Proceedings of ICRC 2001: 2856 © Copernicus Gesellschaft 2001

ICRC 2001

Correcting the pointing of the Durham Mark 6 Cherenkov Telescope

P. M. Chadwick, T. J. L. McComb, K. J. Orford, J. L. Osborne, and S. M. Rayner

Department of Physics, Rochester Building, Science Laboratories, University of Durham, Durham, DH1 3LE, U.K.

Abstract. The Durham Mark 6 Cherenkov telescope was established in Narrabri, NSW in 1995. The resolution of sensing the pointing direction was designed to be ~ 1 arc-minute. The method used to calibrate and correct the pointing of the telescope in order to achieve an accuracy equivalent to the resolution is described in detail. A CCD camera was used to take regular images of the telescope's field of view. These were combined with frequent measurements of the position of the brightest star in the field of view to calibrate absolute digital encoders on the telescope steering axes. The gravitational bending of the focal supports was allowed for.

1 Introduction

The University of Durham Mark 6 Atmospheric Cherenkov Telescope (ACT) operated in Narrabri, NSW from 1995 until 2000. Its construction has been fully described (Armstrong et al., 1999). It comprised three 7m diameter f/1.0 parabolic dishes on a single alt-azimuth mounting. The form of drive, from the centre, and the location, on a sandy plain prone to occasional flooding, resulted in particular problems in driving and sensing the pointing directions. The solutions adopted for correcting the pointing direction in the data analysis are the subject of this paper.

2 Steering

The telescope was steered using a DC servo system with tachometer feedback. The error signal for the servo system was provided by a PC which compared the top 12 bits of a 14-bit axis encoder with the calculated axis position. This comparison was carried out 10 times per second and resulted in a drive signal generated by a digital to analogue converter. The transfer function was calculated according to a table which allowed for the inertia of the telescope. The calculated position was updated every second.

Correspondence to: K. J. Orford (k.j.orford@dur.ac.uk)

The calculation of the target values for the encoders took into account the non-verticality of the ACT's azimuth axis. The position of the axis was initially determined from widely-spaced star sightings, taken using the central PMT of the camera on the central dish. The anode current resulting from exposure to a star of typical magnitude 3.0 was used to plot contours of equal light intensity as the pointing direction of the ACT was adjusted. The CCD image of the star was used to record the stellar image position relative to the telescope framework. The centre of the contours was regarded as the optical axis position and the position of the star in the CCD field of view was noted.

A separate method was used to check the accuracy of this locating of the optical axis. The image of a star of magnitude ~ 3.0 was placed in the camera. The anode currents of all of the PMTs were recorded over a period during which the star's position was varied, and the encoder values recorded simultaneously with the anode currents. The currents allowed an estimate of the position of the axially-symmetric point spread function of the star's image to be determined when sufficient adjacent PMTs received illumination. This kind of measurement of the position of the optical axis relative to the encoders was found to be quicker and more easily reproduced. Three such widely-spaced comparisons are sufficient to solve for the spatial direction of the azimuth axis. This was stored by the steering PC as the effective latitude and longitude of a telescope with a geographically vertical azimuth axis, parallel to the axis of the Mark 6 ACT. In fact, twelve such comparisons were made every month so that the accuracy and long-term stability of this determination could be checked.

As a result of the frequent monitoring it was found that there was a small seasonal variation in the direction of the azimuth axis which was ascribed to the large variations in water content of the sandy soil structure supporting the foundations. The relationship between the axis encoders and the true position of the ACT's azimuth axis was consequently changing slowly. In addition, gravitational distortion of the telescope structure caused relative movement between the

