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Design of Remote Control System for Physics Experiments based on STM32

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Abstract

In order to make up for the shortcomings of traditional physical experiments and virtual simulation experiments, a remote control system for physical experiments based on STM32 was designed. The system uses the STM32F103RCT6 microprocessor as the control core, and provides detailed circuit diagrams for the stepper motor drive circuit, external power failure protection circuit, network communication, etc. At the same time, the underlying embedded control program of the lower computer is written, and a web operation interface is developed and designed. The successful development of the online experimental system indicates that online remote teaching based on offline real instruments is completely feasible, and this scheme ensures good consistency in online and offline experimental operations.

Keywords

STM32; Remote Control; Secondary Development; Virtual and Real Fusion.

1. Introduction

The traditional teaching mode of physics experiments has the drawback of low resource utilization. Due to the limitations of experimental venues and time, students are unable to use experimental devices for pre class preview, and it is difficult to make up for missed or incorrect experimental data after class. The quality of teaching is difficult to ensure, and the requirements for autonomous learning are difficult to meet [1-2]. Compared with traditional experiments, virtual simulation experiments do not limit space and time, have high flexibility and save a lot of money, but there are still shortcomings. Although virtual simulation experiments can create realistic virtual environments, objects, and processes, factors such as response speed, driving ability, circuit interference, parameter errors, and measurement accuracy in physical experiments cannot be experienced in simulation, resulting in insufficient simulation of experimental parameters and overly idealized data [3]. Therefore, according to the development needs of offline experiments, we have closely combined virtual experiments with offline experiments to improve the effectiveness of physical experiments [4-5]. The designed remote-control system that combines virtual and real has completed the hardware, control program, and operation interface design, which is a good supplement to traditional offline experiments and virtual simulation experiments.

2. Overall System Scheme Design

The remote-control system for physics experiments is suitable for multiple physics experiments, and the overall framework of the system is basically consistent. The system consists of a remote-control platform, cloud server, laboratory server, and intelligent physics experimental instruments. The remote-control platform is used to operate experiments, obtain experimental data, process, and monitor the operation of experimental equipment. The cloud server used is Alibaba Cloud server, with a 2-core 4G shared standard model. Intelligent physics experimental instruments include traditional experimental instruments, angle sensor circuits, power modules, video monitoring

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modules, motor drive modules, and network communication. The user logs in to the web operation interface, makes a successful appointment, drives the motor for the experiment, reads and records the experimental data in real-time video, and the overall system diagram is shown in Figure 1.

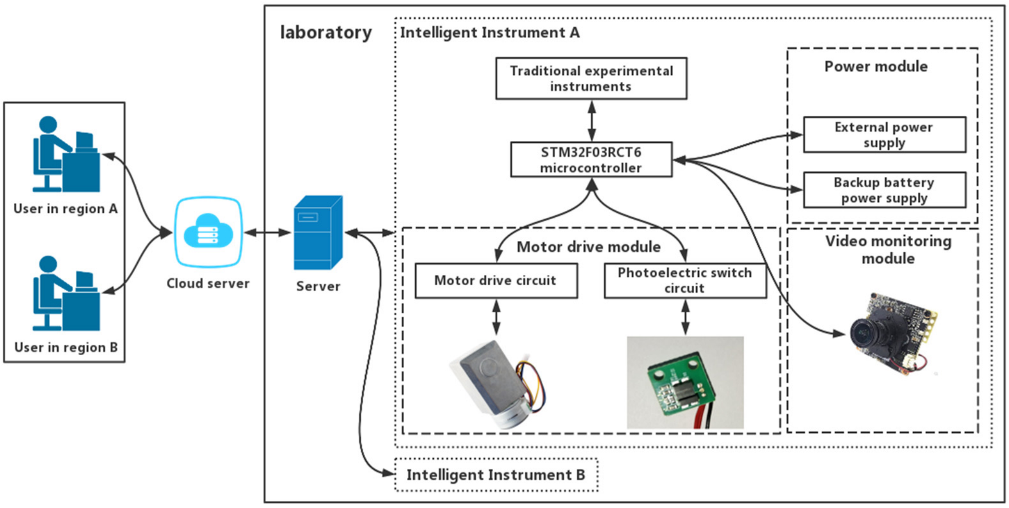

Fig 1. Overall system block diagram

3. System Hardware Design

3.1 Main Control Module

The embedded chip used in the remote-control system is STM32F103RCT6, with an ARM Cortex-M3 core. Its maximum operating frequency is 72 MHz, the flash program memory is up to 256 KB, and the SRAM space is up to 64 KB. At the same time, it also integrates peripheral devices and interface circuits such as ADC, SPI, and CAN internally. The chip has low cost, low power consumption, and powerful functions, and is widely used in multiple fields [6-7].

