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State Estimation for a Small Scale Flybar-less Helicopter

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Abstract

Unmanned helicopters have been used extensively in the last few decades as a research platform for different applications. Flybarless, single-rotor helicopters are famous for their increased agility and high maneuverability, which makes them a suitable platform for many challenging applications. This paper is concerned with the problem of attitude and flapping angles estimation of a flybar-less small scale single rotor helicopter. A nonlinear model for the Maxi Joker 3 helicopter is used to simulate test data. A Kalman filter is designed and implemented to estimate both the attitude and the flapping angles of the helicopter. Results are shown at the end of the paper to validate the performance of the proposed approach.

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Keywords: UAV; Small Scale Flybar-less Helicopter; Attitude Estimation; Kalman Filter; Flapping Angles Estimation.

1. Introduction

Major research attention is aimed at the development of autonomous, small-scale helicopters. Helicopters are considered a viable candidate for many different applications such as surveillance missions, power line inspection, wildlife monitoring, and many military applications. Recently, researchers have focused on the design of various navigation and autonomous control systems to control vehicles in different missions [1]. In order for any control law to work, an accurate knowledge of the different states of the vehicle is needed. In this paper, the Maxi Joker 3 helicopter is utilized (see Figure 1).

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Fig. 1. Maxi Joker 3 flybarless helicopter

During the past few years, a large number of studies addressed the problem of formulating the dynamic model of different small-scale helicopters. In [2-4], a complete six-degrees of freedom dynamic model, with the flapping angles, was introduced for a small-scale helicopter. In [5], the generation of forces and moments from the main and tail rotor was derived. In [6], the system identification of the Joker 3 helicopter was obtained.

Precise state estimation is essential for controlling the helicopter autonomously. Nevertheless, it is hard to obtain accurate values for different helicopter states because of the large drifts, possible measurement bias, and immense noise of the onboard sensors [7, 8]. These sensors are commonly used in VTOL UAV because of their small weight, small size, and small power consumption. By fusing the measurements of different sensors, an accurate estimate can be obtained [9-13].

To estimate the vehicle's attitude, a number of approaches have been explored. For instance, the strapdown method, which is based on integrating the angular rates to get the Euler angles, was introduced in [9, 10]. Alternatively, the vehicle's attitude can be estimated using the bi-vector method. In this method, the attitude can be estimated by obtaining the acceleration and the magnetic field readings from the accelerometer and the magnetometer sensors. Moreover, the global positioning system (GPS) and the image sensors were used for vehicles' attitude estimation in [11].

The strapdown method has the disadvantage of generating an accumulative error during angular rate integration. This error keeps increasing over time because of the MEMS sensors' offsets. Therefore, for long-term maneuvers, an incorrect estimation will result. On the other hand, the bi-vector method has a different drawback. In this method, the vibration generated from the UAV rotors will affect the accelerometer's readings, which will lead to an inaccurate estimate of the attitude. A tri-axial magnetometer was used in [12] to enhance the heading angle estimation accuracy by improving the system's overall state observability. However, the paper uses a kinematic system model rather than incorporating the dynamics of the vehicle. In [13], a helicopter pitch and roll angle estimation technique is proposed that uses a single antenna GPS receiver and gyroscope measurements. The attitude is estimated by determining the thrust vector. The thrust vector is obtained by estimating the helicopter's acceleration using a Kalman filter.

The helicopter's flapping angles, while essential to characterizing the vehicle's dynamic model, cannot be measured directly using any sensor. It is not possible to place a sensor on the main rotor of the helicopter to measure its orientation. Therefore, an estimation algorithm needs to be used to estimate the angles. In this paper, a Kalman filter will be presented to estimate both the attitude and the flapping angles of the helicopter.