LAMOST control system: past and future

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ABSTRACT

The project of much-anticipated LAMOST (Large sky Area Multi-Object fibre Spectroscopic Telescope) has successfully been inspected and accepted at national-level evaluation. It will become the world's most powerful meter-class level ground astronomical optical survey telescope. The ever-ambitious project throughout the development history of Chinese astronomical optics telescopes has brought an extraordinary challenge to its control system from all-round aspects. Painstaking effort has been made to the R&D of the control system from its design strategy, functionality analyses to most subtle technical solutions, and of course efficient engineering management is also included. A number of papers highlighting the anticipated LAMOST control system have previously been published during the course of the project evolving. However, much lesson and experience have been learned since 10 years ago. Now the telescope with all its facilities and observation chamber has been put into trial observation. This is the time to review the past and ponder over the future of the control system as a whole against the functional telescope in current reality. Lesson and experience are discussed. Some considerations for improving the system efficiency and the accessibility are presented too in this paper.

Keywords: control system, telescope, Lesson and experience, LAMOST

1. INTRODUCTION

The LAMOST telescope, one of the national large scientific projects was successfully inspected and accepted at national-level evaluation on June 4, 2009. It has become the world's most powerful meter-class level ground astronomical optical survey telescope with an effective aperture of over four meters, the biggest of its kind in the world with 4,000 optical fibers that can simultaneously track space and decode starlight into enormous amounts of spectrographic data. According to the inspection report the optical-mechanical-electrical design specifications have been met in general, and pointing accuracy 4.89 arc seconds, close loop tracking accuracy 0.64 arc seconds (RMS) as the motion control of the telescope mount concerned in particular. Now the giant structure of LAMOST stands tall and upright on top of a 960-meter hill 170 kilometers northeast of Beijing. It looks fantastic seen from outside shown in figure 1.

It has been more than 10 years since the project was funded by the Chinese Government. Painstaking effort has been made to the control system building and development, from its design strategy, functionality analyses to most subtle technical solutions. A number of papers highlighting the LAMOST control system have previously been published during the course of the project evolving. However, much lesson and experience have been learned. Now the telescope with all its facilities and observation chamber has been put into trial observation, soon ready to search on large scale into deep space for celestial bodies with high scientific output.

This is the time to review the past and ponder over the future of the control system as a whole against the functional telescope in current reality. Lesson and experience are discussed. Some considerations for improving the system efficiency and the accessibility are presented too in this paper.

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Figure1:LAMOST stands on top of a 960-meter hill

2. RESEARCH ROAD MAP

1. Background

The national major scientific project was first initiated by the CAS (Chinese Academy Sciences) and later officially recognized and funded by Chinese Government more than 10 years ago. This is an astronomical optics survey telescope with enormous potential ability of data acquiring, actually no. 1 in the world. It is ambitious project with decades' dream of Chinese astronomical community. However, at the time of the project initializing the largest previously ever built astronomical optics telescope in Chine was an equatorial telescope with diameter of 2.16m. Obviously this meant a big jump, a milestone for Chinese astronomical community. Also at the time of the project initializing PC, IT, Internet and advanced automation techniques, all highly regarded necessary for building LAMOST telescope, were still quite new and lacking in China. Tremendous challenge was presented before all the members of design team inclusive of control design group, who were greatly inspired by such a high profile of the project objective. As control technology is updating and advancing the R & D of LAMOST control system has always been coupled with it.

2. Design philosophy

The design philosophy of the telescope control system is guided by contemporary control theory in conjunction with a number of interdisciplinary cutting edge technologies. The control system as a whole is built on a network platform facilitated with a real time database. Thus the engineering design concept with research practice has guaranteed that the system features:

- High accuracy and automation
- Real time
- Reliability,
- Networking based, multilayer, distributed and expansibility

The control system mainly consists of 3 subsystems at first level:

- High accurate tracking system with large moment of inertia driven at ultra-low speed to operate the MA alt-azimuth mount, the rotation of field of view on the focal plane as well as the guiding correction applied to both altitude and azimuth axes of the mount and the axis of the field of view.

