Control system for 6 degree of freedom electric platform of sub-mirror in the giant telescope

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ABSTRACT

Giant telescopes with extremely large aperture widely adopt segmented mirror active optics technology, so active adjustment mechanism of displacement is one of the critical techniques. A novel 6-DOF mechanism featuring structural compactness in size and partial decoupling in degrees has been proposed as a potential supporting mechanism for sub-mirrors. It is of important significance to carry out profound study on the control strategy for large scale use of the 6-DOF adjustment mechanism in a highly segmented giant telescope. This paper presents first the control system design for a prototype of the 6-DOF mechanism and further the control strategy modeling for the future large-scale application of the mechanism in giant telescopes. The control system implemented for the prototype mechanism has been successfully tested by photogrammetry at lab. It provides closed-loop control and real-time measurement of all motors of one 6-DOF mechanism and is proved to be a system of high precision and efficiency. Afterwards, we explore and extend the control design of the novel 6-DOF mechanism to large-scale use in all sub-mirrors in a giant telescope. The principle, constitution, control algorithm and realization are covered and commented. The study and experiment carried out in this paper are also informative for the control of parallel manipulators in other industries.

Keyword: control system, 6 degree of freedom (6-DOF), wireless net control system, giant telescope.

1. INTRODUCTION

Due to high rigidity, low error rate, high precision, 6-DOF motion platform is widely used in many important areas such as aviation, spaceflight, auto-motive industry and so on. Since 1980s, 6-DOF began to be introduced in the telescope and other astronomical instruments, for example the secondary mirror unit in the SOFIA telescope. And in National Astronomical Observatories, CAS, Five hundred meter Aperture Spherical Telescope (FAST) has adopted six cables to regulate the trajectory of cabin[3].

Extremely large aperture telescopes such as TMT, E-ELT, JELT and so on adopt the advanced techniques of segmented mirror active optics[1]. Most of the giant telescopes are segmented by sub-mirrors. The number of them is enormous, so

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the research on micro-displacement control system of a large scale sub-mirrors is one of the critical techniques. The researchers should exert to develop the design proposal featuring full function, credibility, low price and structural compactness. This paper firstly introduces a control system for 6-DOF electric platform of one sub-mirror in the future giant telescope, and based on the result of the experiment, then explores the control system of 6-DOF of all sub-mirrors in the whole telescope. A novel 6-DOF platform of one sub-mirror is showed in figure 1.

Figure 1 6-DOF platform

2. DESIGN OF CONTROL SYSTEM FOR ONE SUB-MIRROR

2.1 Hardware design

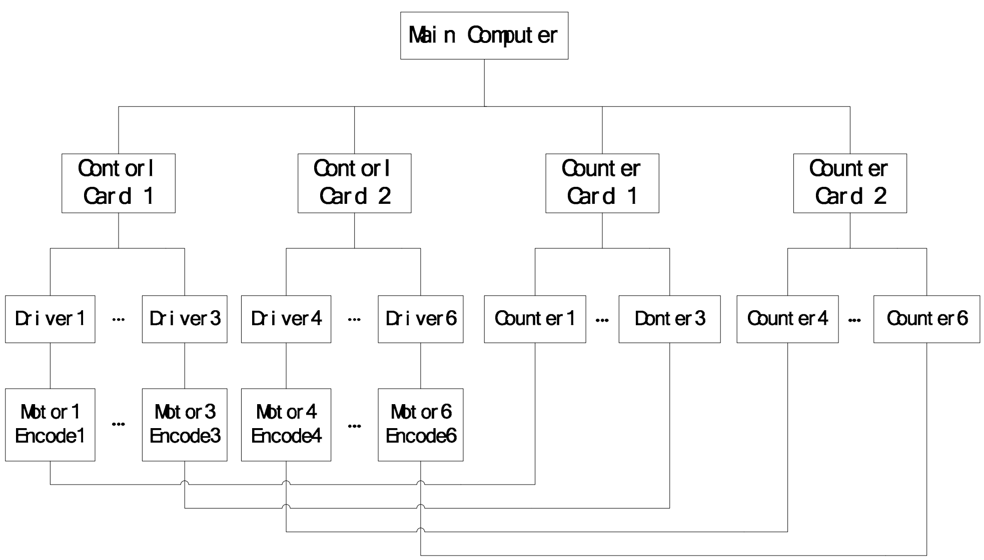

Figure 2 Hardware configuration

According to the demand, the control system adopts two control cards to control six stepping motors and two counter cards to count six encoders. Their physical configuration is summarized in figure 2.

2.1.1 Control card Features

The control card can control three stepping motor. It is showed in Figure 3. And the main characteristics of it are as follows[6]:

1) High-speed three-axis control: It has three single-chip pulse generators on-board, which enables the simultaneous and independent control of three motors.
2) Operating modes: Two-pulse mode (+or-direction) or one-pulse (pulse-direction) mode.
3) Limit switch inputs: It has six limit switches for additional control of the output, which can real-timely monitor the limit signals and immediately protect the motor drivers.
4) High-voltage isolation on isolated Output channels(2500V).
5) High output driving capacity.

