Network control system of LAMOST telescope

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ABSTRACT

The ongoing Chinese ever-ambitious project of Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST) has brought about a tremendous challenge for the control engineers. To the bottom line the giant 4-meter class ground telescope is a comprehensive optomechatronic platform to achieve high performance and functionality, such as its capability of observing 4000 stars simultaneously, which will set a world record in contemporary ground survey telescopes. This paper outlines the R&D stages of the control system for the project along with its integrated strategy of optomechatronic components in general and network control framework in particular. The approach is to make a careful investigation with respect to the time crucialness for execution of different tasks so as to utilize different networks. However, the overall network framework is based on a distributed platform, hierarchical structure and open architecture to boost the flexibility. Vigorous study has been invested and a number of cutting edge techniques have been applied to meet the tough network control requirements, such as real-time database, powerful interfaces, sophisticated controllers, remote control, etc.

Keywords: network control system, lAMOST, QNX, GSM, GPS

1. INTRODUCTION

LAMOST telescope configuration layout is shown in figure 1. It is a meridian reflecting Schmidt telescope with its optical axis unconventionally fixed in the meridian plane. The telescope's structure consists of three major components, a reflecting Schmidt corrector mirror M_A at the northern end, a spherical primary mirror M_B at the southern end and a focal plane in the middle with 20-m apart to either M_A or M_B. 4000 optical fibers are arranged on the focal plane for receiving simultaneously the lights originally emitted from 4000 celestial observed objects, and pass them down to a spectrograph room for recording. M_B is stationary on its foundation, which is a distinct feature from conventional ground optical astronomical telescopes. The tracking motion is done by maneuvering the direction of the normal line of M_A. M_A is held on the alt-azimuth mount. During a tracking process of a celestial object the direction of the normal line of M_A is controlled by both of the azimuth servo and the altitude servo coordinated with each other. The servo loops so strictly follow the object's apparent motion that the object's incident ray hits on the M_A and is reflected by it, generating the reflected ray that is always aiming at the M_B throughout the tracking process. Finally, the ray entering the M_B is reflected by it again then imaged on the focal plane. For better image quality, the attitude and focusing of the focal plane might be adjusted somehow before each observation. Also during an observation the focal plane rotates on realtime in order to compensate the image rotation on the field of view so that stable image can be acquired.

Optomechatronic Systems Control, edited by Farrokh Janabi-Sharifi, Proc. of SPIE
Vol. 6052, 605209, (2005) · 0277-786X/05/$15 · doi: 10.1117/12.640498

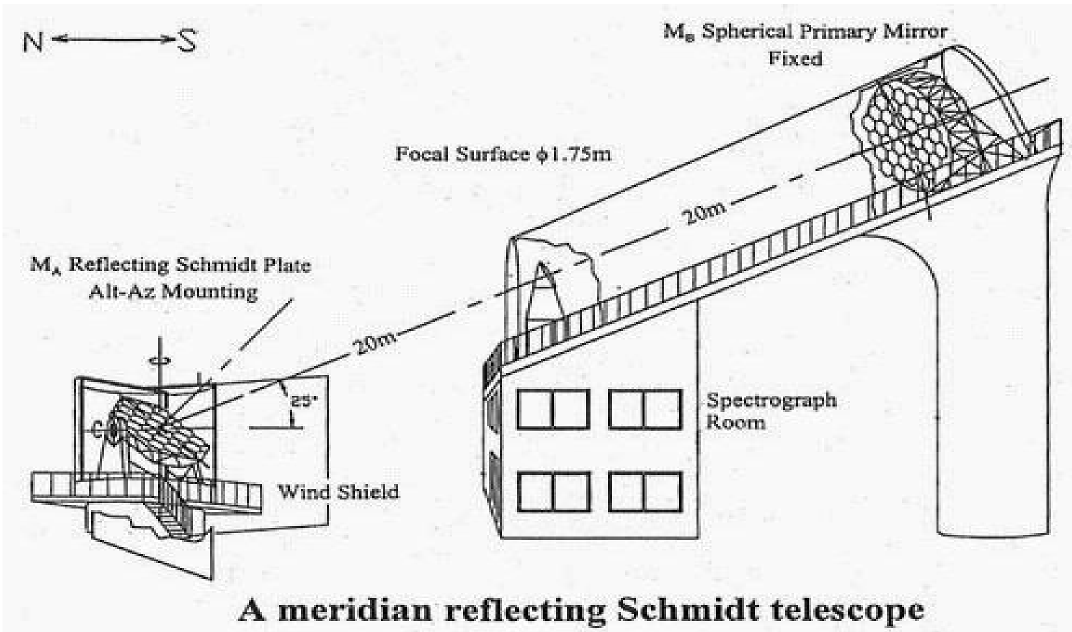

Figure 1: LAMOST telescope configuration layout

The telescope will be set up at the site of Xing Long observational station, longitude 117:34:42E and latitude 40:23:47N, which is subordinated to the National Astronomical Observatories. The telescope with 4-m aperture is going to be the largest astronomical optical telescope in China. What is more，its efficiency of observing 4000 celestial objects simultaneously will make it the most powerful survey telescope in all known contemporary large astronomical optical telescopes.