- The system of thin mirror active optics correction and segmented mirror co-focusing correction to drive approximate 1000 force actuators and displacement actuators in total under active control with quick response and high accuracy.
- The system of real time environmental monitor & control and fault-diagnosis including the dome control, temperature monitor & control in the observational chamber, the wind screens and the ventilation windows control, the rain and dew monitor & control, the alarming facilities, the remote monitor and control, etc.

3. Road map of the control system building

- Preliminary study and concept design. This is completed to the end of last century.
- From 2000 to 2005
  - ✓ Marketing investigation and commercial procurement. National and international collaboration.
  - ✓ Model mount with alt-azimuth structure applied with both drive servo simulation and active optic control simulation. The model mount called small LAMOST in LAMOST jargon actually is a model telescope set up at the campus of NIAOT (Nanjing Institute of Astronomical Optics & Technology) to better understand and predict to some degree the telescope's performance in reality. The test setting simulates the way of the star ray coming, through the model telescope and finally forming an image on the focal plane. The optical configuration is illustrated in figure 2. In the test only one segment mirror is taken as the corrector, and one spherical segment mirror is taken as the primary, which in the reality also consists of 37 segment mirrors. The distance between the corrector and the primary is 40 meters with the focal plane in the middle of the two. The primary is stationary on the foundation, presenting another distinguishing feature from conventional ones. The corrector rests on the model mount and follows the star passage during the observation. Primarily the test is meant to demonstrate the active force correction of the corrector while tracking. Many factors contributing to the tracking performance in the test will come to play too for LAMOST under site circumstances. The test is vital and meant to assure the group members of the success with the final LAMOST version.
  - ✓ Engineering design of LAMOST control system.
  - ✓ Lab simulation of LAMOST control network at different levels, and a real-time database for LAMOST network was built.
  - ✓ Workshop test of drive servo on the alt-azimuth structure before transportation to Xinglong site.
  - ✓ Workshop test of drive servo on the focal plane structure before transportation to Xinglong site.
- From 2005 to June 4, 2009
  - ✓ Site network set up.
  - ✓ Installment of mechanical and electrical hardware and software on site.
  - ✓ Hardware and software on site test.
  - ✓ Inspected and accepted by CAS.
  - ✓ Inspected and accepted by Chinese Government.
- From June 4, 2009 to date
  - ✓ Weather station devices set up.
  - ✓ Further improvement in the aspects of electromechanical unification.
  - ✓ Further improvement in the aspects of active optical control for higher scientific output.
  - ✓ Endeavor to get ready soon for routing observation.

3. THINGS DESERVING SPECIAL MENTION

As a telescope-specific control system it is meant to unconditionally satisfy error budgets from overall telescope design specifications. Normally this means to listen and try to understand what requirements are from structural design perspective, generally from optical configuration for particular optical telescopes, the LAMOST in our case. In the final analysis, the LAMOST is unique in the sense that such optical unconventional concept has never been known until its berth. With such a design concept big advantage has been gained. That is LAMOST combines both large clear aperture and wide field of view into one single sky-monitoring instrument, which enables the highest spectrum acquiring rate in the world. Yet at the same time it has brought an extraordinary challenge to its control system. Figure 2 shows the simplified schematic for LAMOST optical configuration. The telescope's reflecting Schmidt corrector consists of 24 segmented mirrors, which need to be under co-focusing control. And each segment surface has to be corrected by active force for better image quality. Moreover during the observation the corrector has to be driven on both azimuth and altitude axes. The combination of these four controls stated above and applied on one Schmidt corrector mirror are:

- active optical co-focusing by displacement actuators,
- active optical shape correction by force actuators,
- azimuth drive
- altitude drive

This modes combination on the corrector is unprecedented among all known astronomical telescopes in the world. However, it has given LAMOST control engineers unprecedented challenge technically. The mount drive of the control system must drive the giant corrector at the velocity of sub arc-seconds per second, a typical difficult issue of motion control at extremely low speed with large inertia. The above is just a concept. The following is to better elaborate.

