Design and realization of the real-time spectrograph controller for LAMOST based on FPGA[1]

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ABSTRACT

A large Schmitt reflector telescope, Large Sky Area Multi-Object Fiber Spectroscopic Telescope(LAMOST), is being built in China, which has effective aperture of 4 meters and can observe the spectra of as many as 4000 objects simultaneously. To fit such a large amount of observational objects, the dispersion part is composed of a set of 16 multipurpose fiber-fed double-beam Schmidt spectrographs , of which each has about ten of moveable components real-timely accommodated and manipulated by a controller. An industrial Ethernet network connects those 16 spectrograph controllers. The light from stars is fed to the entrance slits of the spectrographs with optical fibers.

In this paper, we mainly introduce the design and realization of our real-time controller for the spectrograph, our design using the technique of System On Programmable Chip (SOPC) based on Field Programmable Gate Array (FPGA) and then realizing the control of the spectrographs through NIOSⅡ Soft Core Embedded Processor. We seal the stepper motor controller as intellectual property (IP) cores and reuse it, greatly simplifying the design process and then shortening the development time. Under the embedded operating system μC / OS—II, a multi-tasks control program has been well written to realize the real-time control of the moveable parts of the spectrographs. At present, a number of such controllers have been applied in the spectrograph of LAMOST.

Keywords: real-time spectrograph controller, Field Programmable Gate Array (FPGA), System On Programmable Chip (SOPC), NIOSⅡ, intellectual property (IP), stepper motor, Ethernet network, LAMOST

1. INTRODUCTION

16 spectrographs are installed on the control stages at 6th and 7th floors of the main building. On each control stage, several tens moveable parts are mounted. For the sake of swiftness, precision, safety and coordination, the control system should be an industrial–control computer which can not only transfer various commands and status, collect the working status and process protection modes, but also, or even more important, be a real-time controller with high stability so as to correctly point the objects and reliably work. In this paper, the developing process of the real-field controller for spectrographs is introduced, including software environments, hardware structure and software frames, and the design and realization of control programs flow. At present, the cotroller has been basically finished. All the system is under overall mounting and adjustment. Results show that the controller is highly flexible, convenient for modification , and easy to copy. At the same time ,it has good expansibility , small size and low power consume, fitting to the real field control for LAMOST use.
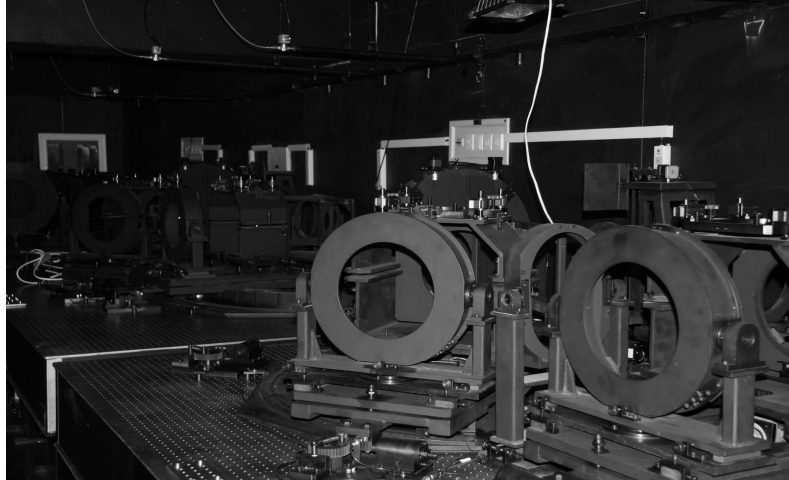
Fig. 1.   LAMOST's spectrographs

