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Application of UAV Dynamic Performance Simulation System Based on Virtual Simulation Technology

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Abstract: Targeted at cultivating high-quality professionals for unmanned aerial vehicle (UAV) industry, this project develops a comprehensive management software for virtual simulation data of UAV power systems. The software integrates UAV power information, motor performance data and other related data, and supports the configuration management of power systems to ensure their stable operation. It also records performance logs to facilitate the analysis of UAV power conditions. The system provides robust data support for performance optimization and flight safety guarantee, enabling users to fully grasp the operating status of UAV power systems.

Keywords: Virtual Simulation; Unmanned Aerial Vehicle (UAV); Dynamics; Performance Simulation.

1. Introduction

UAV Assembly, Commissioning and Maintenance is a core compulsory course for UAV application technology majors. This course requires students to master the skills of component assembly and overall commissioning of UAVs, and cultivate the ability to independently disassemble, assemble and debug small UAVs. The disassembly and assembly of UAVs impose high requirements on students' professional proficiency and debugging capability, making it a relatively difficult practical training item. In addition, UAV commissioning involves potential safety hazards.

Based on virtual simulation technology, this project develops a comprehensive management software for virtual simulation data of UAV power systems. Students are required to conduct repeated exercises on the software and pass the corresponding assessment before carrying out physical disassembly, assembly and maintenance of UAVs. This approach effectively reduces training costs and ensures the safety of practical training[1].

Dynamic performance and overall lift characteristics are critical flight parameters of multi-rotor UAVs. In practical operations, the dynamic performance and lift performance directly determine operational efficiency and quality. Therefore, the performance inspection of power components is a prerequisite for UAV flight. However, direct in-flight testing carries an extremely high risk of UAV crash; even minor operational errors may lead to the damage of both test instruments and UAVs.

The virtual simulation experiment for multi-rotor UAV power performance can replace high-risk in-flight tests to a certain extent. It vividly demonstrates the working principles and operation methods of sensors as well as basic knowledge of UAVs. The system cuts down experimental costs, saves site and time resources, and improves experimental safety. This virtual simulation platform is also applicable to similar courses including *UAV Structure and System* [2] [3], *UAV Virtual Simulation Technology* and *UAV Aerodynamics*, and presents reference value and universality for experimental teaching of relevant courses.

2. Research Process

2.1. Working Principles of the Experiment

The principles and knowledge points of this experiment cover multiple courses such as *UAV Structure and System*, *UAV Assembly, Commissioning and Maintenance* and *UAV Aerodynamics*[4].

2.1.1. Dynamic Performance Test of UAV Power Components

This test is mainly implemented during the development of multi-rotor UAVs. It examines the mechanical and electrical properties of each component of the power propulsion system to maximize the load capacity of UAVs. The test is generally conducted indoors with complete safety protection measures.

2.1.2. Overall Performance Test of UAVs

This test is carried out in the stage of overall commissioning and flight test of multi-rotor UAVs, aiming to measure the overall dynamic performance of the aircraft. Actual flight tests are conducted at dedicated flight test sites or general aviation airports with approved airspace.

2.1.3. Design of Multi-rotor UAVs

In accordance with the functional structure and application scenarios of multi-rotor UAVs, a three-dimensional virtual UAV component library and flight environment maps are established[5]. Standardized and modular parts are assembled to help students learn UAV design, and understand the intelligent functions of multi-rotor UAVs in different operating environments.

2.1.4. Evaluation Methods for Overall UAV Performance

Two indicators, namely power load and weight efficiency, are adopted to evaluate the overall lift characteristics.

The calculation formula of power load is as follows:

$$q = \Sigma F / P$$

Where: q = Power load of multi-rotor UAV, unit: N/W; ΣF = Total lift of the multi-rotor UAV under a given voltage, unit: N; P = Total power consumption of the UAV, unit: W.

The calculation formula of weight efficiency is as follows:

$$k = F_a / G$$

Where: k = Weight efficiency (dimensionless); F_a = Net lift, unit: N; G = Empty weight of electric multi-rotor UAV, unit: N.

2.1.5. Relevant Knowledge Points

1. Composition of UAV systems and working principles of power components;
2. Selection and installation of test devices;
3. Measuring principles of voltage and current sensors, tension sensors, torque sensors, speed sensors and temperature sensors;
4. Signal conditioning and digital signal processing;
5. Performance evaluation of the overall power system of multi-rotor UAVs.

2.2. Experimental Instruments and Equipment

1. Single electric rotor power component test bench;
2. Tethered multi-rotor UAV performance test platform;
3. Remote controller, voltage and current sensors, tension sensors, torque sensors, speed sensors, temperature sensors and other supporting devices.

2.3. Experimental Materials

Table 1. Models and Parameters of Motors, Electronic Speed Controllers (ESCs) and Propellers

No.	Motor Model	ESC Model	Propeller Model	Wheelbase
1	HYLQ11KV85	HobbyWing Xrotor Pro HV80A	Carbon 38*9.5	1700 mm
2	HYLQ11KV85	HobbyWing Xrotor Pro HV80A	Carbon 38*9.5	1700 mm
3	T-Motor U13 KV85	T-Motor Flame 80A	T-Motor 34*11 CF	1500 mm
4	T-Motor U13II KV130	T-Motor Flame 80A	T-Motor 36*11.5 CF	1600 mm

