Synchronization of off-centered dome and 3.6m Devasthal Optical Telescope

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ABSTRACT

A 3.6m aperture telescope has been installed at Devasthal recently and once commissioned this would be the largest optical telescope in India. The integration of the telescope was carried out by lifting the components from inside the telescope building. To make this possible, the position of the telescope was shifted by 1.85m from the dome centre at an angle of 255 degree with respect to the north. This posed a serious challenge in synchronizing the dome with the telescope movement. In this contribution we will be presenting the synchronization algorithm and dome control software.

Keywords: Dome Control System, Dome Synchronization, DOT

1. INTRODUCTION

Most of the optical telescopes are housed within a dome or similar structure, to protect the delicate instruments from the elements. At the same time, a telescope housing should provide maximum amount of space for the telescope to maneuver at minimum of the material used for the construction and hence the cost. Telescope domes have a slit or other opening in the roof that can be opened during observations of celestial objects, and closed when the telescope is not in the use. In most cases, the entire upper portion of the telescope dome can be rotated to allow the instrument to observe different sections of the night sky.

The 3.6m Devasthal Optical Telescope (DOT) has a cylindrical dome with a tapered roof to allow the snow to slide off from the dome roof easily. The dome and the telescope rotate independently. The telescope is sitting on a pier structure which is structurally isolated from the telescope housing. While observing a celestial object through the telescope, the dome slit opening should be suitably positioned so that an unobstructed view of the portion of the sky is always available to the telescope. In most cases, the dome and the telescope centres coincide making it practically easy to synchronize the movement of the dome with that of the telescope.

In the case of DOT, it was decided that the assembly and integration of the telescope will be carried out by hoisting the telescope components through the inside of the telescope building. Two 10 ton capacity overhead cranes were used for hoisting the telescope components. For this purpose, the telescope was positioned little off centered from the dome centre to create enough space for an opening in the telescope floor through which the telescope components could be hoisted. This made the synchronization of the movement dome with respect to the telescope line of sight a big challenge.

In Figure 1, the dome of the DOT is presented. In this poster we present the algorithm we developed to synchronize the movement of the dome with respect to the motion of the telescope line of sight. We begin with a description of the dome parameters in section 2. The scheme with which we developed the algorithm is presented in section 3. We also describe the software in which we developed the algorithm and the GUI to control the dome movement in section 4. The hardware used in the synchronization of the dome is described in section 5.
2. TELESCOPE ENCLOSURE

The telescope enclosure is cylindrical in shape up to a height (h) of 9.6 m (Figure 2). The height of the housing is measured from the level of the primary mirror. The roof of the housing is conical in shape with the radius same as the cylindrical part and has a height of 2.2 m. The telescope is located at a distance 1.85 m from the dome centre making an angle of 255° with respect to the celestial north. The slit-width of the dome is 4.4 m. The dome parameters used for developing the algorithm are listed in Table 1 below.
### 3. THE ALGORITHM

Given the declination ($\delta$) of a star, latitude of the place ($\varphi$), hour angle (HA), we can estimate the telescope altitude ($\varepsilon$) and azimuth ($\phi$) to that star as

$$\varepsilon = \sin^{-1} \left( \sin \delta \sin \varphi + \cos \delta \cos \varphi \cos HA \right) \quad (1)$$

$$\phi = \cos^{-1} \left[ \frac{\sin \delta - \sin \varepsilon \sin \varphi}{\cos \varepsilon \cos \varphi} \right] \quad (2)$$

The altitude and the azimuth thus obtained define the line-of-sight (LOS) to that star which is same as the optical axis of the telescope. The dome is said to be synchronized with the telescope when this LOS or the optical axis of the telescope intersects the center line of the slit at a point defined by the dome azimuth ($\psi$) and the telescope elevation. This is true when the telescope and the dome centres coincide. In the case of 3.6 m DOT, the telescope (T) is off centred towards south-west of the dome center (see Figure 3.). This presents additional complications which makes, the otherwise simple calculations, complex.

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**Table 1.** The values of the dome parameters used in our calculations.