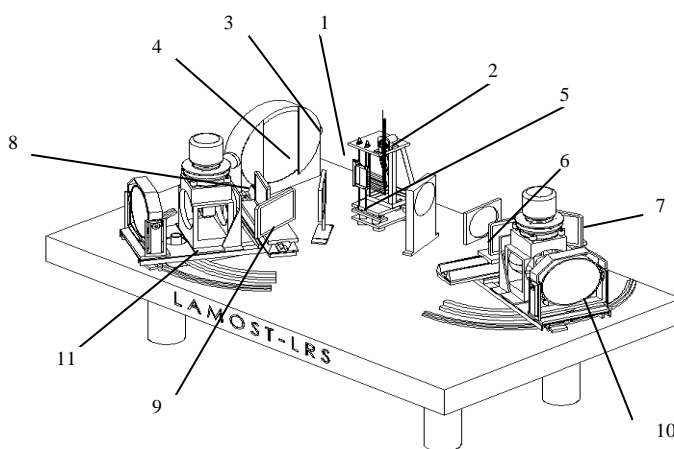## 2.   THE CONTROLLED PARTS AND THE CONTROL SYSTEM FRAME

On each optical stage where LAMOST's spectrographs are placed, there are moveable parts such as slit shutter, slit switch , two of Hartmann shutters, electrically-controlled focal adjustor, grating switch, rotating equipment for camera, back-illumination facility for fiber etc.

slit shutter: The switch speed working in the range of 1/10s to 1 s. No special requirements in precision.
slit switch: electrically-switching the slit between slit mode and slitless mode. No special requirements in precision.
Hartmann shutters: shelter the collimator in half aperture or full aperture along with electrically-focal adjustment. No special requirements in precision.
grating switch and rotator for camera: On each stage, two camera rotators are placed for blue and red range respectively, while on each rotator, there are two sets of gratings with low resolution and middle resolution respectively. The gratings may be switched under control. Due to limited space, switching has to be carried out in strict order. From low resolution to middle resolution, shift a stage to put the middle resolution grating at working place,and then the whole camera is rotated counterclockwise. On contrary, when from middle resolution to low resolution, the whole camera has to be rotated clockwise first, then shift the low resolution grating to working position . Fig 2 is the sketch diagram of the moveable parts of the spectrograph.

1. slit shutter

2. slit switch

3. 4. Hartmann shutters

5. electrically-focal adjustment

6. low resolution grating of red range

7. middle resolution grating of red range

8. low resolution grating of blue range

9. middle resolution grating of blue range

10. rotator for camera of red range

11. rotator for camera of blue range

Fig 2 The sketch diagram of the moveable parts of the spectrograph

The control system of the spectrograph is a dedicated net composed of a main control computer and several of real-field controllers, forming a concentrative distributed control scheme. The main control computer is in control room, carrying out central control strategy, which accepts the commands from superior and local operator , then decompose them as instructions for each spectrograph and send to each real-field controllers. At the same time, accept and display the data of working status of the spectrographs from real-field controllers. Fig3 is the structure of the control system.
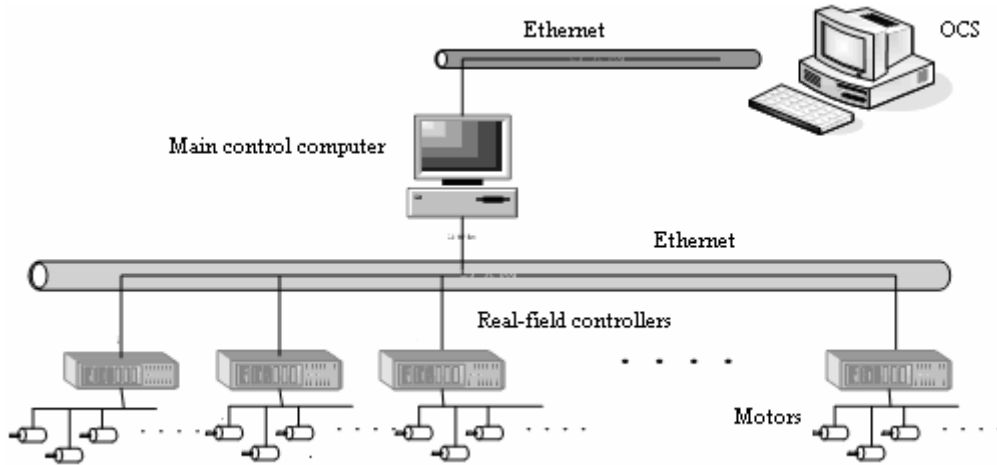

Fig3   The structure of the control system.

