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ABSTRACT

The 2225 actuators are the main and key control devices for the deformation control of FAST(Five-hundred-meter Aperture Spherical radio Telescope) reflector. The control behavior of the reflector deformation such as tracking and scanning, is implemented by the central coordination of the actuators. For each actuator, various operation state data should be uploaded to the monitoring center on time. The actuators are controlled from the upper computer in the control center and by the PLC in the relay room. OPC protocol is used in the acquisition and control process. OPC protocol is configured to set related variables. There are significant importance for the data acquisition of the actuators of FAST main reflector. The results can be used to analyze the life of the components of the actuator. They can also be used to monitor the operation status and to analyze the reason of failure, which may be of great help to the function extension, improvement and upgrading.

Keywords: Control; Acquisition;Protocol; Radio telescope; Reflector; Actuator; OPC; LabVIEW

1. INTRODUCTION

FAST(Five-hundred-meter Aperture Spherical radio Telescope) was constructed by NAOC(National Astronomical Observatory of the Chinese Academy of Sciences)[1,2]. It is currently the largest single dish radio telescope in the world. One of the main innovations of this project is its active reflector. The active reflector of the telescope is composed mainly of active reflecting panels, ring beams, main cable net, pull-down cables, actuators and ground anchors, etc. The active reflector is a 500-meter diameter reflector, which consists of 4450 reflector panels. There are 2225 connection nodes between the reflector panels, and the corresponding pull-down cables and actuators are connected to each node (Fig.1 shows the a typical actuator connected to the node). During operation, the entire active reflector is controlled by 2225 actuators to achieve a series of 300m aperture paraboloids on the 500 m spherical surface[3,4]. It is therefore critical to monitor the state and control the 2225 actuators effectively. The status of the actuators includes various parameters such as actual displacement, oil pressure, actual velocity, load force, hydraulic oil temperature, control board(PCB) temperature, driver temperature, control pulse frequency etc. The control includes positioning control, tracking control, and scanning control modes.

Figure 1 One actuator connected to the node

The actuator is the key device to control the deformation of the reflector. It is an integrated mechanical, hydraulic, electrical, optical device. The deformation, tracking, and scanning of the active reflector of the FAST telescope is controlled by 2225 actuators. To control and collect the large amounts of data, each actuator must transmit dozens of data such as actuator operation status, motor alarming information, actuator alarming information, and real-time operation data during the operation of each actuator. The data length is ranged between 8 bytes and 24 bytes. A total of 24 8-byte data are uploaded during the operation of each actuator. During the control operation, each actuator transmit control commands and control setting parameters with the same length ranged from 8 bytes to 24 bytes. In the control process, a total of 20 8-byte data is transmitted down to the actuator to monitor and control the actuators. Furthermore, for the subsequent analysis of the actuator operating data, it is particularly important to build a system to monitor and control the 2225 actuators.

2. HARDWARE SYSTEM

The operation control and real-time acquisition data system of the actuators consists mainly of 2225 actuators, PC server upper computer, SIEMENS PLC300 (CPU317-2DP/PN PROFIBUS communication module CP342-5) and other hardware. The control hardware of the entire system is Siemens. S7-300 series PLC module. OPC protocol is used for data transmission between host computer and PLC stations. PROFIBUS protocol is used for the communication between the actuators and PLC stations. LabVIEW is used to construct the system control software on the host computer, which enables the system to control the actuator, and to collect, display and store data. The main function of PLC is to implement OPC communication with the host computer to transmit commands, parameters and receive operation data, parameters, etc. The flow chart of the hardware system is shown in Figure 2:
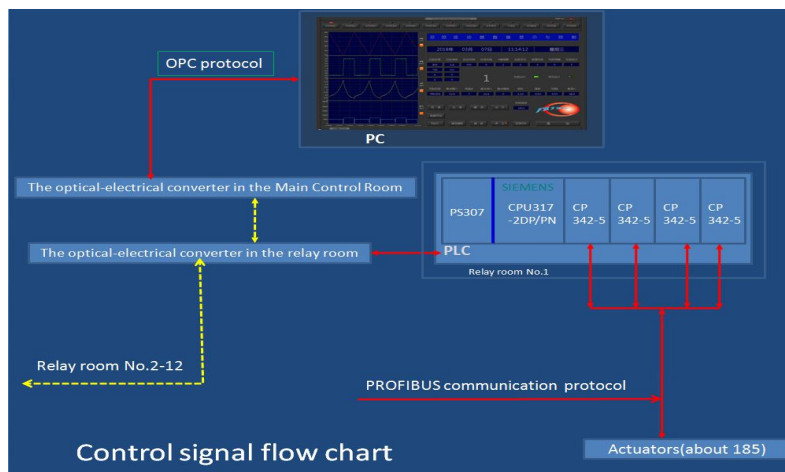