Such a unique design philosophy is an extraordinary technical challenge for the LAMOST control team. Among other things, M_A mirror with effective diameter of 4-m and thickness of 25-cm is required to have its aspherical surface shape to change during the observation to compensate the optical aberration. The shape change of mirror surface is realized by active force precisely based on a certain rule. Thickness of 25-cm is rather thin compared with diameter of 4-m for an optical mirror, and the way to correct thin mirror surface is called thin mirror active optics technique in astronomical telescopes' jargon, which demands nanometer technique. At the same time M_A is driven on both azimuth and altitude axes in subarcsecond accuracy for tracking the stars. Moreover, M_A and M_B mirrors are comprised of 24 segment mirrors and 37 segment mirrors respectively in order to reduce the manufacture cost, however at the expense of adopting the so called co-focusing active optics technique, another cutting edge technique in large telescopes' design philosophy, to concentrate all the segmented mirrors' focal points onto one point. In addition, for acquiring the spectrum of 4000 celestial objects simultaneously the parallel positioning of 4000 fibers on the focal plane each manipulated by two motors with a couple of tens of micron accuracy is another headache.

To the bottom line the telescope is a comprehensive optomechatronic and information platform. The main features from control point of view are highlighted below.

- The telescope will be able to handle target selection, observation operation, data processing, data archiving and so on. All are automatically done to gain scientific return.
- The telescope will be the national facility and also open to the astronomical community in the world. For efficiently utilise the limited source an optimized observation scheduling strategy needs to be worked out.
- The telescope will be able to acquire amount of up to several gigabytes of raw observation data per night. Such great amount of information calls for mass data handling technique.
- The telescope will eventually be able to operate in remote control mode, which obviously involves internet communication and control.
- Architecturally the telescope mainly consists of a Schmidt corrector mirror M_A, primary mirror M_B and a focal plane. These three components physically separated with 40-m apart between M_A and M_B and the focal plane in the middle are combined under control during operation to align the telescope accurately to targets and tracking them for 3 hours.
- The telescope is roofed by an observation chamber, which is also controllable to make sure no block of the star light during observation and to protect the telescope from wind disturbance.
- A weather station will be set up outside the observation chamber to monitor the environment conditions. Also inside the chamber various kinds of sensors will be distributed at many spots to monitor the inner-environmental conditions such as temperature, humidity, air pressure including any signs that call for activating the warning system.
- The telescope will be armed with many CCD cameras and spectrographs of different kinds as image or spectra detectors. And some of CCDs will be utilised as a star guide or a calibration tool for converting the celestial sphere coordinates into focal plane local coordinates.
- For applications of thin mirror surface shape change and co-focusing of the mirrors as mentioned above more than one thousand of actuators and hundreds of sensors are physically connected to these mirrors to close the servo loop.
- The mount and the focal plane both with large moment of inertia need to be driven smoothly and slowly at variable speed down to less than 1"/S, i.e. 15 days per revolution without stick slip, which requires multi-motors parallel friction drive under cascaded servo loop control.
- The side effects such as heat dissipation and cross talk among 8000 step motors on the back of the focal plane for the positioning of 4000 fibres are big deal since these disturbances might worsen the image quality.

2. R&D STAGES OF THE CONTROL SYSTEM

Our solution for the R&D of LAMOST' control system lies in the follow ing aspects.

- For building the control system of such high-tech profile with comprehensive aspects a consortium approach is a good choice with each member of the consortium coming from institutes in China that are in the leading positions of their respective technical areas pertain to LAMOST control system.

- China is a developing country currently towards more open to the international exchange. It is particular true in the non-profit astronomical community. The lesson and experience from R&D of contemporary astronomical telescopes internationally are particular useful for us to prudently stride our first step with our own creation in the very beginning.
- Divide the whole system into a number of subsystems and invite public biddings nationally and internationally to contract out some of subsystems in an attempt to attract eligible bidders with cost effective solutions. However, we are determined to be active in cooperation with our contractors so as to make the later transition from our contractors to LAMOST team as painlessly as possible.
- Set up in our campus a scale down model of LAMOST telescope, "small LAMOST" as we call it, with only one segment mirror each for M_A and M_B. This approach has been proved productive leading to some of important conclusions on the active optics technique and tracking technique, which is vital knowledge and reference for real LAMOST.
- In the wake of rapid advance of computer, communication and network hi-techs the software simulation technique is an inevitable means of tool for the development of complicated control systems of LAMOST. The progressive simulation for LAMOST control system evolves from level-0 to level 2 inclusive.
  - ✓ Level-0 simulator: Lowest level only working with simulation data and giving the feel and look for the interface of LAMOST control software.
  - ✓ Level-1 simulator: Upgrade of the level-0 simulator with major portion of the codes for the basic LAMOST control functions. The characterization of the mount drive servo and active optics modeling has to be done during this phase in order to get important parameters for the telescope. If some hardware is available then hardware-in-loop simulation could be conducted in this phase too.
  - ✓ Level-2: Upgrade of the level-1 simulator, a comprehensive working software package featuring fully automation. The simulator should work almost perfectly in reality on site, and provide simulated operation environment in lab for the users.

