Overview of LAMOST control system

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ABSTRACT

Based on an unconventional design concept the LAMOST telescope will become the world's most powerful meter-class level ground astronomical optical survey telescope when it is completed. From technical perspective the goal with such a high profile has brought an extraordinary challenge to its control system. For better image quality the telescope's segmented reflecting Schmidt mirror has to be actively controlled by nanometer technique. At the same time the mirror is driven on both azimuth and altitude axes in subarcsecond accuracy for tracking the star. Vigorous study has been done and a number of cutting edge techniques are applied to meet the tough requirements. This paper gives the overview of LAMOST control system, outlines its distributed, real time, reliable and expansible configuration and the simulation approach. The current status of the control system is briefly reported in this paper too.

Keywords: Lamost Telescope, Control System, Overview, LAN

1. INTRODUCTION

The unconventional optical configuration of LAMOST will make it by its completion the world's most powerful meter-class level ground astronomical optical survey telescope that will be able to observe 4000 celestial objects simultaneously. The price of such a unique design philosophy is an extraordinary technical challenge. The aspherical surface of the Schmidt corrector mirror M_A should change precisely based on a certain rule during the observation to compensate the aberration. At the same time M_A will be driven on both azimuth and altitude axes in subarcsecond accuracy for tracking the stars. Moreover, both the M_A and the primary mirror M_B are segmented mirrors in order to reduce the cost. Therefore three cutting edge control techniques, namely tracking, thin mirror active force optics correction and segmented active optics for co-focusing, would be applied in coordination to M_A in real time in the way that never before has any known astronomical optical telescope ever done in the world. In addition, the positioning of 4000 fibers each manipulated by two motors with a couple of tens of micros accuracy is another headache. Of course, the realization of such a task would put unprecedented challenge to our control group.

As a developing country China lacks the experience in building large astronomical optical telescopes. The previously largest one made ever in China was 2.16-meter equatorial telescope, which has been in routine operation at Xing Long station of Beijing Observatory since 1989. In many aspects the requirements for the 2.16-meter telescope's control system are not so much tough as for LAMOST. Our solution for the development of LAMOST' control system lies in the following approach.

- Make full use of latest technique that is advanced and has successfully been tried on a number of contemporary astronomical telescopes.
- Adopt as many commercial products needed as affordable.
- Conduct the research and development in partnership with a number of institutes in China that are in the lead of their respective technical areas pertain to LAMOST. Currently the consortium responsible for LAMOST control system is comprised of Nanjing Institute of Astronomical Optics & Technology, Beijing Astronomical

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Observatory and the University of Science & Technology of China. All of these three belong to the Chinese Academy of Sciences, and the former two are also members of National Astronomical Observatories.

- Invite a public bidding internationally in an attempt to attract most eligible bidders with cost effective solutions as nowadays the trend of global economy is becoming a fashion and China is no exception, let alone China was entitled to the WTO membership last year. However, we must bear in mind that no matter who we cooperate with we will be bound to conduct the development process in harmony and effectively so as to make the later transition from our contracts to LAMOST group as painlessly as possible.
- In the wake of rapid advance of computer, communication and control hi-techs the simulation technique is an inevitable means of tool for the development of complicated control systems for contemporary large astronomical optical telescopes. The LAMOST will be the first one ever in the evolution history of control systems for Chinese astronomical telescopes to apply such a comprehensive simulation methodology from level-0 to level 2 inclusive.

This paper outlines general aspects of the control system for the LAMOST with emphasis on its control architecture, key technical points involved, progressive simulation approach and interim test with a scale down real model.

2. HIGH LEVEL VIEW OF LAMOST CONTROL SYSTEM

Figure 1 presents the software design to show the control levels within the system and the control and data flows between the various systems and subsystems.

