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비선형 비행 시스템을 위한 H∞ 접근법 기반 적응 신경망 동적 표면 제어

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Adaptive Neural Dynamic Surface Control via H∞ Approach for Nonlinear Flight System

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Abstract - This paper presents an adaptive neural dynamic surface control (DSC) approach with H∞ tracking performance for a full dynamics of a nonlinear flight system. It is assumed in this paper that model uncertainties such as structured and unstrutured uncertainties and external disturbances influence the nonlinear aircraft model. In our control system, self recurrent wavelet neural networks (SRWNNs) are used to compensate model uncertainties of the nonlinear flight system, and an adaptive DSC technique is extended for disturbance attenuation of the nonlinear flight system. From Lyapunov stability theorem, it is shown that H∞ performance from external disturbances can be obtained. Finally, we perform the simulation for the nonlinear six-degree-of-freedom F-16 aircraft model to confirm the effectiveness of the proposed control system.

1. Introduction

Recently, the DSC method [1] proposed to overcome "explosion of complexity" problem of the backstepping design technique. In this paper, we propose an adaptive DSC technique using SRWNN to attenuate the external disturbance of the nonlinear flight system. It is considered that the full dynamic model of the aircraft system with model uncertainties such as structured and unstrutured uncertainties, and external disturbances. SRWNN [2] is employed to approximate the model uncertainty term of the aircraft model, and an adaptive DSC technique is extended for disturbance attenuation of the nonlinear flight system. The adaptation laws for all weights of SRWNN is induced from the Lyapunov stability theorem and projection algorithm. In the stability analysis, it is shown that H∞ performance from external disturbances can be obtained. The simulation results of the nonlinear six-degree-of-freedom F-16 aircraft model are presented to validate the good tracking performance and robustness of the proposed control system.

2. Dynamics of an Aircraft with Uncertainty

Consider the dynamic equations of motion for an aircraft about the body axes over a flat Earth as follows: [3]

$$\begin{aligned}
\dot{V} &= \overline{f_v}(x_1, x_2, \theta, V, u),\\
\dot{\theta} &= \overline{f_\theta}(\phi, x_2),\\
\dot{\psi} &= \overline{f_\psi}(\phi, \theta, x_2),\\
\dot{x}_1 &= f_1(x_1, \theta, V) + \Delta f_1(x_1, \theta, V)\\
&\quad + [g_1(x_1, \theta) + \Delta g_1(x_1, \theta)]x_2 + \overline{h_1}(x_1, V)u + d_1,\\
\dot{x}_2 &= f_2(x_1, x_2, V) + \Delta f_2(x_1, x_2, V) + [g_2(x_1, V) + \Delta g_2(x_1, V)]u + d_2,
\end{aligned}$$

where $x_1 = [\alpha\ \beta\ \phi]^T \in R^3$, $x_2 = [p\ q\ r]^T \in R^3$, $u = [\delta_e\ \delta_a\ \delta_r]^T \in R^3$. The explanation of system variable as illustrated in [4] will be omitted for conciseness.

3. Adaptive DSC system for disturbance attenuation

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 with H∞ performance

The control objective is to design an adaptive DSC system with H∞ tracking performance for the angle of attack, sideslip angle, and bank angle to track the desired trajectories. More explicitly, given a desired level of disturbance attenuation $\rho > 0$ and a positive definite diagonal matrix K_1, find a robust adaptive state feedback controller such that the following H∞ performance is achieved:

$$\int_0^T \| S_1 \|_{K_1}^2 dt \le Z_0 + \rho^2 \int_0^T \| \nu \|^2 dt \qquad \forall \nu \in L_2[0, T]$$

for $T \in [0, \infty)$ where S_1 is a tracking error, Z_0 is a positive constant depending on initial conditions and ν denotes an external disturbance term.

3.3 Stability Analysis

In this subsection, we prove that the proposed control system can obtain H∞ tracking performance, and the adaptation laws for all weights of the SRWNN are derived from this procedure.

4. Simulation Results

In this section, to demonstrate the validity of the adaptive DSC system using the SRWNN, 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 [3] 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 [4] and assume that this model is uncertain. It is assumed that the external disturbances given by $d_1 = [d_{11}\ d_{12}\ d_{13}]^T$ where $d_{11} = \begin{cases} 0.1, & \text{if } 7 \le t \le 7.5 \\ 0 & otherwise \end{cases}$, $d_{12} = \begin{cases} 0.1, & \text{if } 2 \le t \le 2.5 \\ 0 & otherwise \end{cases}$, $d_{13} = \begin{cases} 0.1\cos(3t), & \text{if } 5 \le t \le 10 \\ 0 & otherwise \end{cases}$, and $d_2 = 0$ influence the nonlinear flight system. The disturbance attenuation level is chosen as $\rho = 0.1$.

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

5. Conclusion

In this paper, we have proposed an adaptive neural dynamic surface control (DSC) approach with $H\infty$ tracking performance for high-performance aircraft systems. 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.