Currently the LAMOST control system has come to the end of level-1. It is predicted that the telescope will receive first light next year, and by the year of 2007 will be operational.

3. MODULE LEVEL LAYOUT OF THE CONTROL SYSTEM

For the system outlined above the control framework needs to be carefully considered. For one thing, the telescope is not just a monoliphic object, rather physically separated components associated harmoniously with respective software packages. For another, the control of each component requires different time criticalness, and most prominent realtime nature in the system happens to be the tracking of celestial objects, which requires the time tick of less than 1-ms contrasted with once per a few minutes for sampling of weather conditions. Apparently it is feasible and reliable to employ a distributed hierarchical network control for flexibility, expansibility and maintainability.

Figure 2 shows the high-level module level layout for LAMOST control system. The main modules at system level are Observatory Control System (OCS) on the hierarchy top, Telescope Control System (TCS) as the control center, Instrument Control System (ICS) and Data Handling System (DHS). Subordinate to OCS is Survey Strategy System (SSS). 8 subsystems, namely AZIMUTH DRIVE, ALTITUDE DRIVE, FOCAL PLANE, GUIDING, M_A ACTIVE OPTICS, M_B ACTIVE OPTICS, DOME CONTROL and ENVIRONMENT, are subordinate to TCS. Again there are two subsystems, SPECTROGRAPHS and FIBER POSITIONING, under ICS. Finally, Spectroscopic DataBase (SDB) and Catalogue DataBase (CDB) are under DHS. All the communication among these high-level modules are popular Ethernet based, which is not good for realtime application though, yet adequate in the practice here for information flow essentially with non-time-critical nature. On the other hand, all the 8 subsystems of TCS require realtime implementation, and some of them are very much time critical such as the process happening in AZIMUTH DRIVE, ALTITUDE DRIVE, FOCAL PLANE, GUIDING. The solution is that two sophisticated Universal Motion and Automation Controllers (UMAC) are utilized, one for AZIMUTH DRIVE and ALTITUDE DRIVE and the other for FOCAL PLANE and GUIDING. With DSP and bussing techniques the UMAC Has demonstrated powerful abilities to tackle with all those realtime tasks. For those realtime tasks but with less time criticalness such as DOME CONTROL and ENVIRONMENT monitoring & controlling an industrial PS (plus a PLC) each is used as a controller. As for M_A ACTIVE OPTICS, M_B ACTIVE OPTICS, SPECTROGRAPHS and FIBER POSITIONING because these modules involve implementations of thousands of electronics elements, such as actuators, micro-step motors and sensors, field bus approach is applied. TCS itself has been built on ONX OP, an excellent and well known realtime OP, since TCS acts as the center of controlling many realtime tasks. A realtime database is built on the QNX OP to boost TCS's realtime capability. Socket communication technique with TCP/IP protocol is adopted between every tow modules on Ethernet network if they need to talk each other.