2.1.2 Counter card Features

The counter card is showed in figure 4. And the main characteristics of it are as follows[6]:
1) Four 32-bit up/down counters
2) Single ended or differential inputs
3) x1, x2, x4 counts for each encoder cycle
4) Optically isolated up to 2500V DC
5) 4-stage digital filter with selectable sampling rate
6) On board 8-bit timer with wide range time-base selector
7) Multiple interrupt sources for precision application

Figure 3 Control card

Figure 4 Counter card

2.2 Software design

The main work of software design is to control all the stepping motor, to counter all the encoders and to achieve closed-loop control. Three major tasks are involved, namely send commands to the control cards, exchange data with the counter cards and provide a human-machine interface for easily manipulating the whole system. The software structure is showed in figure 5.

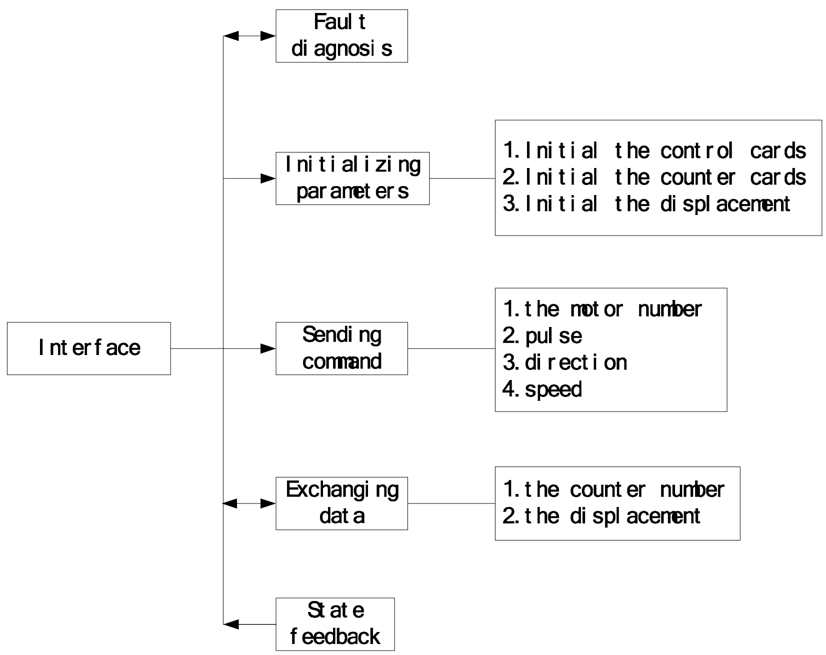

Figure 5 Software structure

The control system implemented for the prototype mechanism has been successfully tested by photogrammetry and simulated by MATLAB in lab. The error of simulation displacement and measure displacement are showed in table 1.

Table 1 The error of displacement[2]

position	△x/(mm)	△y/(mm)	△z/(mm)	△θ/(^{0})	△Φ/(^{0})	△ψ/(^{0})
RMS	0.1604	0.1090	0.0502	0.1032	0.0687	0.1007
Max error	0.2807	0.2382	0.1528	0.2326	0.1802	0.2350

3. THE WHOLE CONTROL SYSTEM DESIGN

The 6-DOF mechanism features prominent advantages such as structural compactness in size and partial decoupling in degree of freedom, which can solve effectively problems such as large size, low rigidity and difficult installation and maintenance caused by 3-DOF actively adjustable mechanism, can reduce pose deviation of sub-mirror caused by environment change such as gravity, wind load and so on, and can lower initial installation precision. However the increase of DOF doubles the number of motors and controllers, increases wiring difficulty, the weight and the inertia of the telescope, and increases the research difficulty and the production price. Traditional control system doesn't satisfy the performance need of the giant telescope control system. This paper explores the control design of the novel 6-DOF mechanism based on TCP\IP network protocol and wireless sub-network communication. The wireless network control reduces the number of the cable, alleviates the burden of the telescope, and is easy of maintenance.

Considering to the number and the position of the motor controllers, they are divided into several groups. The host computer communicates the communication controllers through the network cables, and the motor controllers and the communication controllers transfer data through wireless network. Every sub-system comprises 100 step controllers and one communication controller, and all sub-systems constitute the whole distributed control system for the telescope. The structure of control system is showed in figure 6.

