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An intelligent self-repairing control for nonlinear MIMO systems via adaptive sliding mode control technology

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Abstract

In this paper, an intelligent self-repairing control scheme is proposed for a class of nonlinear MIMO system. A direct self-repairing controller of a nonlinear SISO system is firstly designed, and then the control scheme is promoted to a nonlinear MIMO system. The error signals are replaced by the state variables to deal with the high derivate problems of the desired signals and a nonlinear regulating function is brought in to improve the performances of the sliding mode. The self-repairing controller is made up of four parts: the nonlinear regulator, the equal controller, the compensator I and the compensator II. The control method is applied to a helicopter flight control system with loss-in-effectiveness faults. Some simulation results illustrate the effectiveness and feasibility of the proposed control scheme in the paper.
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1. Introduction

The helicopter is widely used in the world. However, as we all know, it is difficult to ensure the good transient performances and stability of helicopter for its MIMO, nonlinearity, heavy coupling, varying parameters and model uncertainty [1–3]. Lots of solutions had been used to deal with them, which involved adaptive control, fuzzy control, neural network control, sliding mode control and so on.

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For the nonlinear MIMO systems, an adaptive fuzzy control scheme is adopted [4–9], in which the desired signals can be tracked by the outputs of the systems, but the track convergence rate is slow and the robustness of the control system is not satisfied. Enso Ikonen et al. propose a multiple model-based control using finite controlled markov chains for nonlinear MIMO systems [10], but the control law is designed off-line. The control system has no self-regulating capacity. Gros, C puts forward a novel concept of active neural networks [11], but it is difficult to be used in the flight control systems.

Nowadays, sliding mode control has become a hot research topic, for its robustness to model uncertainty and disturbances, especially it is effectively used in the nonlinear control systems [12,13]. However, the chattering is a great problem in using this theory, on which many experts have made lots of studies. The boundary layer concept is successfully brought in sliding mode control by Slotine to decrease the chattering, while it is difficult to get good static state performances [14–16]. An integral scheme is brought in to improve the steady-state performances, while the transient performances are bad with a big initial error, the large shots, and even being unstable [17,18]. An improved sliding mode control scheme is presented, in which the stable errors are effectively reduced, but it is very difficult to achieve the conditions that the desired signals and their high derivatives exist [19–21]. A novel sliding mode control is adopted [22,23] in which the error signals are replaced by the state variables in the process of constructing the sliding mode switching functions, and it overcomes the high derivate problems. However, it is lack of generality and it is only used in the low-level systems.

Fault tolerant control for nonlinear systems has been a hot topic recently, and the advantages are very obvious, especially in uncertain systems, discrete-time systems and time-delay systems [24,25]. Sliding mode control used in uncertain system is very effective based on the above summaries. While the robust adaptive fuzzy sliding mode control used in a class of uncertain discrete-time nonlinear system also proves the point, however the scheme is proposed for a discrete-time nonlinear system [26]. The dynamic integral sliding mode control improves the uncertain nonlinear system [27], however, the paper only considers the SISO nonlinear system, the scheme is needed to be improved.

So in this paper an adaptive sliding mode control scheme is adopted. Compared with the above control schemes, not only the high derivate problems are overcome, but also the good performances of the sliding mode control are ensured. A nonlinear regulating function is brought in constructing the sliding mode surfaces which could eliminate the chattering. This control scheme is extended to the general nonlinear system and the design progress is shown in the following chapters. The selected control scheme is used to the nonlinear MIMO helicopter control system with loss-in-effectiveness faults. The simulation results illustrate the effectiveness and feasibility of the scheme.

2. Description of the system

The nonlinear system for helicopter with faults is generally shown as the following form:

$$\begin{cases} \dot{x} = f(x) + g(I - \sigma)U \\ y = Hx \end{cases} \tag{1}$$

where $x = [x_1, x_2, \ldots x_n]^T \in R^{n\times 1}$ is state vector; $f(x) = [f_1(x)\ f_2(x)\ \ldots\ f_n(x)]^T$ is the function of x; $U = [u_1\ \ u_2\ \ \ldots\ \ u_m]^T$ is the control vector; $y \in R^{n\times 1}$. I is a unit matrix. g and H are the system parameter matrixes, here we suppose the H is unit matrix; σ is the fault coefficient matrix, which

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