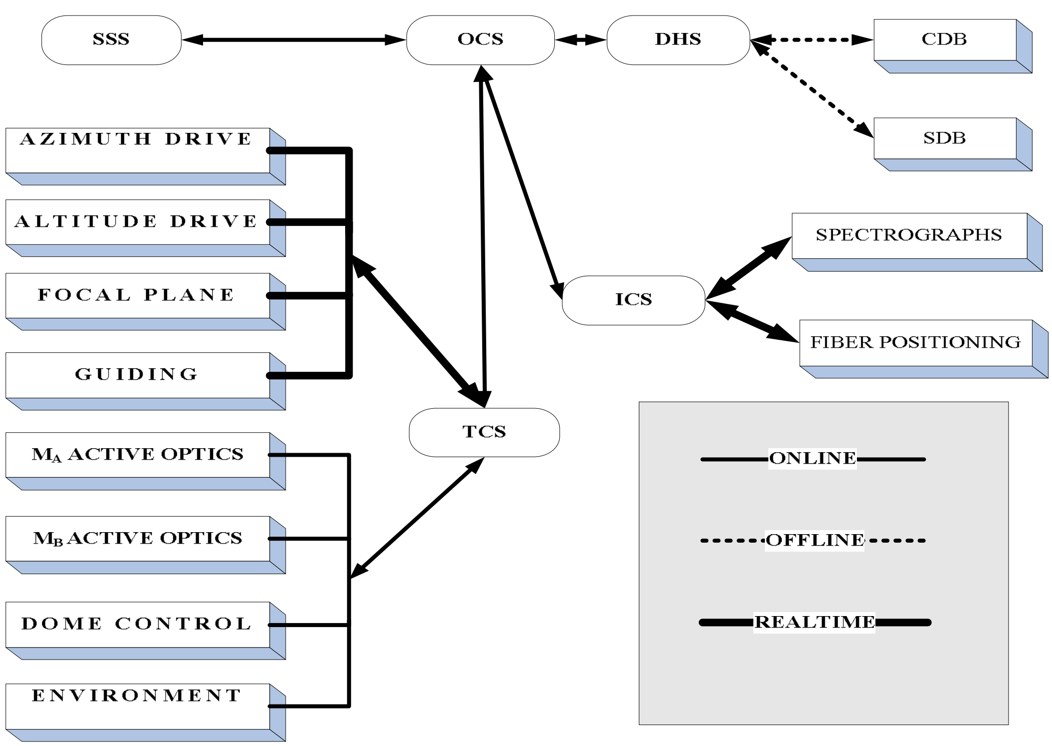

Figure 2: LAMOST high-level module layout

4. OPERATING SYSTEM AND REAI TIME DATABASE

TCS is the centre of network control. A great amount of its routine is involved in realtime applications, most of them coming from its 8 subsystems. As afore mentioned many measures have been taken to strengthen their realtime performance by introducing smart controllers and bussing techniques in these subsystems. Still, it is inevitable to adopt realtime OS and to build realtime database around TCS platform to further boost the control system's realtime ability as a whole. Many contemporary large telescopes in the world have taken such an approach, and LAMOST is no exception.

QNX OS has been chosen as the corner stone for network realtime application. The reason for the choice of QNX is as follows. QNX itself is well known distributed real time OS. With QNX's FLEET networking protocol it is possible to form a switching platform by scaling to as many subsystems (nodes) as are required in a software-transparent manner. It also provides multitasking, priority-driven preemptive scheduling, and fast context switching –all essential ingredients of a real time system.

Database in the applications of comprehensive control system of large telescopes has its own right because of its powerful abilities of data processing. We opt for a database product of Empress as the realtime database built on QNX OS to further develop realtime applications for LAMOST network control. Empress' Realtime DataBsae Management System (RDBMS) is one of the most powerful and cost-effective database management systems available for developing embedded, real-time applications. It serves as a storage and platform for data flow, recording and updating timely various status of moving components in the telescope structure as well as environmental parameters around it. The database joins harmonically in the administration of TCS. For efficient access database-tables most frequently accessed ones are placed along with its process on the same node so as to reduce the communication traffic greatly. We have utilized a number of techniques in the development of GUI for these applications such as the dynamic creation of control widgets, dynamic query and share memory. The seamless connection between Empress and the graphical development tool of QNX's Photon Application Builder (PhAB) has been realized.

5. HARDWARE PLATEFORM FOR NETWORK CONTROL SYSTEM

Figure 3 shows LAMOST network hardware schematic in its simplified illustration. Many network hardware elements in the figure are easy to identify. There are 6 servers in the figure, namely OCS SERVER, TCS SERVER, TIME SERVER, REMOTE CONTROL SERVER, DATABASE SERVER and WEB SERVER. The functions of these servers are self-evident as their names imply. Particularly we have already mentioned TCS and DATABASE above. As apposed to TCS built on realtime QNX OS platform, OCS SERVER is built on non-realtime Linux OS, nowadays one of favorite OSs for astronomers. Linux is chosen for OCS is because of its powerful tools for astronomical data processing. WEB SERVER is set up with QNX OS too, which provides web service for the telescope's remote control via Internet. The network time scale is generated by a GPS based TIME SERVER. The TIME SERVER ticks to generate network activity cycles. Using GSM net, REMOTE CONTROL SERVER can provide wireless control service by mobile note. ENVIRONMENT SYSTEM monitors temperature, humidity, wind speed, wind direction and so on. TCS SERVER has two network adapters. One network adapter only talks with OCS, and the other for communicating with all the subsystems. This way ensures that OCS SERVER has no way to get across TCS to communicate directly with TCS's subsystems. WEB SERVER has double network adapters too. One network adapter connects to Internet and the other to TCS LAN. User can access Internet only by WEB SERVER to ensure network safety.