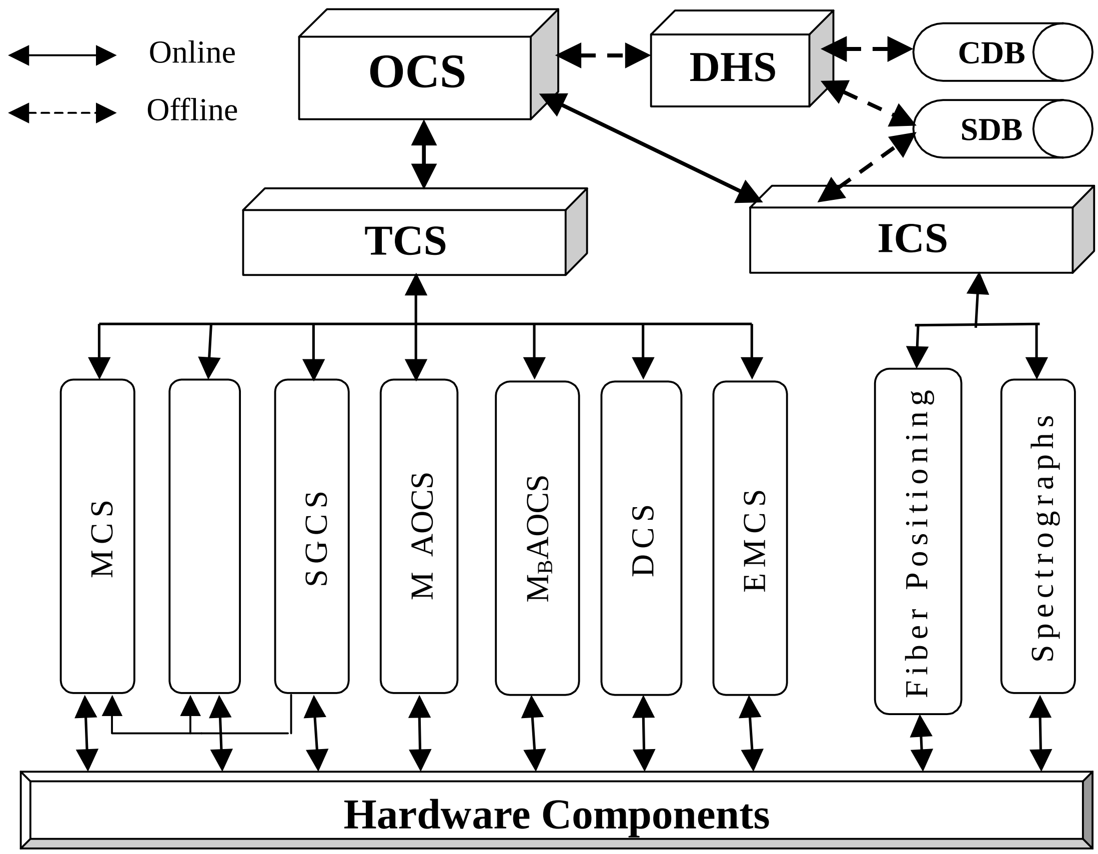

Figure 1: LAMOST high-level control and interfaces

- The Observatory Control System (OCS) is at the top in the hierarchy responsible for supporting the on-site observer and system operator in their tasks and coordinates the activities of the other three principal systems immediately at one level below the OCS in the hierarchy, namely Telescope Control System (TCS), Instrument Control System (ICS) and Data Handling System (DHS).
- The DHS archives the observed data into the Spectroscopic Database (SDB) and implements varieties of processes such as observation planning from the input Catalogue Database (CDB), image processing, spectrum analysis and data publish.
- The ICS controls the instruments, such as the fiber positioning system, spectrographs and CCDs.
- The TCS receives observation commands with coordinates of the right ascension and declination of the sky area center to be observed and manipulates its subsystems in conjunction with ICS to complete the pointing and tracking of the target. For better tracking the TCS might also get a set of guide stars' coordinates in the target sky area as the tracking references.
- A brief account of each subsystem of the TCS is given below.
  - ✓ The Mount Control System (MCS) is to slew the mount on both azimuth and altitude axis so as to get the target onto the center of field of view, and then keep tracking the target motion for a period of time.
  - ✓ The Focal Plane Control System (FPCS) is to adjust the focal plane's tip and tilt, and focusing before observations. During the observation FPCS provides a compensation for the rotation of the field of view.
  - ✓ The Star Guide Control System (SGCS) is to generate both the mount position error signals and the focal plane rotation error signals during an observation so as to close the tracking servo.
  - ✓ The M_A Active Optics Control System (M_AAOCS) is to implement two kinds of active optics corrections, one being the force active correction applied by a couple of dozens of force actuators on the M_A to modify its surface shape for better image quality and the other being active co-focusing applied by 3 displacement actuators on each segment of M_A, which consists of 24 segments in total, for image stack.
  - ✓ The M_B Active Optics Control System (M_BAOCS) is to implement an active co-focusing applied by 3 displacement actuators on each segment of M_B, which consists of 37 segments in total, for image stack.
  - ✓ The Dome Control System (DCS) is to manipulate the dome and its accessories in accordance with the observation.
  - ✓ The Environment Monitor & Control System (EMCS) is to monitor or adjust the meteorological conditions in the enclosure, and provide safety and alarm mechanism.
  - ✓ Normally, the TCS subsystems do not communicate directly with each other. The exception is that the error signals generated by the SGCS might feedback directly to the MCS and the FPCS for better servocontrol.

