# Control and network system of force actuators for deformable mirror active optics in LAMOST 

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#### Abstract

The reflecting Schmidt plate $\mathrm{M}_{\mathrm{A}}$ of LAMOST consists of 24 segmented hexagonal sub-mirrors. Each sub-mirror is 25 mm thick and 1.1 m in diagonal. There are 34 force actuators on the back of one sub-mirror which need to be controlled to offer precise load to create correct mirror deformation. This paper presents the control method and network configuration of force actuators for one sub-mirror. Master computer running Windows NT operation system and slave controllers running DOS operation system are connected together via Ethernet local area network (ELAN) by means of TCP/IP protocol. Adopting five slave controllers, 34 force actuators are combined into a distributed system. Master computer controls five slave controllers and five slave controllers operate 34 force actuators. Master computer communicates with slave controllers normally, which receives state of each force actuator from slave controllers and sends instructions to slave controllers via Ethernet LAN. Each slave controller operates 8 force actuators to offer correct load. Axial load capacity of force actuator is $\pm 150 \mathrm{~N}$ (pull and push) with accuracy $\mathrm{RMS} \leq 0.05 \mathrm{~N}$. Force sensor is used as close-loop feedback apparatus to detect the micro load of the actuator.


Keywords: Force actuator, Distributed control, Ethernet LAN

## 1. INTRODUCTION

Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST) is composed of three major parts, the reflecting Schmidt plate $M_{A}$, the spherical mirror $M_{B}$ and focus plane apparatus. $M_{A}$ and $M_{B}$ are both segmented. $M_{A}$ consists of 24 hexagonal plane sub-mirrors with 1.1 m in diagonal and 25 mm in thickness. $\mathrm{M}_{\mathrm{B}}$ consists of 37 spherical hexagonal submirrors with 1.1 m in diagonal and 75 mm in thickness.

Comparing those existed segmented mirrors of large telescopes in the world with LAMOST $\mathrm{M}_{\mathrm{A}}$, the remarkable characteristic of $\mathrm{M}_{\mathrm{A}}$ is that deformable mirror active optics technique and segmented mirror active optics technique are adopted simultaneously. Force actuator provides pull and push force to change mirror aspherical surface. The function of control and network system of force actuator is to realize deformable mirror active optics technique.

This paper presents control and network system of 34 force actuators in one sub-mirror, including hardware construction and network framework, software control method and deformable mirror active optics experiment. Force actuators supply different loads to maintain the sub-mirror to be a plane (accuracy error $\mathrm{RMS} \leq 0.04$ wavelength). The experiment result and the performance of control system of force actuators will be illustrated.

## 2. HARDWARE CONSTRUCTION

The control system of force actuator for one sub-mirror contains a master computer, five slave controllers, 34 force actuators, a switch and one sub-mirror. On the back of the sub-mirror, 34 force actuators are fixed to create precise mirror deformation. Five slave controllers (SC) running DOS operation system control these actuators. Master computer (MC) is an industrial personal computer running Windows NT operation system. MC and SC connect together via Ethernet local area network (ELAN) by means of TCP/IP protocol.

### 2.1 Slave controller

Each SC consists of four parts, PC104 board, force actuator control circuit board, A/D convert circuit and small-signal amplification board, which offers 8-channel signal input of force sensors and 8-path stepper motor output. The first four slave controllers control eight actuators respectively and the fifth slave controller controls only two actuators. The stepper motors (UBB2N08D15CNNP) are ordered from SAIA Inc. Force sensors (SN-200, Interface Inc.) are used as close-loop feedback apparatus to detect whether the micro loads of actuators meet the required value.

### 2.1.1 PC104 board

PC104 is a popular standardization for small computing modules and widely used in control systems. In this system, it is adopted NC-529 low-power embedded CPU mini-board (586/300M) with RS232/485 serial port, 100M Ethernet, LCD/VGA interface, DOC, Keyboard and Mouse, etc. Startup program and control program are stored in a Compact Flash card.

### 2.1.2 Force actuator control circuit board

The circuit board is composed of 32 Bit optoelectronic isolating I/O and 8-channel motor driver, which can control 8 stepper motors to work at the same time.

