Motion control for LAMOST focal plane

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ABSTRACT

Taking as an example the focal plane control system for the largest optical telescope being built in our country, the paper focuses on Universal Motion and Automation Controller (UMAC) based servo control system with high accuracy, and analyzes its design scheme. The scheme analysis and preliminary test demonstrate a broad outlook of UMAC based application in complex control systems with high precision, real time, fast action, easy adaptation and open architecture. A brief research summary and a preliminary test of the Focal Plane Control System (FPCS) are presented. The FPCS is one of components for the control system of Large sky Area Multi-Object fiber Spectroscopic Telescope (LAMOST), which is a national large scientific project. The design scheme features distributed, hierarchical and expansible network architecture with UMAC based control technology. A number of advanced techniques are integrated with some control software and hardware, which presents a solution to requirements of precision, real time and open architecture for the FPCS in the design of large optical astronomical telescopes.

Keywords: UMAC, focal plane, servo control, tracking, drive system, LAMOST

1. INTRODUCTION

The ongoing project of LAMOST is one of a few national large scientific and engineering projects in China. The astronomical optical survey telescope with a Field Of View (FOV) 5^0 on its focal plane will be able to take simultaneously the spectra of up to 4,000 distant and faint celestial objects down to 20.5 magnitude over a wide area of sky, thus making the telescope the most powerful spectral survey tool ever.

As is well known in the application of a ground optical astronomical telescope with an alt-azimuth structure for astronomical observation the telescope must smoothly and accurately track the apparent motion of celestial objects on both axes for a couple of hours. Moreover the focal plane must also rotate precisely at variable velocities to compensate the possible image rotation on the field of view by a pair of field rotation motors through friction drive shown in figure 1. Note in the figure only one motor of the pair is shown. All these motions must be under a realtime control because of the celestial objects' motion following strictly the astrometry principle. Besides, in order to improve the image quality it is required that the attitude of the focal plane should be adjusted in three-dimensional space and the focusing be sharply tuned along the normal line of the focal plane before each observation. The attitude adjustment is done by 3 tilting drive units and the focusing is done by focusing drive unit. Note in figure 1 only two tilting drive units are shown. Roughly the focal plane can be described as a thin round disc with diameter of 1.75-m accommodating FOV 5⁰. The schematic of the focal plane associated with these motions control gadgets as a whole is shown in figure 1.

In addition to the above motion controls of the focal plane, several CCDs will be installed on the focal plane for easing the celestial object finding, image de-drifting, and serving as calibrating devices to transform the coordinates of image positions on the field view into sky coordinates of celestial objects being observed. The FOV is divided into 4000 small areas each with an optical fibre set in it. Each fibre is aligned with an object being observed and is manipulated by a pair of step motors wherever in the small area. From the outline above the focal plane motion control plus 8000 step motors manipulation for 4000 optical fibres positioning has made its control as a whole a complex system. In the focal plane chamber equipped are environmental parameter sensors and ventilation monitoring & controlling system.

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Optomechatronic Systems Control, edited by Farrokh Janabi-Sharifi, Proc. of SPIE Vol. 6052, 60520N, (2005) · 0277-786X/05/\$15 · doi: 10.1117/12.640494



Figure1: Focal plane motion control schematic

This paper focuses on control of the focal plane rotation, attitude adjustment and focusing, hereafter referred as Focal Plane Control System (FPCS).

2. FPCS IN HIERACHICAL CONTROL STRUCTURE

LAMOST network control strategy features distributed, hierachical and expandable. Each node in the network consists of a high-level module fulfilling a group of functions. UMAC-based FPCS is such a module shown in figure 2. One level above the FPCS is Telescope Control System (TCS). Again one level above the TCS is the Observatory Control System (OCS). At the same level as the FOCS and immediately under TCS are 7 other modules with each administrates a particular subsystem. Immediately under FPCS are various kinds of hardware, such as electronics, motors, encoders and sensors. Some of abbreviations designated in the figure that have not been mentioned above are explained here: Survey Strategy System (SSS), Data Handling System (DHS) and Instrument Control System (ICS).





