

Control and network system of position actuators in LAMOST

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ABSTRACT

In LAMOST project, the reflecting Schmidt plate (M_A) and the spherical primary mirror (M_B) are constructed with segmented mirrors. M_A consists of 24 submirrors and M_B consists of 37 submirrors. Three position actuators are mounted on the back of each submirror to support the submirror and maintain the co-focus of the submirrors. The position actuators are the critical components in the system. They must make precise movements under large loads. A set of position actuators for one submirror and its electronics system in the lab will be presented in this paper. The character of one actuator and the networking of handling its position will be described in the paper in detail. Adopt the field bus technology to combine these position actuators into a distributed control system. This paper gives a function description of the distributed system and an implementation and the performance of the experimental subsystem.

Keywords: active optics, position actuator, field bus, distributed control

1. INTRODUCTION

1.1 The LAMOST project

LAMOST is an abbreviation of “the Large Sky Area Multi-object Fiber Spectroscopic Telescope.” It is a horizontal meridian reflecting Schmidt telescope with an active correcting plate. It will be located at the Xinglong Station of the National Astronomical Observatory. It has an aperture of 4m and a 5° field of view. The marked characteristic of LAMOST is that it adopts the thin-mirror active optical technique and segmented-mirror active optical technique in one system. The telescope consists of three major parts, the reflecting Schmidt plate, M_A and the spherical mirror, M_B and focus plane apparatus. M_A and M_B are all segmented mirrors. M_A is composed of 24 hexagonal plane submirrors which are 1.1m in length measured across the diagonal and 25mm in thickness. M_B is composed of 37 spherical hexagonal submirrors which are 1.1m long measured across the diagonal and 75mm thick. The segmented-mirror active optics of LAMOST will organize all the submirrors to keep them maintain co-focus¹.

In order to keep all the submirrors of M_A and M_B co-focus, three position actuators will be mounted on the back of each submirror to correct three freedoms of the submirror: tip-tilt and piston. In LAMOST, two special Shack-Hartmann (S-H) test apparatus are used to detect the misalignment of submirrors. One is put at the focus of LAMOST for M_A , and the other is put at the center of the curvature for M_B . As an example of M_A , when a reference point light source projects light to the lenslet array of S-H test apparatus and a star image also projects light to it, two groups of images from the reference point light source and the star image should be exactly same, if submirrors of M_A aligned at co-focus state. This is the foundation theory of segmented-mirror active optics in LAMOST¹.

1.2 Control Area Network

CAN is an acronym of Control Area Network. It is originally presented by BOSCH, and applied to transfer the measurement data and control data in automotive application. Now it is an ISO standard communication protocol and has developed to meet more applications that have the critical real time requirement.

CAN broadcasts data in short frames. The maximum payload of one frame is 8 data bytes, thus transport time of one frame is very short and the requirement of bus becomes easy. The urgent message can get response in short time. For example, about the maximum time is 134us when the bit rate is 1MBps. It fits for the critical real time application.

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Because of its short transport time the message is rarely disturbed. CAN nodes are also able to distinguish short disturbances from permanent failures. Defective nodes are switched off. CAN fits for high level of security⁴.

1.3 Experiment subsystem²

In order to validate the position actuators and the control electronics, a submirror control experiment system is built in the lab. Because the position actuators are the critical components, the characters of one actuator have been tested, including resolution, hysteresis, backlash, and slip/stick. The results show about 5nm resolution, about 1500full steps backlash. And the actuator has about an 80nm jump at the start of movement. All these errors vary with load and must be corrected in the control process. In the open-loop operation mode, all these errors must be corrected through look-up table. In the close-loop mode, all the errors can be corrected without look-up table. The close-loop test also has been done with a capacitive position sensor with 4nm resolution

In the paper, the network system of position actuators in LAMOST is put forward. CAN is adopted to connect all the actuators. The network Framework, the hardware and software all are described. Also a submirror network experiment system has been built in the lab. Three slave nodes are used to control three actuators of a submirror. A master node manages all the slave nodes. The close-loop test also has been done on this system.

