MAGIC Major Atmospheric Gamma Imaging Cerenkov Telescope

MAGIC-TDAS 01-09
010925/RBock etal

Telescope Positioning, Tracking and Precision Questions

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25 September 2001

Abstract

This note summarizes our present state of knowledge concerning the telescope control systems relevant for positioning and calibrating the telescope and for tracking stars or other gamma ray sources, and hence for the precision analysis of events. In detail, we deal with the tracking system, the oscillation monitor, and the AMC (automatic mirror control).

Contents

1 Motor and axis control

Both axes (zenith angle, azimuth) are controlled at low level by a micro-controlled box (Macs), which receives commands from the high-level tracking/positioning control program (the 'positioning control' for short). It translates them into motor-specific commands (ramping speed up/down, controlling possible oscillations) to the motor-gearbox assembly, using a high-level language called APOSS. Its own feedback passes through a rotary encoder, also accessible to the positioning control. Additional feedback to positioning control is by the shaft encoders mounted directly on the axes (hence slack-free). The shaft encoders are single-turn and presently have a 14-bit precision (1 least count = 360/16384 = 0.022 deg), well precise enough for MAGIC tracking. The rotary encoder has a substantially smaller (by at least a factor 50) least count, which is adjustable.

2 Positioning and tracking

Positioning of the telescope is achieved by issuing commands in catalogue celestial coordinates (declination, right ascension) if the target is a star, directly in zenith angle and azimuth (Za/Az) if the target is terrestrial. The translation of these coordinates into local systems (through apparent Za/Az to encoder values) are done in positioning control (for the transfer coefficients containing additional corrections, see below). Za/Az values for celestial targets are time-dependent, of course.

For positioning the telescope on a terrestrial target, the result of positioning is cross-checked by comparing the shaft encoder readings after completion of the positioning command; iterations will be executed if necessary, verifying that convergence is achieved.

For positioning on a celestial target (star or source), all positions need to be related to the time at which they are achieved. Hence a prediction of the position after the estimated time taken by the positioning operation (presently set to 1 sec) is required, as is a calculation of the speed needed for following the target. Cross-checking is again by comparing to shaft encoder values, after initial positioning iterations, subsequent corrections are in speed adjustments only. Precision better than the shaft encoder least count can, in principle, be obtained by recording the precise time of changes in the shaft encoder reading and using the rotary encoder to subdivide. Also the CCD, apart from an indpendent cross check, can provide higher precision; the necessity for the added precision in MAGIC is, however, not obvious to all, at the present moment.

3 Coordinates

Sky coordinates for stars are given in catalogue declination and right ascension (dec/ra or δ, α). They are corrected according to the FK5 norm (this includes proper motion, precession, nutation, etc., and also terms of atmospheric refraction); the results we call apparent celestial positions. This correction is mediated by the Slalib package, and the details of the conventions used and the correction terms, together with a much more comprehensive naming scheme can be looked up in the Slalib documentation (via http://magic.uni-sw.gwdg.de/stesy). The transformation from dec/ra into apparent zenith angle and azimuth (Za/Az or θ, ϕ) at time t for a given geographical position has been written down by W.Wittek (TDAS note 01-05, 30 August 2001); also these formulae are part of Slalib.

Telescope axes being aligned to the horizontal and vertical directions only with limited precision, coordinates close in definition to zenith angle and azimuth are obtained simply from the encoder readings: the observed local coordinates. Further Corrections between apparent coordinates and what we observe are due to misalignments, mechanical imprecisions and deformations, possibly position-dependent.

Coordinates in the PMT camera are given in pixel positions with respect to the camera center, and again the relation between (Cartesian) camera coordinates and telescope observed local coordinates are given in TDAS 01-05, without the possible rotation and translation of the camera axes.

Like the PMT camera, the tracking CCD will have its own Cartesian coordinates, and its own misalignment. It has, however, a slightly larger field of view (5 deg). If sensitive enough (and if weather permits), it could be used for tracking like a starguider, following a visible (and known) star. It is expected that the eventual tracking CCD will see stars up to 9th magnitude, making it likely that a star is in the filed of view whatever the source.

4 Determining relations between the coordinates

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The transformation from celestial to local coordinates (shaft encoders or CCD positions), including all corrections to star positions, axis distorsions, and corrections due to the displacement of the camera ('bending' induced by position-dependent distortions of mechanical origin), can be obtained by a series of measurements of known celestial objects, adjusting each of them to the camera center and fitting the results according to an ansatz containing all assumed corrections. The first step, from catalogue to apparent positions, is mediated by the Slalib software (see above). For the telescope-dependent part, a (commercial) software system TPOINT, much used in astronomical telescopes, has been purchased from Tpoint software, Abingdon (UK). A series of at least 50 stars, preferably more, spread over the interesting range of zenith angle and azimuth will be measured (initially), recording for each object both the shaft encoder and the CCD coordinates (the latter may need some pattern recognition to define the star position??). Thus a relation (around 20 possible parameters are foreseen) suitable for tracking with the camera (center) will be established for both shaft encoder and the CCD, allowing to use one or the other for tracking.

