XMM OM

X-ray Multi-mirror Mission Optical Monitor
Report on OM Magnifier tracking

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Contents

1 Introduction

The purpose of this document is to explore the magnifier tracking problem and to provide explanations of software fixes. The performance of the XMM Optical monitor's tracking algorithm has been found perform poorly when an observation is simulated using the magnifier. This loss in performance can be attributed to two factors:

1. The guide star selection parameters are invalid for magnified guide stars. This leads to only faint guide stars being selected by the guide star selection algorithm and therefore the tracking solution is not optimal.
2. The tracking science window (TSW) size is reduced by 1/4, reducing it to a 4″ square window. If the spacecraft motion is of the order of $\sim \pm 1 - 2''$ around the pointing, this will result in the possibility of the star PSF at least partially leaving the tracking window.

These problems and solutions are discussed in the follow sections. Tracking algorithms and tests of tracking in various starfields using non-magnified tracking are discussed in XMM-OM/PENN/TC/0019.

2 Guide star selection

It is clear that for a magnified image the constraints used for guide star selection in unmagnified data will no longer apply for magnified data, as the characteristic shape of the PSF will be different. The current guide star selection parameters when used with the magnifier, tend to select only dim stars in the image. As the quality of the tracking is a function of the total number of counts in the guide stars, this is undesirable.

It is therefore necessary for a different set of parameters to be used when selecting guide stars for magnified mode data. The current parameters for unmagnified data are well tested and it is not desirable to change these at this late date, so I suggest the new parameters should only be used when magnifier tracking is used.

A new set of guide star selection parameters where defined in the `white_default.h` with the prefix `MAG_` to distinguish them from the unmagnified tracking parameters.

```
#define  MAG_MAX_XY_MOMENT          8
#define  MAG_MAX_IMAGE_SIZE         26
#define  MAG_MAX_MOMENT_DIFF        2.5
#define  MAG_MAX_NONCIRC            4.
#define  MAG_MAX_OFF_CNTR           3.
#define  MAG_MIN_COUNTS             16
#define  MAG_MAX_SQ_MOMENT          16.
#define  MAG_SATURATION_THRESHOLD   6000
```

The following code change was made to `su_scangs.c` to implement the swapping of guide star selection parameters:

```
   /* Select which guide star selection  parameters we use */

#ifdef SUN
   if (blue_filter == 8) {
#else
   if (blue_filter == 2) {
#endif
       /* If this exposure uses the magnifier use these parameters */
```

```
#ifdef SUN
       fprintf (stderr, "SCANGS: Setting magifier guide star parameters\n");
#endif
       max_off_cntr = MAG_MAX_OFF_CNTR; /* QUALITY BIT #1 */
       max_noncirc  = MAG_MAX_NONCIRC;  /* QUALITY BIT #2 */
       max_image_size = MAG_MAX_IMAGE_SIZE; /* QUALITY BIT #3 */
       max_sq_moment = MAG_MAX_SQ_MOMENT; /* QUALITY BIT #4 */
       max_moment_diff = MAG_MAX_MOMENT_DIFF; /* QUALITY BIT #5 */
       max_xy_moment = MAG_MAX_XY_MOMENT; /* QUALITY BIT #6 */
       saturation_threshold = MAG_SATURATION_THRESHOLD; /* QUALITY BIT #9 */
       min_counts = MAG_MIN_COUNTS; /* QUALITY BIT #10 */
       nominal_x_dim = MAG_NOMINAL_X_DIM; /* larger for mag tracking */
       nominal_y_dim = MAG_NOMINAL_Y_DIM;
   } else {
       /* Otherwise use the normal parameters */
#ifdef SUN
       fprintf (stderr, "SCANGS: Setting normal guide star parameters\n");
#endif
       max_off_cntr = MAX_OFF_CNTR; /* QUALITY BIT #1 */
       max_noncirc  = MAX_NONCIRC;  /* QUALITY BIT #2 */
       max_image_size = MAX_IMAGE_SIZE; /* QUALITY BIT #3 */
       max_sq_moment = MAX_SQ_MOMENT; /* QUALITY BIT #4 */
       max_moment_diff = MAX_MOMENT_DIFF; /* QUALITY BIT #5 */
       max_xy_moment = MAX_XY_MOMENT; /* QUALITY BIT #6 */
       saturation_threshold = SATURATION_THRESHOLD; /* QUALITY BIT #9 */
       min_counts = MIN_COUNTS; /* QUALITY BIT #10 */
       nominal_x_dim = NOMINAL_X_DIM;
       nominal_y_dim = NOMINAL_Y_DIM;
   }
```

This code is executed at the beginning of every exposure (at the start of the `scangs()` function), therefore the extra overhead associated with this change is only during the initial part of the exposure.

3 Errors in tracking:

The ability of the OM to track on magnified guide stars is strongly affected by the the drift of XMM, which in our simulations is defined by the `tdrift.dat` file. The currently used `tdrift.dat` obtained from simulations performed at BAe is plotted in Figure 1a.