3. TCS NETWORK LAYOUT

The TCS LAN layout is shown in figure 2, which features distributed, hierarchy and expandable. A Local Control Unit (LCU) with embedded QNX microkernel and task specific codes controls each main hardware component. QNX is one of well-known real time operating systems on the current world market. The cost effectiveness of the QNX contributed to our consideration of choice of real time system under our limited budget. The LAN is built on Ethernet connection with TCP/IP standard for data traffic. In addition, there is also proprietary Fleet protocol among the QNX nodes machines, which makes them behave like a virtual computer with combined individual computer capacity, resources shareable and transparency. The idea to employee LCUs is to isolate the hardware components from the TCS main working station and lend a hand to software programmers to write high-level software module without worrying too much the specific nature of each hardware component. Obviously such a network layout is characterized with plain module design, economy and easy maintainability.

The network time scale is generated by a GPS based unit. The major component of the unit is a GPS receiver GSU-25 made in Japan, which possesses 12 reception parallel channels, 1Sec. ± 300ns time mark pulse, 10KHz time mark pulse that is synchronized to the UTC time mark pulse. The receiver gets GPS signals from a number of GPS satellites, usually more than 3, and processes the information and again in conjunction with the 1second time mark pulse and 10KHz time mark pulse by a home made hardware gadget to acquire 0.1ms accuracy synchronization time tick in the time server on the LAN. The time server in turn may either actively distribute or passively get the time synchronization requests to or from various nodes on the LAN. Typically the time scale among the real time QNX nodes can thus reach 1ms accuracy thanks to the Fleet protocol, which is enough to meet all the real time task requirements for LAMOST.