- The global corrector in LAMOST actually consists of 24 segmented mirrors. Azimuth axis is driven by azimuth drive torque produced by 3 pairs of motors, and altitude axis is driven by altitude drive force produced by 2 motors. On both axes friction drive is applied. The azimuth drive servo loop and the altitude drive servo are electronically independent from each other. This motion drive mode is nothing new from what we have seen on conventional mount drive of large astronomical telescopes. Figure 3 shows mount drive schematic.
- Several tens of force actuators are attached on each segmented mirror to change the surface of the segmented mirror during telescope tracking according to certain predefined rules. The problem is that the surface change of segmented mirror will inevitably change the corrector global axis, thus affects the pointing and tracking stability. Some people may argue that the change is so small that actually can not affect the tracking stability at all. However this is not true. Based on our site test the worsening did occur, no matter how little it is, seen from the CCD image on the focal plane during pointing and tracking. What is more, the mount servo loop can do nothing about it, because these elements by their nature can not be included in the mount servo. So far we reduce the deterioration by introducing the CCD feedback signal into the mount servo. Of course this does not serve the blind tracking because of no CCD involved. Another consideration to solve the problem is on the assumption that all the facts stated above contributing to optical axis error are predictable during tracking by pre-calculation, although very much complicated and subtle. Therefore it can be coded in servo software to compensate the error. We have not conducted such a research yet. Now it is time to do it to further improve the performance of both active optical control and mount tracking.