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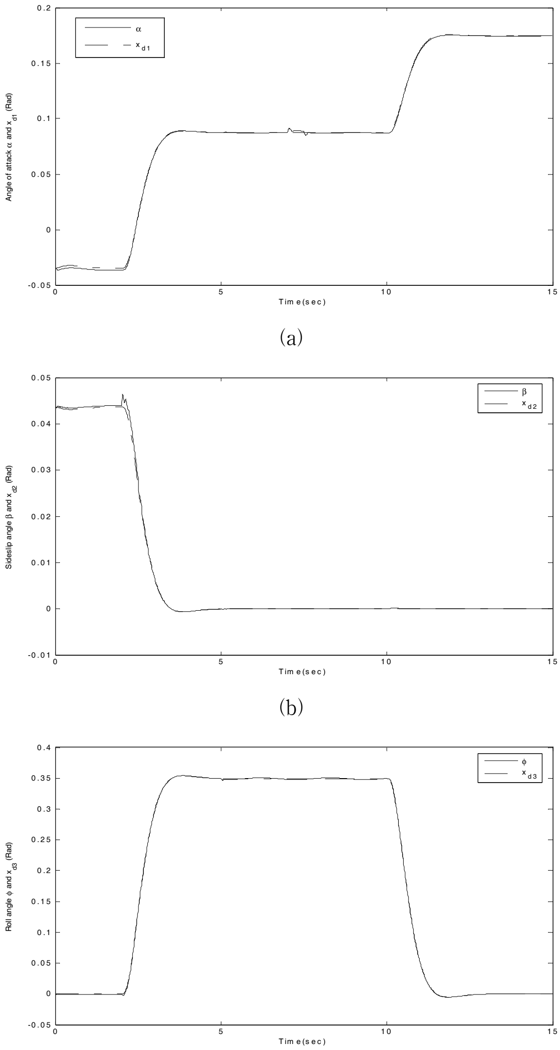
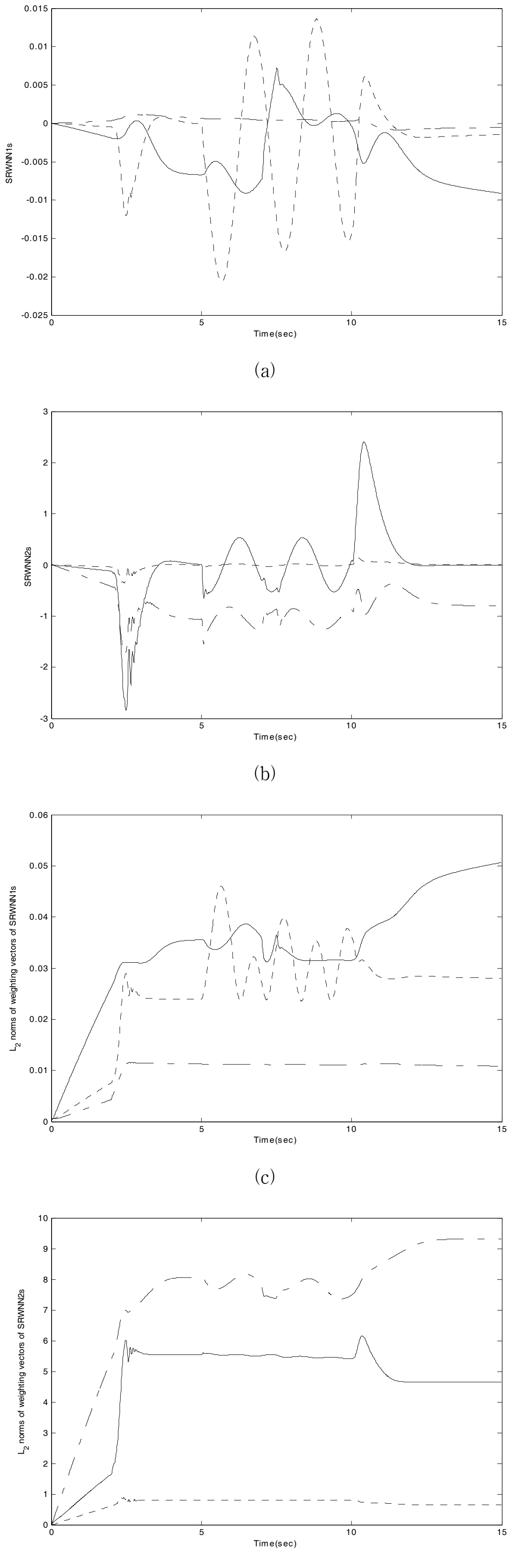


(a)

(b)

(c)

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



(a)

(b)

(c)

(d)

Fig. 2. Outputs and L_2 norm of the weights of SRWNN (a) SRWNN1 (b) SRWNN2 (c) SRWNN1 (d) SRWNN2.