Figure 2 Signal flow chart of the hardware system

There are 12 sets of S7-300 PLC hardware components, each was installed in a relay room. Optical fibers are used for the communication between the relay rooms.. Each PLC-CPU is connected to four DP modules. PROFIBUS protocol is used for the communication between the DP modules and the control module of the actuators to transmit control command, to receive and upload various types of data. Averagely about 185 actuators are control by one set of control modules in one relay room. In the 12 relay rooms, the main CPUs use the CPU317-2DP/PN module. The CPU 317-2 PN/DP has large-capacity program memory suitable for application in centralized I/O structure. The execution time of each binary instruction is approximately 25 ns. For word, double word, and 32-bit fixed-point instructions, the module have extremely high processing speeds. PROFIBUS-DP is a popular communication protocol in the world's industry. It has the advantages of stability, reliability, and rapidity. CP342-5 is used as a PROFIBUS DP master station to communicate with the actuators.

The reflector actuator is a key component of the FAST telescope. It is an integrated design actuator of mechanical, electrical, hydraulic, and optical. The actuator is composed mainly of components such as hydraulic system, control board, displacement sensor, stepping motor, and gear pump etc. There are mainly two operation modes of the piston rod extending and retracting. The movement of the piston rod of the actuator is controlled by controlling the running direction and speed of the stepping motor. The process is controlled by control instructions (including operating parameters, etc.) from the host computer. PLC parses the command code and control parameters. The control module of the actuator receives the control command and operation parameters from the PLC. The stepper motor is controlled so that the piston rod drives the load according to the setting parameter.

3. METHODS AND SOFTWARE

The operating system of the PC host computer is Windows Sever. Siemens STEP7 is used for PLC configuration and programming[5]. LabVIEW is used for host computer programming[6,7,8]. OPC(OLE for Process Control) protocol is used for the communication between the host computer and PLC[9]. The OPC protocol has bridged the gap between Windows-based applications and on-site process control applications. In the past, in order to access the data information of field devices, special interface function is required for each application software. Due to the wide variety of field devices and the continuous upgrading of industrial products, users and software developers often meet heavy workload. Normally this cannot meet actual industrial requirements. System integrators and developers need plug and play device drivers with high efficiency, reliability, openness, availability and interoperability. In this situation, the OPC standard was created. The OPC standard is based on Microsoft's OLE technology. It is accomplished by providing a standard set of OLE/COM interfaces. The OLE standard allows multiple microcomputers to exchange documents, graphics and other objects. Normally the OPC server supports two types of access interfaces, which provide access mechanisms for different programming language environments. The two interfaces are: Automation Interface and Custom Interface. Generally the automation interface is the standard interface defined by OPC technology for the scripting programming language which has been widely used in the field of domestic industry (for example: Data acquisition technology, Historical data access, Alarm and event processing, Data redundancy technology, Remote data Access etc.). It works well in the following aspects: 1)Heterogeneous issues in device driver development 2)Data exchange between heterogeneous network in fieldbus systems 3)Can be used to access the middleware of specific database 4)Easy for the integration of different types of data 5)Enables the separate design of the control software and the hardware.

The key to realize the real-time communication between PC and PLC is to use the LabVIEW OPC Client and PLC to establish shared variables for data exchanging. OPC is configured to create shared variables. For 2225 actuators, 2225 upload and download data shared variable arrays need to be created, totaling 4450 OPC array shared variables.