3.2 Backup Battery Circuit

The external power supply voltage of the experimental instrument is 220V, and at the same time, it is converted to 3.3V through a relay to supply power to the hardware circuit. Considering the normal experiment caused by accidental drop, a backup battery circuit is designed. When an external power outage occurs, it will automatically switch to a backup battery to supply power to the hardware circuit. At the same time, the external power outage signal will be uploaded to the user, and the upper computer operation interface will remind the user to pause the experiment. All adjustable devices will return to their initial positions for next use. When powered externally, the backup battery can also be charged. The chip LTC2943 is used to measure the battery charging status and battery level. SCL is the serial bus clock input, SDA is the serial bus data input and output, and the backup battery circuit is shown in Figure 2.

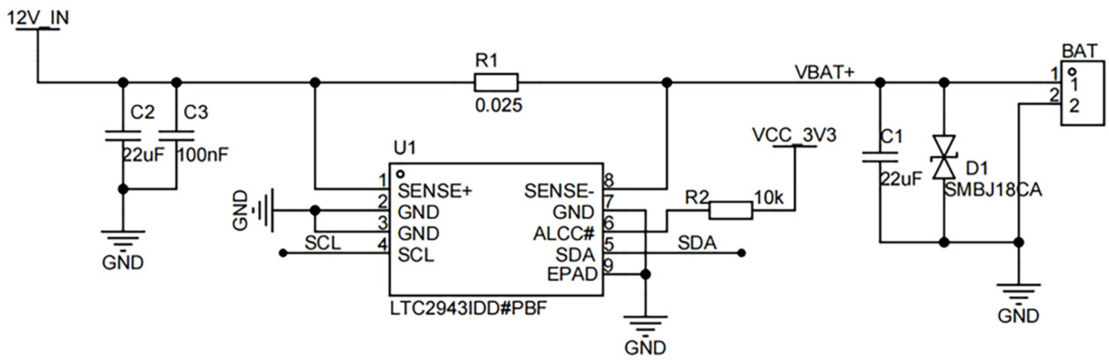

Fig 2. Backup battery circuit

3.3 Program Download Circuit

As shown in Figure 3, SWD is a serial debugging interface. Compared to JTAG, SWD only requires two wires, SWCLK and SWDIO, reducing the occupation of the GPIO port of the micro-controller. Among them, SWCLK is a serial clock line that provides the required clock signal (sent by j-link to the CPU), and SWDIO is a serial data line used for data reading and writing. In addition, two wires, GND and VCC, need to be connected. SWD comes with a reset protocol, so there is no need to connect to the NRST pin [8].

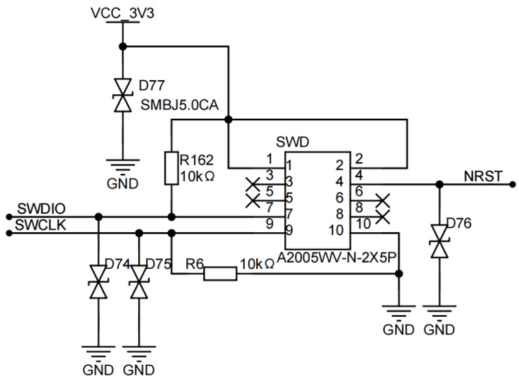

Fig 3. Program download circuit

3.4 Stepper Motor Drive Circuit

The stepper motor driver chip used in the remote-control system is LV8713T. Figure 4 show the driving circuit of the motor module. OE is the output enable signal, VREF is the constant current control reference voltage, STEP is the output pulse signal, FR controls the rotation direction of the motor, and MD1 and MD2 are excitation mode switches. OUT1A, OUT1B, OUT2A, and OUT2B are connected to the four pins of the stepper motor. The chip adopts PWM control technology, which is efficient, reliable, and stable. When the motor is unloaded, it will automatically enter sleep mode to reduce power consumption and extend the lifespan of the motor. Equipped with functions such as overheating protection, over-current protection, under-voltage protection, etc., it can provide comprehensive protection for stepper motors and extend their service life. The hardware circuit design has four motor driver board interfaces, and the number of driver boards can be inserted according to one's own needs. Each driver board supports 4 channels of stepper motors, and can connect up to 16 channels of stepper motors.