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The rotation of axes in the local system of cameras (both for the PMT camera and the CCD) will not be covered by TPOINT, and needs to be determined separately, e.g. by measuring two or more stars visible simultaneously in the camera. This is a parameter needed for tracking only in the CCD, which uses off-center stars; for the PMT camera, it is a necessary parameter for data analysis.

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Schematically, and much simplified, the operations are the following:

Catalogue coordinates for stars, in declination δ and right ascension α

Fine corrections to star positions (Slalib routines)

Apparent star coordinates, in δ and α

Textbook transformation (Slalib routines)

Apparent star coordinates for telescope location at time t: zenith angle θ and azimuth ϕ

Translation to the system of telescope observations: misalignments, deformations etc., relations are obtained by fitting coefficients to multiple measurements in TPOINT)

Observed local coordinates on shaft encoders

Optionally: further corrections to PMT or CCD camera systems

5 Oscillation monitor

The oscillation monitor is expected to record short-term and mostly periodic displacements of the camera due to irregular (typically wind) forces, with respect to its position without such forces. It operates by recording at high frequency in a dedicated CCD (oscillation CCD) the position of several LEDs fixed to the camera frame, e.g with the CCD's 25 Hz. From each measurement a lateral displacement vector with respect to a time-averaged position is obtained, allowing to determine time-dependent corrections to the camera position by periodic analysis (Fourier-like).

6 Automatic mirror control (AMC)

Although not directly influencing coordinate systems and analysis, we mention AMC here as no other description is available as yet. The function of the AMC is to ensure that all mirror modules are adjusted optimally, i.e. such that the overall mirror surface spans a parabola with an axis close to the camera. Originally four mirrors are, manually and in the laboratory, adjusted mechanically as best one can, on a 4- mirror module of 1 sq.m., which also carries a laser. Once mounted on the mirror dish, there is again a manual pre-adjustment of the mirror modules. Subsequently, a light source distant by about 1000m will be used to adjust lasers and modules such that the light of the mirror hits the center of the camera, and the laser is close to a reference point (itself defined by a laser) on a screen close to (and rigidly connected to) the camera. Pointing to the camera center will be achieved by driving the motors of each module such that the light passing through a central hole in a screen in front of the camera is maximized. Crude pre-positioning could be by GPS or theodolite measurements, resulting in Za/Az (time-independent for once!) at which to position the telescope.

A CCD (the mirror control CCD) then records the position of the module's laser on a screen next to the camera, with respect to a reference point defined by one of the lasers. This position will have to be reproduced in different positions of the telescope, an operation which can be executed automatically by a program turning on and off the lasers and comparing the position on the screen with the target position. If no adjustments by the module motors are required, the operation for all 239 modules is expected to take less than one minute (few adjustments are expected, if the motor settings for different camera positions are pre-recorded).

7 Assumptions

• the apparent Za/Az coordinates and the telescope observation axes, including all corrections like camera position and bending, have a relation that does not vary on short time scale (determining it is work for many hours);

• the oscillation monitor allows time-dependent periodic corrections about an average position, but wind pressure does not affect the average position;

• there is slack in the motor/gearbox causing differences between the commands given to the motor control and the movements executed. This slack has no influence on tracking as long as the direction of movement does not change sign (e.g. in tracking a star). We assume that a single slack parameter per direction of movement is applied in the high-level control program, and that the slack parameter is determined by a short program, at setup time;

• the tracking CCD is a higher-precision option which may be used when conditions allow, but all tracking operations can also be executed based on the shaft encoders alone. Initially, all tracking will be based on the shaft encoder alone;

• the tracking CCD is fixed on the mirror table near the horizontal axis, and will hence not be subject to bending;

• the adjustment of mirrors by the AMC will use a reference focal point which is independent of the camera movements, e.g. a point on the screen generated by one of the mirror module lasers or by a separate laser;

8 Open questions

• some of the above assumptions are critical; do we have to work on fallback solutions for some of them if they turn out not to hold?

• is it acceptable to rely for all relations between coordinate systems (rotations in camera excepted) on a single TPOINT overall fit? how long will the TPOINT calibration take? how long will the results be valid?

• to shorten the coordinate calibration time, can we devise an automated procedure to drive the telescope to the position which maximizes the light in the central pixel? Or do we update the measurements with a few stars at regular intervals, re-computing the TPOINT coefficients after each update?

• do we need the inverse relation (from encoder values to apparent celestial coordinates)? our current belief is we don't. does TPOINT give that relation by switching input and output? this presumably assumes that the corrections are small and the same formulae can be used, essentially only changing sign;

• is the additional precision of the rotary encoder something we need or at least want (see above)? this is independent of the role of the rotary encoders inside the motor driving mechanism.

• does tracking precision improve if done by the tracking CCD (as opposed to shaft encoder alone), and if so, by how much?