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Pointing-accuracy for the 1.2m Gurushikhar telescope — measurement and improvement

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Abstract. A study has been made for the pointing accuracy of the 1.2m telescope at Gurushikhar Observatory. The errors in pointing have been carefully mapped in a region of the sky extending from 70° to –20° in declination and –45° to 45° in hour angle. From these errors, a pointing model has been developed which gives the corrections to be applied, during acquisition, to the co-ordinates of an object. These corrections can be fed to the telescope control system to enhance pointing accuracy.

Key words : pointing accuracy, telescope pointing

1. Introduction

In this work we have measured the pointing-errors, for the 1.2 metre Gurushikhar Telescope, at different locations of the sky. The aim of the exercise is to develop a pointing-model which can be utilized to ensure better accuracy. Such studies are generally done to improve telescope performance (Tosti et al. 1996). The 1.2m IR Telescope was designed for achieving a pointing accuracy of $5''$ (or better), defined as the maximum allowable difference between the co-ordinates of a star when it is imaged on the optical axis at the Cassegrain focus and the co-ordinates displayed on the console (IRAT01, IRAT03, 1983). It was estimated that the telescope control system would contribute a r.m.s. value of $3.5''$ to this, with a similar contribution from the mechanical system of the telescope.

The absolute shaft encoders of $1.24''$ resolution (20 bit) are mounted on both the axes of this equatorially mounted telescope - the Right Ascension (RA) and the Declination (DEC) axis - for determining the telescope pointing direction. The Telescope Control Computer (TCC) reads both the absolute encoders at 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 - slew, set, track (guide/fine guide) - or even when it is stationary.

The telescope drive is a closed loop feedback control system with an inner current (torque) loop nested by a speed (velocity) loop. 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 arcsec/sec or better, with a loop bandwidth of about 2 Hz. With these specifications the Gurushikhar IR telescope optics and the mechanical system was designed and erected by the SHAR Centre, Indian Space Research Organisation. (ISRO).

Regular observations on this telescope have started since 1994 and have continued till this date (Deshpande, 1995). Observations are being routinely carried out in different fields viz. photometry, imaging, spectroscopy, polarimetry etc. Although the telescope pointing is good, there is in general a need to make quantitative measurements of the telescope pointing errors and improve the pointing accuracy as far as possible. Good pointing accuracy saves valuable time and effort in object acquisition. Especially in the Infrared, where the object is not visible in the eyepiece, a good pointing accuracy is imperative. With this in view, a few nights in March and April 1997, were specifically used for carrying out an exercise for determining the pointing accuracy, at the f/13 Cassegrain focus, of the IR telescope.

2. Observations

As a first stage, it is intended to find the pointing errors over a section of the sky which is commonly used for observations. Towards this end, star positions were observed in a region, starting from and upto 45° from the zenith position, in all azimuth directions. That is, errors were mapped in the altitude range 45° - 90° and azimuth range 0° - 360°. It is intended in the future, in the second stage of studies, to cover regions of the sky not included in the present study. In this invesitgation, ten stars were chosen to determine the pointing errors. They are HD 122909, 122740, 122236, 122326, 122456, 122364, 121845, 122104, 122135 and 122491. The reference RA and DEC co-ordinates of these stars were taken from Hirshfeld and Sinnott (1982). The stars were selected so that each was separated from its instant neighbours by approximately 10° in declination, thereby enabling an approximately equispaced sampling of the sky in declination. The position of each of these stars was then recorded at intervals of approximately 7.5° in hour angle (or 30 minutes in time) as the star transited in the sky. As a result, data was recorded at 120 positions in the sky. At each position, the observed values of RA and DEC (from the console) were noted and also the actual values (from the Catalogue RA and DEC values updated for the epoch of observation). The errors in pointing may then be defined as :

$$(\mathrm{err})_{\mathrm{DEC}} = (\text{actual value})_{\text{catalogue}} - (\text{observed value})_{\text{console}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 1$$

$$(\mathrm{err})_{\mathrm{RA}} = (\text{actual value})_{\text{catalogue}} - (\text{observed value})_{\text{console}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 2$$

During observations, to get the observed RA and DEC values of a star, it needs to be centred with respect to a reference point. In order to keep the subjective errors of centering to a minimum, instead of an eye piece, an EEV intensifier CCD camera was used having a spatial resolution of 0.25 arc seconds per pixel. The ICCD video output, at TV frame rates, was monitored on a TV receiver tube affixed with a transparent grid for accurate centering of the stellar objects. The Local Sidereal Time (LST) display from the Control Console was also recorded. It may be noted that the RA display on the console is the computed difference between the LST and the Hour Angle (HA) as read by the absolute encoder. Thus the error in HA will be equal in magnitude but opposite in sign to the error in RA (as given by equation 2). In succeeding analysis, we consider the errors in pointing, in terms of errors in declination and hour angle.