<table>
<thead>
<tr>
<th>Dome Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floor radius (R)</td>
<td>8.25 m</td>
</tr>
<tr>
<td>Curved surface height (h)</td>
<td>9.6 m</td>
</tr>
<tr>
<td>Height at the dome centre (H)</td>
<td>11.3 m</td>
</tr>
<tr>
<td>Distance between dome centre and telescope centre (d)</td>
<td>1.85 m</td>
</tr>
<tr>
<td>Slit-width (w)</td>
<td>4.4 m</td>
</tr>
<tr>
<td>Telescope off-set angle</td>
<td>255 degree</td>
</tr>
</tbody>
</table>
3.1 **Main points considered while developing the algorithm**

Below we list certain important facts that are required for developing the algorithm.

1. The dome shape is cylindrical.
2. The roof of the dome is conical in shape.
3. The dome is off-centred from the telescope centre.
4. There will be a height difference between the telescope and the dome zenith point on the roof.
5. The telescope beam size will vary with the telescope/dome azimuth. It will also vary with the elevation of the star.
6. Two geometries need to be considered in order to develop the algorithm:
   (a) Regime 1: when the LOS to a star passes through the curved surface of the cylindrical dome. (left panel of Figure 4)
   (b) Regime 2: when the LOS to a star passes through the conical roof. (right panel of Figure 4)
7. In the case of regime 1, the following facts are trivial from the geometry:
   (a) the telescope and the dome azimuth will be same at two values, 75° and 255°
   (b) TO will be maximum and minimum at 75° and 255° respectively and the corresponding values are 10.1 m and 6.4 m.
8. In the case of regime 2, the following facts are trivial from the geometry:
   (a) if DO ≥ TD, then the telescope and the dome azimuth will be same at two values, 75° and 255°.
   (b) if DO < TD, then the dome azimuth will be 255° for the telescope azimuths of 75° and 255°.
Now let us consider the two geometries separately and develop an algorithm.

3.2 Regime 1: when the LOS is through the curved surface of the cylindrical dome

As long as the LOS to the star is through the curved surface of the cylindrical dome, the dome azimuth can be evaluated from the telescope azimuth using the projection of the LOS intersection point on the dome floor (O) which results in a simple geometry as shown in Figure 4 (left panel). The expression used to calculate dome azimuth is given by

$$\Psi = \phi + \sin^{-1} \left( \frac{d \sin(\phi - 255)}{R} \right)$$  \hspace{1cm} (3)

But because the telescope is off-centred, the line TO will vary as a function of $\phi$ (or $\Psi$). Using the geometry shown in Figure 4 (left panel), we can calculate TO for different $\Psi$ in terms of $d$ and $R$ from the expression (using the cosine rule)

$$TO = \sqrt{d^2 + R^2 - 2dR \cos(255 - \Psi)}$$ \hspace{1cm} (4)

The value of TO is maximum ($d+R=10.10$ m) when the $\phi$ (or $\Psi$) is 75° and minimum ($d-R=6.40$ m) when $\phi$ (or $\Psi$) is 255°. The TO versus $\phi$ (line in red) and $\Psi$ (line in blue) for a star with 75° elevation is shown in Figure 5. This curve is valid for all those elevations which gives $TO \times \tan(\epsilon) \leq 9.6$ m (the height of the cylindrical dome wall). There is one more effect which needs to be considered due to the off-centred position of the telescope and that is the effective slit-width presented by the dome slit to the telescope beam at various $\phi$ (or $\Psi$). The effect is mainly due to the difference between the angles $\phi$ and $\Psi$ which is clearly evident in Figure 5. The dome slit will present full slit-width ($w$) only for two angles i.e., at 75° and 195° where, $\phi - \Psi = 0$. 

Figure 4. Left: When the LOS passes through the curved geometry of the dome. Right: Geometry when the LOS passes through the roof of the dome.
3.3 Regime 2: when the LOS is through the conical roof of the dome

For regime 2 the LOS, instead of passing through the curved surface of the dome, will pass through the conical roof as shown in Fig. 6. The geometry of its projection on the dome floor will be as shown in Fig. 6. In such a situation, the dome azimuth is calculated by finding out the point of intersection between the LOS and the line PQ which joins the top of the curved surface of the cylinder with the top of the conical roof. This calculation was effected using parametric formalism.

