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Robust Adaptive Control for Unmanned Helicopter with Stochastic Disturbance

Rong Li[a], Qingxian Wu[a,*], Mou Chen[a]

[a]*College of Automation and Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210000, P.R China*

Abstract

In this paper, the problem of robust adaptive control is concerned for a class of small-scale unmanned helicopter systems in the presence of system uncertainty, stochastic disturbance and output constraint. The adaptive neural network approximator is introduced to handle the unknown system function. Meanwhile, a prescribed performance function is employed to deal with output constraint. It is proved that the proposed control method is able to guarantee the ultimately bounded convergence of all closed-loop system signals in mean square via Lyapunov stability theory. The effectiveness of the developed robust controller are illustrated and confirmed by numerical simulations for a class of unmanned helicopter systems.

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Keywords: Unmanned helicopter; Stochastic disturbance; Adaptive control; Output constraint.

1. Introduction

In the recent years, the growing demand for advanced unmanned helicopter systems has inspired significant research and development for the flight controller design[1,2]. A structure robust linear control approach was proposed for unmmaned helicopters[3]. In 4, an adaptive attitude control method was investigated for the unmanned helicopter, which considered a kind of input nonlinearity. In 5 and 6, the adaptive tracking control was developed for a class of model-scaled unmanned helicopters. A disturbance observer based robust nonlinear tracking control approach was proposed for unmanned helicopters[7].

It is well known that the stochastic disturbance often exists in the unmanned helicopter systems. In 8, by using the Kalman estimator, a robust control approach was developed for a class of linear systems with stochastic disturbance. A class of mean-square $H\infty$ filter was proposed for the linear system with stochastic disturbance[9]. Among the existing control methods, backstepping technique has been widely adopted for the stochastic nonlinear systems[10,11]. However, there are few existing research results for the unmanned helicopter control systems with stochastic disturbance and

* Qingxian Wu
E-mail address: wuqingxian@nuaa.edu.cn

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output constraint. In this paper, we will study a robust control scheme for unmanned helicopter with the stochastic disturbance by using radical basis function neural networks (RBFNNs).

Motivated by the above observation, the prescribed performance based robust adaptive control scheme is developed for the unmanned helicopters with stochastic disturbance and output constraints. The remainder of this paper is organized as follows. Section 2 presents the problem formulation and preliminaries. In Section 3, a prescribed performance based nonlinear control approach is developed for the unmanned helicopter system, and the closed-loop system stability is rigorously illustrate by using Lyapunov synthesis. Simulation results are given to demonstrate the effectiveness of the developed control scheme in Section 4. Finally, Section 5 draws the conclusion of this paper.

2. Problem statement and preliminaries

This section aims to briefly review the complete nonlinear stochastic dynamic model of unmanned helicopters and introduce some preliminary knowledge.

2.1. Helicopter Modeling

The rigid-body attitude dynamics of an unmanned helicopter with stochastic disturbance can be expressed as[5]

$$\begin{aligned} d\Theta &= H(\Theta)\,\Omega dt \\ I_m d\Omega &= \left(-\Omega \times I_m\Omega + G\tau - Q_T a_1 - Q_M a_2 + \Delta M\right)dt + h_\Omega dw_\Omega \end{aligned} \tag{1}$$

where $\Theta = [\phi, \theta, \psi]^T$ and $\Omega = [p, q, r]^T$ denote the attitude angle and angular rate, respectively. $a_1 = [1, 1, 0]^T$, $a_2 = [0, 0, 1]^T$, g represents the gravitational acceleration, $m \in R$ indicates the total mass, and $I_m \in R^{3\times3}$ denotes the inertial moment matrix. Q_M and Q_T respectively denote the main rotor anti-torque and tail rotor anti-torque. $G \in R^{3\times3}$ is the control gain matrix related to the control torque. $\tau \in R^3$ denotes control torque on the helicopter. ΔM indicates the parameter uncertainty, $h_\Omega(\Omega) \in R^3$, are unknown nonlinear functions. $w_\Omega \in R$ are the independent standard Brownian motion. $H(\Theta)$ stands for the transformation matrix. To proceed with the design of the robust adaptive control for the small-scale helicopter system (1) with stochastic disturbance, we make the following assumptions.

Assumption 1[4]: The desired trajectories $\Theta_d(t) = [\phi_d, \theta_d, \psi_d]^T$ are the known bounded sufficiently smooth functions of time, with bounded and continuous first derivative.

Assumption 2[1]: All state vectors are measurable.

Assumption 3[5]: The roll angle ϕ satisfies inequality constraint $-\pi/2 < \phi < \pi/2$, and the pitch angle ψ satisfies inequality constraint $-\pi/2 < \theta < \pi/2$.

Assumption 4[6]: The uncertain function ΔM is bounded $\|\Delta M\| \le \Delta\bar{M}$, and $\Delta\bar{M} > 0$ represents unknown constant.

2.2. Stochastic Nonlinear System

To develop the robust adaptive control for the unmanned helicopter with stochastic disturbance, consider a class of stochastic differential equation as follows

$$d\chi(t) = f(\chi(t))\,dt + h(\chi(t))\,dw(t) \tag{2}$$

where $\chi(t) \in R^n$ represents the state, and w denotes the Wiener process. Continuous functions $f : R^n \to R^n$ and $h : R^n \to R^n$ satisfy $f(0) = 0$ and $h(0) = 0$. To analyze the stability of the nonlinear stochastic system (2), we need the following definition and lemmas.

Definition 1: For any give $V(\chi) \in C^2$, associated with the stochastic system (2), the infinitesimal generator L can be defined as follows[10]:

$$LV(\chi) = \frac{\partial V}{\partial \chi} f(\chi) + \frac{1}{2} tr\left\{h^T(\chi)\,\frac{\partial^2 V}{\partial \chi^2} h(\chi)\right\}. \tag{3}$$

Lemma 1[10]: Consider the stochastic system (2). Suppose that there exist an C^2 function $V : R^n \to R_+$, class K_∞ functions $b_1(|\chi|)$, $b_2(|\chi|)$, and two constants $\eta > 0$, $\vartheta > 0$, such that, for all $\chi \in R^n$ and for all $t > t_0$, the inequalities

$$\begin{aligned} &b_1(|\chi|) \le V(\chi) \le b_2(|\chi|) \\ &LV(\chi) \le -\eta V(\chi) + \vartheta \end{aligned} \tag{4}$$