3. Results and analysis

From the 120 points at which observations have been made, a grid of data points has been generated, comprising of the errors in pointing for different locations in the sky. This grid is shown in Figure 1. Since the pointing-errors were found to be typically of the order of arc minutes, it is not possible to show it on the same scale as that of the main coordinate scale of Fig. 1. We have therefore magnified the errors 50 times, and the magnitudes of the errors may be read directly from the scale given in the top corner of Fig. 1.

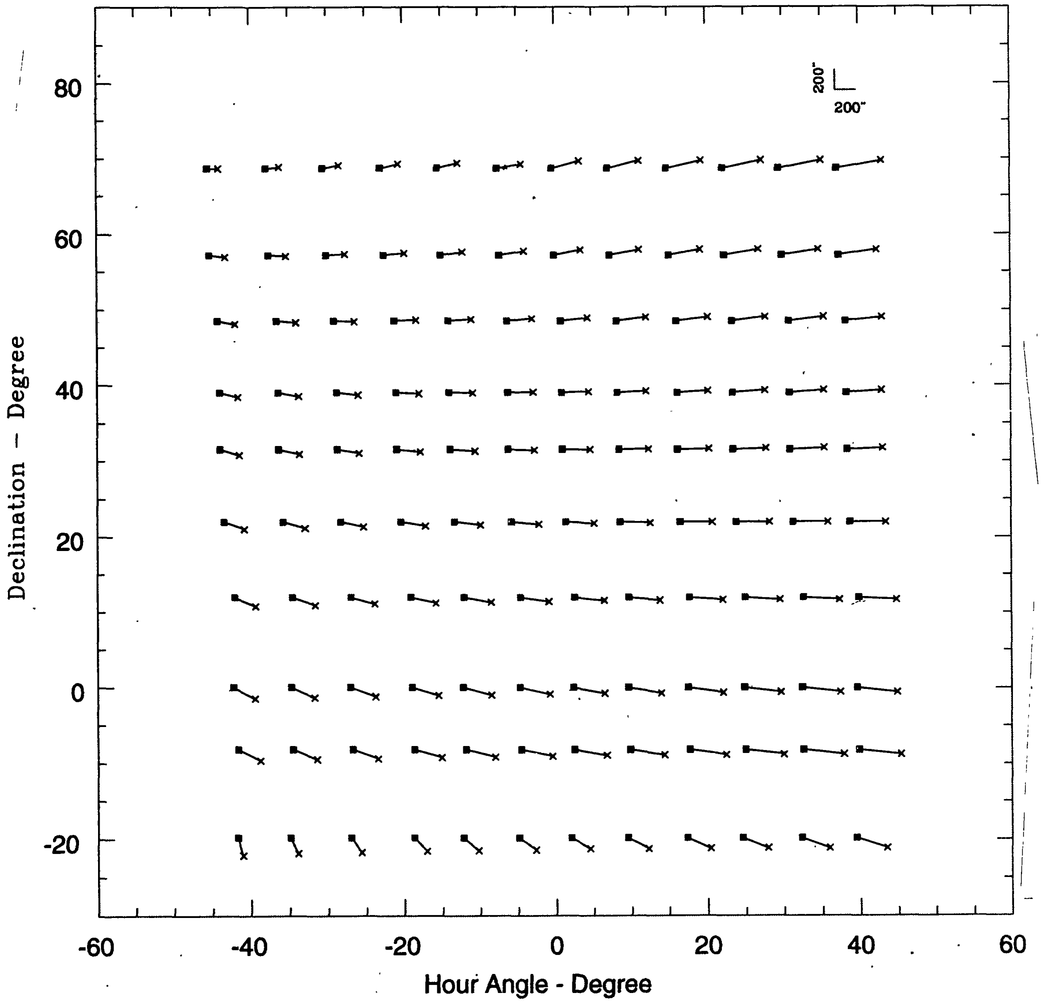

Figure 1. The observed pointing-errors, at different parts of the sky, are shown here by a short line with a square and a cross at the two ends. The square represents the expected, catalogue co-ordinates of the star, while the cross is the observed position. The magnitude of the pointing-error, determined by the extent of the line, is to be read from the scale given in the top corner of the figure.