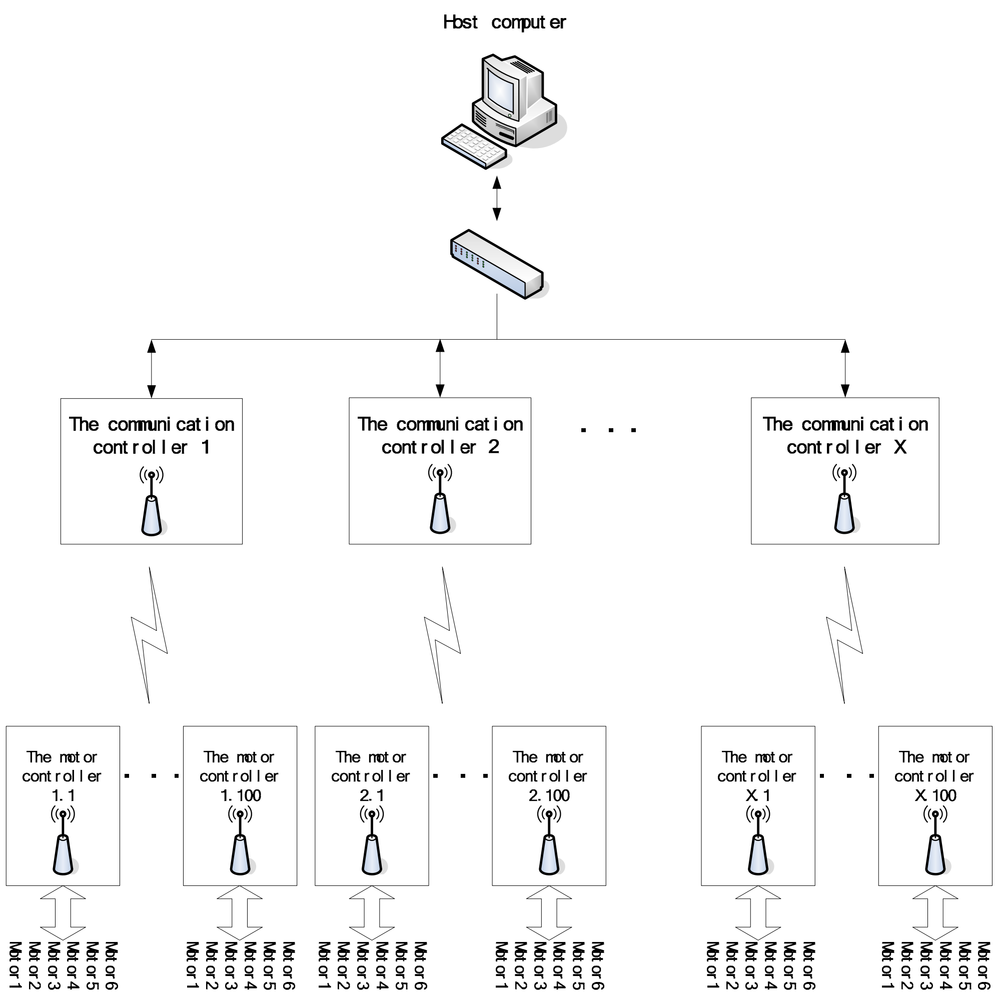

Figure 6 The structure of control system

3.1The communication controller

The communication controller is the core of the sub-system. Once there is some thing wrong with it, the whole sub-system would paralyze. So the researchers must pay more attention to functional reliability. And the main functions of the communication controller are as follows:

1) Receive real-timely command from the host computer, and transfer data in sub-network.
2) Wireless transceiver.
3) Fault diagnosis of sub-network.
4) TCP/IP net protocol
5) Mass data storage

3.2 Wireless network communication

With the development of the technology about the computer, information processing, storage and so on, short distance wireless communication technology develops quickly and is wide used in industrial system, factory automation, motor control, medical equipment and so forth. The most widely used short distance wireless communication technologies are Bluetooth, Wi-Fi, IrDA, Zigbee, Ultra Wideband, NFC, WiMedia, GPS, DECT, antenna 1394 and so on[5]. And they have their respective characteristic. Based on transmission speed, distance, power and capacity of resisting disturbance, the researchers choose the most appropriate communication way. Recently, wireless network control is used successfully in focus fibers communication in LAMOST. And it can be applied to the optical telescope.

Star network has been adopted because of there is no need to communicate between the motor controllers. Every sub-system is centralizedly managed by the communication controller, which is responsible for transferring all data of the sub-system. Though the star network features such advantages as follows: easy to control and manage, easy to diagnose and isolate the faults, it requests higher demand on the communication controllers.

3.3 The motor controller

The motor controllers are mostly placed on the trussed. Because the heat elimination when their working affects the astronomical seeing and the mechanical structure, the design of the motor controller must pay attention to the power consumption. Because of high integration, low price, high reliability, low power, ARM is suitable for the core of the motor controller. In this system, each ARM controller controls six motors of one 6-DOF platform, includes six counter circuits, one wireless transceiver, limit protection circuits and zero bit detection circuits. One ARM controller controls one 6-DOF electric platform of one sub-mirror. All ARM controllers constitute the whole distributed control system for the telescope.

4. CONCLUSIONS

The paper explores the control design of the novel 6-DOF mechanism based on TCP\IP network protocol and wireless sub-network communication. And the control system implemented for the prototype mechanism of one sub-mirror has been successfully tested by photogrammetry at lab. Yet there is still a long way to develop both hardware and software to make the whole control system perfect. The core of the communication controller is the key part and the researchers must choose the suit CPU and consider the backup to assure the telescope to work smoothly. The structure of control system is also informative in other control field.

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