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) is a graphical programming language for creating applications using icons instead of text lines. LabVIEW is a program development environment similar to C and BASIC development environments, but LabVIEW is significantly different from other programming languages. LabVIEW uses a graphical editing language G to write programs. The resulting program is in the form of a block diagram. Similar to C and BASIC, LabVIEW is a general-purpose programming system with a large library of functions to accomplish miscellaneous programming tasks. LabVIEW's library includes data acquisition, GPIB, serial port control, data analysis, data display, data storage, and many more. LabVIEW also has traditional program debugging tools, such as Breakpoint setting, dynamic displaying of data and its subroutine (subVI) results, single-step execution, etc., to facilitate the debugging of the program.

4. INTERFACE DESIGN

The software is written in LabVIEW. The software in the host computer includes the following function sub-interfaces: Single actuator control and monitoring, information query and warning, viewing of relay room data, view of all data, data storage and analysis, and control of overall actuator.

4.1 The interface of single actuator control and monitoring.

The eight sub-interface functions are mainly used to view the working status of interested actuator and its surrounding actuators. The sub-interfaces are also used to perform single point positioning, reciprocating movement and follow-up movement of any one actuator. This interface can be used to display displacement, velocity, oil pressure, driver pulse frequency curve and driver temperature, hydraulic oil temperature, control board temperature, alarm information, motor failure, load force, device status, motor current and other data. The current data can be exported to Excel file.

4.2 The interface of information query and warning.

The interface is mainly used to view the basic information of an actuator among the 1-2225 actuators (Relay room number, address, actuator type, core node number, sector node number, line number, power supply box transformer number, anchor coordinate etc.). This interface can also be used to monitor the six maximum value of a certain type of data (such as oil pressure, load force etc.) of the actuators among all the operating actuators. By setting alarming threshold value, when the data reaches the warning value, it can alarm by flash sound so that the operation of the actuators can be stopped on time to avoid damage to the reflector of the telescope. The maximum data can also be exported to the Excel file.

4.3 The interface for viewing of relay room data and all data.

These two interfaces use tabular mode to view the operation data of the actuators. The 6 maximum values are displayed in six different font colors. The uploaded data information of one relay room actuator and all actuators can be viewed. The operation status of all the actuators in the reflector can be obtained. The tension of the cables of the reflector can be obtained too. All the current data can be exported to Excel file.

4.4 The interface of data storage and analysis.

By menu selection, all the actuator data can be stored, and the data storage function can be switched ON/OFF. The data is stored according to name and saved to .txt text file. 2225 new .txt files is created every day to limit the size of a single file within about 2M bytes for convenient and quick data reading and analyzing of an actuator. At the same time, this interface can also be selected to view and analyze the stored data of the actuators for comparison. The table data can be exported to the Excel file.

4.5 The interface of the overall actuator control.

Tabular input is used in the interface. Each of the actuators can be controlled by inputting corresponding control data such as displacement, velocity and other parameters.

The six sub-interfaces completely consist the software system. The completion of the entire software is to realize the reading/writing control of the shared variables of all 2225 actuators. The corresponding data control process is shown in Figure 3:
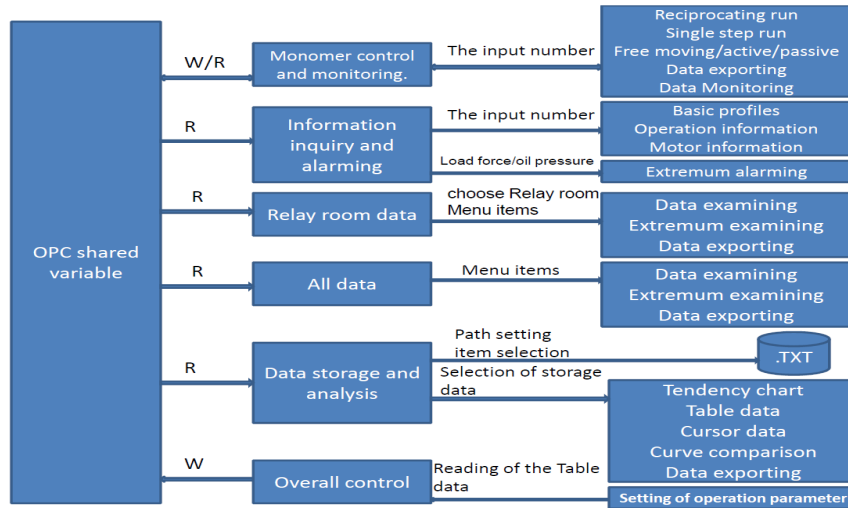
Figure 3 Data Control Process