3.   HARDWARE OF THE REAL-FIELD CONTROLLER FOR SPECTROGRAPHS

The real-field controller for spectrographs is used for real-time control of moveable parts on each control stage. It has two main functions, one for components movement control, the second for network communications with main control computer.The real-time control for spectrographs is mainly to control the positions of each part.
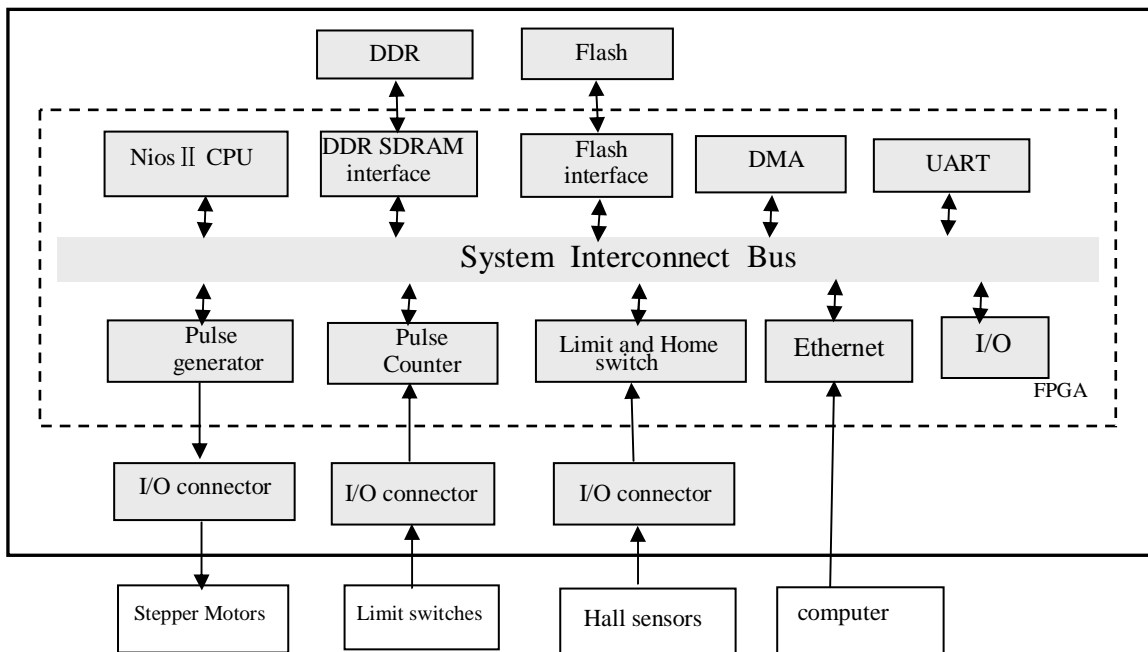

Fig. 4   The real-field controller block diagram composed of embedded system

It draws up the parts to approach the object position subsequently step by step, so as to reach high precision and self-locked when power supply fails. Nevertheless no strict demands on smoothness and speed are required. For convenience, stepper motors are used as executors. Therefore the control signals are driving pulses and directing signals. Besides, to minimize interfere, the real-field controllers had better locate as close as the optical stage. For saving space, we select embedded system as the kernel of the controllers, that is, a Slice-On-Programable-Chip(SOPC) based on FPGA . It is featured as small size, low power consume, flexibility in hardware tailoring, good expansibility and an easy-to-use real-time operating system provided. All the design of the system may be divided into two parts, hardware design block diagram as shown in Fig. 4.

3.1 Hardware

The hardware on the control board consists of Cyelone II made by ALTERA Co. Basic configuration is: Cyclone Ⅱ EP2C35F672C6ES FPGA, SRAM 2MB, Flash 16MB, two 5V-tolerant expansion/prototype headers each with access to 41 FPGA user I/O pins、MAX® EPM256AE CPLD control logic, serial FPGA EPCS64, Ethernet network interface （RJ45）, serial port（RS232）and so on . Integrate these functional modules to a FPGA chip, plus a IP (Intellectual Property) core which controls the stepper motors, a SOPC system is designed. Finally write the circuits to FPGA. Hardware for real-field controller for spectrogram is completed.

