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Robust hierarchical control of a laboratory helicopter

Hao Liu[a,b], Jianxiang Xi[c,*], Yisheng Zhong[b]

[a]School of Astronautics, Beihang University, Beijing 100191, PR China
[b]Department of Automation, TNList, Tsinghua University, Beijing 100084, PR China
[c]High-Tech Institute of Xi'an, Xi'an 710025, PR China

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Abstract

This paper deals with the robust position control problem for a three degree-of-freedom (3DOF) laboratory helicopter. The 3DOF helicopter system is a nonlinear multiple-input multiple-output (MIMO) uncertain system, and has the elevation, pitch, and travel angles. The proposed robust controller is a hierarchical controller including an attitude controller and a position controller. The position controller generates the desired reference of the pitch angle based on the tracking error of the travel angle, while the attitude controller achieves the reference tracking of the pitch and elevation angles. It is proven that the tracking errors of the three angles can converge into the given neighborhoods ultimately. Experimental results on the laboratory helicopter demonstrate the effectiveness of the proposed hierarchical control strategy.
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1. Introduction

Unmanned aerial vehicles (UAVs) are suitable for various civil and military tasks and have received much attention in the academic domain (see, e.g., [1–11]). Unmanned helicopters have advantages over the fixed-wing UAVs because of their abilities to hover and vertically take-off and land. However, the unmanned helicopter is an underactuated multiple-input multiple-output (MIMO) system and its dynamics involves various uncertainties such as nonlinearity, coupling, parametric uncertainties, and external disturbances. Its flight controller design is a challenge in the control community.

*Corresponding author. Tel./fax: +86 029 84744111.
E-mail addresses: liuhao13@buaa.edu.cn, liuhao9141@163.com (H. Liu), xijx07@mails.tsinghua.edu.cn (J. Xi), zys-dau@mail.tsinghua.edu.cn (Y. Zhong).

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The hierarchical control method has gained a growing interest for unmanned helicopters to achieve trajectory tracking in recent years. By separating the helicopter system into two subsystems with slow and fast dynamics respectively, hierarchical control can be achieved. Based on the assumption that the closed-loop subsystem with fast dynamics can converge much faster than the closed-loop subsystem with slow dynamics, the controllers for the two subsystems can be designed separately as shown in [11]. In [8], a nonlinear hierarchical controller was designed for a reduced-order model helicopter under the assumption that the motor dynamics was much slower than that of the main rotor. The attitude and position subsystems, in general, are selected as the subsystems with fast and slow dynamics respectively. In [9], the position and attitude controllers were designed for the two subsystems of the HeLion helicopter respectively. A hierarchical control approach was proposed in [10] with a model predictive controller to track the desired trajectory references and a nonlinear robust controller to stabilize the attitude. In [12], based on the trajectory linearization control method, translational motion and rotational motion of a tripropeller vertical-takeoff-and-landing UAV were controlled respectively. The hierarchical control schemes were also discussed for four-rotor helicopters as shown in [13–15]. In these previous studies on the hierarchical control method as shown in [8–15], the influence of the inner dynamics on the tracking performance has not been fully discussed. Besides, many works mainly focus on restraining uncertainties involved in the rotational subsystem, whereas the tracking performance of the closed-loop position subsystem cannot be guaranteed.

In this paper, a laboratory reduced-order helicopter with three degree-of-freedom (3DOF) is used (see, Fig. 1). This helicopter is produced by the Quanser Company and has attracted an increasing interest in the control community (see [16–25] to mention a few). As depicted in Fig. 2, the 3DOF helicopter has three outputs: the elevation angle, the pitch angle, and the travel angle, while possesses two control inputs: the voltages applied on the front motor and the back motor as shown in [26]. Thus, this helicopter system is an underactuated MIMO system. If the elevation and pitch angles are chosen as the interested outputs, it is an attitude control problem as depicted in [23]. Besides, the position controller focuses on tracking the desired references for the elevation and travel angles and pitch angle dynamics is considered as the inner dynamics. Furthermore, the 3DOF helicopter system is an uncertain system containing nonlinear and

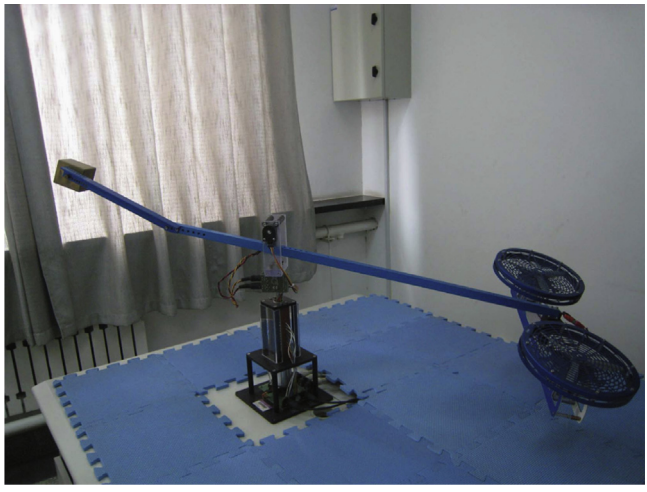

Fig. 1. The 3DOF helicopter.

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