5. SOFTWARE PROGRAMMING

The upload array shared variables of each actuator include: Status information, alarming information, motor fault, actual displacement, actual velocity, oil temperature, oil pressure, board temperature, driver temperature, driver pulse frequency, driver current, total distance, total time and other data information. The software is used to obtain the above information after the separation of the data uploaded by the actuator and then used to detect the status of the actuator and for data storage analysis. Sub VI module is used to package the data separation module VI (as shown in Figure 4). The shared array variables downloaded from the host computer include: time stamp, control command, given displacement, given time, given velocity, movement coefficient, command sequence and other data information. The control data will be synthesized by the software and transmitted to the actuator for operation control. A control module VI is also packed by the subVI module, as shown in Figure 5.
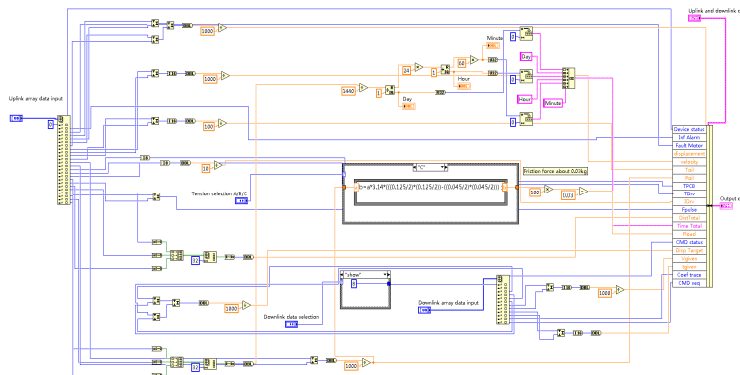
Figure 4 Data Separation Module VI
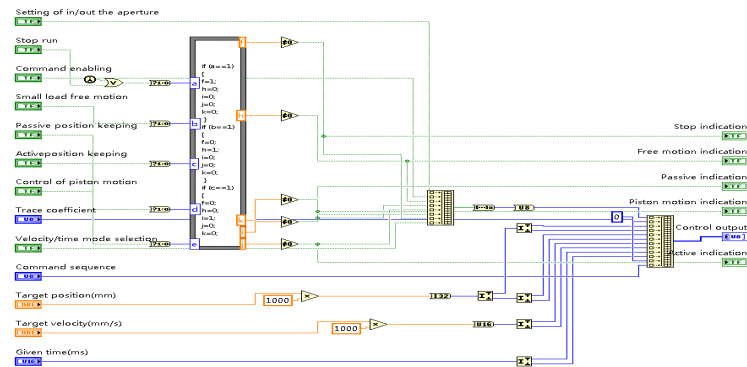
Figure 5 Control Module VI

In order to realize the functions of the six sub-interfaces, the key is to call the above two modules in the sub-interface program structure and process the module data.The corresponding interface will be displayed and controlled.

5.1 Single actuator control and monitoring module.

Eight same sub-modules "Single actuator control and monitoring VI" and control interface are constructed in the system. The module uses selecting structure to call the upload data from the actuator using "data separation module VI" and the download data from the upper computer using "control module VI" to select and control the 2225 actuators. Static calling mode is used in the software to ensure the continuity of the curve data. The 8 subVI modules are contained in a timing while loop, ensuring the time accuracy of the control signals of the 8 modules. A screenshot of this part of the software is shown in Figure 6:
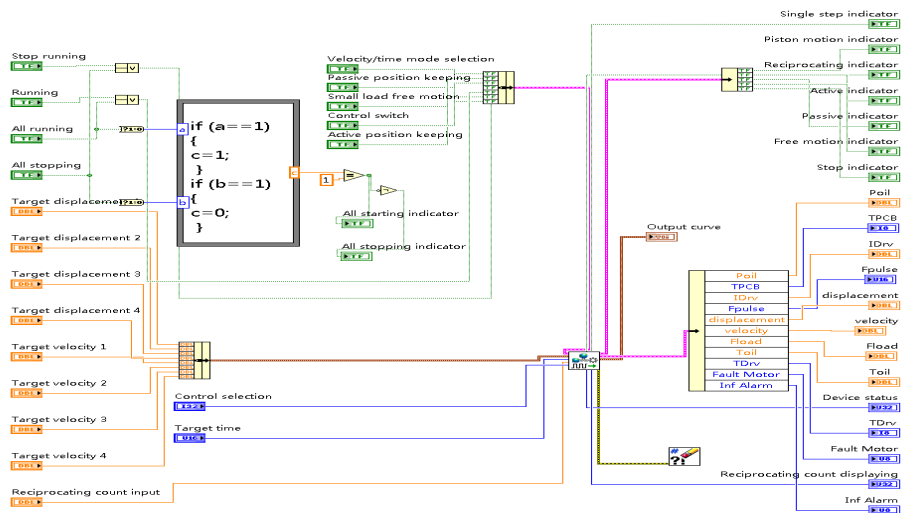
Figure 6 Control and Monitoring Module VI