3.2 The design of on-chip stepper motor controller

In order to reduce design period and easy to expend, we seal the stepper motor controller in a IP core so that it can be copied repeatedly in SOPC Builder. The circuits on chip is mainly a complex of 9 stepper motor controllers. These controllers are connected to AVALON bus. They may communicate with NIOS II Soft Core, and output signals to drive the stepper motors. The coordination between 9 stepper motors is done by software, which is solidified in FLASH on chip. As soon as power on, the programs run automatically. Fig5 is the hardware design of on-chip stepper motor controller.
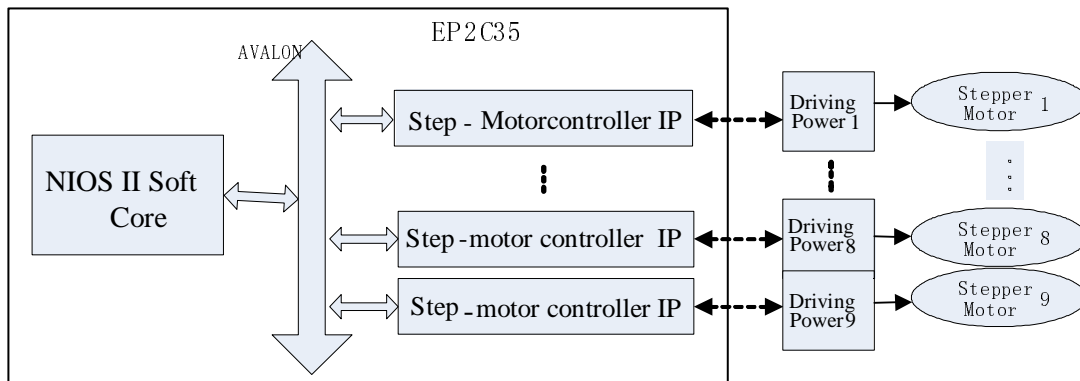

Fig5   The hardware design of on-chip stepper motor controller

Designed from top down to base ,the control IP Core is realized with Verilog HDL. The control module of stepper motor controller is divided into two layers. The top layer is motor_driver_avalon_interface.v . This file defines the signal relation between two base modules and transfers the parameters to base modules. File motor_driver_regs_2.v defines inner register module for stepper motor controller. This file realizes the interface between hardware and software. File motor_driver_core.v realizes the kernel control logic, mainly outputting the stepper motor control signal and setup signal, also backing out working status of the stepper motors. Schematically the modules of stepper motor controller are divided as Fig. 6 .
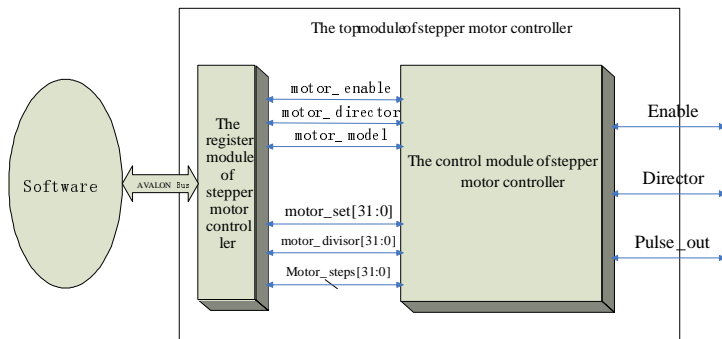

Fig. 6.The modules of stepper motor controller

Following the hardware file, write the driving files for facilities and pack self-defined function. Having all the files ready, open module manager in SOPC Builder. New stepper motor controller may be integrated to the module base in SOPC Builder. Since then, the module may be called directly to project. We need not write the same module each time.

In SOPC Builder, set the connection , interrupt , base address and clock. Then form the processor system necessary for this design.

Having completed IP core of stepper motor controller, instantiate 9 stepper motor controllers, compile and form CPU module. Then call the complied modules in QUARTUSⅡ ,connect CPU periphery circuits and distribute the pins and finally compile overall. The resultant .sof files are downloaded to development board. To this point, the design of hardware for the stepper motor real-field controller has completed.

