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신경 회로망을 이용한 강인 비행 제어 시스템: 동적 표면 설계 접근

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Robust Flight Control System Using Neural Networks: Dynamic Surface Design Approach

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Abstract - The new robust controller design method is proposed for the flight control systems with model uncertainties. The proposed control system is a combination of the adaptive dynamic surface control (DSC) technique and the self recurrent wavelet neural network (SRWNN). The adaptive DSC technique provides us with the ability to overcome the "explosion of complexity" problem of the backstepping controller. The SRWNNs are used to observe the arbitrary model uncertainties of flight systems and all their weights are trained on-line. From the Lyapunov stability analysis, their adaptation laws are induced and the uniformly ultimately boundedness of all signals in a closed-loop adaptive system is proved. Finally, simulation results for a high performance aircraft (F-16) are utilized to validate the good tracking performance and robustness of the proposed control system.

1. Introduction

In this paper, the new method for reconfigurable flight control of high-performance aircraft in the presence of large changes in the aerodynamic characteristics, unmodeled dynamics, and the reduction of the control effectiveness by the control surface damage is proposed via the adaptive DSC technique[1] using SRWNN[2,3]. That is, we apply the DSC technique to the multi input and multi output system, the aircraft system. First, we present the full dynamic model of the aircraft with model uncertainties, then we design the adaptive reconfigurable flight control system using DSC technique and SRWNN for the command following of the angle of attack, sideslip angle, and bank angle of the aircraft. In our control system, the SRWNNs are used to observe unknown model uncertainty terms of the aircraft system. The adaptation laws for all weights of SRWNN are induced from the Lyapunov stability analysis, which are used for proving the uniformly ultimately boundedness of all signals in the closed-loop system. Finally, we simulate the nonlinear six-degree-of-freedom F-16 aircraft model to show the effectiveness of the proposed scheme.

2. Dynamics of an Aircraft with Uncertainty

The dynamic equations of motion for an aircraft about the body axes over a flat Earth presented in [4] are used. It is assumed that the aerodynamic forces and moments can be described by functions of the angle of attack, sideslip angle, angular rates, and control surface deflections[5]. Here, the control surface deflections denote the Elevator, aileron, and rudder deflection. In this paper, the modeling errors are considered as the model uncertainties together with the variations of the aerodynamic coefficients.

3. Adaptive DSC System Design Using SRWNN for Flight Systems

3.1 SRWNN

The SRWNN, a modified model of a wavelet neural network(WNN), has the attractive ability such as dynamic attractor, information storage for later use. Unlike a WNN, since the SRWNN has the mother wavelet layer which is composed of self-feedback neurons, mother wavelet nodes of the SRWNN can store the past information of the network[2]. Thus the SRWNN can be used as a better tool to approximate the nonlinear systems than a WNN.

3.2 Flight Controller Design

The control objective is to design an adaptive DSC system using SRWNN uncertainty observer for the angle of attack, sideslip angle, and bank angle to track the desired trajectories. The control design procedure is similar to [1] except the SRWNN uncertainty observer concept.

3.3 Stability Analysis

Generally, the stability analysis of the DSC system is more complicated than that of the backstepping control system because the extra first-order filters must be considered. In this subsection, we prove the uniformly ultimately boundedness of the solution of the proposed control system, and the adaptation laws for all weights of the SRWNN are derived from this procedure. We first derive analytic expressions of the closed-loop system via the error surface vectors, a boundary layer error vector, and the weight estimation errors.

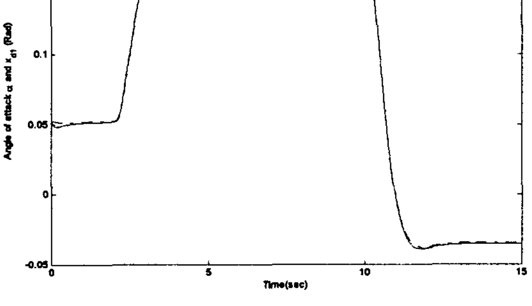
4. Simulation Results

In this section, to demonstrate the validity of the adaptive DSC system using the SRWNN uncertainty observer, the simulation for the tracking control of the nonlinear F-16 aircraft with the model uncertainty is performed. We consider the F-16 aircraft flying at a speed of 700 ft/s and the altitude of 20000 ft, initially. The system parameters for the F-16 aircraft model defined in [4] are used in this simulation. For example, m=20500 lbs, T=1478.5 lbf, moments of inertia and so on. In addition, we employ the aerodynamic coefficient model for the F-16 aircraft presented in [5] and assume that this model is uncertain.