The operation of the interface is designed as follows: In the interface, select and click "control interface 1-8" button to enter one certain sub-interface. In the interface "control selection", enter the number of the actuator No. 1-2225 and choose to control or monitor the actuator numbered.

To control the operation of the actuator, the "Target Position" and "Target velocity" data must be configured and the "Control ON" button clicked, and the "Run" button clicked to complete the control (If "Target Position" and "Target Velocity" are only one group of data controls, only a "single run" can be performed. If multiple sets of data are set, only "Reciprocating movement" can be performed.

To view the data and data curves of the actuator during operation, enter the appropriate actuator number in "Control Selection". The "Curve Updating" button in the interface can be used to clear the current undesired curve. The "X Scale"

button can be used to adjust the time length of the current curve. The "Data Export" button can be used to export the actuator data to the Excel spreadsheet for analysis and viewing. Press the corresponding orange button of "Displacement", "Speed", "Hydraulic Pressure", "Pulse", etc. on the curve interface to make the curve partially enlarged for detailed data viewing. The interface which controls the actuator operation is shown in screenshot as Figure 7:
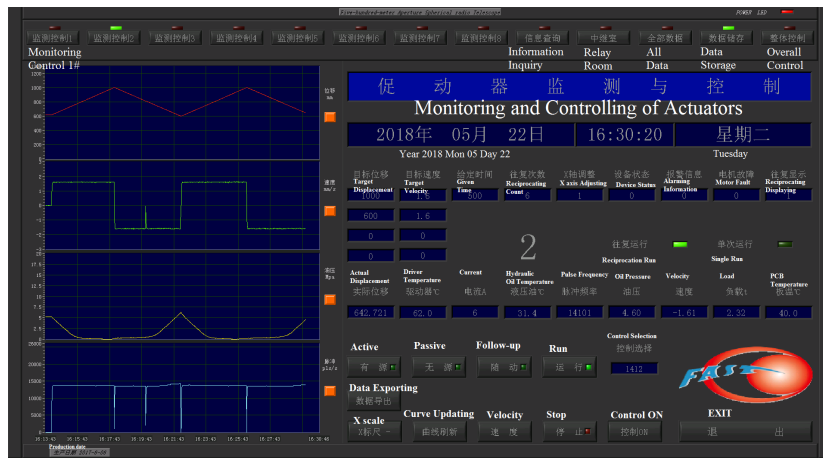