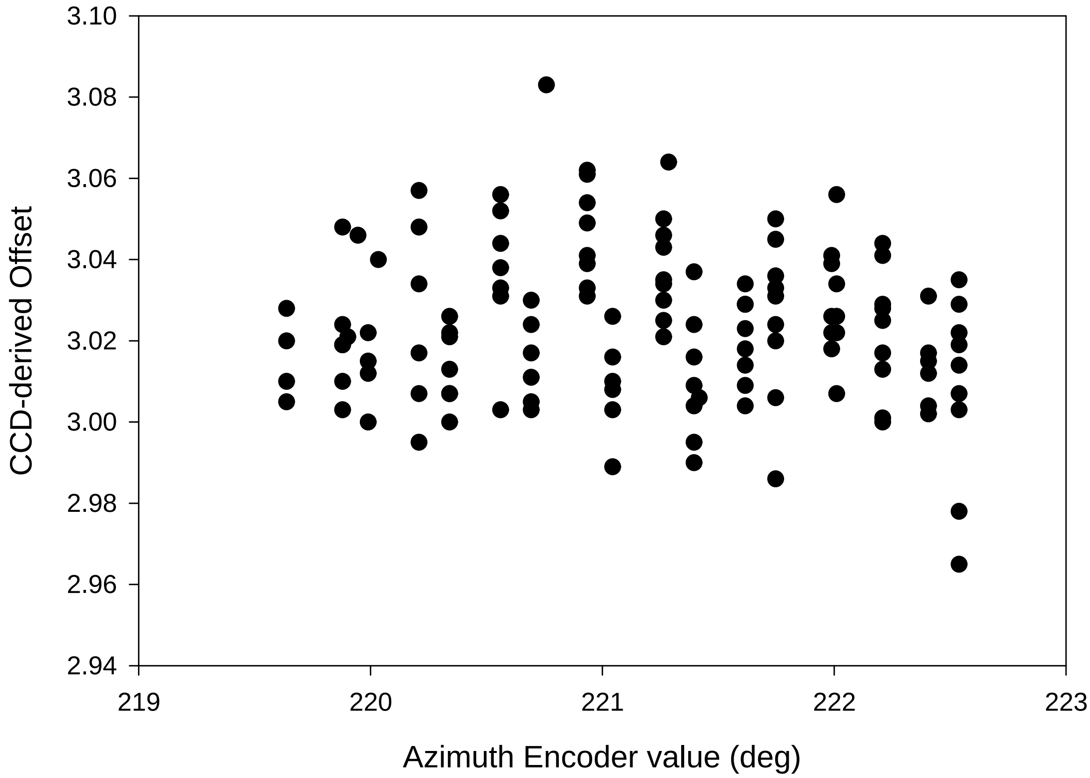

Fig. 1. The difference between the azimuth encoder values and the predicted position of the source being tracked, in degrees, as a function of time during a sample 15-minute run. The offset of ~ 3 degrees was intentional.

optical axis and the encoders. The solution to both problems was the use of a CCD camera taking frequent (~ 20 per minute) exposures of the star field containing the ACT's optical axis.

3 The CCD System

A CCD camera (SBIG ST5) was mounted near the centre of the central dish of the telescope. This was capable of detecting 8th magnitude stars. The CCD was operated in two modes:

1. full-frame mode was used to take an image of the whole star field at the start of every observing run. This was to ensure that the camera had not suffered any damage or been moved in any way and to provide an image which could be used to confirm the angle between the X-axis of the CCD frame and the azimuth axis of the telescope.
2. single-star mode was used to provide a frequent update of the CCD frame. In this mode, the camera was instructed only to return the position and brightness of the brightest pixel after the exposure. This information was latched and recorded with each event in the data stream.

4 Analysis of CCD Data

The historical nature of the information recorded with each event required a two-pass analysis of the data. In the first pass, each event was allocated to an exposure frame based on the exposure count included in the data stream. Each exposure frame was then placed into one of two categories depending on whether either of the 14-bit encoder values had changed during the exposure or both had remained constant. In the former case, no further use was made of the frame. In the latter case, the exposure frame was flagged for further use. It contained the two 14-bit encoder values, but the CCD information concurrent with those values was that of the preceding exposure frame. The flagged encoder values were therefore associated with the CCD information from the succeeding exposure frame.

In the second pass through the data, every usable exposure frame was taken as a spot calibration of the axis encoders to the geographical coordinates. The brightest pixel in the CCD frame was associated with a star in the field of view using an algorithm which was based on that used routinely in radar systems. In this, an initial association of the brightest pixel with a star is made by using a set of starting values of the transformation from CCD pixel position to celestial coordinates, from calculation based on the time stamp of the CCD exposure. An 'acquisition box' is placed around the brightest pixel's predicted celestial location and the database of stars is searched for the brightest star in this box. The brightness of the pixel is used to predict the magnitude of the star. If there was agreement then the association of this star with the brightest pixel was made. The pixel/star association was maintained by using a 'maintenance box', of smaller size than the 'acquisition box'. If for any reason the association was lost, for example because of a long run of discarded exposure frames, a new acquisition cycle was started. This cycle was also initiated when the brightest star in the CCD field moved out of the field or was replaced by a brighter star entering the field. For each axis independently, a regression was made between the calculated geographical angles of the star and the encoder value. The regression was made over the duration of a data segment, almost always of 15-minute duration. The coefficients derived allowed for an accurate transformation of every encoder reading in that segment into accurate azimuth zenith values.

An example of raw data from which the regression was derived is shown in Figure 1. The points represent the difference between the azimuth encoder values measured during each static exposure and those calculated for the appropriate star. The offset of about 3 degrees was due to the fixed and deliberate offset of the azimuth encoder zero from true zero. The vertical scatter of the points is due mainly to the jitter in the selection by the CCD camera of the pixel with the highest illumination in the stellar image, which usually produced measurable light in several adjacent pixels.

5 Summary

The position of the astronomical source in the field of view of the camera of the Mark 6 Durham ACT was calculated for each event using the following steps:

1. the encoder values were transformed to geographical azimuth/zenith using the coefficients derived from the regression described above, the azimuth/zenith values being ascribed to the centre of the PMT camera.

2. the zenith angle was corrected for gravitational bending, using a table of measured values,

3. the azimuth and zenith angles were calculated for the astronomical source,

4. the position of the source in the PMT camera field of view was calculated and recorded for that event

All subsequent calculations of the parameters of each event used the final source position as calculated above. The resultant accuracy of the pointing was set by the bit resolution of the 14-bit absolute shaft encoders, at approximately 1 arc-minute.

References

Armstrong, P., et al., Exper. Astron., 9, 51, 1999.