Figure2: FPCS in hierachical control structure

motions of celestial objects require more time criticalness such as FPCS than those not tight bonded with realtime motions such as the environmental subsystem. UMAC-based controller is incorporated with some sophisticated software for efficient control of FPCS, which boosts the overall performance.

3. PERFORMANCE REQUIREMENTS

The performance requirements for FPCS are collectively shown in the following table.

Control items	Performance requirements
Tracking range of field of view rotation	$\pm 22.5^{0}$
Tracking velocity of field of view rotation	±(0"-15"/S)
Manual control in velocity switching of field of view rotation	Fine-tuning: tracking velocity ± 1 "/S
	Micro-adjustment: tracking velocity ± 5 "/S
	Slow maneuver: ±5'/S
	Fast acting: $\pm 1^0/S$
Maximum rotation velocity	$\pm 1^0/S$
Maximum rotation acceleration	$\pm 0.3^{0}/S^{2}$
Focusing range	±200mm
Tilting adjustment range	0'-10'
Tracking accuracy of field of view rotation	±1"
Focusing accuracy	±0.01mm
Tilting adjustment accuracy	±2"

From the table above the tracking accuracy of ± 1 " for FOV rotation and the tilting adjustment accuracy of ± 2 " are most crucial and rigorous. The difficulty for fulfilling such requirements arises from the so called stick-slip phenomena frequently taking place in ultra-slow motions with large moment of inertia.

4. FPCS DRIVE HARDWARE SETUP

4.1 Field rotation drive

The field rotation drive is a servo mechanism. It is supposed to rotate FOV, i.e. the focal plane, at velocities tuned precisely following the image rotation, which is a particularity for alt-azimuth telescopes during observations. The rotation of FOV compensating the image rotation contributes to an appearing stable image on FOV, which is essential for astrometry. At a velocity range of $0^{"}/S - \pm 15^{"}/S$ with accuracy of better than 1" for rotating the focal plane mechanism of moment of inertia 2000 kg m² a pair of brushless motors are employed. Either motor in the pair is co-axially connected to a friction driving roller that moves the friction disk so as to rotate the focal plane disk shown in figure 3. The application of friction drive is one of fashions nowadays for accurately rotating mechanisms with a large moment of inertia in contemporary large astronomical telescopes. The friction force arises from the pressure between cylindrical surfaces of the roller and the friction disk. On the focal plane axis furnished is a tape encoder with two reading heads plus the interpolation electronics giving angular position readout and feedback signals at the resolution around 0.1". There is a power-off brake engaging with the circumference of the friction disk preventing a possible slippage of the focal plane in case of power failure.



Figure3: Field rotation schematic

4.2 Attitude micro-correction

The attitude of the focal plane is determined by the direction of the plane normal line. Again, based on the mathematical relationship that the direction of a plane normal line is determined by 3 points distributed in the plane, therefore a unit of tilting mechanism is attached to each point of the three to achieve the attitude micro-correction. Each unit consists of a motor with a velocity reducer generating displacement of the corresponding point through a lead screw and a nut. Given the attitude required of the focal plane the amount of adjustment for each unit can be obtained from a set of equations corresponding to that attitude. Associated with each unit is installed a leaner encoder to send displacement feedback signals to close the position servo loop, thus achieving accuracy better than 0.005mm.

4.3 Focusing

The focusing is achieved by linear motion control of a moving nut along a precision ball bearing guide rail. The nut is on a precision lead screw that again is driven by a motor via a reducer. A leaner encoder installed along the focusing axis gives the feedback signals and closes the displacement servo loop.

4.4 General view of drive hardware for FPCS

Motors and encoders for FPCS were selected from high-end product catalogues and supplied by internationally well-known companies. The following table gives a general view for the major drive hardware.