2. POSITION ACTUATOR

There are 72 position actuators needed to support the reflecting Schmidt plate, M_A . Because the submirror in the center of M_A is defined as the reference, only 69 position actuators need to be controlled. There are 111 position actuators to support the spherical mirror, M_B and only 108 actuators needed to be control for the same reason. Position actuators are the critical components in segmented-mirror active optics system. They not only support the weight of the segment, but also make very precise movements.

2.1 Mechanical characters

In the test system, position actuators (2200-025-AM1524LT-5752-40-V1-S001HD) are ordered from Diamond Inc. The selected actuator is essentially a lead screw driven by a motor through a high ratio gear head. It can be divided into three major parts, a stepping motor, a high ratio gear head and a lead screw. Figure 1 gives the schematic diagram of the actuator. The actuator uses an Arape two phases stepping motor, the motor produces 24 steps per revolution, the gear head ratio is 5752:1, and the lead screw is 40 TPI, So it can get the theoretical resolution about 4.6nm. In the specification the gear head exhibits as much as 4° of backlash, equivalent to 1533 full-steps in the actuators. In addition Diamond Inc can provide zero-backlash gear head for the actuator. Although using zero-backlash gear head is able to reduce the backlash markedly, it increases friction and diminishes lifetime. The leads crews have maximum peak- to-peak pitch errors ranging from $\pm 0.5\mu\text{m}$ to $5\mu\text{m}$. Thermal expansion of drive-train components influences the actuator's positioning accuracy. The actuator also owns two End-of-Travel sensors to protect itself⁷.

Some mechanical characters of the actuator are tested on homemade controller and fixture. Figure3 shows the test fixture in the lab. A capacitive displacement sensor (made by Tianjing University) is used to detect the micro movement of the actuator. This displacement sensor has 4nm resolution.

Resolution, hysteresis, backlash, and slip/stick are tested. Figure3 and Figure4 show the movements and five-step distances under different load. The hysteresis occurs when actuator starts to move or reverse. The position error of hysteresis results from the relaxation of elastic force in the drive-train component, and varies with different load and acceleration. The lost motion at the beginning of curve indicates the hysteresis of the actuator. Comparing fig3, 4(a) with fig3, 4(b), the play increases with load increment. The backlash occurs when the actuator reverses the movement direction. It is caused by the clearances between moving parts of the actuators. Figure3, 4 shows about 1000 full steps backlash. With the load increasing the backlash increases. Because the coefficient of static friction is greater than that of dynamic friction, a jump occurs when the static friction is overcome. The first pitch is about 80nm, and varies with load. Also the repeatability tests have been done. Figure5 shows that the actuator has an excellent repeatable performance. When actuator works in an open-loop mode, all these errors must be corrected through look-up table⁵.

2.2 Control system

One actuator controller controls three actuators. A block diagram is shown in Fig 6. It is separated into two parts, control electronics and driver. The driver operates in a PWM mode so that it has the excellent performance of high frequency. The control electronics are based on a 16-bit DSP⁸.

The software contains three tasks, the emergency task, operation task and communication task. The communication task will be described in the third part. Because the controller controls three actuators simultaneously, the software becomes complex slightly. Three actuators not only can make movements respectively, but also can produce movements simultaneously. Figure 7 shows one actuator's state transition diagram (STD). The STD of these actuators is almost as same as Figure 7. In RUN state the software collects the capacitive position sensor data, the encoder impulse numbers (option), implements the close-loop algorithm.

2.3 Close-loop test

With homemade fixture and controller, close-loop test has been done. The controller reads the data of capacitive position sensor and gets the error between the actual position and the expected position, then works out the output of control. PID algorithm is used in the test. Different from open-loop operation which any errors needed to be corrected by look-up table, close-loop operation can guarantee the stability and absolute accuracy without look-up table. Figure 8 shows one test result⁶.