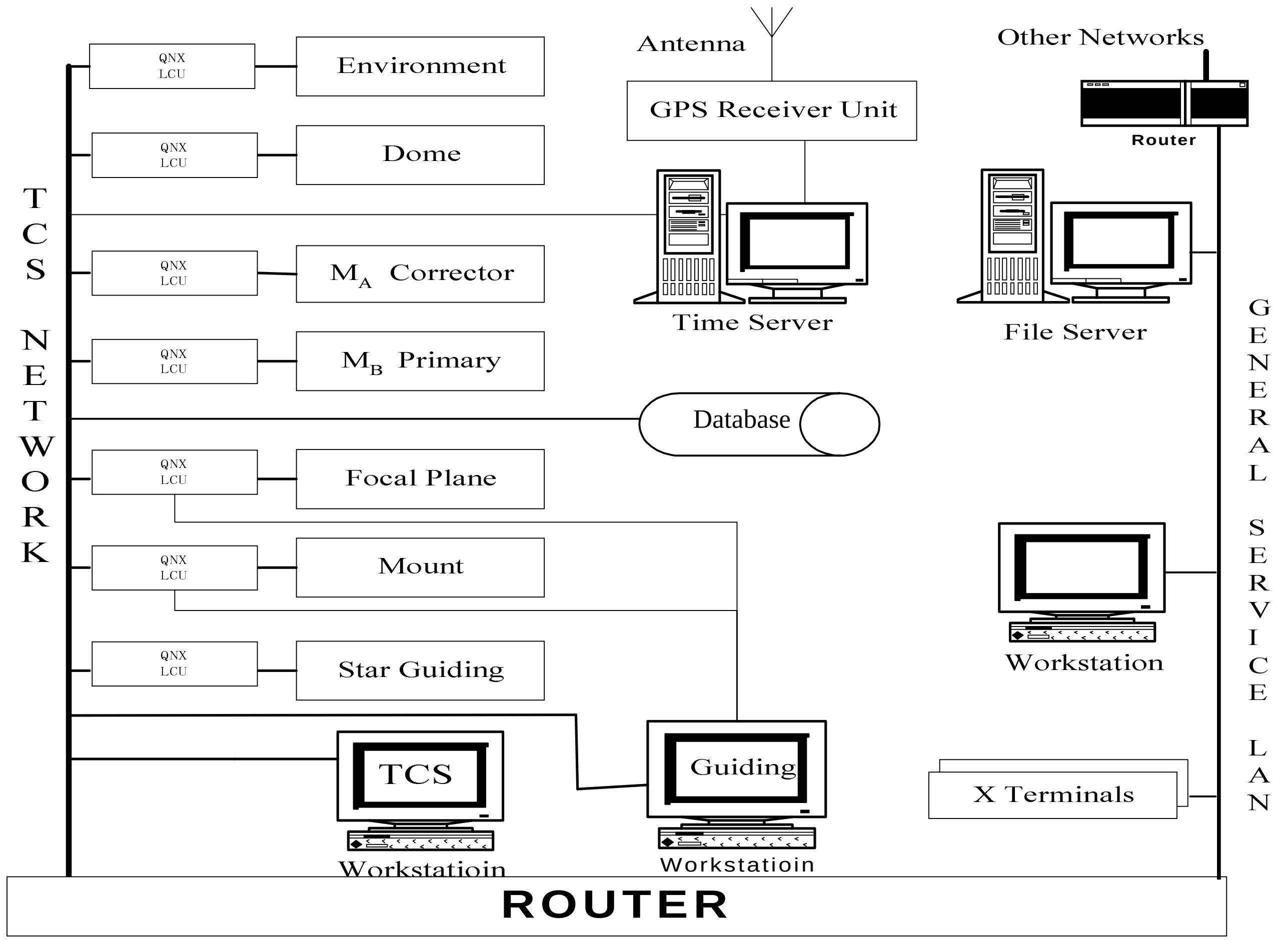

Figure 2: TCS Network Layout Schematic

A provisional real time distributed database containing about 13 thousand of lines of C source codes has been built on the Empress platform, evaluation version 8.60, under QNX OS environment. It is an important mechanism for a variety of system functions occurring on the TCS LAN such as recording various kinds of data for online data analysis or offline play back study. A number of advanced skills, such as the shareable memory and dynamic creation of objects and tables etc, have been implemented, which has made the database management system easy to manipulate with Windows style even it has been built under QNX, a Unix like OS. So far around 10 tables have been created shown below.

- The Mount Presetting and Tracking Table (MPTT).
- The OCS Command Flow and corresponding TCS Return Flow Table (CFRFT).
- The Active Optics Control Table (AOCT).

- The Device and Plug-In Card Parameter Table (DPICPT).
- The Environment Parameter Table (EPT).
- The Dome Control Table (DCT).
- The LAN Status Table (LST).
- On-Line Help Table (OLHT).
- The Debugging Table (DT).
- The On-Line Data Analysis Table (OLDAT).

4. SIMULATION APPROACH

The concept of virtual telescope that was originally associated with pointing/tracking has been around for a couple of decades. However as the advent of three "C" era, namely "computer, communication and control", the research and development of large astronomical telescopes have undergone a forward leap in the control system design from concept down to practice. As the PC still takes strong hold on the market, not showing any sign of post-PC as some experts predicted, more powerful yet cheaper PCs have come into being. On the one hand, taking such an advantage the network control mode plus a certain real time distributed operating system has become prevailing for almost all the contemporary astronomical telescopes. On the other hand, because of relatively long period of development, 7 years in LAMOST's case as scheduled, it is hardly anticipated that during the lab development all the hardware would be available, not to mention that some of hardware can never been installed until on site test. Therefore we have defined the simulator concept for LAMOST control system, which is an application, a complex software package that is operated on a local area network. The package comprises various function modules of different levels in the hierarchy, plus rich and friendly user interfaces. These modules and user interfaces run in accordance with a certain strict regulations to simulate all sorts of commands and status of hardware components in reality. However, any physical electro-mechanisms to be controlled in reality are not participated in the operation of the simulator.