Item	Туре	Quantity	Purpose
Brushless ring torque motor	TMA0210-070	2	To rotate the focal plane through friction drive to compensate image rotation on FOV
Quadrature Angle encoder	ERA881C with 2 reading heads	1	Installed on the focal plane axis to measure the rotation angle and give feedback signals
Brushless servo motor	HJT155D8-260	4	3 motors for attitude adjustment of the focal plane, and 1 for focusing
Linear encoder	LF183	4	To measure the displacements of focusing and 3 tilting units each to give feedback signals

5. UMAC BASED CONTROL

5.1 UMAC controller

A UMAC controller from Delta Tau Data Systems, Inc. is utilised for FPCS, which is shown in figure 4. UMAC controller is a 4 to 18 slots stand alone rack, connected to network with TCP/IP link. UMAC is a modular PMAC system built with a set of 3U-format Eurocards. The configuration of any UMAC system starts with the selection of the PMAC CPU and continues with the addition of the necessary axes boards, I/O boards, communication Ethernet board, axis control board etc. Individual boards can slide in and out of the rack, simplifying configuration and troubleshooting. Large selection of accessories is available as standard components. This gives a large



Figure 4: UMAC controller

modularity, which assures possible evolution of the controller according to eventual extension of peripheral devices to be controlled or to be taken into account.

The following features of UMAC are particularly useful for the motion control of FPCS, which is involved in various kinds of realtime tasks, particularly the servo loop update for the tracking of celestial objects when FOV is required to rotate at variable velocities under a servo loop control.

- Turbo PMAC is a full computer in its own right, capable of standalone operation with its own stored programs. Furthermore, it is a realtime, multitasking computer than can prioritize tasks and has the higher priority tasks pre-empt those of lower priority (most personal computers are not capable of this). Turbo PMAC's ability to run multiple tasks simultaneously, properly prioritized, can take a tremendous burden off the host computer and its programmer, both tin terms of processor time, and of task-switching complexity.
- PMAC2-style Servo ICs permit programmable configuration on the frequency of the key clock signals that drive the hardware and software processes on the controller s.
- Servo loop update: In an automatic task that is essentially invisible to the Turbo PMAC user, Turbo PMAC performs a servo update for each motor as a fixed frequency (usually around 2 kHz). The servo update for motor consists of incrementing the commanded position, comparing this to the actual position as read from the feedback sensors, and computing a command output based on the difference. This task occurs automatically without the need for any explicit for any explicit commands.
- Commutation Update: If Turbo PMAC is requested to perform the commutation for a multiphase motor, it will perform commutation update automatically at s fixed frequency. The commutation or phasing update for a motor consisting of measuring and/or estimating the rotor magnetic field orientation, then apportioning the command that was calculated by the servo update among the different phases of the motor. This task occurs automatically without the need for any explicit commands.

The electronics configuration selected for FPCS is as follows:

- Up to 32 axes of motion control.
- CPU board: Turbo PMAC2-3U CPU board.
- 100 MHz CPU.
- Expanded 512 K x 24 SRAM user data memory.
- Expanded 512 x 24 compiled/assembled p rogram memory.
- 4M x 8 flash memory.
- Configuration selected includes a high accuracy clock crystal (+/- 15 ppm) for long term velocity accuracy.
- Axis board: 8-axes board with 8 TTL encoder inputs and 8 1-Volt ptp encoder inputs x 4096 interpolation.
- Number and type of the digital inputs and outputs: 48 Inputs / 48 TTL outputs.
- Power supplies.

5.2 FOV rotation drive servo

FOV rotation drive sever block is shown in figure 5. Two channels are used for the pair of motors. A cascaded feedback loop is adopted (current, velocity and position). The field rotation encoder closes the position loop.



Figure 5: Field rotation drive block

5.3 Tilting drive servo

The tilting drive servo block is shown in figure 6 with each channel for an independent tilting unit. Also a cascaded servo loop is adopted.



