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# The telescope control system at Mt. Abu infrared observatory

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**Abstract.** The 1.2 m Mt. Abu telescope at Gurushikhar is operated by the Astronomy & Astrophysics Division of Physical Research Laboratory, Ahmedabad. The evolution of the telescope control system to its present form has been described. Along with the telescope, the auxiliary systems in the Gurushikhar Observatory also are upgraded from time to time and have been listed. Future plans are described.

## 1. Introduction

The 1.2 m Mt. Abu telescope was installed at Gurushikhar, Mt. Abu, Rajasthan, in Western India, in 1990. The Gurushikhar Observatory is situated near the highest peak in Aravali range of mountains at 1680 m height above the mean sea level. The regular astronomical observations, here, started in October 1994. Observations are being carried out in different observing techniques viz. photometry, imaging, spectroscopy and polarimetry. The back-end instruments that are currently in operation at the Mt. Abu Observatory on a regular basis are as follows: (i) NICMOS Camera System (256 x 256 element IR Array) (ii) Two-channel infrared photometer (iii) Imaging Fabry-Perot Spectrometer (iv) Fiber-Linked Astronomical Grating Spectrograph (FLAGS) (v) Optical Polarimeter and (vi) CCD Camera System.

## 2. Description of the telescope

The 1.2 m Mt. Abu telescope is an equatorially mounted open truss and fork type and has a 1.2 m parabolic primary (f/3) and 300-mm hyperbolic secondary. It has a Cassegrain

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focus (f/13) behind the primary at a nominal distance of 380 mm from the Cassegrain plate/instrument ring (Banerjee, 1997). At 15.6 m effective focal length of the telescope, the plate scale is 13"/mm that remains linear over the telescope field of view of 10 arcmin diameter. The diameter of the primary central hole is 230 mm. The primary was polished from a mirror-blank of Cervit and weighs 300 kg whereas the secondary made up of Zerodur weighs 6 kg. The primary mirror is mounted in a mirror cell enclosure and is supported on floating axial (18 nos.) and radial (12 nos.) support pads. Each supporting pad is connected to an astatic lever and a balancing counterweight. The mirror support system allows the mirror to float inside the mirror cell with maximum deformation of 20 nm over the entire mirror surface against the cell flexure in any telescope position. The secondary mirror is mounted with a mounting ring at a distance of 2820 mm in front of the primary and is supported by 4 streamlined radial wings.

For mounting a back-end instrument on the telescope, an instrument ring of 450-mm diameter is provided. The instrument ring can be rotated about the optical axis of the telescope as it is attached to a bearing, which is fixed in the plate of the cell. The bearing is of a heavy-duty type and can allow an instrument as heavy as 150 kg to be mounted at the back. To accommodate the back-end instruments of different focal lengths, the secondary mirror can be moved up (20 mm) and down (60 mm) remotely from a console by a stepper motor drive giving a total range of 300 to 2200 mm from the Cassegrain plate.

## 3. Original telescope control system

The telescope was designed for achieving a pointing accuracy of 5" (or better). It was estimated that the telescope control system and the mechanical system of the telescope together would mainly contribute to this accuracy. The absolute shaft encoders of 1.24" resolution (20 bit) are mounted on both the axes of this equatorially mounted telescope - Right Ascension (RA) and the Declination (DEC) axis - for determining the telescope pointing direction. The Telescope Control Computer (TCC) reads both the absolute encoders every 20-millisecond intervals and displays the telescope position on the digital readouts on the Main Control Console (MCC). The telescope position is displayed in terms of hours, minutes, seconds and tenths of a second for RA and degrees, minutes and seconds for DEC. This happens during all the modes of the telescope motion selected by the operator from the MCC - SLEW, SET, TRACK and GUIDE/FINE GUIDE) - or even when the telescope is stationary.

The telescope drive is a closed loop feedback control system with an inner current (torque) loop of 25 Hz bandwidth nested by a velocity loop of 8 Hz bandwidth. During tracking, the outermost position loop is closed through the TCC, wherein the incremental encoder/gear combination giving 0.01" resolution in position helps in achieving the tracking speed accuracy of 15 0.1"/sec or better. The position loop has bandwidth of 2 Hz. This ensures that an abrupt change in the load torque on the telescope would disturb the tracking only for duration of about half a second. The bandwidths in the torque, velocity and position loops were designed on the basis of the expected telescope structural resonance frequency of 10 Hz. The entire telescope mechanical and control system was designed and executed by the SHAR Center, Indian Space Research Organization (ISRO) (Bobra, 1998).

The petal covers to protect the primary mirror can be opened or closed remotely from the MCC. The hemispherical dome mounted on the circular rail on top of the observatory building can be rotated in clockwise or anti-clockwise direction from the MCC on manual commands. Alternatively, the dome can be synchronized with the telescope movement by using synchro-resolvers interfaced with the TCC. The petal cover drive employs a stepper motor and the dome drive uses 2 DC motors mounted diametrically opposite to each other on the circular rail on which the dome rotates. An openable slit in the dome - the mechanical shutter system uses a couple of 3-phase AC induction motors and has no computer control for its operation.