The LAMOST simulation approach in its control system development is divided into three progressive phases from level-0 simulator up to level-2 as follows.

- Level-0 is a lowest level of the simulator giving the feel and look for the user interfaces. Virtual hardware components are represented with graphical sketches when needed to show on screens, and so is the status transition of components generated by the simulation status generator. One simple such an example is illustrated in figure 3 where a hand controller is shown. The user is asked to pre-select one of the three possible velocity and then keep press of the mouse on any direction key of the four possible choices, that way would make a virtual mount shown on another screen yet not shown here to move accordingly until the mouse is released. It is a visual simulation in its nature for user interfaces and gives responses graphically on the screens.

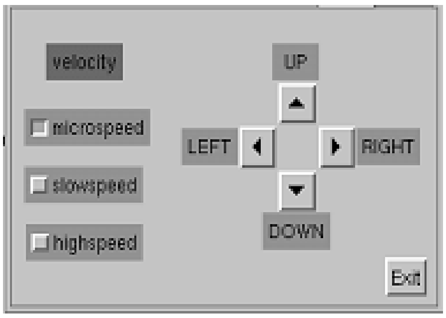

Figure 3: Hand Controller

- Level-1 is upgrade of the level-0 simulator with major portion of the codes for the basic LAMOST control modes available. For example, the code of some of such commands should be included as follows.
  - ✓ TcsSelfCheck: TCS-Self-Check command.
  - ✓ TcsCheckNet: TCS-Check-Network status command.
  - ✓ TcsCheckGps: TCS-Check-GPS time command.
  - ✓ TcsEnvironmentControl: TCS-Environment-Control command.
  - ✓ TcsOpenDome: TCS-Open-Dome command.
  - ✓ TcsPointingTo: TCS-Pointing-To command.

- ✓ TcsTracking: TCS-Tracking command.
- ✓ TcsStartGuiding: TCS-Start-Guiding command.
- ✓ TcsStandBy: TCS-Stand-By command.
- ✓ TcsBackHome: TCS-Back-Home command.
- ✓ TcsCloseDome: TCS-Close-Dome command.

The simulator of this level can work on its own with virtual hardware components, it should also, if needed, work for the real telescope on site to receive first light manually, which can be called hardware-in-the-loop simulation. Characterization of the mount drive servo and the actively controlled optics has to be done during this phase in order to get important parameters for the simulator. Moreover, as aforementioned a provisional real time distributed database has been built at this level in assistance to the simulator to play a variety of functions.

- Level-2 is upgrade of the level-1 simulator, a comprehensive working software package featuring fully automatic with all codes needed available. The simulator should work almost perfectly in reality on site, and provide simulated operation environment in lab for the users perfectly.

5. TELESCOPE MOTION CONTROL

The tracking error budget after offsetting the drift by guiding is 0.64” (RMS), which reflects about 0.32” (RMS) tolerance on the mount motion because it is the normal of the M_A that is tracking the star in LAMOST unconventional optical path design. Moreover, the mount tracking is a combined motion of both the azimuth axis and altitude axis, which results in 0.23” (RMS) on each axis approximately.

In order for satisfying the requirement vigorous study and investigation have been carried out, and the following table outlines the mount drive and gives various parameters in mount servo drive.

Azimuth

Locked rotor frequency-- 10 HZ
Moment of inertia---2.02e5 kg-m^2
Variation of friction torque--2000～4000 N-m
Drives-------6 friction-coupled drive motors with 60^0 apart between 2 adjacent motors. The motors are products of KOLLMORGEN, model D103A, peak torque 305 N-m, rated speed 2 rps, rotor inertia 0.175 kg-m^2, maximum steps/rev 1048576 giving the resolution of 0.027” on the axis with drive disk ratio of 45.
Drive disk ratio---45
Encoder-----tape encoder, product of HEIDENHAIN, model ERA 780C with 90000 lines giving 0.08” accuracy when with 8 scan-units and after star correction.
Maximum angle acceleration---0.5^0 / s^2

Altitude

Moment of inertia --1.99e4 kg-m^2
Variation of friction torque--320～800 N-m
Drives-------2 friction-coupled drive motors. The motors are the same as for azimuth yet giving the resolution of 0.03” on the axis with drive disk ratio of 40.
Drive disk ratio---40
Encoder-----same as for azimuth

Maximum angle acceleration---0.5^0 / s^2

The following table shows the requirements and electronics for the focal plane control.