Figure 6: Tilting drive servo block

6. FPCS SOFTWARE PLATFORM

FPCS software mainly consists of FPCS Coordinate and UMAC Realtime Executive Routine (RER) with FPCS Coordinate is one level above RER in the control hierarchy. FPCS Coordinate runs on an industrial PC with Windows XP OS, and is written by Visual C++6.0. The PC provides the user with GUI and communicates with TCS through TCP/IP protocol receiving commands and feeding back various kinds of focal plane states. Having obtained the data, FPCS Coordinate further processes the data and calls UMAC's respective commands to conduct interpolation. The FPCS Coordinate features module structure and object-oriented program. Each module is built in the form of class, making it easy for independently development and debug so as to enforce expansibility, updatability and maintainability. Winsock technique and multi-threads are utilized in the programming. 5 major tasks are involved, namely communication with TCS at up level though TCP/IP protocol receiving commands and feeding back various kinds of focal plane states, exchange data with UMAC through USB interface, calculate the velocity of field rotation for target tracking and convert the field rotation velocity into motor velocity, make focusing before the observation and resolve the equation group to get the correction displacement for each tilting unit, display the states with corresponding date for various aspects of the focal plane.

RER runs in UMAC MACRO environment with PMAC programming to conduct realtime interpolation, servo parameter update, error calculation, compensation estimation, motor motion control and process the data from I/O ports. Delta Tau has provided a dynamic link library PCOMM32.DLL accommodating various kinds of communication forms so that the user could be conveniently write own cods to control UMAC. We employ an ActiveX control widget PtalkDT, which is an interface for PCOMM32. The ActiveX is embedded in program in VC++ to ease the communication between TCS and PMAC.

TCP/IP protocol is utilized for communication between the industrial PC and TCS. The protocol employs two threads, a server thread for receiving commands from TCS and client thread for feeding back states. The client/server threads are running background while a main thread runs in front fulfilling all the routine activities. The multi-thread environment is beneficial for realtime operation. In the multi-threads programming we have employed Microsoft Foundation Class (MFC). In order to guarantee the synchronization among threads we adopted a critical section to make sure that a resource is accessed only by a thread at one time.

7. TESTS

After the simulation is done we carried out the test of hardware-in-loop in our assembly workshop with the giant focal plane mechanism stood there. The preliminary trial has been encouraging and promising. All the basic requirements are meat. First we carefully observed the motion of rotating focal plane at different given velocities from 1"/S to $1^0/S$. It appeared stable without stick-slip. We also did the repeatability test by put an indicator around the disk. A small iron block is attached on the disk so that at the starting position the block is pressed on the indicator spring rod giving an initial indicator value. Then let the disk move for certain angle and reverse the procedure, thus clockwise and counter-clockwise to record the values on the indicator. The error gives the mechanical repeatability and fine tuning ability of the servo. The data analysis has shown that the repeatability is within 1" at all the velocities tested. Thanks to the UMAC's ability in its motion coefficient setup so that even at maximum velocity of $1^0/S$ with moment of inertia 2000 kg m² it still could be able to position the target point properly without missing the point by 1". Next we checked the servo performance by collecting the following errors and calculated their RMS values. The following error is the error derived from discrepancy between the target position and the real position sampled at intervals while the position servo is on. The following error can be viewed in interface screen and recorded in UMAC programming. Tests have shown that for the range of tracking velocities from 1"/S to 15"/S the following errors (RMS) are less than 0.45".

8. CONCLUSION

The design of FPCS based on high-tech UMAC as its realtime controller plus its board slide-in ability has been proved effective, precise in control with expansibility. Preliminary tests in our workshop have shown the fulfillment of the design goal in broad aspects. However, some aspects in reality when the telescope is transported to Xinglong station might still exist. One of issues that large number of cables for those 8000 step motors on the back of the focal plane will probably bring unpredictable torque variation thus worse the field rotation stability. So the issue of increase the torsion rigidity for the rotation control system is the issue that calls for careful study.

ACKNOWLEDGMENTS

Many thanks to Mr. Hai Wang for the discussion with him on various aspects regarding the system, which has been beneficial. We would also like to thank Mr. Yizhong Zeng for his electrical assembly work done throughout the test. Our gratitude also goes to Mr. Guoping Li, Mr. Guomin Wang and Mr. Bozhong Gu, for their persistent effort to improve the rigidity of the mechanism.

We particularly acknowledge Mr. Christophe Daugny for his part during the course of the test.

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