From the preliminary studies of the trends in the pointing-error, it is apparent that many factors are likely to be contributing to the observed errors. These factors, which may not be exhaustive, are listed below :

a) Zero setting of the absolute encoders

b) Refraction

c) Telescope body flexure

d) Collimation (Error in the alignment of the primary and secondary mirror axis).

e) Non perpendicularity of the two axes of the telescope

f) Polar axis misalignment

g) LST computation error due to (1) An error in the UT provided by the local Time Code Generator (2) Error in the Observatory coordinates used in the software

h) Aberration

i) Nutation

j) Precession

k) Uncertainty in locating the position of the star image due to the atmospheric seeing effects.

It is rather difficult, to quantify the relative contribution of each of the above factors to the total observed error. However, a few comments may be made. The effects of nutation and precession are taken care of, while updating the coordinates of the star, for the epoch of observation. Estimates have been made for the pointing errors caused due to refraction. Refraction causes errors in both declination and hour angle and, in general, this error is zero at the zenith and increases towards the horizon. Using programmes form Duffett-Smith (1985) and Meeus (1991), the error due to refraction, for the region of the sky covered in this study, was estimated at different positions. As expected it is found to be maximum at the lowest altitude covered in this study i.e. at 45°. The magnitude of the pointing-errors, at this altitude, are typically of the order of 50 arc seconds in both declination and hour angle. It may be noted that the programmes used for this purpose (Smith, 1985), estimate the errors for a model atmosphere with a given temperature and pressure. By varying the temperature and pressure over a large range (950 to 1050 mbar, 0° to 30° C), we note that only marginal changes of approximately 2 to 3 arc seconds occur from a mean value.

It is possible that a substantial part of the observed pointing error, is due to telescope flexure. Also it would appear that there is some collimation and/or zero setting errors, since at zenith position, where errors due to flexure and refraction are nil, some observed errors are still present. However, for our purpose of pointing the telescope in the desired direction, it is primarily necessary to know the magnitude of the error-corrections to be made rather than the source of the error.

Given the data for the pointing errors at the 120 fixed points of Figure 1, the next step is to estimate the error in pointing for any in-between or intermediate point. To estimate this, it is necessary to interpolate between the data points of Figure 1. The interpolation will necessarily have to be a two-dimensional interpolation i.e. in both hour angle and declination. However, the standard packages for two-dimensional interpolation (Press et al. 1993) need that the reference data be equispaced, in both directions of interpolation. Our data is not truly equispaced, but nearly so, in both hour angle and declination. We have therefore, first used a one-dimensional interpolation package POLINT (Press et al. 1993) and interpolated the errors (for a fixed declination) so as to get the errors at equal intervals of 7.5° in hour angle. Next, interpolation using POLINT was done (for a fixed hour angle) to get the errors at equal intervals of 10° in declination. Thereby a two dimensional grid of data points has been constructed, spanning from –45° to +45° in hour angle and from 70° to –20° in declination. The data is in regular intervals of 7.5° in hour angle and 10° in declination.

This data grid is shown in Figure 2. It can now form the reference data set, for a two dimensional interpolation, to find the errors in pointing at intermediate values of hour angle and declination. As a cross check, for the numerically generated grid of Figure 2, we have run the two dimensional interpolation program POLIN2 (Press et al., 1993) and checked what errors are generated at the 120 observed points of Figure 1. Comparison of the generated