Figure 7 Screenshot with actuator 1412# selected

5.2 Information query extremum viewing module.

In this part of the software, a combination of for loop structure and selection structure was used to cyclically call the upload data module "data separation module VI" for 2225 times to obtain the data of the actuators. The corresponding data can be obtained by entering the actuator number. The subVI module is contained in a separate while loop structure. Some software screenshots are shown in Figure 8:
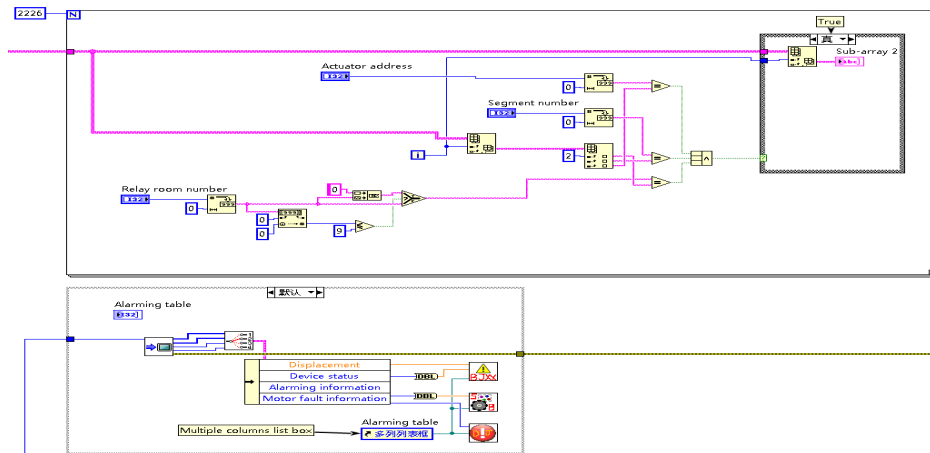
Figure 8 software query part of the software screenshot

The operation in the interface is designed as follows: In the interface, click the "Inquiry" button to enter the sub-interface. By entering the corresponding data in "node number input" or "sector number input" and "relay room number, segment number, and address", the basic information of the inquired actuator can be obtained.

In the "node number input" input field, the alarm information, motor failure, device status, etc. of an operating actuator can be obtained by entering the corresponding actuator number. If there is an alarm, the corresponding alarm information becomes red in font color.

By entering the corresponding pre-alarm value in the "alarming value setting" field and selecting the query data types such as: load force, actual displacement, oil pressure, oil temperature and other data in the "Item selection" field, the 6 maximum values of the currently selected data type can be viewed when all actuators are running. If the warning value is

exceeded, the maximum value changes font color and alarm by blinks and sounds. Button "Extremum Export" can be clicked to export the maximum value to an Excel file.

In Fig. 9, a screenshot of the display and alarm status when the "Load Force" is selected when querying the basic information of the actuator No. 1538 and the operation alarm condition and warning value setting to 5.

Figure 9 Screenshot of information querying and alarms for actuator No.1538

5.3 Relay room data viewing module and all data viewing module

This part of the software module is operated in a while loop structure. In the "relay room data viewing module", the selection structure is used to select a relay room. Then the for loop structure is used to cyclically call the upload data module "data separation module VI" according to the number of actuators belonging to the relay room, so to read the operation data of all the actuators of the selected relay room. Then the table control is used to display and viewing data according to the "relay room" and "item selection". The screenshot in Figure 10 shows the software module partially.
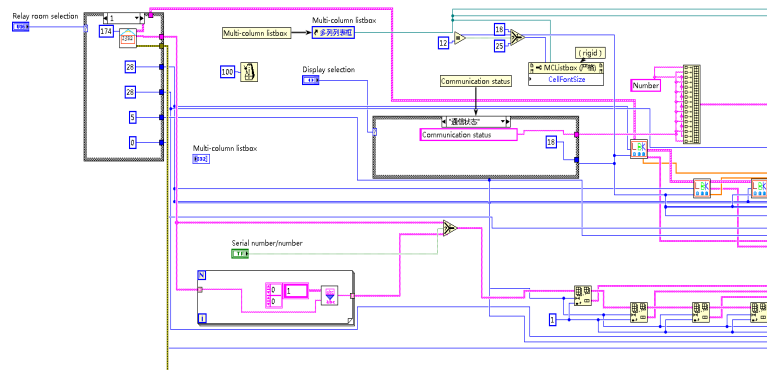
Figure 10 Relay Room Data Viewing Software Screenshot

