Information Sciences 316 (2015) 123–131

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Self-repairing control of a helicopter with input time delay via adaptive global sliding mode control and quantum logic

Fuyang Chen [a,b,*], Rongqiang Jiang [a], Changyun Wen [c], Rong Su [c]

[a] College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China
[b] Jiangsu Key Laboratory of Internet of Things and Control Technologies, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China
[c] School of Electrical & Electronic Engineering, Nanyang Technological University, Nanyang Avenue, 639798 Singapore, Singapore

ARTICLE INFO

Article history:
Received 13 September 2014
Received in revised form 31 March 2015
Accepted 11 April 2015
Available online 18 April 2015

Keywords:
Adaptive control
Global sliding mode control
Helicopter
Quantum logic
Time delay

ABSTRACT

This study proposes a solution to the problem of designing adaptive global sliding mode controllers for a class of linear helicopter systems with actuator faults and time delay. An adaptive global sliding mode control approach is proposed based on dynamic nonlinear sliding mode function and adaptive law. The advantages of the controller include elimination of the reaching movement of traditional sliding mode control, realization of online identification of the fault value, and overcoming of the effect of the actuator faults and time delay. In addition, quantum information technique is used to increase the control accuracy of helicopter. Simulation results demonstrate the efficiency and superiority of the proposed method.

1. Introduction

Helicopters are widely used in land, naval, and air force missions, and play a huge role in air travel. While a helicopter can complete a mission, its properties have caused widespread concern. For example, nonlinearity, heavy coupling, varying parameters and model uncertainty can cause difficulty in controlling the helicopter [11,17,26]. Hence, much work has been done in the field of helicopter controller design. Thus, the several proposed helicopter control schemes involve adaptive, fuzzy, neural network, and sliding mode control [1,20,36] Sliding mode control (SMC) [16,19,24,35] is a robust method that is used to control nonlinear and uncertain systems. The trajectory of the traditional sliding mode control consists of two phases, namely, reaching and sliding modes. Studies have shown that the sliding mode control system is robust only when the system is in sliding mode phase. Moreover, the system is susceptible to outside interference and parameter changes in reaching mode phase. Therefore, ways to shorten reaching time has become an increasingly important issue in sliding mode control. Lu and Chen proposed a global sliding mode system [13,21,28]. The system introduces state-related time-varying factor entries in the sliding mode control law. In addition, the switching function is constructed such that the trajectory of the system is on the sliding surface from the very beginning. This condition eliminates the reaching mode phase and exists only in the sliding mode phase. This system improves the transient performance of the system and overcomes the influences of unknown parameter perturbation, which ensures the robustness of the whole process of the system from the initial state to the equilibrium point [7,12,18,32,34].

* Corresponding author at: College of Automation Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, PR China. Tel.: +86 13505169064.

E-mail address: chenfuyang@nuaa.edu.cn (F. Chen).

http://dx.doi.org/10.1016/j.ins.2015.04.023
0020-0255/

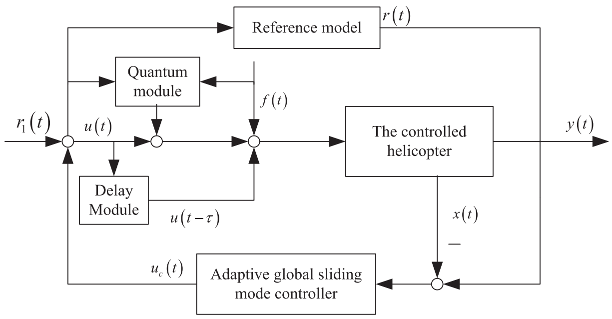

Fig. 1. Basic structure of the system.

Adaptive control is a controversial issue as well. Adaptive control aims to estimate uncertainties in the plant on-line, and is based on measured signals. The conventional adaptive control can solve a few problems of uncertain systems, but is not appropriate for very uncertain systems or rapidly changed systems. The global sliding mode control does not rely on accurate aircraft mathematical model, and it is insensitive and robust to model uncertainties and disturbances in the system. Hence, the control system will be strongly robust to uncertainty by using combined adaptive global sliding mode control [8,9,22].

In the actual industrial processes, a system will suffer time delay phenomenon inevitably because of the insensitivity of information transfer and measurement. The existence of time delay is frequently a source of poor system performance and instability. Hence, control problems of time-delay systems have received considerable attention over the past years [2,10,25,27,30,33]. In these studies, the sliding mode variable structure control is a very effective method to stabilize time-delay systems.

Considering the existence of actuator faults, this study introduces quantum information technique. Research on quantum information technique is controversial because this technique is applied widely. In this study, quantum logic is used to increase the control accuracy of helicopters [3–6,14,15,23,29,31].

This study introduces an adaptive global sliding mode controller via quantum logic to control helicopter flight control systems. The designed controller allows the control system to track the desired signal with high accuracy, and allow the faulty aircraft to continue to possess strong stability and tracking properties. Simulation results demonstrate the effectiveness of the proposed approach. The powerful fault-tolerant ability of sliding mode control and the great parameter estimation ability of adaptive control are directly applied for the system. The fault-tolerant control method we proposed here has the following advantages. First, the whole system is easy to be realized, as each fault consists of the same fault-tolerant controller. Second, the sliding mode observer can estimate uncertainties effectively even though the system has delay part, which is seldom discussed in published studies related to helicopter fault-tolerant control. Third, the accuracy of helicopter control is increased by the quantum information technique.

This paper is organized as follows. Section 2 introduces the problem statement for helicopters. Section 3 presents the quantum information technique and develops the design of the adaptive global sliding mode control. Section 4 discusses simulation results that demonstrated the feasibility of the designed controller. Conclusions are drawn in Section 5.

2. Problem statement for helicopter

In this study, an adaptive global sliding mode controller via quantum information technique is introduced to control the helicopter flight control system. The basic structure of the system is shown in Fig. 1.

Consider a linear model of helicopter that is described as

$$\dot{x}(t) = Ax(t) + Bu(t) \tag{1}$$
$$y(t) = Cx(t) \tag{2}$$

where $x(t) \in R^n$ and $y(t) \in R^p$ are respectively the state and output of the system. $u(t) = [u_1, \ldots, u_m]^T \in R^m$ is the control input.

In this study, we focus on a class of additive actuator faults. Additive fault representation is more general than multiplicative ones, which can be modeled as additive actuators. We consider that time-delay frequently occurs in many practical systems. A faulty system with input time delay is described as:

$$\dot{x}(t) = Ax(t) + B[u(t) + f(t)] + B_1u(t-\tau) \tag{3}$$
$$y(t) = Cx(t) \tag{4}$$

where $A \in R^{n\times n},\ B \in R^{n\times m},\ B_1 \in R^{n\times m}$ and $C \in R^{p\times n}$ are the parameter matrices. $f(t) \in R^m$ represents the additive actuator fault. τ is the delay. The following assumptions are made: