MULTIPLE MIRROR TELESCOPE OBSERVATORY

Smithsonian Astrophysical Observatory *and* Steward Observatory, University of Arizona

MMTO Tech Memo 84-17 June 11, 1984

From: B. Ulich, J. Montgomery, A. Poyner, C. Janes

Subject: Correcting Periodic Error in Telescope Absolute Encoders

A. Summary:

Mount tracking has been improved by applying periodic error corrections from a look-up table, generated by an automatic procedure of averaging observed errors over several cycles of the fine absolute position encoders. This memo details results of tests performed on the MMT on June 7-8, 1984.

B. Description of the Technique

The MMT is positionally encoded in both axes by on-axis Inductosyn absolute encoder systems. Each encoder consists of a coarse transducer and a fine transducer. Small manufacturing imperfections in the fine encoder and imbalances in the electronics that process the transducer outputs cause encoding errors of several arc-seconds amplitude. These errors repeat as a function of the period of the fine transducer, which is 1/512th of a circle, the major components being 1/512th, 1/1024th and 1/2048th of a circle.

Previously, these periodic errors have been reduced in the mount computer by subtracting sine waves approximating the errors. The method of determining the phase and amplitude of these sine waves was by trial and error (see Tech Memo 84-7), which was a tedious process with imprecise results.

The new method automatically builds a look-up table of encoder errors at increments of 1/64th of the fine transducer cycle. The same sky measurements are used as before, with a centroiding algorithm in the TCS computer measuring star position every 2 seconds while tracking, but the position errors are now transmitted to the mount computer. The errors for each axis are stored in a 64-element table, each element containing the error for the corresponding 1/64th segment of the fine transducer cycle. At present, the error table is smoothed over several cycles of the fine transducer by a "leaky memory" technique, but this will be replaced with a straight average in the next version.

The error table is generated by tracking a star while no computer corrections of periodic error are being applied. A second table is generated showing the number of samples gathered for each 1/64 element. These tables can be read by the operator at any time during the table-filling process.

When the required amount of data has been collected, the table-filling routine is turned off and correction for periodic error can now be applied. Note that periodic error correction must not be used while the error tables are being filled. As observational data-taking would always require these corrections, it follows that the error tables cannot be updated during observing. Newly generated error tables will be stored on the parameter diskette for regular use.

C. Results

The routine was successfully tested on June 7-8, 1984. The error tables were built using no sinusoidal correction in azimuth and an artificially introduced error in elevation. Plots of the encoder errors were made on a strip chart recorder at a speed of 2.5 cm per minute and an amplitude scale of 0.7 arc-seconds per cm. Azimuth error was divided by cos(elevation) to correct the plotted measurement to the horizon. Azimuth error on the sky can be determined by multiplying the error shown by cos(elevation).

Figure 1 shows the "uncorrected" periodic errors. Figure 2 shows the measurement of tracking using the old sinusoidal correction method. Figures 3 and 4 show the worst and best case tracking measured with the new table corrections applied.

The figures show that the worst error is less than 1 arc-second and the best is less than 0.5 arc-seconds, peak-to-peak. This is better than a factor of two improvement over the old method.

Periodic errors that remain have periods longer than 1/512th of a circle. One error was noticed at 1/64th of a circle, or 8 fine transducer cycles. This error was substantially repeatable over the same positions of the encoder, and may be removable by making the error table large enough to cover 1/64th instead of 1/512th of a circle. To remove all such errors presumably would require a table covering all used encoder positions. With the present table, the 1/64 error can be minimised by averaging the error table over 8 or more transducer cycles.

D. Operational Procedures

The routine will undergo final testing and will be installed operationally on the mount computer the week of June 18th. At that time an updated operations procedure will be produced. At present, the operation is as follows.

a) On the TCS Computer

1. Select a suitable bright star (low elvation, approximately 35°, with velocities in both az and el greater than 10 arc-sec per sec).

2. Align az and el such that positive el is "up" and positive az is "to the right" using the instrument rotator.

3. Do a point stack so that the TCS computer can calculate the scale.

4. Use one telescope (B) and move the others out of the way.

5. Box the star using the following commands:

    pb - position boxes routine
    b - select box for telescope B
    A - add the box to the screen (note capital A)
    Move box over star using arrow keys (shift-H, -J, -K, -L)
    ESC - to get out of pb routine

6. Set the Grinnell parameters:

20 !it set the integration time to 2 seconds
5 !sd set the "leaky memory" shift down to 5 (2 seconds)

7. Start sending the position errors to the mount computer:

te - tune encoders

8. To stop sending error information to the mount computer:

qq - quit quickly

b) On the Mount Computer

1. Set up the initial conditions, using the commands:

tcs-ignore - ignore all errors coming from TCS computer

el erase-arrays set all the tables to zero
az erase-arrays

el no-periodic-error do not use the tables to correct position
az no-periodic-error

ppec - check to see if any of the old sine corrections are being used. If so, zero them.

2 sd ! - set error table shift down (THIS WILL BE CHANGED)

2. Now to build the tables. The errors will be output on d/a channels 0 (el) and 1 (az). Connect these d/a outputs to the strip chart recorder to monitor the error signals. Start filling the tables:

el-tune - set flags to allow tables to fill
az-tune

tune-encoders - and start the data flowing

3. Error data must now be collected for several cycles of the fine transducer. As we have noticed a component at 1/64th of a circle, at least 8 cycles should be covered. The minimum time for filling the error tables can be calculated. One fine transducer cycle (1/512th of a circle) is 2,531 arc-seconds, therefore time for 8 cycles is 8*2531/v seconds, where v is the smallest of the az and el velocities in arc-sec/sec. This approximates to 340/v minutes. Collection can be monitored by:

el ?errors - shows the error table
az ?errors

el ?samples - shows the number of data points collected for each table element
az ?samples

4. When error data collection is complete:

no-el-tune **no-az-tune**	-	will stop filling the tables, but will continue to display on the strip chart recorder
tcs-ignore	-	will stop all communication with TCS

5. To use the tables to apply periodic error corrections:

el remove-pe **az remove-pe**	-	remove periodic errors

E. <u>Frequency of Updating the Tables</u>

The optimum frequency for updating the error correction tables will be determined by experience. In the interim, updating should be performed approximately monthly, or at any time that the astronomer requests it. Normally this will be done during M&E time, unless some emergency condition exists. By picking a star with appropriate velocities, the procedure should take less than 45 minutes, and it can be done on a bright star very early or late in the night. Use of dusk periods should be tempered with caution - more accurate results will be obtained when the telescope has reached thermal equilibrium.