3. CONTROL NETWORK

Adopting field bus in application breaks through the framework of traditional control system. End to end connection of the devices is adopted in traditional control system. It is obvious that traditional control system becomes more complicated and unsafe for a grand system. Now the field device has the ability of transferring the data. They can directly deliver the signal. Many functions can be completed on the spot. Thus the distributed control network makes the system more simple and more reliable and lower cost.

There are about 177 position actuators needed to control in the observation. The control system of these position actuators controls them to produce the expected movements according to S-H test apparatus. This will be described in detail below. Every 1.5 minutes all the actuators need to refresh. Field bus will be applied in the control system to regulate all the movements of these actuators.

3.1 Hardware³

The network consists of two CAN segments. One CAN segment is located at the back of the reflecting Schmidt mirror, M_A . The other is situated at the back of the spherical primary mirror, M_B . A logistic master CAN node is appointed in every CAN segment. Use a CAN bridge to connect the two CAN segments. CAN bridges can make the control system of position actuators communicate with other parts of LAMOST control system. A block diagram is presented in Figure 9.

Master Nodes

Each CAN segment has a logistic master node. The master handles all slave nodes and coordinates the operation of the position actuators. From S-H test apparatus wave front information is obtained. Master nodes analyze the wave front and get the position deflection of actuators, then send these position offsets to the slave nodes. Master nodes also monitor the state of network and interface to GUI.

Slave Nodes

Each submirror has a slave node. A slave node is developed around a fast 16-bit Digital Signal Processor with a CAN controller on chip. We selected a Motorola DSP56F807 because it not only has many resources fit for motor control application such as I/O ports, PWM ports, Timers and Encoder ports, but also has a MSCAN controller on chip. A slave node carries out two primary Functions. The first function receives and sends data to master node or other slave nodes. The second controls three position actuators. A slave node receives the refresh command of the actuator from a master

node and then make the actuator reach the expected position. CAN supports multi-master mode, that is, “When the bus is free any unit may start to transmit a message. The unit with the message of high priority to be transmitted gains bus access.” Slave node can actively send message when meets urgency⁸.

3.2 Software⁴

First the application layer of CAN must be defined before designing the application software. Four types of services are defined, urgent message, command message, general message and request message. Urgent messages have the highest priority. They are used to transmit the message such as the position actuator out of control and so on. The command messages have the second higher priority. They are used to transfer the command messages with critical real time requirement and the period data. General messages often transmit the data without critical real time requirement. They have the third rank of priority. The request message is often used to help system maintenance. They have the lowest propriety.

The Arbitration rule of CAN make this kind of definition possible. The bus access conflict is resolved by bit wise arbitration using the IDENTIFIER. The first two bits of CAN IDENTIFIER are occupied by services type of message. Using 6 bits to identify the CAN node address. Thus the Message Format is defined as follows.

{type, commandID, node address, data length} for request message

{type, node address, data length, commandID, data} for others

3.3 Algorithm of position actuators¹

From S-H test apparatus, two sets of image points are obtained, one set of image points formed by the reference light point. The other set formed by the light reflected from the segmented mirror. There are three image points corresponding to a submirror. If the segmented mirror is co-focus, the two sets of image points are strictly similar in geometry. If the segmented mirror loses focus, the deflection can be rectified referred to the central submirror. Each submirror is corrected respectively according to the equation.

$$\begin{cases} a_{i1}d_{i1} + a_{i2}d_{i2} + a_{i3}d_{i3} = -(y_i - ky_{i0}) \\ b_{i1}d_{i1} + b_{i2}d_{i2} + b_{i3}d_{i3} = -(z_i - kz_{i0}) \\ d_{i1} + d_{i2} + d_{i3} = 0 \end{cases} \quad i = 2, 3, \dots, 24(37)$$

$$\begin{cases} a_{i1} = \frac{\partial y_i}{\partial d_{i1}}, & a_{i2} = \frac{\partial y_i}{\partial d_{i2}}, & a_{i3} = \frac{\partial y_i}{\partial d_{i3}} \\ b_{i1} = \frac{\partial z_i}{\partial d_{i1}}, & b_{i2} = \frac{\partial z_i}{\partial d_{i2}}, & b_{i3} = \frac{\partial z_i}{\partial d_{i3}} \end{cases}$$

d_{i1}, d_{i2}, d_{i3} are the displacement of three position actuators of i th submirror, $a_{i1}, b_{i1}, a_{i2}, b_{i2}, a_{i3}, b_{i3}$ can be obtained by measurement or calculation. k is the linear dimension ratio of those two images triangles.