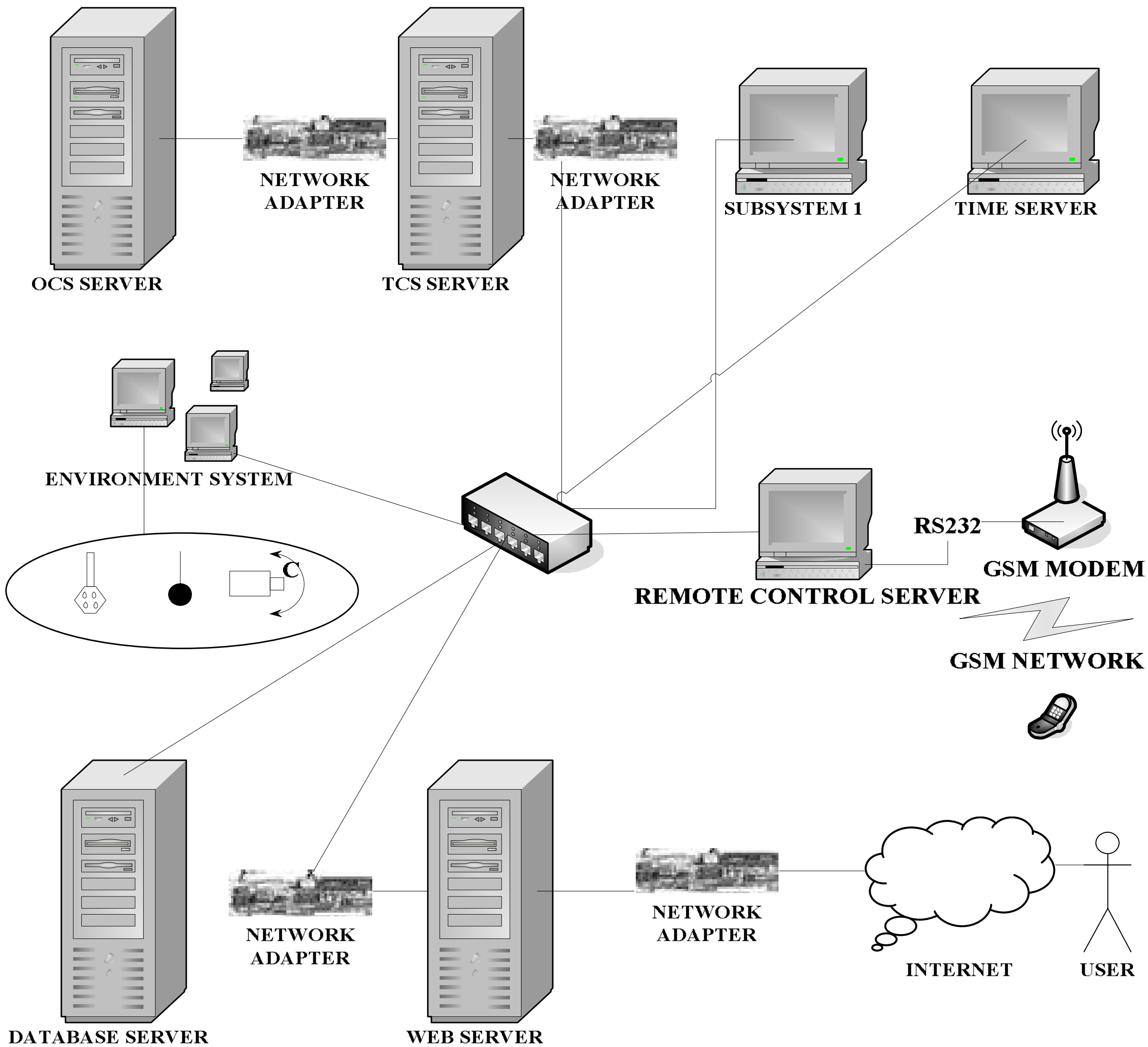

Figure 3: LAMOST network hardware schematic

6. TCS NETWORK FUNCTIONS

Figure 4 shows the major TCS network functions. The 7 function modules are OCS COMMAND ACCESS, SUBSYSTEM ACCESS, DATABASE MANAGE, ENVIRONMENT CONTROL, GPS-BASED TIME, REMOTE WIRELESS CONTROL and ONLINE HELP.

The console application, which runs on TCS SERVER, is the kernel of all the network control system. It not only accepts and replies the commands sent by OCS but also communicates with all the subsystems, function modals and control them. The console application can easily switch to all the subsystems' interface under QNX OS's Fleet.and to issue commands there, a nice feature for engineering maintenance of subsystems without TCS's intervention.

