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硕士学位论文

无人自转旋翼机建模与控制技术研究

Research on Modeling and Control Technology of Unmanned Gyroplane

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摘 要

自转旋翼机是一种依靠空气来流驱使旋翼自转提供升力的旋翼类飞行器，具有机械结构简单、经济成本低、飞行安全性好等特点，有着广阔的应用前景。旋翼机理论建模置信度较低，空中飞行纵横向/高度速度控制耦合强，起降有其自身的特点与难点。本文研究了基于参数辨识的自转旋翼机建模技术，开展了全自主飞行控制的设计，进行了基于 FlightGear 平台的起降仿真，并实现了飞行演示验证。本文的主要研究内容如下：

本文开展基于有人操纵主动激励的气动参数辨识技术的自转旋翼机建模方法。合理设计有人驾驶旋翼机飞行参数采集方案，经过相干性简化模型结构、辨识精度评估以及时域模型验证，基于时域线性回归和频域方程误差的参数辨识算法获得在空速 70mph 下的线性模型，为旋翼机飞行控制律设计奠定基础。

考虑到自转旋翼机与直升机以及固定翼飞机的飞行原理有差异，对其进行气动特性分析。基于辨识得到的线性模型同时结合旋翼机的气动受力情况，对自转旋翼机进行纵横向静稳定性以及操纵特性分析，同时分析不同前向力、配重、纵向力以及海拔高度下对旋翼机的气动特性的影响。最后统计驾驶员起降数据，研究旋翼机的起降规律，为旋翼机的全自主起降方案提供数据支持。

提出飞行控制总体设计方案，纵向采用推力控制高度、桨盘纵倾控制速度以及俯仰控制作为阻尼的控制策略，横侧向采用内回路滚转控制外回路航迹控制的控制策略。基于辨识线性模型并使用旋翼机不同状态下的配平舵面和油门作为前馈，在确定飞行控制结构的基础上，设计并整定飞行控制律。然后设计无人自主起降方案。采用低速大增益高速小增益的纠偏控制方案；旋翼机抬前轮瞬间压杆动作较危险，设计合理起飞策略以避免机身姿态不稳；采样等下滑角的陡下滑方式，提高着陆精度；针对下滑段机身姿态低头严重，提出两种姿态拉起的着陆控制策略；同时给出适合旋翼机的横侧向抗侧风策略。

为验证全自主起降控制策略，采用基于 FlightGear 软件的 YASim 建模方式，建立演示样机 ELA07 的全包线气动模型，搭建半物理仿真平台，最终实现全自主控制。同时考虑起降段的不确定因素以及环境干扰进行起降段飞行仿真，从而

验证无人自转旋翼机的控制律及控制逻辑的正确性。

提出合理的飞行试飞方案，给出在线调整控制参数的步骤，最后成功实现样机 ELA07 的无人化首飞。试飞数据表明空中巡航和自主起降的控制逻辑正确、控制参数合理。

关键词：无人自转旋翼机；系统辨识；控制方案设计；半物理仿真；试飞验证

ABSTRACT

Rotary rotorcraft is a rotor-type aircraft that relies on the air to drive the rotor to rotate. Because of the gyroplane characteristics of simple mechanical structure, low economic cost and good flight safety, the unmanned gyroplane has wide application prospect. However, gyroplane theory modeling confidence is low, vertical/horizontal and hight/speed control coupling is strong, take-off/landing control has its own characteristics and difficulties. In this paper, the gyroplane modeling technology based on parameter identification is studied to design the autonomous flight control. The flight simulation based on FlightGear platform is carried out and the flight demonstration verification is realized. The main contents of this paper are as follows:

A gyroplane modeling method based on aerodynamic parameter identification technology with active control is introduced and a reasonable maneuvering gyroplane flight parameter acquisition scheme is designed. By the coherence model structure simplification, the identification accuracy evaluation and time domain model verification, the linear model at a velocity of 70mph based on the time - domain linear regression algorithm and the frequency domain equation error algorithm is obtained, which lays the foundation for the flight control law design of the gyroplane.

Considering the different generatation ways of rotor lift in which the gyroplane compared to helicopters and fixed-wing aircraft, gyroplane aerodynamic characteristics is analysied. Based on the identification results combined with the gyroplane aerodynamic force analysis, the gyroplane’s vertical and horizontal static stability and maneuverability is analysied. At the same time, the influence of different forward force, longitudinal force, counterweight and altitude on the gyroplane aerodynamic characteristics are studied. Finally, human take-off and landing data are statistically averaged in order to study the take-off/landing control strategy and to provide data support for the autonomous take-off/landing scheme of the gyroplane.

The flight control scheme is proposed. The longitudinal control strategy are used, including the height control by thrust, the speed control by longitudinal paddle position and the pitch control as the damping of speed control. The inner loop of lateral control strategy is roll control and the outer loop is path control. Based on the identified linear model and using the matching control surface and the throttle trim in the different state of the gyroplane as feedforward, the flight control law is designed and set up on the basis of determining the flight control structure. And then the unmanned take-off/landing scheme is designed. The low-speed high-gain and high-speed small-gain of the skid correction control scheme is carried out. Because the pressure longitudinal paddle position action in the moment of the gyroplane's front wheel lifted up is very dangerous, a reasonable takeoff strategy is designed to avoid the fuselage posture instability. Take the same down angle to track down the trajectory for improving the landing accuracy. Aiming at the seriousness of the low fuselage posture in the sliding section, two kinds of landing control strategies are proposed. At the same time, the lateral anti - lateral wind strategy is proposed.

In order to verify the autonomous take-off/landing control strategy, the YASim modeling method based on FlightGear software is used to build the all-inclusive aerodynamic model of the prototype ELA07, and the semi-physical simulation platform is built to realize the fully autonomous control. At the same time, considering the uncertain factors of the take-off/landing section and the environmental disturbance, the flight simulation of the take-off/landing section is carried out to verify the correctness of the control law and control logic of the unmanned gyroplane.

Put forward a reasonable flight test scheme, given the steps to adjust the control parameters online, and finally succeeded in the prototype ELA07 unmanned first flight. The flight test data indicate that the control logic of the air cruise and autonomous takeoff/landing is correct and the control parameters are reasonable.

Key words: unmanned gyroplane; system identification; control scheme design; semi-physical simulation; flight test

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