4. SOFTWARE DESIGN FOR THE STEPPER MOTOR REAL-FIELD CONTROLLER

Software is the programs solidified in FPGA. The software development environment of programs is NIOSⅡ integrated development environment (IDE). The solidified programs in FPGA include two parts. The first is driving program for stepper motor controller which is in the system library. Add in project when compilation. The second is subroutine for controlling communication and subroutine for coordinating motors, which is in FLASH. As soon as the system power on, CPU loads programs from certain address in FLASH and begins to execute.

All programs are based on the hardware abstraction layer (HAL) system library. Tight integration between SOPC Builder and Nios II integrated development environment (IDE) allows the HAL system library to be generated automatically. After SOPC Builder ,generates a hardware system, the Nios II IDE can generate a custom HAL system library to match the hardware configuration.

4.1 Driving programs for stepper motor controller

The program realization and the interface of hardware for step-motor controller including 3 files:

altera_avalon_motor_driver_regs.h is an image file for registers. It defines a macro for w/r registers and a few parameters of registers. This file is sole interface.

altera_avalon_motor_driver_routines.h is a head file of facilities provided for users' application programs. This file declares motor control functions for calling by up layer programs and the parameters concerning motors.

altera_avalon_motor_driver_routines.c provides the codes of driving functions for motor controllers.

4.2 coordinately programs for many motors

The actions between many motors have to be coordinative to meet a certain time order. The order in our case is as follows:

 Slit transferring motor and CCD shutter control motor should act following the related instructions.

 Hartman shuttle 1 motor should open first, then Hartman shuttle 2 motor opens. When closing, Hartman shuttle 2 motor acts first, then Hartman shuttle 2 motor.

Electrical focus motor, apart from the control of directions, should work on single step mode and preset steps mode as well.

Each motor for transferring and rotation between red region and blue region has two positions: "A" and "B". When transferring motor for red grating is on"A" position , the rotation motor for red camera is responsive, while the red rotation motor is on "B" position ,the transferring motor for red grating is responsive.

The similar is for blue region. When transferring motor for blue grating is on"A" position , the rotation motor for blue camera is responsive, while the blue rotation motor is on "B" position ,the transferring motor for blue grating is responsive.

The program is compiled and downloaded to development board on FLASH. It works immediately as power on. As per the control signals from communicating port and the status of external IO, following the time order, each step-motor will work properly. Fig 7 is the flow chart of the spectrogram control program solidified in FLASH.
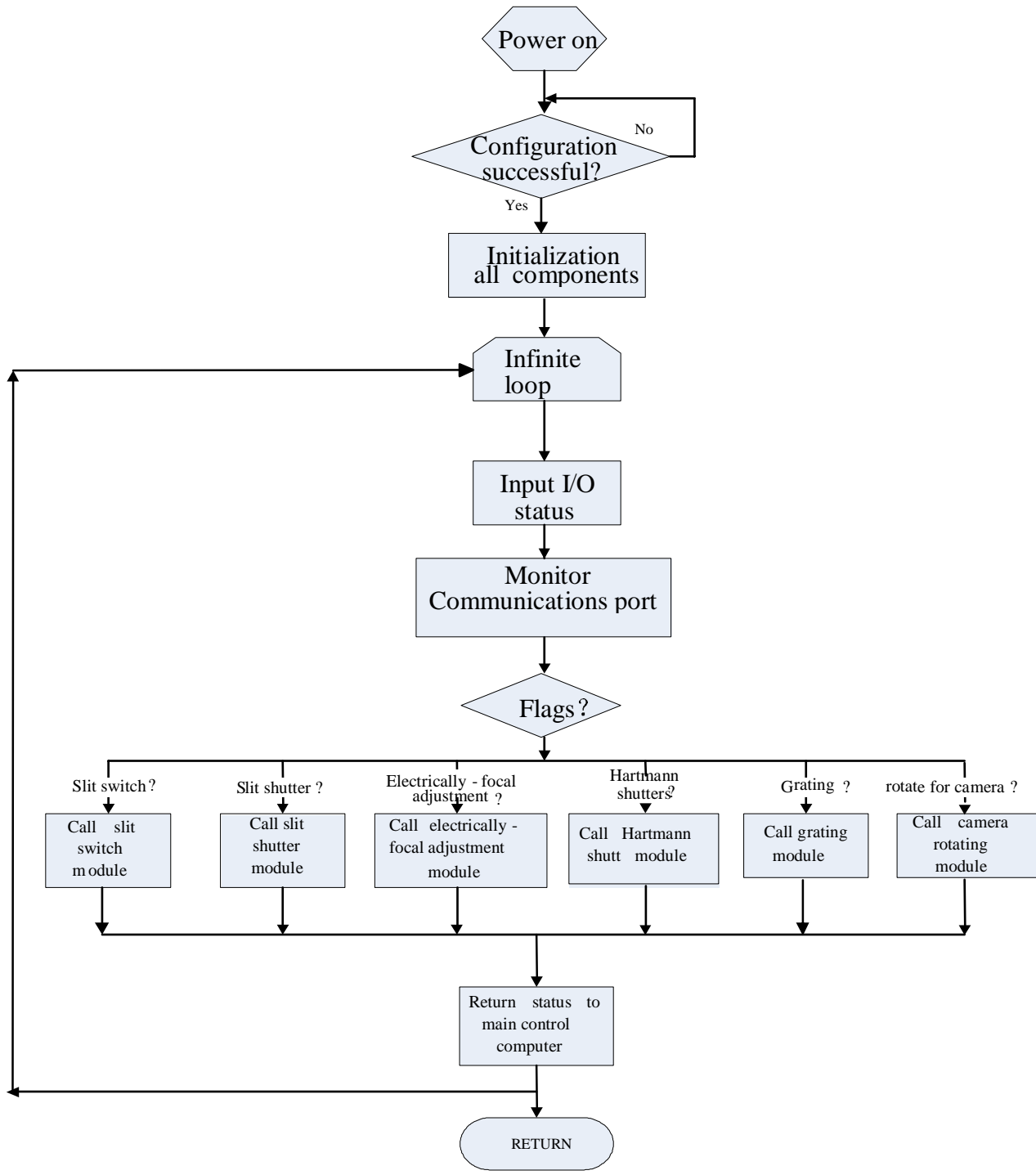
Fig 7 The flow chart of the spectrogram control program solidified in FLASH