Focusing range---±50mm
Focusing accuracy---±0.1mm

Focusing detector----------A slim grating with length of travel ±50mm and 100 raster lines per millimeter corresponding resolution of 0.01mm or a linear motor with equivalent resolution depending on the mechanical realization.

Tilting adjustment range---0-6'
Tilting adjustment accuracy--±20"

Tilting adjustment---------The tilting of the focal plane is collectively determined by 3 sets of tilt adjusting gadgets, each of which consists of a motor with a coaxial encoder. The motor step resolution is 0.01mm. Based on the tilting requirement of the focal plane the amount of adjustment for each motor-encoder gadget can be drawn from a set of equations corresponding to that requirement.

Tracking range---$\pm 22.5^0$
Tracking accuracy---±3"

Tracking servo-------------A pair of motors is friction coupled to the two ends of a diameter of the focal plane rotation disk. The angle readout and feedback are realized by an inductosyn with resolution of 1 arc second. During tracking process of celestial objects the focal plane is under a PID servo control to compensate the star image rotation.

Tracking velocity--0"-15"/S
Maximum velocity---1^0/S

Figure 4 shows the mount drive and focal plane servo schematic. The servo features 4 cascade feedbacks, and the innermost loop is closed by a current feedback for a better disturbance immunity due to the friction torque variation. The next loop immediately encompassing the innermost is the analog velocity feedback aimed to smooth velocity variation. Next again is the position feedback by means of an encoder with 8 scan units for a better readout accuracy generating the mount axis angle at frequency of a fixed value between 20~50HZ. The outmost loop is completed optic-mechanic-electronically with 2 CCD cameras detecting guide-stars and generating error signals at 0.1~1HZ for the mount drive and focal plane drive compensation respectively. The idea of adopting 2 CCD cameras is because the LAMOST is a survey telescope with 5^0 field of view and 4000 stars to be observed simultaneously. Consequently, the sky area for each observation should be accurately positioned onto the field of view of the telescope. Suppose one of the two cameras is made for targeting a guide star near the center of the sky area and bringing the star image to the center of field of view, and the other camera for targeting another guider star close to the edge of the sky area and bringing its image onto corresponding coordinates of the field of view, this way would determine the sky area to be observed onto a known visual reference frame.

The tracking servo algorithm is based on classical PID or a contemporary techniques depending on reality.

6. CURRENT STATUS OF CONTROL SYSTEM PROGRESS

As aforementioned that the research and development of the control system has been conducted in partnership, here we present what has been done in Nanjing Institute of Astronomical Optics and Technology so far.

- By the end of 1998 the preliminary design came through an expert evaluation and vigorous review. However, the working plan did not get approved until the year of 2000 for some reason in the nature of administration. At present time we are still at the stage of detailed design for some portion of the telescope.