More information can be obtained from “Large sky Area Multi-object Fiber Spectroscopic Telescope and its key technology”.

3.4 Network experiment subsystem

A network experiment subsystem that contains 3 slave nodes and a master node is built in the lab. Slightly different from the frame described before, only one module of each slave node is used to control one actuator of a submirror, so three slave nodes are used to control a set of actuators for one submirror. Close-loop test has been done on the system and the result is as similar as that described in Section 2.3.

ACKNOWLEDGEMENTS

The authors acknowledge helpful discussions with Kunxin Chen and Zhengqiu Yao and Guoping Li. We also thank You Wang and Guanqun Liu and other mechanical and electronic technicians to help build the test system.

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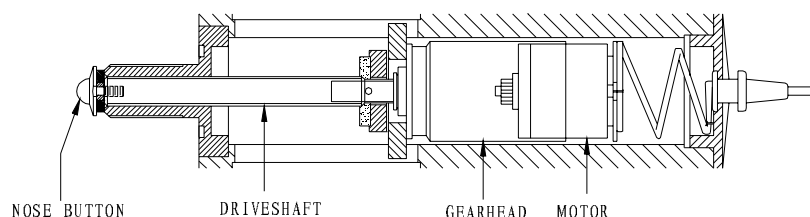


Figure 1 Schematic diagram of actuator

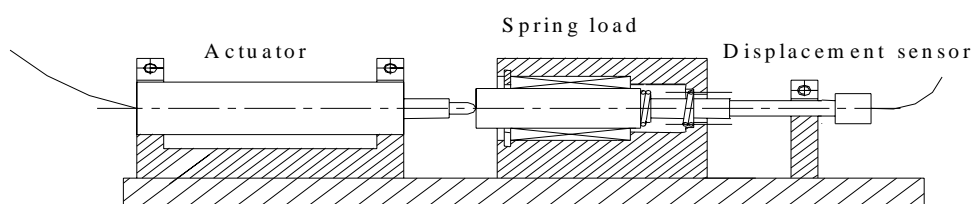


Figure2. Actuator test fixture

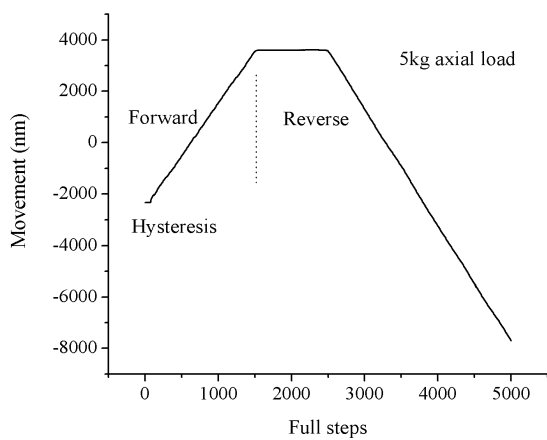


Fig 3 (a) Under 5kg axial load

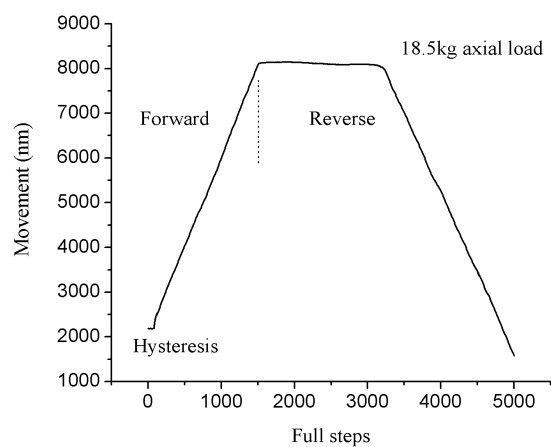


Fig 3 (b) Under 18.5kg axial load

Figure 3. Movement of actuator

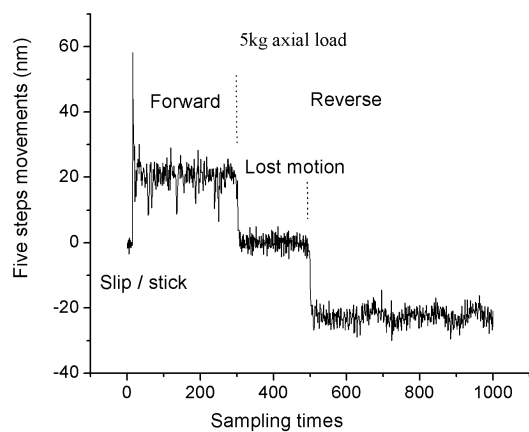