"All data viewing module". For loop structure is used in this module to cyclically calls the upload data module "Data Separation Module VI" 2225 times to query the operation data of all actuators. The method of reading the query data is similar to the "Relay room data viewing module". In the above two modules, data comparison and sorting are used to obtain the 6 maximum values of the current data, which are respectively represented by 6 font colors such as white, blue, orange, purple, green, and yellow. The screenshot in Figure 11 shows the software module partially.
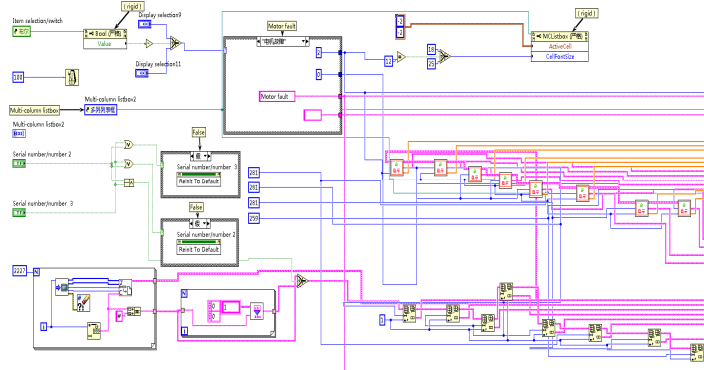
Figure 11 Screenshot of all data view of the software(Partially)

The interface operation is designed as follows: Click "Relay Room" button on the interface to enter the sub-interface, click "Select Relay Room" to select the corresponding relay room, click "Item Selection" to select the data type to view the data, click "Data Export" to export data in the table to Excel spreadsheets. For example, select the relay room 12, and click "Actual displacement" in the "Item selection" menu to view the actual displacement data of all actuators in the 12# relay room, as shown in Figure 12.

Similarly, click on the "All data" button to enter the interface of all data, click "Item selection" to select the data type to view the data. The operation of viewing the data content and exporting data content "relay room" interface is similar. In this interface, "Sort" can be clicked to arrange the current data in descending order. As shown in Figure 13, click on the "Item selection" menu and select "Actual Displacement" to see a screenshot of the displacement data for 2225 actuators.

Figure 12 Screenshot of relay room viewing module of the software

Figure 13 Screenshot of viewing the actual displacement of 2225 actuators

5.4 Data storage and data analysis module

The storage module of the software also uses for loop to call upload the data module "data separation module VI" for 2225 times and select structure are used to select the data type for storage. The data analysis module software use event driving structure to read the stored data and select the data type for curve trend display or curve comparison. In this part of the software, the functions of storage switch, storage path selection, curve updating, data exporting and other functions are also designed. A screenshot of part of the module software is shown in Figure 14.
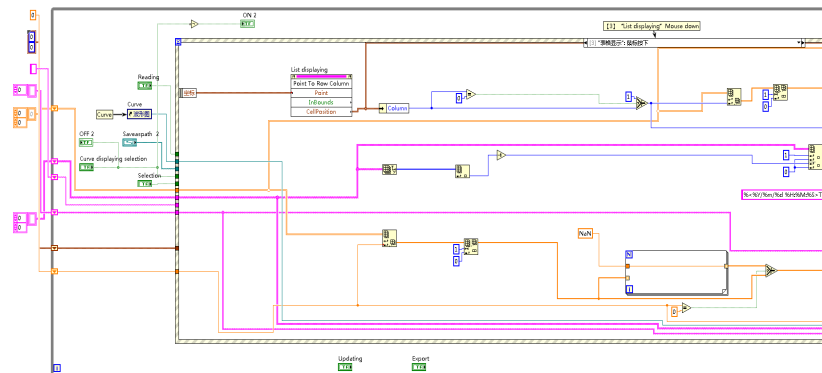
Figure 14 Screenshot of data storage software

The operation in the interface is designed as follows: Click "Data Storage" button in the interface to enter the storage and analysis interface, click "Save ON" button to open or close the storage function. The data storage path can use the default "D:/actuator data" or select the saveas location. Click on the "path selection" button and click on the folder icon to complete the saveas path selection. Select the desired data to store as needed. Click the corresponding button on the "Item selection" button to select and save the data. The green one indicates a selection while yellow one is not selected.

To view and analyze data, click the folder icon under "Curve Selection" to browse for the text file named by the actuator number. After selection, click the "Data Read" button. All the stored data of the actuator are read into a yellow table. Click on the data column to be viewed in the table, and the graph will show the trend curve. To compare the curves, click the "Curve Comparison" button to select the corresponding curve name, and click the corresponding curve column in the table to view the trend graphs of the selected two curves. The table cursor can be used to view the data of a certain curve.