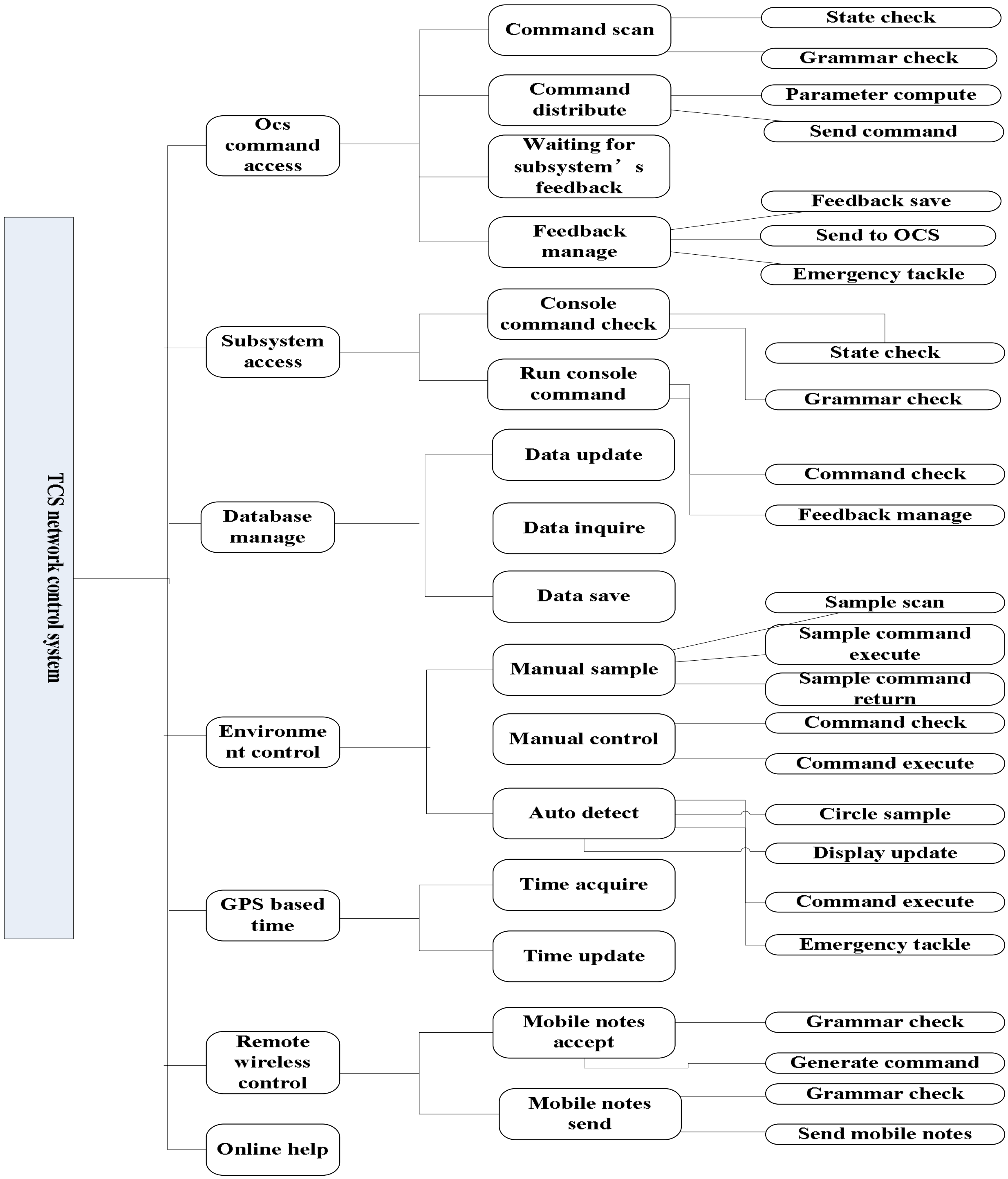

Figure 4: TCS network functions

7. ENVIRONMENT CONTROL SUBSYSTEM

The environment control system detects the temperature, humidity, wind direction, wind power, fire warning and so on using various kinds of sensors. It also inspects the system, diagnoses and debugs system malfunction at intervals. The environment control system can collection information and transfer it to the ENVIRONMENT SERVER to process under the support of network and database by using communication and intelligence technology. Video monitors any important sports of the chamber, and audio alarms are ready to set off when irregularity occurs. The system can even offer some suggestions for the operator to consider. Figure 5 shows the structure of the environment control system.