Consider the dome to be infinitely tall cylinder. The LOS to a star with elevation such that the TO x tan (ε) > 9.6 m will then intersect the curved surface of the dome at some point, A. The dome azimuth, ψ∞, in such a case can be calculated using equation 3. Considering a right hand coordinate system centred at the center of the dome with the east taken along x-axis and north along y-axis, the telescope location is taken as T (Tx, Ty, 0), the height of the dome cylinders is taken along z-axis. The point of intersection of LOS with the infinitely tall cylindrical dome, A(R sin ψ∞, R cos ψ∞, TO tan (ε)). Then the LOS can be represented parametrically as

![Figure 5](http://proceedings.spiedigitallibrary.org/proceedings.cfm/9913/99134O-6/99134O-6.pdf)  
Figure 5. TO versus φ (red color) and ψ (blue color) for a star with 75° elevation.

![Figure 6](http://proceedings.spiedigitallibrary.org/proceedings.cfm/9913/99134O-6/99134O-6.pdf)  
Figure 6. The geometry of the dome when the LOS passes through the dome roof.
\[ X_{\text{LOS}} = T_X + (R \sin \Psi - T_X)t \]  \hspace{2cm} (5)

\[ Y_{\text{LOS}} = T_Y + (R \cos \Psi - T_Y)t \]  \hspace{2cm} (6)

\[ Z_{\text{LOS}} = [TO \tan(\varepsilon)] \cdot t \]  \hspace{2cm} (7)

Where \( t \) is the parameter. The dome slit with the dome azimuth, \( \psi \) is the line joining the points \( P(0, 0, H) \) and \( Q(R \sin \psi, R \cos \psi, h) \). Then the equation of the slit in the parametric form \( (r) \) is given by

\[ X_{\text{slit}} = r \sin \Psi \]  \hspace{2cm} (8)

\[ Y_{\text{slit}} = r \cos \Psi \]  \hspace{2cm} (9)

\[ Z_{\text{slit}} = H - \left( \frac{(H - h)}{R} \right) r \]  \hspace{2cm} (10)

Where \( (0 \leq r \leq R) \)

By equating equations 5 and 8, 6 and 9, and 7 and 10 and solving for \( t \), we get

\[ t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]  \hspace{2cm} (11)

Where

\[ a = (R \sin \Psi - T_X)^2 + (R \cos \Psi - T_Y)^2 - \left( \frac{TO \tan R}{H - h} \right)^2 \]

\[ b = 2 \left[ T_X(R \sin \Psi - T_X) + T_Y(R \cos \Psi - T_Y) + \frac{H(\tan \varepsilon)R^2}{(H - h)^2} \right] \]

\[ c = T_X^2 + T_Y^2 - \left( \frac{HR}{(H - h)} \right)^2 \]

Only those values of \( t \) are chosen for which the values of \( r \) (in the equation resulting from equating equations 7 and 10) are in the range between 0 and \( R \). The calculated dome azimuths corresponding to the telescope azimuths as a function of the hour angles are shown in the Figure 7.
Figure 7. Calculated values of the dome azimuth (blue and cane) corresponding to the telescope positions (green and red) with positive (top) and negative (down) declinations as function of the hour angle.

4. THE DOME CONTROL SYSTEM

Based on the algorithm, we have developed a dome control system (DCS) to operate the dome in accordance with the RA and Declination inputs given to the telescope through the telescope control system (TCS). Below we present a conceptual architecture of the DCS we have developed.

4.1 The conceptual architecture of the DCS

The system will have two login modes; one is the observation mode which will be used by the observers and the other is the engineering mode which will be used for debugging the system. Each mode will have slightly different initialization procedure. The detailed architecture is shown in Fig. 8.

4.1.1 User Interface Layer

This layer would allow the user to communicate with the system through a GUI designed by keeping in mind of the end users, i.e., observers. The user can also communicate with the system by feeding the commands directly through a command window. We are keeping a facility to communicate with the system through sockets using remote login. This facility would be useful, in particular, in case we decide to develop the entire interface through XML. The GUI window is given in Fig. 9.
4.1.2 Application Layer

The function of the application layer is to first validate the command passed by the GUI/command window/remote system. The validation is done based on the parameters that are already in the database such as, the maximum azimuth angle that can be requested for, is 360°. If a value greater that 360° is requested, an error message will be shown. All the commands that have been passed from the interface layer and the system health parameters will be logged at this layer with a time and date stamp for them to be used later by retrieving them based on a range of time or data. The system health is basically the links between the DCS and other components such as TCS, WCS, ICS, etc. The links to various systems will be checked once in every 10ms. If during any check, the link fails, rechecks are made for another 5 times and if the link failure still persists, an error message is generated.