5. PRESENT PROGRESS

At present, 16 real-field controllers of spectrograms have been installed in LAMOST focal plane building at Xinglong Station of National Observatory. Preliminary test indicates that the controllers work stably and reliable. It accepts the instructions from superior, commands the moveable parts on spectrogram stage to precious position, and feeds back the status signals. The controllers are put under the optical stage of spectrogram so that the connecting lines between the motors and the position sensors are as short as possible.
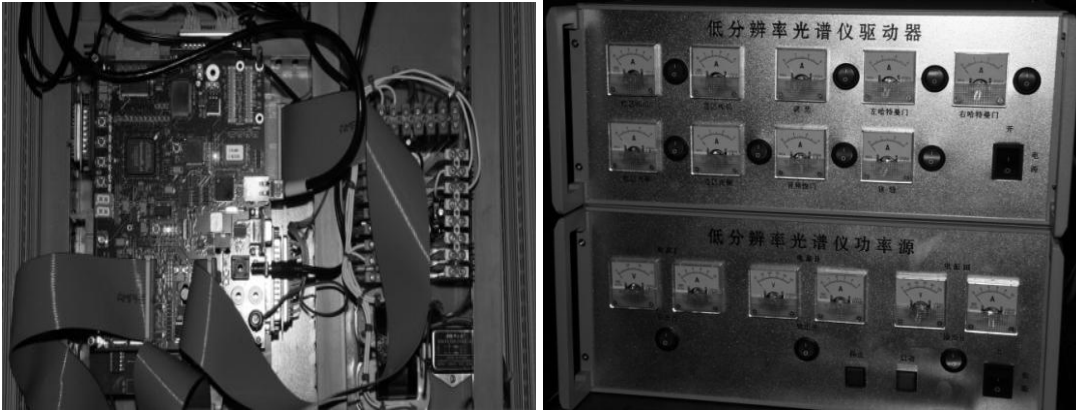

Fig 8 The driving power box for the real-field controllers of spectrograms

In view of the fact that FPGA is flexible for hardware tailoring and easy to extension, the controller may be updated in a relatively long period in the future, without having to renew the hardware components. The experiences in developing may extend to other controlling techniques based on FPGA for those astronomical instruments underway.

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