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Design and implementation of a robust and nonlinear flight control system for an unmanned helicopter

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ABSTRACT

In this work, we focus on the design and implementation of a robust flight control system for an unmanned helicopter. A comprehensive nonlinear model for an unmanned helicopter system, which is built by our research team at the National University of Singapore, is first presented. A three-layer control architecture is then adopted to construct an automatic flight control system for the aircraft, which includes (1) an inner-loop controller designed using the H_∞ control technique to internally stabilize the aircraft and at the same time yield good robustness properties with respect to external disturbances, (2) a nonlinear outer-loop controller to effectively control the helicopter position and yaw angle in the overall flight envelope, and lastly, (3) a flight-scheduling layer for coordinating flight missions. Design specifications for military rotorcraft set for the US army aviation are utilized throughout the whole process to guarantee a top level performance. The result of actual flight tests shows our design is very successful. The unmanned helicopter system is capable of achieving the desired performance in accordance with the military standard under examination.

1. Introduction

In recent years, research and development of unmanned vehicles have gained much attention in the academic and military communities worldwide. They are developed to be capable of working autonomously without interference of a human pilot. Challenge is that they need to deal with various situations arisen in much complicated and uncertain environments, such as unexpected obstacles, enemies attacking and device failures. Besides, they are required to communicate with technical personnel in the ground station. Consideration on a wide range of factors needs to be taken. Control systems are required to integrate both basic input–output control laws, and high-level functionalities such as decision making. Software systems for unmanned vehicles are required to perform multi-level tasks, such as from hardware driving to device operation management.

Among various unmanned aerial vehicles (UAVs), small-scale unmanned helicopters are an ideal platform for academic research. Besides having the characteristics of full-scale rotorcraft, it owns some unique and attractive features such as low cost, easy operation, and extreme agility. During the last two decades, many research groups have chosen such platforms for their research purposes (see, e.g., [18,22,24]). Some commercial companies have also adopted them as the baseline to build their commercial UAV products for practical missions such as aerial photography and surveillance (see, for example, [12,25]).

Flight control system design is one of the core issues in the development of a fully functional unmanned rotorcraft. In the literature, there are a number of control techniques successfully implemented, which include the neural network approach [11], the differential geometry method [17], the robust and H_∞ control approach [13,15,28], the composite nonlinear feedback control with decoupling approach [21], and the model predictive approach [24] to name a few. However, many of the works reported focus merely on the basic autonomy. In other words, the control system design procedures are generally lack of evaluation using professional design specifications such as rotorcraft handling qualities.

The aim of this work is to design a robust flight control system for our small-scale UAV helicopter, HeLion (as shown in Fig. 1), to achieve the desired performance defined in ADS-33D-PRF [1] for military rotorcraft. To realize this goal, we first obtain a high-fidelity nonlinear flight dynamics model for HeLion, and then carry out to design a flight control system with three hierarchical layers, in which an inner-loop layer is for stabilizing the UAV helicopter, an outer-loop layer is for controlling its position and heading angle, and finally a flight-scheduling layer for coordinating flight missions. We would like to highlight that in our design formulation of the inner-loop controller, we formulate wind gusts as an

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