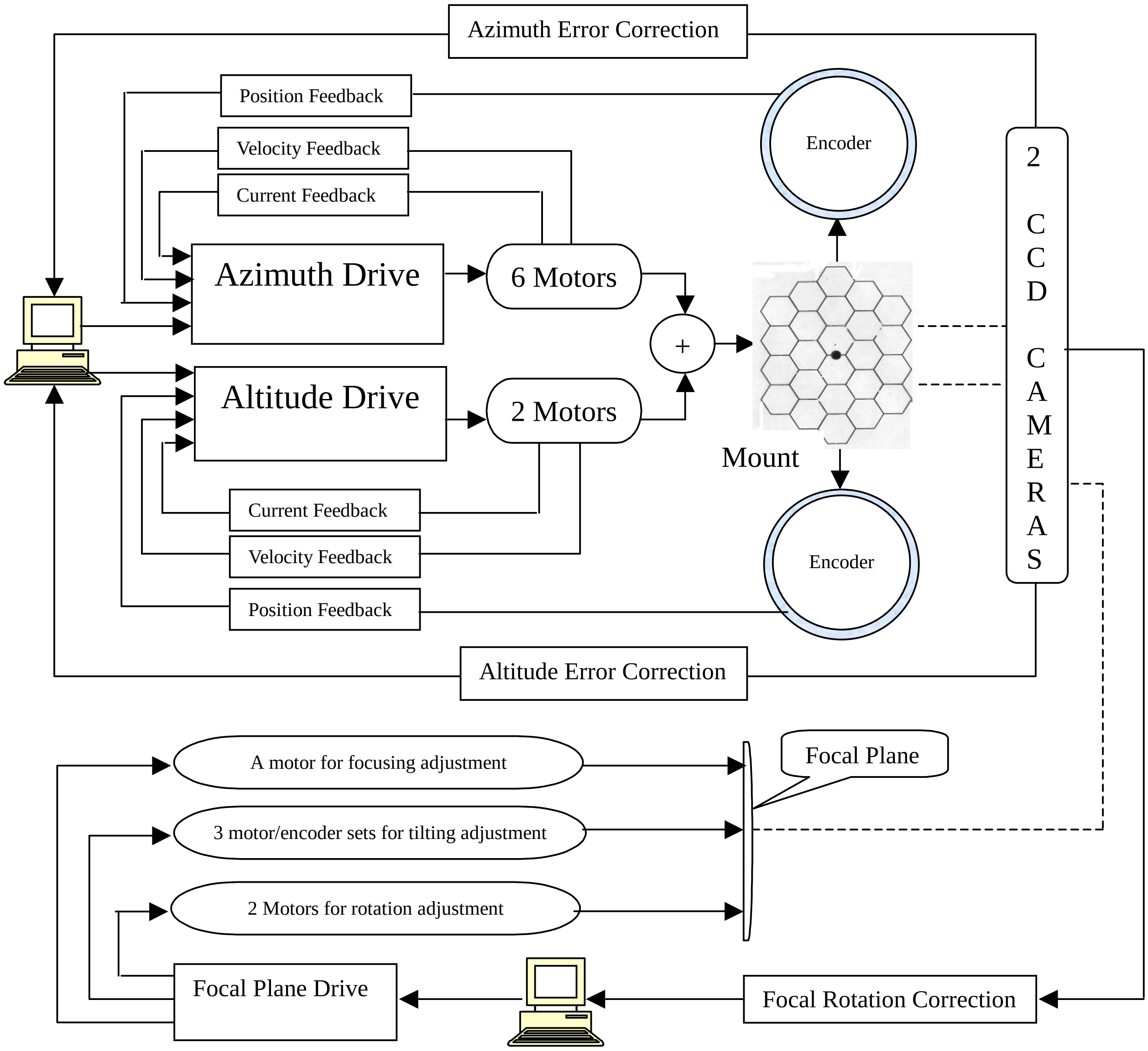

Figure 4: Mount Drive and Focal Plane Servo Schematic

- Outdoor active optics control test conducted in the open area of the institute was initiated in 1999. It is a simplified and scale down simulator of real LAMOST. A hexagonal segment of M_A and a hexagonal segment of M_B, both in size of 1.1 meters angle to angle yet with different thickness, have been set up with 40 meters apart like in real case. At the focus of the spherical M_B segment a S-H wavefront sensor and a CCD camera have been installed. The test purpose is multi-fold. Among other things the effect of active force applied on the M_A segment for image quality improvement is the main objective of the test, and the mount tracking performance is also a big issue as long as the control system is concerned. The test has undergone a variety of difficulties than expected. For economical reason we simply took an existent mount left over from another test years before. Unfortunately, the mount is not rigid enough and has too much backlash. What is more, the friction torque varies while moving, at some points up to 6 times as many as normal. Some refit has been carried out. For example, counterweight has been re-adjusted and the friction drive disk ratio has been raised from 10 to 30, more feedback has been added in the servo and the PID algorithm with different parameters has been tried. So far the azimuth tracking accuracy could obtain around 1" (RMS). For the altitude axis a counter-backlash motor will be added soon and the tracking accuracy is expected to be at the same level as azimuth. Admittedly, it is difficult to acquire such accuracy with some inherent weakness of the test mount while still not satisfying the tracking requirement for the LAMOST. However, it would probably do if the test goal only focuses more on the principle and experience for the future LAMOST. In another development, a number of items have been tried in the active force control test. All the 52 force actuators have been calibrated against a set of precision weights. The range of manipulating force has reached $\pm$100N with accuracy of RMS$\leqslant$50mN. Two sets with different number of force actuators have been experienced. In the test with 37 sets of force actuators applied to a M_A mirror segment a home designed prototype of smart controller has shown a promising capabilities in realizing the design goal. Currently the research group is vigorously engaged in a test with 37 sets of force actuators distributed on a LAN controlled by 5 smart controllers. The actuator control strategy is based on so called distributed-and-centralized mode. Refer to displacement actuator control test, the test for a unit displacement actuator has been done, and multi-unit test is being conducted. The active control group is actively participating in the S-H wavefront measurement for the active force correction. Some progress has been made although no breakthrough yet. The completed servo loop including the force actuator control and the S-H wavefront detector has not successfully closed yet.

- In our simulation approach for high-level software development the level-0 simulator has passed a critical review and an expert evaluation in July of 2001 organized by the LAMOST Engineering Headquarters. A real time distributed database built on Empress platform under QNX OS environment has passed the same evaluation as above in July of 2002. The on-line demonstration of the database package gained unanimously positive response from experts at the evaluation meeting. It also has actually shown a leading step in China in this particular research area for control systems of large astronomical telescopes.