Fig4 (a) Under 5kg axial load

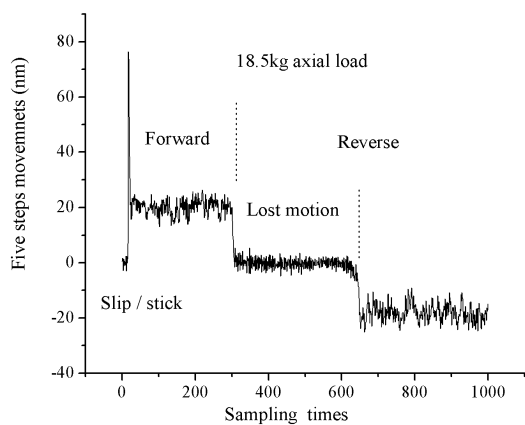


Fig4 (b) Under 18.5kg axial load

Figure 4. Five- step distance of actuator

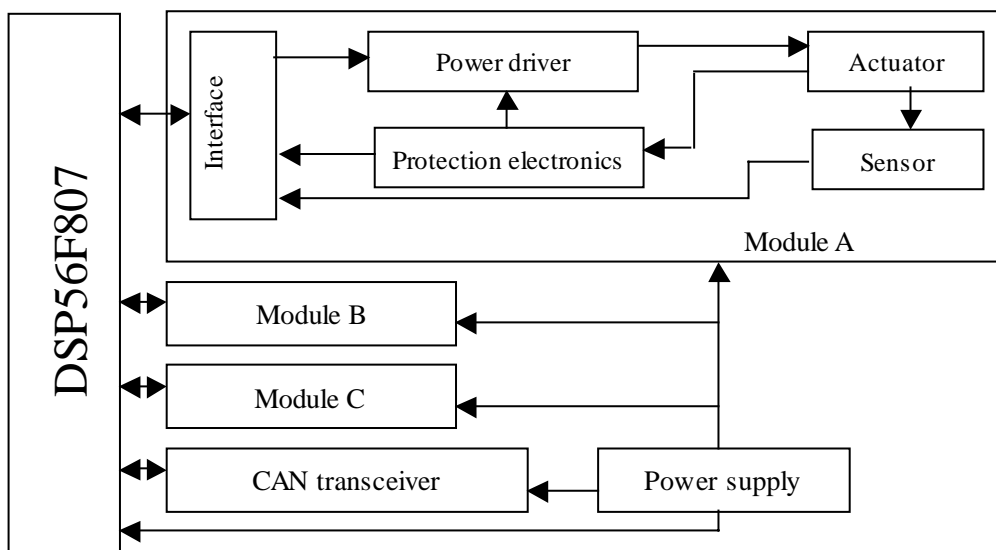


Figure 6. Block diagram of three actuators electronics

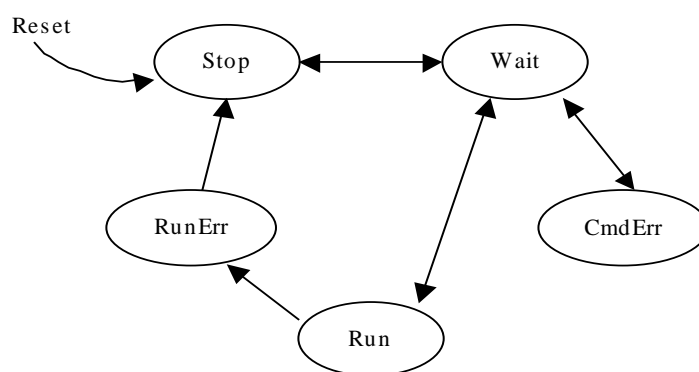


Figure 7. State transition diagram of actuator

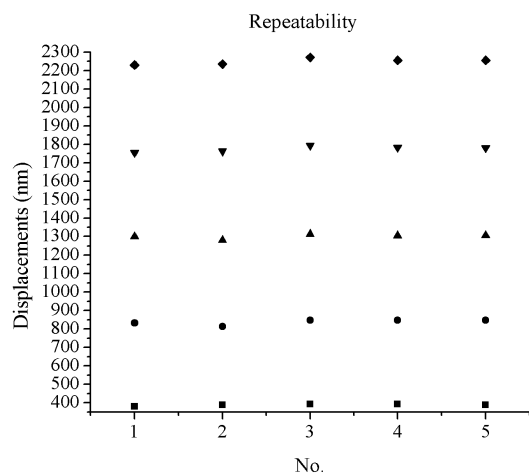


Figure 5. Repeatability test

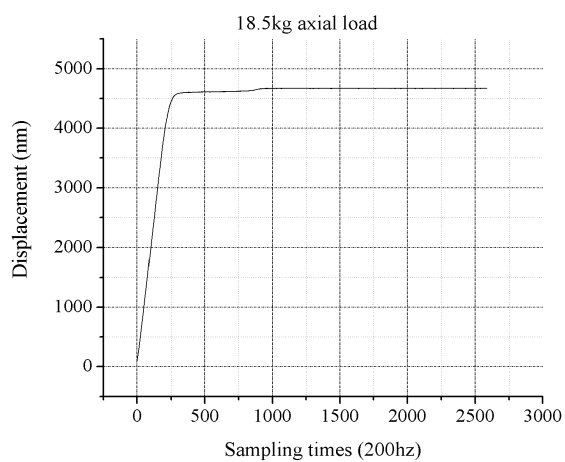


Figure 8. Close-loop test of actuator under 18.5kg axial load

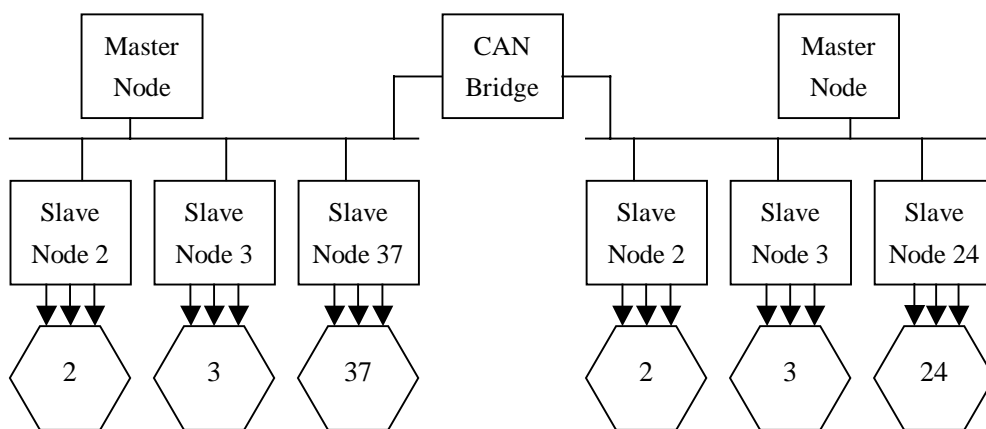


Figure 9. Block diagram of control network