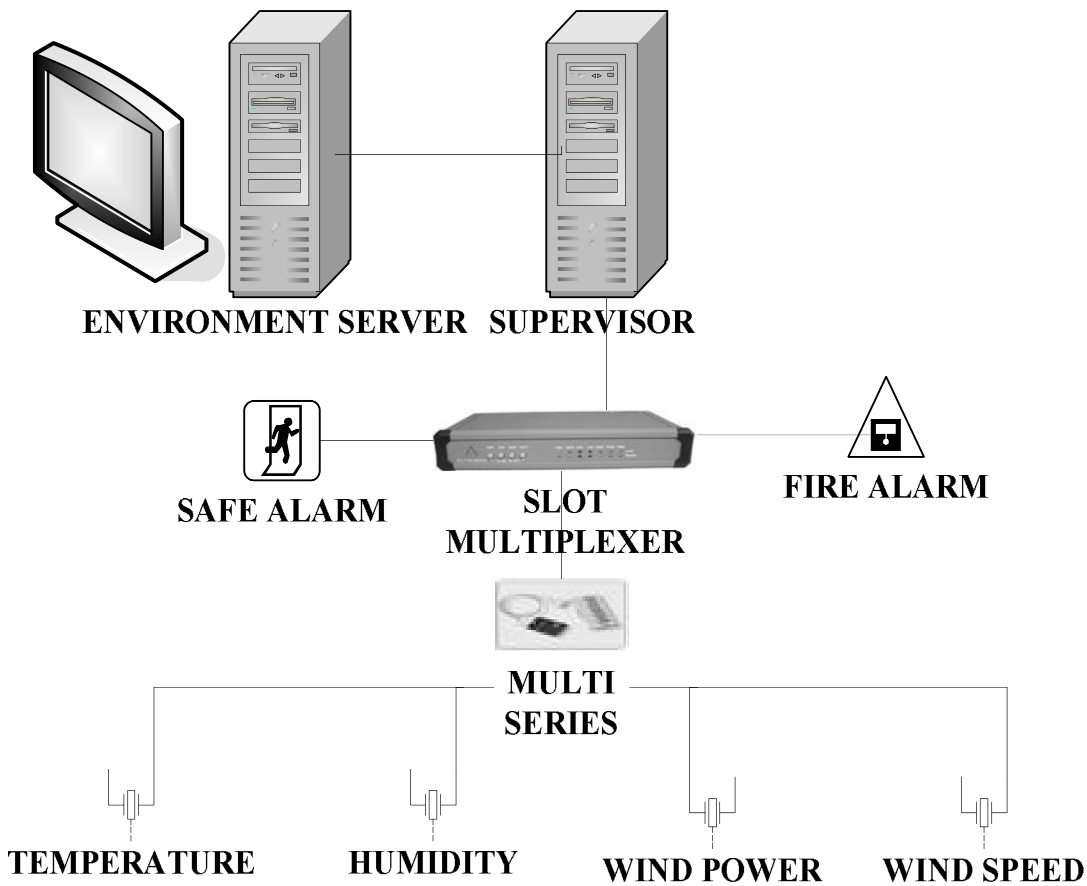

Figure 5: Structure of the environment control system

The slot multiplexer connects with the information collection devices through Ethernet or RS232/RS485. Firstly, it collects the raw data then sends them to the ENVIRONMENT SERVER, DATABASE SERVERD and WEB SERVER. Secondly it receives the commands sent by ENVIRONMENT SERVER and controls the collection devices. The environment console application is executed under the ENVIRONMENT SERVER. It collects, analyses, accounts and queries all the new data, alarm information and history data. The remote authorized user can control ENVIRONMENT SERVE through WEB.

8. GPS BASED TIME SUBSYSTEM

The control system of LAMOST telescope is highly distributed real time system, and the time base is crucial. During the motion tracking for 4000 celestial objects being simultaneously observed the alt-azimuth mount has to be driven on two axes in a servo loop to follow the motion of the objects in a timing system that has to be precise to the level of 1 millisecond. The GPS-based timing system schematic for LAMOST is shown in figure 6.

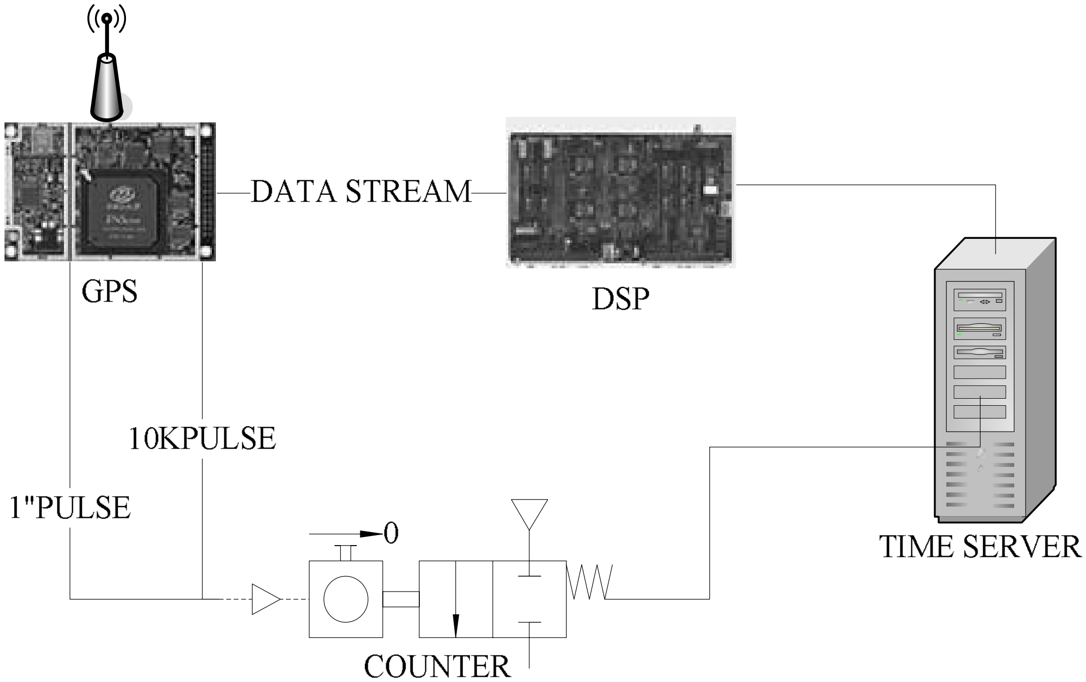

Figure 6: GPS based timing system schematic

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 1PPS time mark pulse and 10KHz time mark pulse through a counter to produce 0.1ms accuracy UTC for the time-server on the LAN. The time-server that is built on QNX node may in turn either actively broadcast or passively get the time synchronization requests to or from various nodes across the network. Typically the timing among the real time QNX nodes can thus reach 1ms accuracy thanks to the FLEET protocol under QNX, which is enough to meet all the real time task requirements for LAMOST.