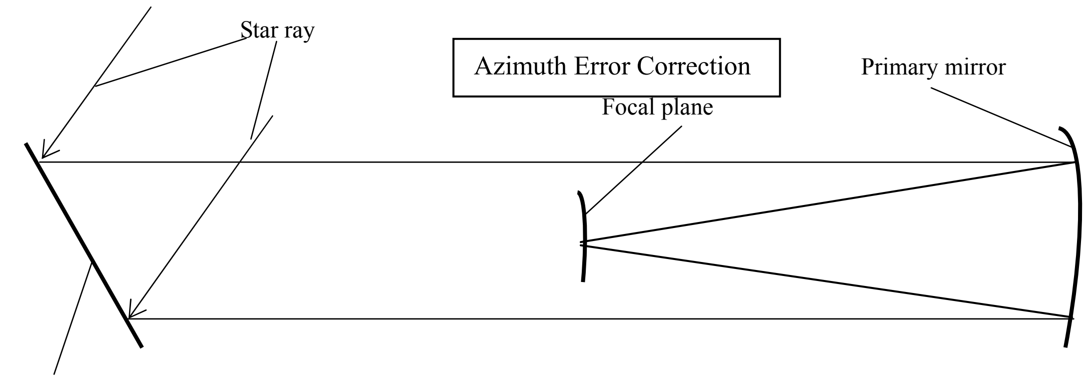

Figure2: Simplified LAMOST optical configuration

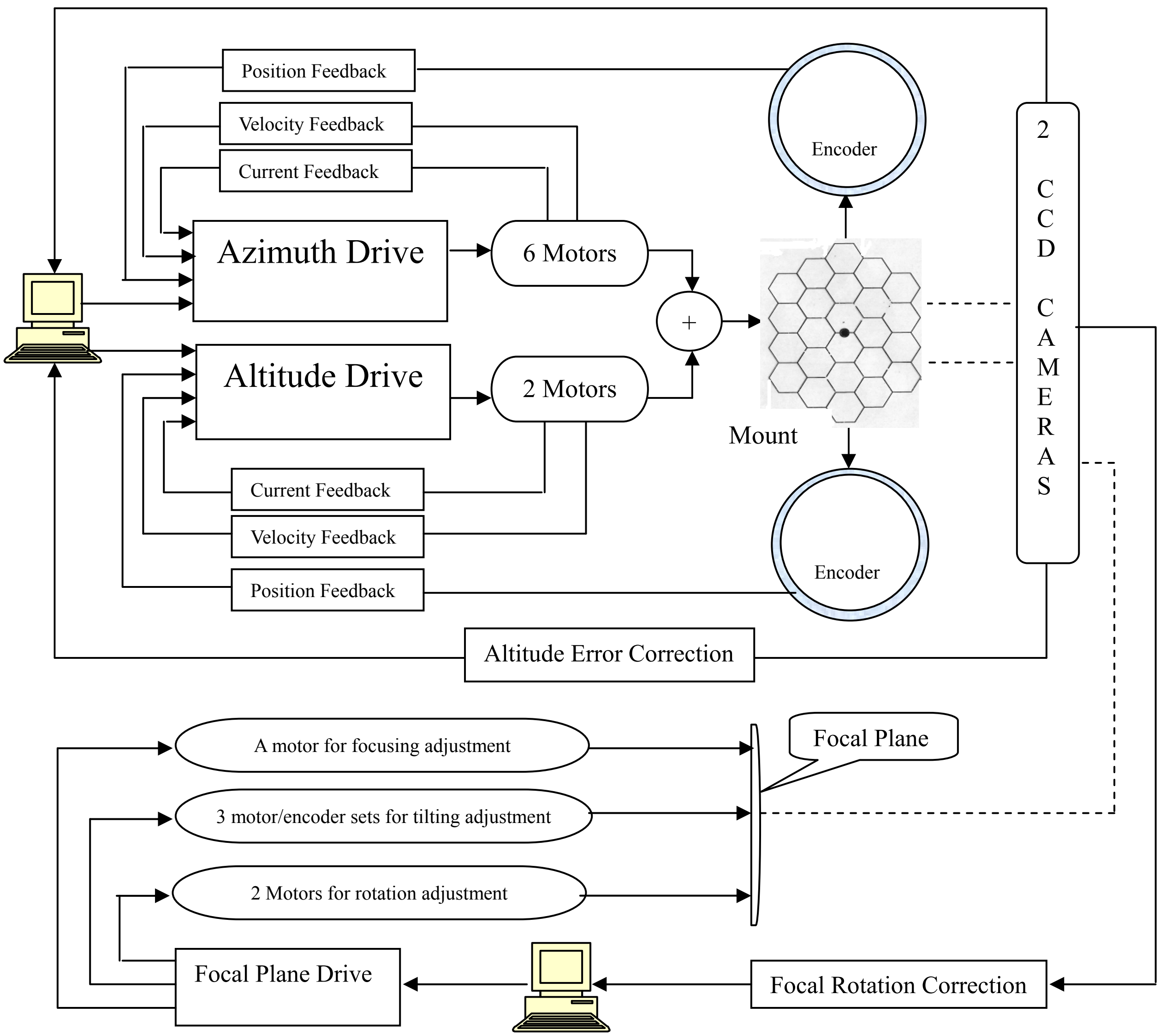

Figure 3: Mount drive and focal plane servo schematic

- On each corrector segmented mirror 3 displacement actuators are attached to do co-focusing of segments as a whole. This does not seem to much interfere with the mount performance because of actuators' low adjustment frequency, normally at the level of once every several ten minutes. However the application of both force active and co-focusing active on one corrector mirror has been unprecedented in the world. Before LAMOST there was only one kind of controls, either force active or co-focusing active technique, applied on a given mirror. This way of combining 2 techniques in LAMOST case on a given mirror is for reducing the cost to meet the budget yet might trigger some interference from each other , one of most difficult issue in the area of optical active control system. Deep and further research on solving the possible interference is necessary. Having said this by no means the implication of successful LAMOST way in this regard should be ignored. Because you can not get a whole mirror with diameter, say of more than 8 meters for future large optical telescopes. In this situation here is the successful example of LAMOST to shed some light on how to deal with the problem.

4. SUMMARY OF LESSON & EXPERIENCE

In the course of 8 years of R & D for the control system. Painstaking efforts have been paid during the years' process, and useful experiences have been accumulated.