The TCC supplied by the Control Group of SHAR Center was based on Intel's MULTIBUS architecture. In this design, a total of 4 numbers of SBC 80/20 processor boards sharing a common bus and peripherals were used. A separate processor board was allotted to the RA drive, the DEC drive and the auxiliary system consisting of the dome; secondary mirror and petal cover drives. One processor board was used as a supervisor that carried out the critical operations (like reading the switches on the MCC and computing the LST) at every 20-millisecond interval derived from an oven-controlled crystal oscillator.

## 4. Enhancements in the telescope control system

The telescope control system provided by the SHAR designers worked very satisfactorily for a few years. The processor boards and other the peripheral boards of the TCC, however, started getting obsolete very soon and it became difficult to maintain the control system due to the frequent failure of the old printed circuit boards. The software in the TCC was written in the machine language and was stored in PROMs. It was not very easy to make any modifications in the control algorithm as desired by the observers. At this stage, it was decided that a single CPU-based Pentium PC (800 MHz) should replace the TCC and the software is written in a higher-level language like Pascal. With this changeover, any modifications could be made in the telescope control algorithm as and when new demands came from the observers to suit their observing schedules.

On reviewing the total telescope control system it was decided that the drives for the RA, DEC, Dome, secondary mirror, petal covers etc. would not be changed. Also the interfaces for the absolute and incremental encoders and the overall structure of the MCC would not be modified. Changing these would have taken a long time and also would have brought the observations to a temporary halt during the changeover. Finally, the engineers and the technicians in the Observatory started the changeover from the Multiprocessor to Pentium PC-based TCC in 1998. In the present version, the TCC is based on a Pentium-IV PC with CPU working at 1.8 GHz, 4 PCI slots for digital and analog interface boards etc. The entire software has been changed to C++ and works under MS DOS.

While re-writing the telescope control software, a bug in the earlier software was detected and removed to improve the tracking performance of the telescope. On carefully analyzing the behavior of the telescope, it was found out that there was a slight inaccuracy in the ratio of the gear coupled with the incremental encoder in the velocity (and position) feedback loop. Due to this, the error between the actual and expected RA reading was increasing with time, resulting in a continuous drift in the star position. When the accumulated drift exceeded 3", the telescope used to show a jerk in the opposite direction and then continue to move with an incorrect tracking speed for a while before achieving the nominal tracking speed.

It was decided, then, that the absolute encoder reading for the RA shaft be used only for acquiring the star and then be removed from the position loop during tracking. During tracking, only incremental encoder be used to read the shaft position. The jerky motion of the telescope, now, has almost vanished with this new control algorithm. There has been a noticeable improvement in the tracking also. Presently, the telescope tracking is maintained to an accuracy of a few arcsec without any break for about half an hour. At this stage, a touch of the GUIDE or FINE GUIDE button on the MCC by the night assistant restores the correct tracking speed.

The PC-based TCC has incorporated many new features also. On a RS232 serial port (COM port) of the PC, it gives all the status parameters of the telescope and the status of the modes selected on the MCC at regular intervals (every 500 millisecond). This enables the observer to include them in his data-header files if he decides to do so.

Apart from giving SLEW and SET commands from the MCC, the telescope can be moved to acquire a star in the Designate Mode by typing RA and DEC co-coordinates of the star from a TCC-PC keyboard. The designate-star coordinates can be supplied also on a serial port (COM port) of the TCC-PC on a RS232 serial link. In this mode, after receiving the RA-DEC coordinates from the keyboard or the serial port, the TCC computes the difference in the expected and actual position of the telescope and starts moving the telescope with a slewing speed. It is slowed down progressively as the designated position approaches. On reaching the designated star position, the TCC automatically goes in the TRACK mode and continues the telescope motion to track the object till a new mode is selected from MCC.

## 5. A few add-ons in the observatory

### 5.1 The GPS receiver/clock

In July 2001, a Datum Model StarTime 9390-1000 clock based on a GPS receiver technology replaced the Time Code Generator that was using an oven-controlled crystal oscillator. The 20-millisecond reference clock derived from the GPS and supplied to the PC-TCC computes the Local Sidereal Time (LST) more accurately, as required. Due to the GPS technology there is no need, now, for manually synchronizing the observatory clock with the WWV time signals received on SW radio frequencies. The use of GPS also helped us in incorporating the correct station longitude and latitude values in the TCC software.

### 5.2 Diesel generator/ UPS

As a backup power supply for the observatory, a 120 KVA Diesel Generator has been installed in the observatory premises. For the sensitive instruments like GPS, EPABX, the LAN hubs and switches, the back-end instrument attached to the telescope and a host of PCs in the observatory, a UPS of 7.5 KVA has been installed. The UPS also supplies the power to the TCC and MCC.