4.1.3 Operational Layer

This layer is responsible for generating commands that are required by the microcontrollers (MCs). These commands are passed on to the appropriate MCs through ethernet to the serial converter.
**4.2 Dome Control Software Scheme**

Graphical User Interface of the DCS is developed in Python language. The Dome Control System (DCS) design is mainly divided into three parts as follows:

- The main program “dcs.py” consists of the code for GUI & Subroutines
- The file “config.py” consists of flags/variables/constants which are private to DCS.
- Last is the database which contains data/logs which can be shared among other programs like Observatory Control System (OCS).

In the final version, Dome Control will be included in OCS and OCS will communicate with DCS using socket interface. The OCS will interact with sub-systems like TCS, DCS, WCS and ICS. These sub-systems like the DCS will write its data and system log in a database that can be accessed by the OCS and all other sub-systems that are connected to the OCS.
5. THE INTERFACE BETWEEN THE HARDWARE AND THE DOME CONTROL SOFTWARE

Dome movement is controlled through the microcontroller based interface card. The concept of interface method between hardware devices and dome control system software is described here. Dome control system is interfaced with the following hardware devices.

(a) Absolute Multi-Turn Encoder for Dome azimuth position.
(b) Three phase AC variable voltage variable frequency drive (VVVFD) for dome movement.
(c) Photoelectric sensors for dome home and absolute reference position.
(d) Electrical hardware status (Ready or Fault) for interlocks and safety.

5.1 The Interface card

Interface card consists of a PIC Microcontroller having Enhanced Universal Synchronous Asynchronous Receiver Transmitter (EUSART) and Synchronous Serial Port (SSP) module. EUSART is also known as Serial Communications Interface (SCI) and On-chip EUSART module is implemented in start bit, 8-bit character data and stop bit transmission/reception mode with desired baud rate of 9600. Back to back consecutive transmission/reception also can be performed. The Synchronous Serial Port (SSP) module is a serial interface used for communicating with encoder and is operated in Serial Peripheral Interface (SPI) mode. PIC Microcontroller has I/O ports to read the signals and generate the control signals. Interface card also includes a circuit that converts from the RS-232 compatible signal levels to the USART's logic levels and vice-versa. Interface card communicate with DCS on Ethernet to RS-232 converter. Its block diagram is shown in Fig. 11.

5.2 Absolute Multi Turn Encoder

CST BEI make Multi-Turn Absolute Encoder, shown in Fig. 12(right panel), is attached on the dome wheel to monitor the dome azimuth position. Multi-turn encoder provides absolute position information over multiple turns of the input shaft. It keeps track of the exact position even when the power is switched off. This avoids any need for a battery backup. The multi-turn encoder is capable of outputs up to 4096 counts per turn and can count up to 256 turns—a total of 20 bits or 10,48,576 positions. The encoder generates SSI compatible serial data output. The PIC microcontroller shifts
out the data from the shaft encoder and send it through a serial port. The dome position information will be used by the dome control system to control the dome position.

![Block diagram of the hardware and the interface of the dome control system](image)

**Figure 11.** Block diagram of the hardware and the interface of the dome control system

![Photoelectric sensor mounted on the dome and Encoder mounted on one of the wheels of the dome](image)

**Figure 12.** Left: Photoelectric sensor mounted on the dome. Right: Encoder mounted on one of the wheels of the dome on which the dome rotates.

### 5.3 VVVFD, Photoelectric Sensors and Electrical Hardware

Siemens make VVVFD is used for dome motion. Its digital input/output ports are connected to the interface card for controlling a dome movement directly from DCS. Depending upon required position condition, start/stop and direction input digital signals to VVVFD are issued from dome control system software through interface card. Two Photoelectric sensors are used at 180 degree from each other on dome circumference for dome homing and absolute reference position. These reference points are used to correct the dome absolute azimuth position due to wheel slippage etc. and for the dome homing position. Whenever the reference point crosses any one position sensor, its digital signals are read through interface card. Electrical hardware status (Ready or Fault) signals are also read through interface card. These digital signals are made available to the dome control system software through interface card.
REFERENCES