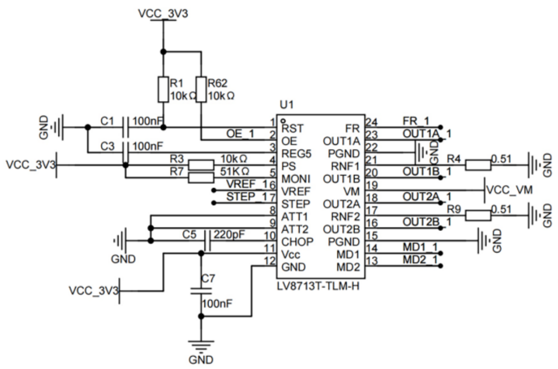

Fig 4. Stepper motor drive circuit

3.5 Photoelectric Switch Circuit

Due to the limited range of device knob adjustment, a photoelectric limit switch has been added to the circuit. On the one hand, it can read the position of the motor, and on the other hand, it can prevent excessive adjustment of the knob, providing protection for the equipment. One module can be connected to four photoelectric switches, as shown in Figure 5. Each switch represents one limit

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switch. When the motor rotates, one direction is photoelectric switch protection, and the other is soft limit protection in the control program.

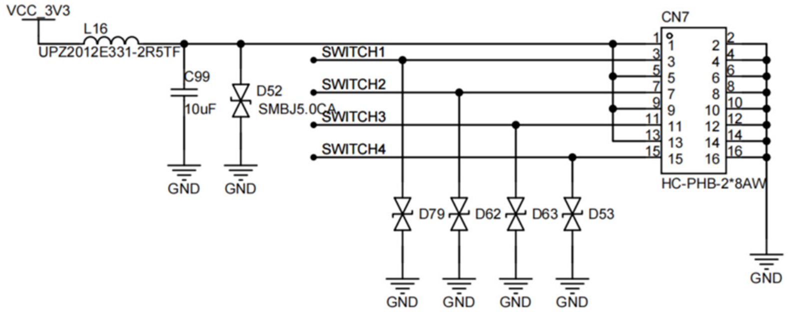

Fig 5. Photoelectric switch circuit

3.6 Network Communication Module

The network communication adopts the Modbus-RTU protocol, which is an open protocol. The control command data frame format in RTU mode is: register address+function code+ information +CRC check code. CRC (Cyclic Redundancy Check) is a cyclic redundancy check that is mainly used to verify errors that may occur after data transmission. It has strong error detection ability and does not occupy too much CPU resources, all devices in the same Modbus network must have the same transmission mode and serial port parameters [10]. Figure 6 shows the serial port to Ethernet circuit, NET_ RXD1 is for receiving data, NET_ TXD1 is for sending data. Due to the need to access multiple camera modules that support the RTMP streaming protocol to read experimental data and monitor the operational status of experimental instruments in real-time, an external switch is also required. When there is an abnormality in the video, the camera module can be refreshed and restarted.

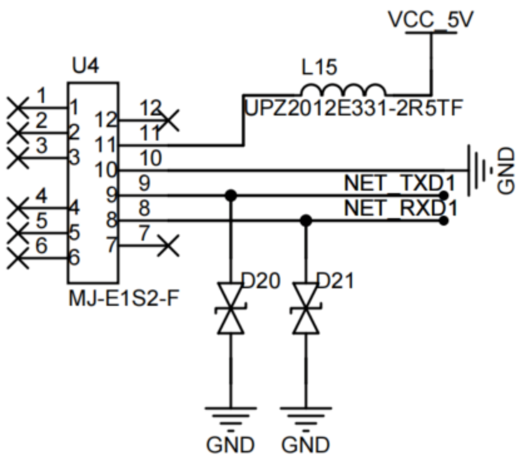

Fig 6. Serial port to Ethernet circuit

4. System Software Design

4.1 Programming

In The STM32F103 micro-controller control program is written in C language on the Keil5 development platform, and after running and compiling, it is burned into STM32F103 through a J-link/ST-link burner. The program design of STM32F103 controller mainly includes main function program, stepper motor control program, serial communication program, timer program, external interrupt program, etc.

Figure 7 shows the flowchart of the motor control program. The stepper motor is driven by an enable signal. When the stepper motor receives the enable signal, it drives the stepper motor to rotate in the direction required by the user.