"Curve Updating" can be used to clear the current curve chart. "Data Export" can be used to export the current table data to Excel file. For example: Figure 15 shows the comparison between the "hydraulic oil temperature" and "actual displacement" trends of the 2226# actuator.
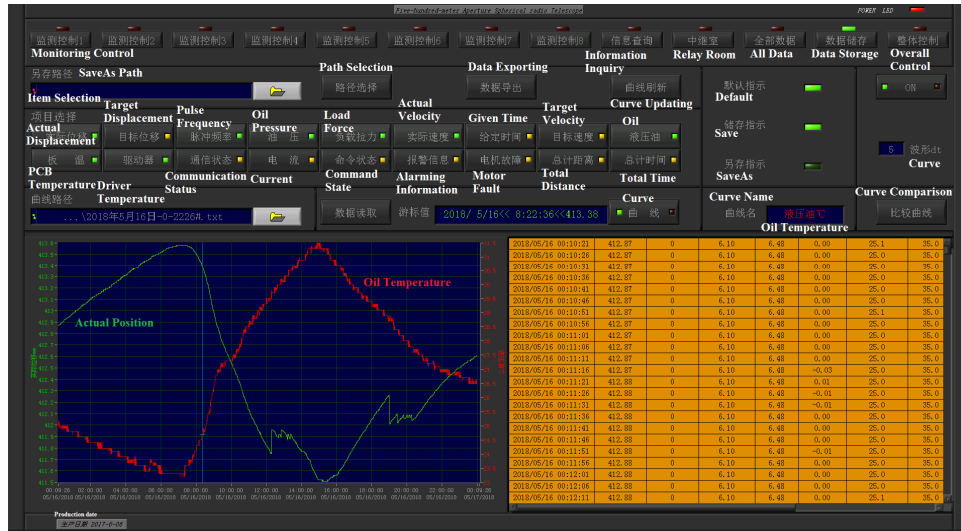
Figure 15 Interface of Data Storage and Data Viewing

5.5 The overall actuator control module

The "Overall actuator control" module is included in a while loop to call the download data module "control module VI" from the upper computer for 2225 times to transmit control commands and control parameters to the 2225 actuators.

The interface operation is designed as follows: Click on the "Overall Control" button on the interface to enter the overall control interface. This interface uses the table field to input the control parameters. Click "Run" for all the actuators to control the reflector to complete the pulling of the reflector. After pulling, all actuators can be automatically stopped or stopped by clicking "Stop" button.

At present, due to limited time, the control module and control interface of this part have not yet been fully completed. The next step is to complete and verify the results as soon as possible.

6. DISCUSSION

After the construction of the hardware system, the control software is designed according to the above functions has been operated and run for several months to test and validate various functions and the system achieves the design goal. For all actuators on the reflector, data monitoring, data acquisition, data storage analysis, and data comparison can be used to obtain the pull force of the reflector. The early warning can be used to predict the life of the main components of the actuators. The analysis data can be helpful to understand the movement process of the actuators, to obtain the operating characteristics of the actuators, and to facilitate fault analysis of the actuators, and provide certain basis for the future upgrading of the actuators. After software designed and programming, the maximum values of the uploaded data are obtained. The maximum values are compared with the set value, alerting by blinks or sounds. All these will be helpful to obtain operation status of the actuators and the cable net of the reflector of the telescope. The easy fault analysis will be helpful for the safe operation of the cable net. With this software, the data on the operation of the actuators can be easily analyzed, and the relationship between different data types of operating data can be found or obtained, and basis will be provided for troubleshooting of the failure analysis.

7. CONCLUSION

This paper focuses on the status monitoring and control of the actuators which are large amount and key components of the FAST active reflector. Experiments have proved that it is feasible to use LabVIEW programming to control and communicate between PC and PLC using the OPC protocol. The host reads and writes the data in the corresponding data fields of the PLC by application created by LabVIEW, which provides a general method for dynamic monitoring of the PLC control system. At the same time, it proves that the OPC communication system is stable, reliable with good real-time performance. This method is also applicable, suitable for almost all SIEMENS PLC modules, using LabVIEW programming there is no need for complicate language programming, which shortens the development time of the

software. It is also easy to compile an attractive and practical human-computer interaction interface, which simplifies the development process.

For the programming of the system software, the main difficulty lies in the large amount of data read and stored. If the for loop method is used, there is unacceptable delay in data reading and acquisition. If the parallel method is adopted, it will cause a large amount of software development.

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