- Now we are still at the stage of level-1 simulator development.
- A renovated GPS-based timescale unit that is greatly improved in accuracy based on a commercial GPS receiver has passed a critical review and an expert evaluation in July of 2002 organized by the LAMOST Engineering Headquarters. The accuracy demonstrated has greatly surpassed the one that the Chinese 2.16 m telescope has ever achieved.
- The electronics design for spectrographs has been finished and the lab control test will begin as soon as all necessary electronic elements and modules are available.
- The dome environment and safety monitor and control subsystem is due to start designing soon associated with a post-graduate thesis.
- For a past period of time we have done a vigorous research in an attempt to get ready for inviting a public bidding domestically and internationally as well. The bidding scope includes two major aspects of the control system, namely tracking control subsystem and active optics control subsystem. Again active optics control subsystem is divided into the active force correction and co-focusing for image stack. A number of domestic companies and institutes and international companies from France, UK and USA are enthusiastic about the tracking subsystem. As opposed to the origin of potential bidders for the tracking subsystem the potential bidders for active optics control subsystem are almost all from foreign companies such as from France and USA. And the type of edge sensor in the image stack servo is also an issue in our investigation. Because we have got types of three different edge sensors to choose from such as capacitive, inductive and photoelectric. In the December of 2001 a group of control professional from LAMOST visited several companies and institutes in the USA to look into this critical issue. The visit has certainly been rewarding since China is still a developing country and we very much cherish the experience and lesson that the developed countries have built up in this regard. The initialization of formal bidding for LAMOST control system is in the hands of LAMOST Engineering Headquarters, and we control group is just responsible for the technical requirements.

One other thing we must mention about here to complete the highlights of current status for LAMOST control system is the positioning system for 4000 fibers. A unit protocol controller consisting of two step-motors for manipulating each fiber that has been designed and built by the University of Science & Technology of China has passed a critical review and expert evaluation. A next step is to make a module with a number of such units collectively controlled on a network to see statistically the positioning precision and reliability. A separate paper will be presented at this conference by the university.

7. CONCLUSION

The LAMOST control group is facing an enormous challenge because of a number of cutting edge techniques for telescope control involved. Our approach is to distribute the whole mission among a number of institutions, each of which is best for the job assigned. Taking the advantage of globalization and China's newly received WTO membership we are going to invite public bidding. The task that the control group of Nanjing Institute of Astronomical Optics and Technology is responsible for has been conduced in progress especially in the high-level software build up. The outdoor active optics control has met a lot of trouble and valuable lesson should be drawn for future.

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