Design of Hardware-In-The-Loop Simulation System for UAV Braking System on Electromechanical Actuator

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Abstract. In the field of unmanned aerial vehicle (UAV), the electric braking system of UAV using electromechanical actuator is applied more and more widely due to its good safety, high reliability, light weight, small size and other characteristics. In order to realize the product development and performance test of the UAV electric braking system, a hardware-in-the-loop simulation platform is designed in this paper. The simulation platform for UAV electric braking system takes “Simulation model + hardware object” as the core and the design of the platform is based on TI company’s DSP28335 controller and the automatic code generation technology of MATLAB. The test results show that the simulation platform of UAV electric braking system has perfect function and reliable performance, which can provide a good research platform for the development and performance test of a certain type of UAV electric braking system.

1. Introduction
The electric brake system of UAV adopts electromechanical actuator to replace the traditional hydraulic actuator, which is smaller in size, lighter in weight, avoiding the risk factors such as hydraulic oil leakage, and greatly improving the safety, reliability and maintainability of UAV. It has become the general trend of the development of modern UAV braking system [1][2]. At present, the research on the hardware-in-the-loop simulation system of UAV braking system mainly focuses on the braking system with hydraulic actuator, and less on the braking system with electromechanical actuator. In order to better grasp and detect the control characteristics of UAV electric braking system, shorten its development cycle, this paper introduces hardware-in-the-loop simulation technology to build the hardware-in-the-loop simulation system for UAV braking system on electromechanical actuator.

2. Composition of the UAV electric braking system
The structure of the UAV electric braking system is shown in Figure 1. It is mainly composed of brake control unit (BCU), electromechanical actuator controller (EMAC), electromechanical actuator (EMA), wheel, wheel speed sensor, etc [3].
The brake control unit is the command control unit in the electric braking system. First of all, the brake control unit receives the braking signals, the current aircraft speed and the feedback signal of the aircraft wheel speed. Secondly, it outputs the given brake pressure signals after calculating according to the corresponding brake control algorithm [4]. And then, the EMAC receives the brake pressure signals and pressure feedback signals to adjust the brake pressure. Next, the EMA receives the brake driving signals by the EMAC, and outputs braking force. Finally, the braking force is applied to the aircraft wheel to realize the aircraft braking process.

3. Hardware design of hardware-in-the-loop simulation platform

The main components of the UAV electric braking simulation system are shown in Figure 2. It includes the master computer, real-time simulation computer based on DSP28335 controller, 1553B signal processing unit, pressure signal processing unit, wheel speed simulator, and the objects of EMAC and EMA.
In the hardware-in-the-loop simulation system for UAV braking system on electromechanical actuator, the EMAC and EMA are the measured hardware objects, and the UAV braking system is a simulation mode including the UAV model, the BCU model, the brake device model, etc.

3.1. Master computer
The master computer adopts a high-performance PC, running MATLAB simulation software, Lab Windows operating interface, and Code Composer Studio 3.3 integrated development software. It is the control device for the hardware-in-the-loop simulation platform of the UAV electric braking system, and realizes the operation control and data display functions of the simulation experiment. On the one hand, the master computer generates the DSP embedded code based on the hardware-in-the-loop simulation model of the UAV electric braking system using MATLAB, and downloads it to the real-time simulation computer to run through the DSP emulator. On the other hand, the real-time simulation data is transmitted back to the master computer through the RS485 serial port communication interface for real-time drawing display and storage, which can observe the hardware-in-the-loop simulation of the UAV braking system in real time and conduct data analysis after the experiment, with good human-computer interaction function.

3.2. Real-time simulation computer
The real-time simulation computer is the core control unit of the hardware-in-the-loop simulation platform of UAV electric braking system. The TMS320F28335 controller is selected as its core processor, with 16 channels of A/D sampling, 4 channels of D/A conversion, 12 channels of PWM signal, full-duplex RS232 communication, half-duplex RS485 communication and other functions[5]. The real-time simulation computer receives the instructions from the master computer, runs the hardware-in-the-loop simulation model of UAV electric braking system downloaded to DSP28335 in real time, and obtains the brake pressure feedback signal at the current moment through the A/D sampling channel to solve the simulation model. After calculation, the real-time simulation computer outputs the brake pressure command signal, aircraft speed signal, aircraft wheel speed signal at the next moment to complete the information interaction between the simulation model and the hardware object.

