used in BSO are investigated in Ref. [32], and the effect of the solution clustering in BSO is analyzed in Ref. [4]. Other researchers also conducted much work to make BSO more effective, and applied this algorithm to solve several real-world problems [9,28,21,12].

In this study, we make some simplifications to the basic BSO, and name the new algorithm Simplified Brain Storming Optimization (SBSO). To illustrate the effectiveness of SBSO, we apply both BSO and SBSO to a set of benchmark functions. Therefore, SBSO is applied to optimize the control parameters in the F/A-18A ACLS. The gains in the inner loop are optimized by fitting the frequency response curve of the closed-loop system with a desired frequency response curve. The control parameters in the H-dot command autopilot and APCS are optimized by minimizing a set of objective functions defined in the time domain.

The remainder of this paper is organized as follows. In Section 2, we briefly introduce the longitudinal model of F/A-18A, and descriptions of the main components of ACLS including the inner loop, the H-dot autopilot loop and APCS can also be seen in this section. A concise introduction of the basic BSO and the detail of SBSO algorithm can be seen in Section 3. In Section 4, the control parameter optimization method based on SBSO is introduced, followed by experimental simulation and result analysis in Section 5. Finally, conclusions are given in the last section.

2. The F/A-18A automatic carrier landing system

2.1. The longitudinal model of F/A-18A

In this work, the longitudinal small turbulence dynamic model of F/A-18A is considered, the model is described in the following:

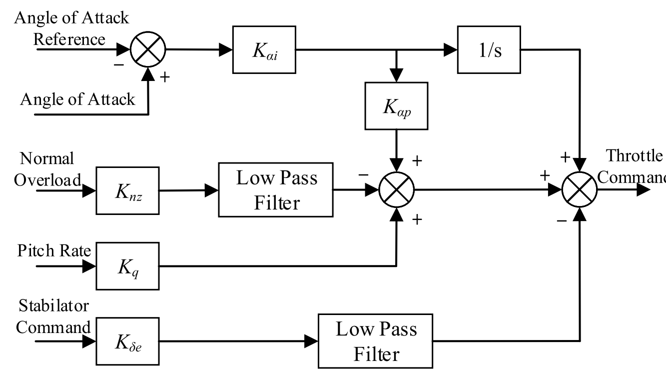

Fig. 2. The block diagram of the APCS.

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases}$$

$$x = (\Delta u/V_0, \Delta\alpha, \Delta\theta, \Delta q, \Delta h/V_0)^T$$

$$u = (\Delta\delta_s, \Delta\delta_{LEF}, \Delta\delta_{PL})^T$$

$$y = (\Delta h, \Delta\gamma, \Delta n_z/V_0, \Delta\alpha, \Delta u, \Delta\theta, \Delta q)^T \quad (1)$$

where, Δu, $\Delta\alpha$, $\Delta\theta$, Δq, $\Delta\gamma$, Δn_z, Δh are the variation of velocity, angle of attack, pitch angle, pitch rate, flight path angle, normal acceleration and height respectively. $\Delta\delta_s$, $\Delta\delta_{LEF}$, $\Delta\delta_{PL}$ are the deflection of stabilator, the deflection of leading-edge flap and the output of throttle respectively. The trim values of the states are: $V_0 = 69.96$ m/s, $\gamma_0 = -3.5$ deg and $\alpha_0 = 8.1$ deg.

2.2. Control system description

The control structure of the inner loop used in the ACLS of F/A-18A is designed to achieve rapid dynamic response to the vertical rate command. The block diagram of the inner loop is shown in Fig. 1. The pitch rate signal is taken as the feedback signal. In the feedback loop, a structure filter is used to eliminate the structure mode oscillation which is sensed by the rate gyroscope. The lag-lead filter is used to provide necessary lead response for the system to achieve high flight path bandpass. In the forward path, a high integrator gain is applied to achieve a flat low-frequency response.

The aircraft cannot trace a landing path precisely without a constant angle of attack and velocity, to this end, the APCS is applied to maintain a constant angle of attack and velocity during the landing process. APCS uses angle of attack α and normal overload n_z as the main feedback signals. The block diagram of APCS is shown in Fig. 2, the APCS maintains a constant α, and consequently a constant velocity can be achieved. The pitch rate feedback is used to increase the damping ratio of the system. The stabilator command signal is introduced into the APCS feedback signal to alleviate the impact of the stabilator deflection. The filers are used to eliminate the high frequency noise in n_z signal and the stabilator command. There are other feedback signals used in the actual F/A-18A APCS, such as the roll angle and the crossover com-

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