9. REMOTE WIRELESS CONTROL SUBSYSTEM

With the rapid development of motion communications the mobile notes operation based on GSM is used widely. The application of such a technique that combines computer communication and mobile notes is one of fancies with mobile new application. We have successfully realized the remote wireless control just by normal mobiles. The way to do it is to connect a GSM modem with a QNX node through RS232. Authorized user can receive alarm and control the network system just by a mobile. REMOTE CONTROL SERVER is set on one of the QNX OS nodes. The system can handle mass notes quickly and correctly under QNX OS. Figure 7 is the flow chat of the remote wireless control.

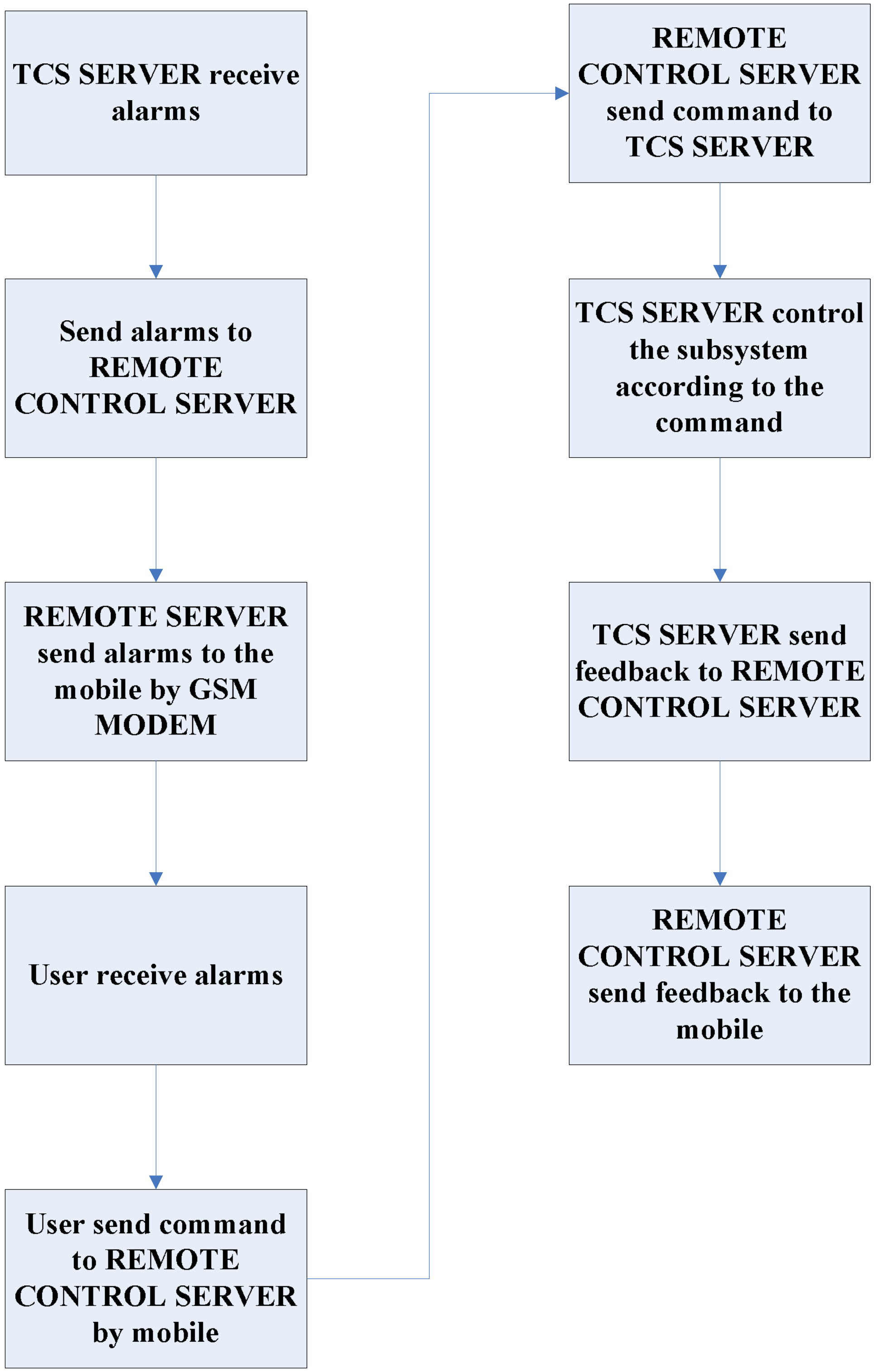

Figure 7: flow chat of the remote wireless control.

10. CONCLUSION

The research work on LAMOST network control system is presented in this paper. The approach of distributed hierarchical and open architecture for the telescope's control network has been proved. Also the system has demonstrated its realtime performance in a number of aspects. Many tests have successfully been conducted in the lab of Nanjing Institute of Astronomical Optics and Technology. Still, we are facing a lot of challenges and determined to further improve the system overall performance, especially its realtime capability, reliability and network safety. It can be predicted that with new IT products coming along and rapidly advancing of IT technology the system will be adapted for taking such advantage without much pain thanks to the current system's network distributed nature and its expansibility.

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