3.3. 1553B signal processing unit
The BCU in the hardware-in-the-loop simulation system of UAV braking system adopts 1553B communication protocol, so it is necessary to design a 1553B signal processing unit to convert the data information output by the real-time simulation computer into 1553B data format that can be received by the BCU. The 1553B signal processing unit is composed of the following two parts: MCU-1553B function conversion board and RS422-RS232 converter. After the real-time simulation computer outputs the communication data in RS232 format, it is converted to RS422 format by the RS422-RS232 converter first, and then converted into the 1553B data format by the MCU-1553B function conversion board. The telemetry information returned by the BCU will be sent back to the real-time simulation computer in the RS232 format after the reverse process.

3.4. Wheel speed simulator
The most important feature of the hardware-in-the-loop simulation system for the UAV electric braking system is that it can simulate the information of aircraft wheel speed. The aircraft wheel speed signal output in the simulation model can be simulated into the electrical signal that can be collected by the aircraft wheel speed sensor[5]. The tested system uses the rotary transformer as the wheel speed sensor, and the wheel speed simulator of the hardware-in-the-loop simulation platform needs to simulate the wheel speed signal that meets the signal acquisition requirements of the rotary transformer. The core signal conditioning circuit part of the wheel speed simulator uses a second-order multiple feedback band-pass filter circuit. It can adjust the square wave signal output from the real-time simulation computer with a frequency of 10KHz and a duty cycle changing according to sine
wave and cosine wave into an electrical signal with a frequency of 10kHz, and the amplitude envelope changing according to sine and cosine law. In order to isolate the simulated aircraft wheel speed signal and make it have the same electrical characteristics with the real wheel speed signal, a real rotary transformer is installed after the signal conditioning circuit, and then the simulated aircraft wheel speed signal is sent to the wheel speed sensor of the tested system after passing the rotary transformer.

3.5. Pressure signal conditioning unit
The function of the pressure signal conditioning unit is to convert the brake pressure feedback signal collected by the pressure sensor into the electric signal which can be directly collected by the real-time simulation computer. Since the pressure sensor outputs the current signal of 4–20mA and the AD interface sampling range of the DSP28335 real-time simulation computer is the voltage signal of 0-3V, the pressure signal conditioning unit is designed to sample, filter and amplify the feedback signal of brake pressure collected by the pressure sensor. After that, the brake pressure signal can be transmitted to the hardware-in-the-loop simulation model of the UAV electric braking system.

4. Simulation platform verification
The hardware-in-the-loop simulation experiment platform of the UAV electric braking system is constructed in Figure 3, including master computer, real-time simulation computer, 1553B signal processing unit, pressure signal processing unit, wheel speed simulator, and the objects of EMAC and EMA. The hardware-in-the-loop simulation experiment of the UAV electric braking system is carried out on this platform. The initial speed of the UAV when landing is 72m/s. The runway type is an ice runway, which is a harsh braking environment. The BCU adopts the optimal slip rate control strategy based on sliding mode variable structure. The theoretical optimal slip rate is 0.13 under the ice runway, and the corresponding maximum binding coefficient is 0.2.

![Figure 3. Hardware-in-the-loop simulation experiment platform of UAV electric brake system](image)

The results of the hardware-in-the-loop simulation experiment under the ice runway are obtained. According to the experimental results, the UAV takes 39 seconds to brake on the ice runway, and the running distance is 1500 meters. The electromechanical actuator acts intermittently under the
adjustment of the brake controller. When the braking process is approaching the end, due to the aircraft speed and the wheel speed is close to zero, the slip rate will be close to infinity, and the fluctuation range will become larger. The coefficient remains near the maximum coupling coefficient 0.2 during the braking process.

5. Conclusions
The experimental results show that the hardware-in-the-loop simulation platform of the UAV braking system based on electromechanical actuators designed in this paper, which can automatically link to MATLAB, and the executable embedded code can be directly generated through the built simulation model of the UAV electric braking system. The platform operation process is simple, the system hardware interface design is reasonable, and the software function is perfect. The performance test of the UAV electric braking system can be completed in the laboratory environment, which can provide a good research and development platform for the development of the UAV electric braking system.

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