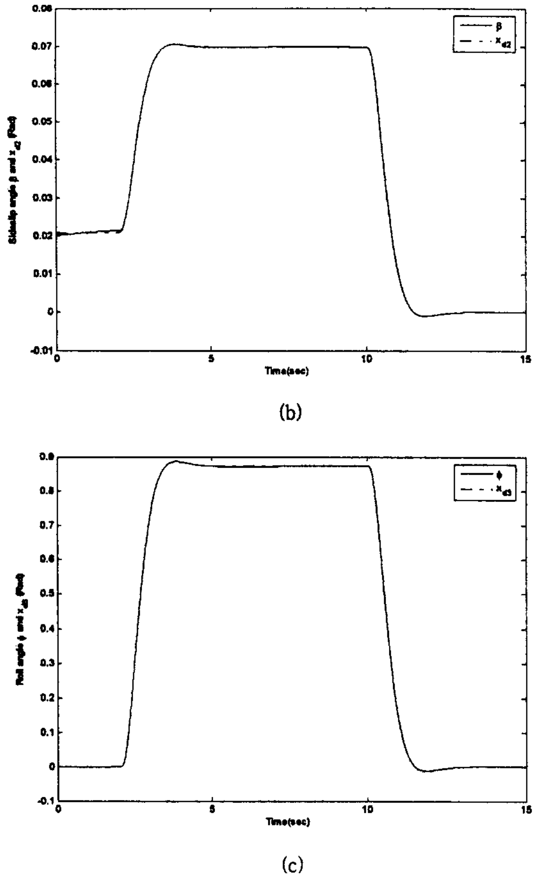
The tracking results and errors of the prrposed control system as shown in Figs. 1 and 2 indicate that the suggested control method can overcome unknown model uncertainties resulting from the faults of the aircraft dynamics. Fig. 3 show the control surface deflections. The outputs of the SRWNNs are displayed in Fig. 4. Note that the uncertainty terms are observed by SRWNNs, effectively.

5. Conclusion

In this paper, the new method for reconfigurable flight control of high-performance aircraft has been proposed using the adaptive DSC technique and the SRWNN uncertainty observer. through the simulation results for the F-16 aircraft system, it has been shown that the proposed control system has the good tracking performance and the robustness against model uncertainties.



(a)



(b)

(c)

Fig. 1. Tracking results for the F-16 aircraft system (a) attack of angle (b) sideslip angle (c) bank angle.

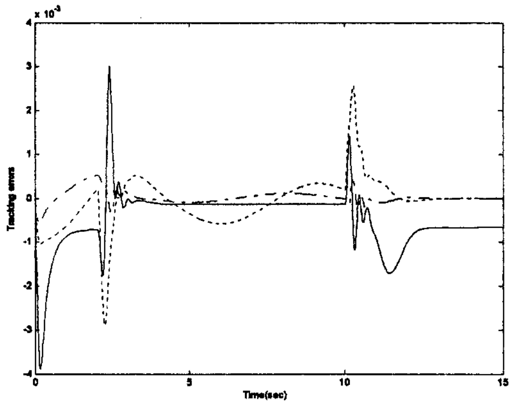


Fig. 2. Tracking errors for the F-16 aircraft system (solid: attack of angle, dash-dotted: sideslip angle, dotted: bank angle).

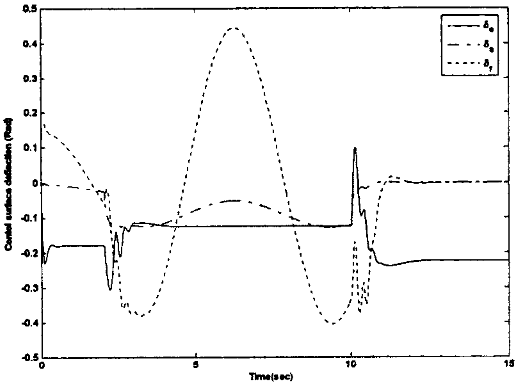
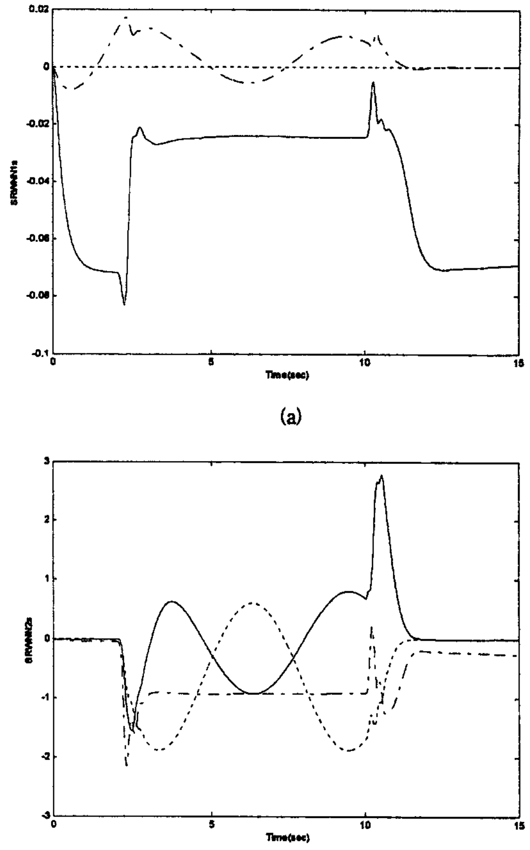


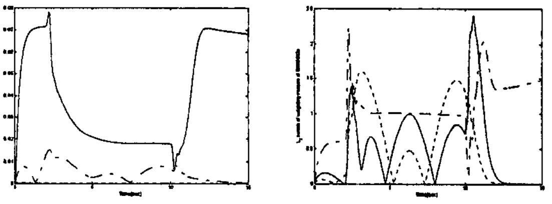
Fig. 3. Control surface deflections.



(a)

(b)

Fig. 4. Outputs of SRWNN uncertainty observers (a) SRWNN1 (b)SRWNN2.



(a) (b)

Fig. 5. L_2 **norm of the weights of SRWNN uncertainty observers (a) SRWNN1 (b) SRWNN2**

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