### 2.1.3 Small-signal amplification board

There are two amplifiers to amplify 8 channel small signals of force sensor. Magnification is 333. AD624 (Analog Device Inc.) is chosen as amplifier chipset. The voltage of high-accuracy driving source is +10 V and stability is $10^{-7}$.

### 2.1.4 A/D converting circuit

Converter element is AD676 (Analog Device Inc). The AD676 is a multipurpose 16-bit parallel output analog-to-digital converter which utilizes a switched-capacitor/charge redistribution architecture to achieve a 100 kSPS conversion rate ( $10 \mu \mathrm{~s}$ total conversion time). Overall performance is optimized by digitally correcting internal nonlinearities through onchip auto calibration. A/D converter circuit is shown in Figure 1.


Fig. 1 High accuracy 16 Bit A/D converter circuit

### 2.2 LAN framework

The frame work of LAN is dendriform. MC connects with SC via a switch. The speed of communication is 100 M . Figure 2 shows network configuration of one sub-mirror. LAMOST is consisted of 24 sub-mirrors. MC can connect SC via switches without changing the LAN framework of each sub-mirror.


Fig. 2 Ethernet LAN framework

MC can communicate with all slave controllers on the network at the same time. SC collects the status of each force actuator and transfers these data to MC. MC analyzes data and sends instructions (pull or push force) to SC. Then SC controls actuators to reach exact stress application.

## 3. SOFTWARE CONTROL METHOD

The system is on and initializes first, five slave controllers control 34 force actuators to be waiting state. Then MC sends data to SC via Ethernet LAN. These data are a set of numerical values and can not be used directly to control force actuators. They must be calculated and get the right instruction. The calculating equation is a 34 dimension array.

$$
\begin{equation*}
\mathrm{F}_{\mathrm{Di}}=\mathrm{F}_{\mathrm{Oi}}+\mathrm{F}_{\mathrm{Li}} * \cos (\theta)+\mathrm{b}_{\mathrm{i}} * \cos (\theta)+\mathrm{F}_{\mathrm{Ci}} \quad \mathrm{i}=1,2, \ldots 34 \tag{1}
\end{equation*}
$$

$F_{D i}$ : the force objective value that No. i actuator should push or pull
$\mathrm{F}_{\mathrm{Oi}}$ : the value that No. i actuator should correct
$\mathrm{F}_{\mathrm{Li}}$ : when altitude angle $\theta$ is $0^{\circ}$, the most initial force value that No. i actuator supports
$\theta$ : the real-time altitude angle during observation
$b_{i}$ : the real-measured coefficient of actuator's dead weight (including force sensor) when the telescope is working from $0^{\circ}$ to $90^{\circ}$
$\mathrm{F}_{\mathrm{Ci}}$ : the open-loop force value that No. i actuator should push or pull. Due to the tracking process during observation, $\mathrm{M}_{\mathrm{A}}$ aspheric surface is variable. The open-loop force value of each actuator is inconstant.

MC solves the array equation, gets the force value that actuators should push or pull, computes the steps that stepper motors should rotate and concludes the move way. Then MC sends data to five slave controllers and instructs them to manage 34 actuators move simultaneously. When one actuator reaches the objective value, the corresponding SC manages to stop this actuator and sends a HOLD instruction. The actuator then is in low-power mode, which can reduce heat to impact optical system. Figure 4 is MC and SC control flowchart.


Fig. 3 MC and SC control flowchart

## 4. DEFORMABLE MIRROR ACTIVE OPTICS EXPERIMENT

### 4.1 Scaling test of force actuators

The requirements for force actuators used in LAMOST are listed below:
(1) Axial load capacity $\pm 150 \mathrm{~N}$ (pull and push) with an accuracy 0.05 N (RMS);
(2) Axial load frequency 1.5 minutes one time;
(3) Correction time $\mathrm{t} \leq 10 \% * 90 \mathrm{~s}$;

There are 816 force actuators in LAMOST $\mathrm{M}_{\mathrm{A}}$. Each actuator must be test to meet the challenge. The test contains initial value of actuators, working range, close-loop linearity and equivalent value of sensors.