Table 2. UAV Models for Overall Lift Performance Test

Manufacturer	Model	Empty Weight	Load Capacity	Endurance Time	Application
DJI	Air 2	14.6 kg	25.6 kg	23 min	Aerial Photography
DJI	Phantom 4	18.5 kg (without battery)	39.5 kg	18 min	Mapping
DJI	T30	14 kg	30 kg	12–15 min	Plant Protection
DJI	F450	282 g	718 g–2218 g	20 min	Commissioning
AMU	Z410	350 g	20 kg	30 min	Commissioning

Table 3. Performance Indicators of Main Sensors and Equipment

No.	Sensor Device	Range	Resolution	Accuracy	Unit
1	Voltage Sensor	3~50	0.01	0.5%	V
2	Current Sensor	0~200	0.01	0.5%±0.2 A	A
3	Infrared Thermal Imager	-25~450	1024×768 px	±1	°C
4	Tension Sensor	40	0.01	0.5%±0.02 g	kg
5	Torque Sensor	15	0.01	0.5%±0.015	Nm
6	Speed Sensor	300~35000	1	0.5%±30	RPM

2.4. Experimental Methods and Procedures

2.4.1. Interactive Operation Procedures for Students

1. Open the browser and enter the link of the virtual simulation platform in the address bar to access the homepage.
2. Click the login button and enter the account and password to log in.
3. After logging in, select one of the following experimental items to enter the virtual experiment interface:

A. Comprehensive experiment of common sensors for UAV power component test;

B. Comprehensive experiment of common sensors for UAV overall performance test;

C.UAV overall power performance test.

2.4.2. Main Experimental Procedures

1. Identify test objects and experimental equipment;
2. Put forward experimental questions;
3. Build the experimental platform and select sensors;
4. Install sensors and set relevant parameters;
5. Connect power supply and circuits, then start the test;
6. Observe and record data measured by sensors for a period of time;
7. Cut off the circuit to terminate the test and export experimental data;
8. Process and calculate experimental data, and analyze or evaluate the performance of power components.

2.4.3. Detailed Experimental Content and Steps

(1) Comprehensive Experiment of Common Sensors for UAV Power Component Test

1. Inspect the test bench, clean the motor base, and fix the test bench horizontally.
2. Select the to-be-tested motor and propeller according to Table 1, and install them on the motor base at the top of the test bench with bolts.
3. Install voltage and current sensors, tension sensors, torque sensors and speed sensors at designated positions in accordance with Table 3.
4. Connect the power supply, electronic speed controller (ESC) and motor circuits in sequence, and link the communication bus of all sensors to the upper monitoring computer.
5. Power on the test platform, set the test voltage, and turn on the remote controller, which will automatically connect to the ESC via wireless signal.
6. Push the left joystick of the remote controller upward to start the power components, i.e. the motor and propeller begin to rotate.
7. Keep the joystick position unchanged, and record data from all sensors for 2 to 10 minutes continuously.
8. Reset the joystick to the neutral position and cut off the power supply.
9. Generate curves of sensor data versus time on the upper computer.
10. Calculate the force-efficiency curve of the motor and propeller based on the formula: $\eta = \Sigma F / (U \times I)$, where ΣF stands for measured tension, U for measured voltage and I for measured current.
11. Adjust the joystick to set the throttle opening between 20% and 100% (10% interval is recommended), or replace motors and propellers. Repeat the above steps to collect test data.
12. Compare the force efficiency under different throttle openings or different motor-propeller combinations, and evaluate the performance of power components based on the test results.

(2) Comprehensive Experiment of Common Sensors for UAV Overall Performance Test

1. Use an electronic scale to measure the empty mass W_0 of the multi-rotor UAV (mass excluding payload, including batteries and other fixed accessories).
2. Measure the mass and length of power cables, and calculate the linear density ρ (kg/m) of the cables.
3. Mount the multi-rotor UAV in the middle of the tethered UAV performance test platform. Connect the four arms of the UAV to limit flexible ropes with buckles, adjust the tightness of the four ropes to keep them consistent, and regulate the height of damping shock absorbers to maintain the UAV in a horizontal suspended state.
4. Locate the force center of the UAV, and install the tension sensor directly below the force center.
5. Connect the DC power supply to the UAV. Set the output voltage as V_1=3.7n (n refers to the number of single battery cells), and set the maximum output current of the power supply to 200 A.
6. Install the infrared thermal imager above the UAV and connect it to the infrared temperature measurement software on PC, then activate the thermal imager and supporting software.
7. Launch the performance test software and calibrate the reading of the tension sensor.
8. Start the UAV and control it with the remote controller to reach the maximum lift state. Push the control lever to the maximum position and keep the UAV operating for 90 seconds. Land the UAV on the test platform and save the test data.
9. Adjust the power supply voltage with a gradient of 1 V based on the initial voltage, until the voltage reaches the maximum rated value 4.2n. Restart the test system and infrared system before each test, then launch the UAV for repeated tests and save all data.
10. After completing the test for one UAV model, lift the UAV to the highest position and measure its height h. Dismantle the UAV from the test platform and weigh the auxiliary equipment such as tension sensors, recorded as W_s.
11. Replace with other UAV models and repeat all the above operations to complete data collection.

3. Conclusion

The virtual simulation comprehensive management software for UAV power systems is developed adhering to the concepts of innovative thinking, new technologies and competency cultivation. This paper elaborates on the virtual simulation experimental project for power performance in the core course *UAV Assembly, Commissioning and Maintenance*, covering the measurement principles, sensor structure, test methods and signal processing technology of UAV thrust, torque, temperature, rotational speed and other dynamic parameters.

Adopting a problem-oriented teaching mode, the platform stimulates students' interest in knowledge exploration. It helps cultivate students' ability to apply theoretical knowledge to solve engineering problems and conduct innovative experiments, and further improves the overall teaching quality of relevant majors.

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