

MMTO TECHNICAL REPORT NO. 3

A PRELIMINARY ASSESSMENT OF
MMT POINTING AND TRACKING

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ABSTRACT

This report details the procedures and results of an engineering run on 28 December 1979 UT with the express purpose of assessing MMT pointing and tracking capabilities at the time. This is a complete presentation of data and results. As such it documents our testing procedure and analysis sufficiently to be useful as a guide for future pointing test runs.

THE TEST CONFIGURATION

The night of 28 December 1979 UT was clear, wind of 5-10 mph, and with seeing ~ 1 to 2" arc. The telescope was operated with the CFA mount control program and a NOVA-800 computer. All observations were performed with the aid of the CID camera system at the focal plane of the 76 cm guide/alignment telescope. This camera has a sensitive area comprised of a 128 x 128 array of CID pixels. The control of the CID camera is up to a Digital Group Z-80 computer and associated electronics. This system is capable of showing the camera output on a CRT monitor, making an exposure in the computer, and providing image analysis on the exposure. In particular, exposure times can be controlled by software, and portions of an exposed field can be processed yielding a centroid measurement of a stellar image. To the computer, the CID field is a cartesian coordinate system with origin at one vertex of the field. Vertices have coordinates (0,0), (0,128), (128,0) and (128,128). One unit in this frame corresponds to one pixel in the camera.

Our pointing determinations are unique in that a star once acquired was analyzed solely via the centroid measurements from the CID camera

system, as opposed to paddling the star to some fiducial point and observing the accumulated paddle corrections. This must be considered an important feature of the MMT for it totally avoids any observer-dependent systematic effects. Thus, our results are limited only by the effects of seeing in the CID camera system.

The entire set of data obtained consists of a log of apparent sidereal times, equatorial coordinates, and az/el coordinates of the telescope in addition to CID centroid coordinates for each object observed.

Calibration of the CID Camera System

The CID camera at the focus of the guide/alignment telescope is capable of some translation and rotation about the optical axis. In order to relate observed camera centroid measurements to position on the sky, it is necessary to calibrate the camera for the position of the optical axis, and the position angle of the camera coordinate frame with respect to the directions defined by elevation motion of the telescope and its normal.

(I) The Optical Axis

To this end we acquired an arbitrary star and paddled its image to what was visually estimated as the optical axis on the CID camera field display. Then pairs of centroids were taken at 4 physical camera rotations spaced by $\sim 90^\circ$. A least squares analysis of these 8 points then yields the best estimate of the optical axis position on the display. The data for this test is shown in Table 1. The least squares analysis in this instance is nonlinear and was performed by a variation of parameters with quadratic interpolation.¹ The process was iterated until no significant change occurred in the χ^2 value. The function to be minimized is

TABLE 1

LOCATION OF THE OPTICAL AXIS ON THE CID DISPLAY

Rotation Angle	X _{CID}	Y _{CID}
Nominal 0°	43.02	61.38
	43.49	62.03
90°	39.59	63.02
	39.95	63.03
180°	40.75	61.06
	40.78	61.48
270°	44.86	60.44
	44.62	60.35

Least squares coordinates of optical axis:

$$X_o = 42.39 \pm 0.03$$

$$Y_o = 62.08 \pm 0.07$$

radius of circle = 2.27 ± 0.03 pixels

These quantities determined by minimizing:

$$\chi^2 = \sum_i \{ (x_i - x_o)^2 + (y_i - y_o)^2 - r^2 \}$$

technique used was a grid search in χ^2 space.

$$\chi^2 = \sum_i \{ (x_i - x_0)^2 + (y_i - y_0)^2 - r^2 \}^2,$$

where x_0 , y_0 , and r are parameters to be solved.

x_0 , and y_0 are the CID display coordinates for the guide/alignment optical axis, while r represents the radius of a circle about the z axis on which the stellar image lies as the camera is physically rotated. x_i and y_i are simply the centroid coordinates of the image at each rotated position.

Because there are 3 parameters we need at least 3 data points, however to be reasonable one should have somewhat more. In our case we had 8 points, (4 pairs at 90° position angle changes) yielding 5 degrees of freedom. The variation of parameters technique is unconditionally stable for this particular problem and is simple enough that it could be performed on a calculator. This, by the way, is the only non-linear fitting problem in the entire analysis to be discussed in this paper.

(II) The Position Angle of the Camera

Next one must calibrate the position angle of the camera with respect to the sky directions defined by elevation motion and its normal.

For this purpose the star is paddled about to a number of arbitrary positions in the camera display and centroid measurements are taken along with noting the accumulated paddle offsets at the mount control console.

For the purposes of this paper, only true angle on the sky will be discussed unless explicitly stated otherwise. Thus, we will talk about ΔE as change in the elevation direction, and $\Delta A \cos E$ as change in the direction normal to elevation motion.

As only Δ motions are significant in what follows we look for a transformation of camera to sky of the form:

$$\Delta A \cos E = 1(x-x_0) + b(y-y_0)$$

$$\Delta E = c(x-x_0) + d(y-y_0) .$$

We decided to perform this calibration at the start and at the end of the night to check for any possible mechanical drift of the camera in the focal plane. These data are shown in Table 2. Performing a least squares fit on the two sets independently we find:

Beginning of Night:

$$a = 0''.746 \quad ; \quad b = -0''.004$$

$$c = -0''.003 \quad ; \quad d = -0''.724$$

End of Night:

$$a = 0''.743 \quad ; \quad b = -0''.014$$

$$c = -0''.002 \quad ; \quad d = -0''.733$$

These data are so consistent that one cannot reasonably concede any change in the relationship of CID camera to telescope during the night. Also, for this particular fortunate instance the cross terms (b and c) are so small that one may reasonably assume the camera aligned to the sky so that we have a transformation of the form:

$$\Delta A \cos E = a(x-x_0)$$

$$\Delta E = b(y-y_0)$$

Combining all of the data for beginning and end of the night we determine:

$$A \cos E = 0''.741 (x-x_0) \pm 0''.75$$

$$E = -0''.723 (y-y_0) \pm 0''.60.$$

TABLE 2

CID/SKY COORDINATE TRANSFORMATION

Telescope Paddle Offsets		CID Centroid Coordinates		
<u>$\Delta A \cos E$</u>	<u>ΔE</u>	<u>X_{CID}</u>	<u>Y_{CID}</u>	
39"94 arc	0"00arc	69.41	53.61	Beginning of Night
67.37	22.31	107.54	21.46	
3.35	22.31	22.37	22.21	
3.36	-42.66	21.76	111.70	
58.48	-42.66	96.69	111.71	
0.02	18.29	20.31	16.01	End of Night
66.16	18.29	109.12	14.66	
66.14	-52.04	111.35	111.38	
-5.06	-52.04	14.90	111.22	
31.26	-18.77	64.09	64.11	
15.65	-16.59	43.02	61.38	
15.64	-16.59	43.49	62.03	