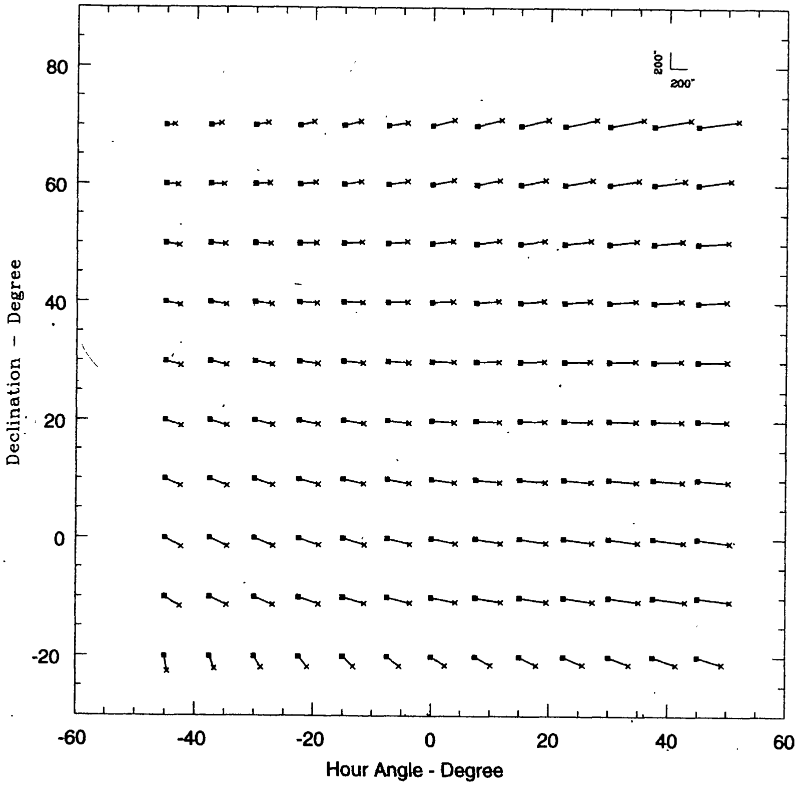

Figure 2. The figure shows the numerically generated, pointing-error map at regular intervals of 10 and 7.5 degrees in declination and hour-angle respectively. The magnitude of the pointing-error, is to be read form the scale in the top corner of the figure. The data here, can be used to generate the pointing-error at any itermediate point, by using two-dimensional interpolation.

errors from POLIN2 with the actually observed errors show a good agreement. The numerically generated and observed errors agree within 0.49% for the hour angle and 0.9% for the declination errors.

It may be noted that POLINT and POLIN2 are polynomial interpolation based subroutines. In both these subroutines, we have chosen to do the interpolation using third order polynomials. This is what is recommended rather strongly, and although higher order polynomials can be used, it is not advisable (Press et al. 1993, p 101). We may refrain from giving the coefficients of the fitting polynomials in POLINT for the following reasons. Firstly there are too many of them. Further, all these coefficients eventually get incorporated into the routine of our final interest i.e. POLIN2. Now in this two dimensional package, for every RA and DEC value considered for interpolation, (and such points will be infinite), there will be an unique polynomial with its corresponding coefficients.

We have checked the accuracy of the pointing model, explained above, in the following way. A fresh group of 10 stars were considered, such that their positions were randomly distributed over the sky area covered in this work. It was ensured that their positions differed considerably from the grid points of the figures 1 and 2. The observed RA and DEC values of the stars were compared with the predicted, model values. It was found that the pointing accuracy increases significantly. The observed positions of the stars deviated from the predicted, model positions by a mean value of only 12″ in RA and 5.9″ in DEC.

4. Discussions

At the observatory, the necessary pointing-error corrections to be made during object acquisition, can be done at present in the following way. The pointing model is available on a PC and the observer can correct the catalogue co-ordinates for pointing-errors. In future, the error corrections will be done directly by the TCC. The present TCC software algorithm will be modified, by including a procedure to correct the actual coordinates of the object by the requisite amount. This process of error correction will be transparent to be observers. Once acquisition is done, further tracking will be carried out by an autoguider which is under development.

It may be added, that accuracy in computation of the LST is essential for correct pointing. For every second of error in the LST, the error in pointing in RA will amount to 15 arc seconds. The calculation of the LST requires the geographical co-ordinates of the observatory to be known with a high accuracy. Towards this end, the geographical co-ordinates of Gurushikhar Observatory were determined with precision using a Global Positioning System (GPS) receiver. By locking on to 5 of the 24 GPS satellites orbiting the Earth (a total of atleast 4 satellites are required for a position estimate), the co-ordinates of the observatory were determined to be : Longitude 72° 46′ 45.9″ E and Latitude 24° 39′ 10.9″ N (correct to an accuracy of ± 3.3″). Moreover, the LST calculations may also go wrong if the observatory clock is in error. Hence the existing Time Code Generator (employing oven-controlled crystal oscillator) supplying the Universal time to the TCC is being replaced by a GPS based digital clock to reduce further the errors in computing the LST.

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