The working range $( \pm 150 \mathrm{~N})$ is divided into 750 points. Get state of actuator at each point and test whether the force accuracy meets the requirement. The max error of each point is 0.1 N (absolute value). The root-mean-square error of 750 points is lower 0.05 N . Figure 4 shows close-loop test results of two force actuators which are selected in random.


Figure 5 Close-loop test results of two force actuators

### 4.2 Deformable mirror active optics experiment

Figure 6 shows the LAMOST $\mathrm{M}_{\mathrm{A}}$ sub-mirror deformable mirror active optics experiment. The sub-mirror is located on the shock isolation flatform of which 34 force actuators are fixed on the back. Optical system detects the surface and transfers force data which should be pushed or pulled on the mirror to MC. Then MC controls force actuators and tries to make the surface as smooth as possible. After $3 \sim 4$ times active correction, the root mean square of wave front error is under 0.04 wavelength ( about $25.3 \mathrm{~nm}, \lambda=632.80 \mathrm{~nm}$ ). See figure 7 . The spending time of force actuator for close-loop control is 7 to 35 seconds ( $1 \sim 3$ times close-loop control ). One times close-loop control time consists of sampling time, computing time, state display time and waiting for force actuator steady time, which totally is about 7 to 10 seconds. The spending time ties with the force. The bigger the forces are, the longer the control time spends. Sub-mirrors contain No.12, 13, 16, 17, 21, 22. The active correction results are shown in table 2.

|  | 12 | 13 | 16 | 17 | 21 | 22 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| RMS(wavelength) | 0.034 | 0.038 | 0.038 | 0.037 | 0.04 | 0.031 |
| PV (wavelength ) | 0.245 | 0.246 | 0.303 | 0.266 | 0.286 | 0.225 |
| $80 \%$ light concentration ( <br> arc-second ) | 0.717 | 0.707 | 0.729 | 0.712 | 0.802 | 0.539 |

Table 2: Active correction results of six sub-mirrors


Figure 6: Sub-mirror deformable mirror active optics experiment

| Measurement Parameters |  |
| :---: | :---: |
| File: | r2-20070316-1409 |
| Wavelength | 632.80 nm |
| Wedge | 0.25 |
| $\mathrm{X} / \mathrm{S}$ Size | $480 \times 736$ |
| Pixel size | 0.00 um |
| Date | 03/16/2007 |
| Time | 14:10:44 |
| Analysis Results |  |
| Ra | 0.029 wv |
| Rms | 0.037 wv |
| 20 Pt . PV | 0.266 wv |
| 2 Pt . PV | 0.34 wv |
| Analysis Parameters |  |
| Terms | Tilt Trim1 |
| Pupil | 100\% |
| Masks: |  |
| Filtering | None |
| Data Restore | No |
| Valid Points | 101401 |



Figure 7: Deformable mirror active correction result

### 4.3 Precision analysis of force

During the control process in experiment, the state of force actuators should be analyzed. Table 3 is the state of force actuator for one times close-loop control. The deal force is the sum of initial force and the correction force for each force actuator. The practical force is the sensor sampling value of each force actuator after close-loop control.