- Looking back on the project progress, preferably the campus model mount test, which is actually a preliminary test but not middle term test, should be conducted before the project was recognised and funded by the Government not after. The reason is obviously. Because the principle of unconventional design should be validated and practically tested before funded by the Government. After funding there should be basically engineering work left.
- In the budget phase it is important to carefully make performance-cost analysis. Blindly pursuing economy in the beginning often turns to be extra money investment in the end. It is especially true for those hi-tech projects. For example, we had decided to build dome drive with a variable frequency speed regulator, which was quite popular. But for economic reason we were told to use relay control, which turned to be poor in speed regulation. Finally the choice of variable frequency speed regulator was back again but with extra money and time consuming. There are some other similar cases too.
- A good earth connection is always one of most critical site conditions for all control tests. We had the lesson that at the first stage of the test a lot of abnormal and unaccountable encounters appeared. With a great effort, the earth resistance has been reduced to less than a couple of ohms, and those unaccountable phenomena greatly subdued.
- Never neglect those wires and cables. Sometimes there are awful lot of them, which give you headache to cope with. Particularly a big bundle of cable incorporated in a servo loop might cause vibration and uncertainty. They must be dealt with carefully or use wireless control in stead if it is no problem.
- The electromechanical unification is crucial for any high-end drive system. This means that the performance of any drive servo depends on both electronics elements and mechanical elements in the drive chain. When problems arise both of electronics engineers and mechanical engineers should sit down and have a talk to solve the problems. Fighting and evasive attitude do not help. This is easy said than done. Frequently we do not know who is to blame, or who should be to blame more. In our experience, more often than not, the electronics engineers are more active in finding problems since the problems do not come to surface until the drive system is powered and electrically tested, but the mechanical engineers often play more vital role in the rigidity-associated drive system. Only that both sides properly deal with electromechanical unification will help.

5. FUTURE

Now the giant structure of LAMOST stands tall and upright on top of a 960-meter hill. Chinese scientists have long considered to utilize the country's big astronomical facilities to make research breakthroughs. The network of virtual observatories might be a wise way to utilize the survey capability of not only LAMOST, but also an on-duty 2.4-meter aperture telescope in Lijiang, Yunnan Province, and several smaller ones. Data-mining technologies would substantially help astronomers onto the fast track for pinpointing new finds in deep space. In a word to get ready to put the telescope in routing observation and gather enormous scientific output is the thing that the astronomical community worldwide would like to expect.

LAMOST is comprehensive in its control system with various kinds of cutting-edge technologies adopted. We must fully utilize the facility and make it accessible as much as possible. In this regard, roboticized LAMOST would greatly benefit astronomical amateurs in their exploring into mystery sky. Also the LAMOST will become important member of network of virtual observatories, a base for cultural and scientific exchange internationally.

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REFERENCES

1. Shou-guan Wang, Ding-qang Su, Yao-quan Chu, Xiang-qun Cui and Ya-nan Wang, Special configuration of a Vary Large Schmidt Telescope for Extensive Astronomical Spectroscopic Observation, Applied Optics, 1996,35,5,55.
2. Ding-qiang Su, Ya-nan Wang,"The Tracking Motion of the Large Sky Area Multi-object Fiber Spectroscopic Telescope (LAMOST)", ACTA ASTROPHYSICA SINICA, Vol. 17 No. 3, 1997.
3. http://www.china.org.cn/china/sci_tech/2008-11/05/content_16716724.htm
4. Xinqi Xu, "Control system and technical requirements - preliminary design", LAMOST Internal Technical Report, 1998.
5. Xinqi Xu, The Control System of LAMOST Telescope, Vol. 20 Supplement, ACTA ASTROPHYSICA SINICA, 2000, P.43-52.
6. Xinqi Xu, Jun Zhou, Lingzhe Xu, Software simulation of the LAMOST control system, SPIE Volume 4757, 2002, P.145-153
7. Xinqi Xu, Lingzhe Xu, Gangping Jin, Overview of LAMOST control system, SPIE Volume 4837, 2002,