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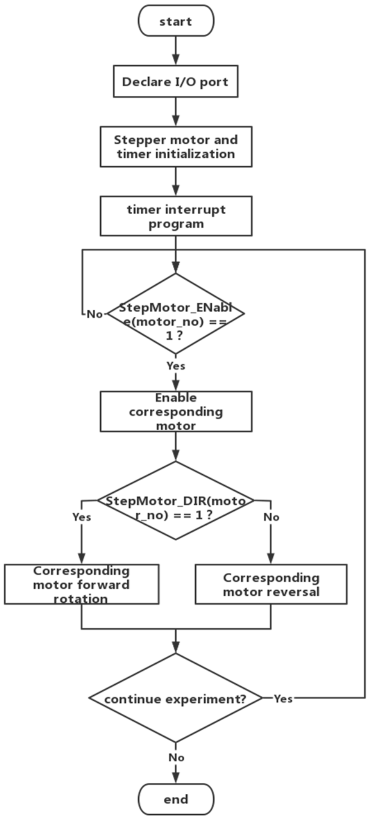

Fig 7. Flowchart of motor control program

4.2 Operation Interface Design

The program for remote operation interface is designed based on Typescript, which is a super-set of traditional web front-end language Java-script. Nowadays, the usage rate of Typescript in the field of web front-end is rapidly developing, becoming a strong new standard for web front-end [11]. The user interface mainly includes online experiments, course arrangements, experimental scores, system settings, and my appointment records. Figure 8 shows the operation interface of the remote-control system applied to the spectrometer experiment. The left and middle parts of the figure show real-time image monitoring for reading and real-time viewing of the instrument's operating status; The upper right corner of the figure shows the instrument model. Which component needs to be adjusted? Simply click on the corresponding component in the model and the adjustment button will appear; The lower right corner of the figure shows the instruction history and exception prompts; Other functions are located at the edge of the image. During the experiment, the experimental data can be recorded in the experimental data record form. After the operation of the experiment is completed, the experimental data can be processed and the experimental report submitted. If necessary, the experimental report can also be downloaded by oneself. Finally, click 'End of Experiment' to exit the experimental operation platform.

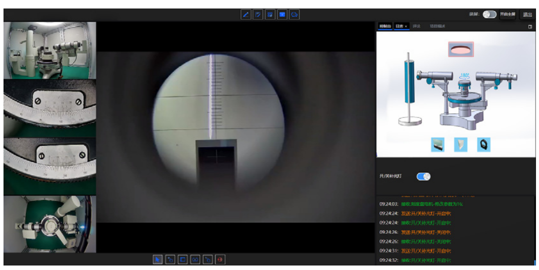

Fig 8. Spectrometer experiment operation interface

5. System Testing

5.1 Network Latency Testing

In order to test the accuracy of network latency, we have placed a developed spectrometer experimental instrument in Binjiang District, Hangzhou City. The test used the millisecond timer of the National Time Service Center standard Beijing Time: http://www.daojishiqi.com/bjtime.asp. The testing method is as follows: First, place a computer monitor with a millisecond level timer turned on within the field of view of a camera module in the spectrometer experimental instrument. Then, remote users log in to the operation interface of the spectrometer experiment, observe the millisecond level timer in the camera module, and open another millisecond level timer interface on the user browser page. Control the spectrometer points through the experimental interface, and use screenshots and other methods to freeze and observe the time difference between the two millisecond level timers. This time difference is the control and communication network delay. Record the time delay at different points of the control spectrometer multiple times, and comprehensively calculate the average time delay value.

In order to present the test results in more detail, we calculated the delay test data of remote-controlled spectrometer instruments in several regions and presented them in Table 1. The results showed that the delay of remote-controlled spectrometer experimental instruments in each region was around 300 ms, which met the requirements.

Table 1. Delay test data

testing area	Xihu District			Jiading District			Zhengzhou City		
test period	morning	afternoon	evening	morning	afternoon	evening	morning	afternoon	evening
average delay/ms	232	265	283	240	277	305	260	287	323

5.2 Comparison of Three Experimental Modes

Comparing traditional experiments, virtual simulation experiments, and virtual reality fusion experiments under this system in terms of data authenticity, user experience, resource utilization, cost, shareability, and convenience, the following results are obtained, as shown in Table 2. Through comparison, this system absorbs the advantages of traditional experiments and virtual simulation experiments, and is a good supplement to traditional experiments and virtual simulation experiments.

Table 2. Comparison of three experimental modes

	traditional	simulation	virtual reality fusion
authenticity of experimental data	high	higher	high
user experience	good	preferably	preferably
resource utilization rate	low	high	high
shareability	low	high	high
prime cost	higher	low	higher
convenience	low	high	high

6. Conclusion

This article designs a remote-control system for physics experiments, providing the main hardware design circuits and software design solutions, and applies them to multiple physics experiments. The

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remote operation interface is flexible, easy to operate, and highly portable. Video monitoring has good real-time and stability, and the structural control accuracy is high. This system achieves centralized management and equipment sharing, improves equipment utilization, optimizes laboratory management, and promotes the development of digitalization and intelligence in laboratories.

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