| No. | Initial force <br> (N) | Correction force <br> (N) | Ideal force <br> (N) | Practical force <br> (N) | Error <br> (N) | Error rate (\% ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 28.4785 | -1.79321 | 26.68529 | 26.6839 | -0.00139 | -0.005208863 |
| 2 | 0.8532 | 0.882723 | 1.735923 | 1.8731 | 0.137177 | 7.902251425 |
| 3 | 7.2079 | -0.85331 | 6.35459 | 6.4135 | 0.05891 | 0.927046434 |
| 4 | 14.0137 | 2.283734 | 16.29743 | 16.2888 | -0.00863 | -0.052953121 |
| 5 | 11.6503 | -0.86316 | 10.78714 | 10.8462 | 0.059062 | 0.547522429 |
| 6 | 20.643 | 1.46345 | 22.10645 | 22.1336 | 0.027151 | 0.122819364 |
| 7 | 4.6091 | -0.41729 | 4.191806 | 4.1874 | -0.00441 | -0.10520525 |
| 8 | 12.9448 | -0.10275 | 12.84205 | 12.8271 | -0.01495 | -0.116414435 |
| 9 | 23.0652 | 2.213653 | 25.27885 | 25.2815 | 0.002646 | 0.010467247 |
| 10 | 4.7268 | 0.16066 | 4.88746 | 4.8837 | -0.00376 | -0.076931576 |
| 11 | 12.7094 | 0.198931 | 12.90833 | 12.9448 | 0.036469 | 0.282522969 |
| 12 | 17.3872 | -1.35807 | 16.02914 | 16.0535 | 0.024364 | 0.151998221 |
| 13 | 4.2169 | 0.820857 | 5.037757 | 5.0406 | 0.002843 | 0.056433845 |
| 14 | 11.0031 | -0.40703 | 10.59607 | 10.5618 | -0.03427 | -0.323421827 |
| 15 | 12.4348 | -0.10486 | 12.32995 | 12.3368 | 0.006855 | 0.055596355 |
| 16 | 11.6699 | 0.68284 | 12.35274 | 12.3564 | 0.00366 | 0.029629054 |
| 17 | 2.7655 | 1.007199 | 3.772699 | 3.7658 | -0.0069 | -0.182892937 |
| 18 | 23.0652 | -2.71265 | 20.35255 | 20.3096 | -0.04295 | -0.211030026 |
| 19 | 7.6688 | -0.59894 | 7.069863 | 7.0804 | 0.010537 | 0.149041078 |
| 20 | 27.5077 | 0.721969 | 28.22967 | 28.302 | 0.07233 | 0.256219786 |
| 21 | 18.3875 | 2.793438 | 21.18094 | 21.1824 | 0.001461 | 0.006897711 |
| 22 | 6.4332 | 0.307217 | 6.740417 | 6.7764 | 0.035983 | 0.533839375 |
| 23 | 22.8789 | 1.272059 | 24.15096 | 24.193 | 0.042042 | 0.174080044 |
| 24 | 4.0796 | -0.45959 | 3.620014 | 3.6481 | 0.028086 | 0.775853353 |
| 25 | 8.62 | 0.090647 | 8.710647 | 8.6887 | -0.02195 | -0.251990466 |
| 26 | 15.2199 | -1.71067 | 13.50923 | 13.5038 | -0.00543 | -0.040194747 |
| 27 | 12.631 | 0.983582 | 13.61458 | 13.5724 | -0.04218 | -0.309814873 |
| 28 | 9.9636 | -2.41357 | 7.550028 | 7.5413 | -0.00873 | -0.11562871 |
| 29 | 7.7178 | 0.0969 | 7.8147 | 7.8061 | -0.0086 | -0.11004901 |
| 30 | 12.1799 | 0.149377 | 12.32928 | 12.327 | -0.00228 | -0.018492569 |
| 31 | 9.2084 | -0.5039 | 8.704495 | 8.6985 | -0.006 | -0.068929903 |
| 32 | 10.4049 | 0.421721 | 10.82662 | 10.8069 | -0.01972 | -0.182143625 |
| 33 | 29.6749 | -1.24886 | 28.42604 | 28.4883 | 0.062261 | 0.219028054 |
| 34 | 28.8512 | -1.53176 | 27.31944 | 27.3311 | 0.011657 | 0.042669245 |

Table 3: State of force actuator for one times close-loop control

The error of No. 2 force actuator is 0.137 N , which is far from the ideal force value. If this type of departure still exists after several close-loop control, it shows that No. 2 force actuator is abnormal and should be replaced.

## 5. CONCLUSION

The control system of force actuators has the following characteristics:
(1) PC104 bus is applied in SC. The voltage of high-accuracy driving source of small signal amplification is +10 V and stability is $10^{-7}$.
(2) Axial load capacity are $\pm 150 \mathrm{~N}$ (pull and push) with an accuracy 0.05 N (RMS). The total time of close-loop control is 7 to 35 seconds.
(3) Adopt centralized-distributed control method, MC changes the non-sphere surface in real time via Ethernet LAN.

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