### 5.3 Installation of observatory LAN/WAN

Recently, a campus-wide 10/100 MB LAN has been set up in the Observatory campus. The Observatory also has a 64 kbps link leased from BSNL with the servers in the PRL Computer Centre in the Main Campus at Ahmedabad. This link is used for applications like data downloading, sending/receiving emails and Web-browsing etc.

### 5.4 Aluminizing plant and PUNTINO

An Aluminizing plant has been installed in the Gurushikhar Observatory campus in May 2002. After a thorough cleaning, the mirrors are placed vertically, in a vacuum chamber. On a mounting ring, fixed opposite to the front surface of the mirror, 12 tungsten filaments coated with pure aluminium material are mounted uniformly. When the vacuum in the chamber reaches the required level, the filaments are switched on and the aluminium on them evaporates and gets deposited over the entire mirror surface in a fraction of a second. A software program, developed in house, was used to simulate this process to obtain aluminium coating of uniform thickness on the entire mirror surface. In October 2002, both the mirrors, the primary and the secondary, were aluminized with due care taken at every stage. Later, the mirrors were again mounted in the telescope and were aligned for getting the best possible image.

This was a very tedious process and took a few nights. This led us to procure a Shack-Hartman Wave front Sensor - PUNTINO -from Spot Optics, Italy. The PUNTINO can check the quality of the telescope alignment, on-line, and suggests quantitative measures to adjust the centering/tilt in the secondary mirror and the axial and radial supports in the primary mirror cell in any telescope orientation. Presently, the PUNTINO is being routinely used for monitoring the deterioration in the quality of images, if any, with the passage of time. Using PUNTINO on a regular basis will help us in tuning the mirror support system. PUNTINO can also be used for monitoring the seeing at the observatory site.

### 5.5 Hexapod drive for the secondary mirror mount

The existing secondary mirror drive can move the secondary mirror, from the main console, with only one-degree of freedom i.e. up or down in z-direction along the telescope optical axis. This only helps in focusing the star image but cannot remove de-center or tilt coma in the image caused by a misalignment of the secondary mirror due to a telescope flexure. The secondary mirror mount does have a provision for a small lateral movement along x and y direction to improve the telescope alignment, but the access to this arrangement is not very easy.

Hence, a new type of secondary drive, based on a hexapod construction is being designed. This construction will give six degrees of freedom to move the secondary mirror from the MCC. The corrections to adjust the secondary mirror position will be directly fed from PUNTINO, if mounted permanently on the telescope axis with the help of a flip mirror. With this new secondary drive, we hope to maintain the image quality throughout the night and in all telescope-pointing directions. We have procured a set of 3 Linear Actuators and Controllers from Physik Instruments, Germany. A prototype secondary drive is being made with a tripod design.

### 5.6 Weather station

A PC Link Professional Weather Station Model WMR 928 from Scottish Para-gliders Centre, UK, has been installed in the Observatory. The digital touch screen of the indoor unit has a wireless link with the various sensors mounted on the roof of the observatory building. The sensors are powered by solar panels. The readings from wind (speed and direction), rain, pressure, temperature and humidity sensors are displayed on the digital screen. The stored data can be read out on the serial port of the weather station. It will also estimate wind chill factor using a model.

## 6. Future plans: remote observing

Recently, another Pentium PC with Meade Epoch 2000sk-ver 2.0 software installed on it, has been interfaced with Telescope Control Computer. This software was actually procured to control an 8" robotic telescope, Meade LX200 that operates through the COM port of the PC.

The Epoch 2000sk program presents on the PC monitor a simulation of the entire sky, including up to 280,000 celestial objects. The program presents most complex star-fields as they actually appear through the telescope. After establishing a communication with the TCC on its serial port, it shows the current telescope position with a pre-selected cursor-shape. The TCC is set in the Designate Mode prior to this. With a click of the PC mouse on any star in the star-field displayed by EPOCH 2000 sk, a Dialog Box appears on the screen identifying the star and an option to "slew to object". On selecting this option, the 1.2 m telescope slews to the commanded star in just a few seconds and starts tracking it as in the TCC Designate Mode. Due to pointing error in the 1.2 m telescope, though, the selected star can be obtained only after a few trials.

In an another option, added recently, the 1.2 m telescope works, now, in a web-enabled mode. In this option, an N-PORT server device (an Ethernet Gateway for serial data) from Moxa, USA, is connected to the Observatory LAN on one side and the TCC-PC on another side through a serial RS232 interface. A Windows PC having the EPOCH 2000 sk installed in it and connected on the same LAN can remotely operate the 1.2 m telescope as in the previous option. The Windows PC, running EPOCH 2000sk on it, could as well be in PRL Main Campus or Thaltej Campus as both the campuses are on the same LAN (WAN). And, thus, Remote Observing, now, has been a reality.

## 7. Summary

The performance of the 1.2 m Mt. Abu telescope is continuously monitored and maintained at the best possible level to suit to new observing requirements and schedules from the observers. The auxiliary facilities at the Mt. Abu observatory are also enhanced from time to time for the observation programs carried out there.

## References

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