The Design of Sliding Mode Controller with Perturbation Estimator Using Observer-Based Fuzzy Adaptive Network

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Abstract

To improve control performance of a non-linear system, many other researches have used the sliding mode control algorithm. The sliding mode controller is known to be robust against nonlinear and unmodeled dynamic terms. However, this algorithm raises the inherent chattering caused by excessive switching inputs around the sliding surface. Therefore, in order to solve the chattering problem and improve control performance, this study has developed the sliding mode controller with a perturbation estimator using the observer-based fuzzy adaptive network. The perturbation estimator based on the fuzzy adaptive network generates the control input for compensating unmodeled dynamics terms and disturbance. And, the weighting parameters of the fuzzy adaptive network are updated on-line by adaptive law in order to force the estimation errors to converge to zero. Therefore, the combination of sliding mode control and fuzzy adaptive network gives rise to the robust and intelligent routine. For evaluating control performance of the proposed approach, tracking control simulation is carried out for the hydraulic motion simulator which is a 6-degree of freedom parallel manipulator.

1. Introduction

Sliding mode control is very attractive method for nonlinear systems [1, 2]. It has been confirmed as an effectively robust control approach for nonlinear systems against parameters and load variations. However, some bounds on system uncertainties must be estimated in order to guarantee the stability of the closed-loop system, and its implementation in practice will cause a inherent chattering problem, which is undesirable in application. To overcome these demerits, many researches are carried out. Lee and Aoshima [3] proposed a sliding mode control algorithm with two dead zones for reducing the chattering. However, this algorithm could not completely reduce the inherent chattering which was caused by excessive switching inputs around the sliding surface. And, Choi and Kim [4] proposed a fuzzy sliding mode control algorithm which was designed to reduce the inherent chattering of the sliding mode control by using the fuzzy rules. However, the number of inference rules and membership functions of the fuzzy-sliding mode controller should be determined only through the trial and error method by an expert who had the knowledge of systems.

Fuzzy control is the most effective method using expert knowledge without the parameters and structure of the nonlinear systems [5]. However, it is difficult to design and analyze the adequate fuzzy rules. Therefore, many researches have been carried out to optimize parameters of the fuzzy system. The neuro-fuzzy system [6] such as ANFIS (Adaptive Network based Fuzzy Inference System) is representative method [7]. The neuro-fuzzy system is obtained by embedding the fuzzy inference system into the framework of artificial neural network.

So, this study has developed the sliding mode controller with perturbation estimator using observer-based FAN (fuzzy adaptive network). This control algorithm is designed to solve the chattering problem of a sliding mode control and select the adequate fuzzy parameters. The perturbation estimator generates the control input for compensating unmodeled dynamic terms and disturbance using the observer-based FAN. The weighting parameters of the observer based FAN are updated on-line by adaptive law in order to force the estimation errors to converge to zero. Therefore, the combination of sliding mode control and FAN (fuzzy adaptive network) gives rise to the robust and intelligent routine. For evaluating control performance of the proposed approach, tracking control simulation is carried out for the hydraulic motion simulator which is a 6-degree of freedom parallel manipulator [8].

2. Observer based fuzzy adaptive network

2.1 Sliding state observer

The dynamic equation of a nonlinear system with n-degree of freedom can be written as follow:

$$\ddot{x}_j = f_j(\boldsymbol{x}) + \Delta f_j(\boldsymbol{x}) + \sum_{i=0}^{n} [b_{ji}(\boldsymbol{x})u_i + \Delta b_{ji}(\boldsymbol{x})u_i] + d_j(t) \qquad j = 1, \cdots, n \tag{1}$$

where, $\boldsymbol{x} \equiv [X_1, \cdots, X_n]^T$ is the state vector, and $X_j \equiv [x_j \ \dot{x}_j]^T$. The term $f_j(\boldsymbol{x})$ and $b_{ji}(\boldsymbol{x})$ correspond to the elements of system matrix and those of control gain matrix, respectively, and these terms are the known values. The $\Delta f_j(\boldsymbol{x})$ and $\Delta b_{ji}(\boldsymbol{x})$ are uncertainties of $f_j(\boldsymbol{x})$ and $b_{ji}(\boldsymbol{x})$, respectively. And, $d_j(t)$ is the disturbance and u_j is the control input.