It has been found that during simulations of magnifier tracking, guide stars can often partially move out of the tracking science window. This behavior can be seen as large variations in the guide star counts per frame (from the `DD_TRH` data output). Figure 2 shows a typical guide star count rate from a magnifier tracking simulation.

This motion out of the TSW is due to a the failure of the guide star centroiding routine, `buildstar1()`, to accurately centroid the the magnified guide star. This is because due to motion within the 20 second frame can be significantly blurred and mishapen, and `buildstar1()`, which is not capable of accurately centroiding such a large PSF (it was tuned mainly using non-magnified PSFs). The consequences of this are that the TSW is placed incorrectly for the next frame which can lead to the guide star leaving the TSW.

By comparing the tracking solution found by the simulation with the input drift file (`tdrift.dat`), it is found that the residuals have a $\sigma \simeq 0.45''$, compared to a value of $\sigma \simeq 0.01''$ for a similar simulation without the magnifier (an example of the residuals for a magnifier run can be seen in Figure 4a). This corresponds

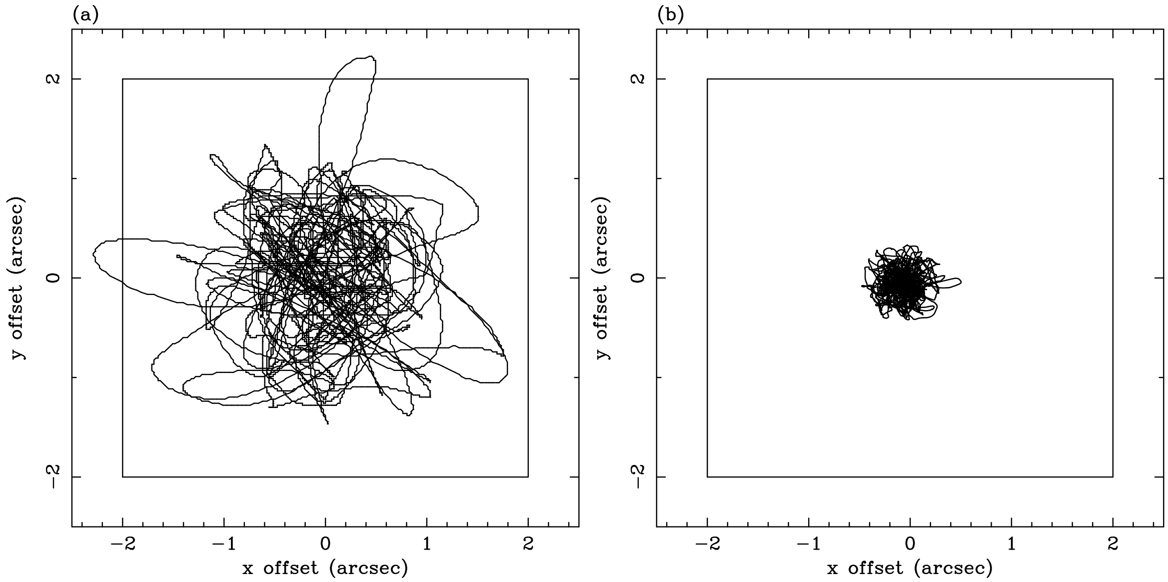

Figure 1: Comparison of two tracking estimates. a) the BAe tracking history file with $4'' \times 4''$ tracking science window overlaid. b) shows the newer tracking estimate.

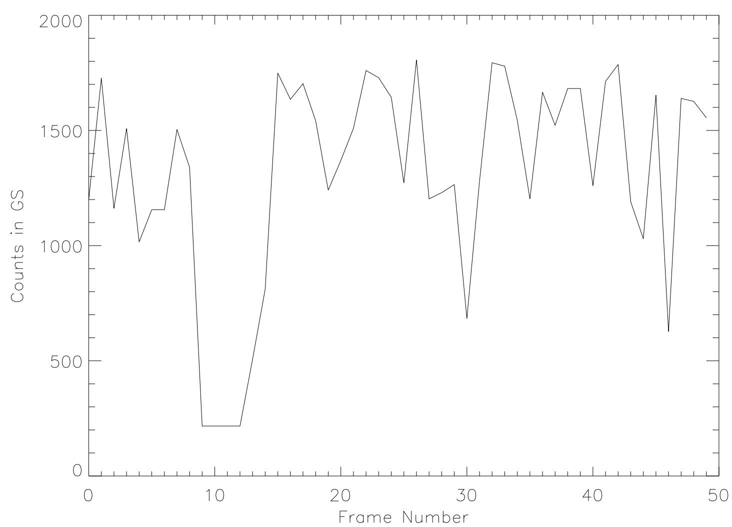

Figure 2: The total number of counts from a guide star derived from `DD_TRH` for the BAe, tracking history. The value which should be constant (barring counting statistics) in fact varies by by up to $\sim 90\%$ of the actual counts. This variation is a symptom of the guide star moving partially outside of the tracking window.

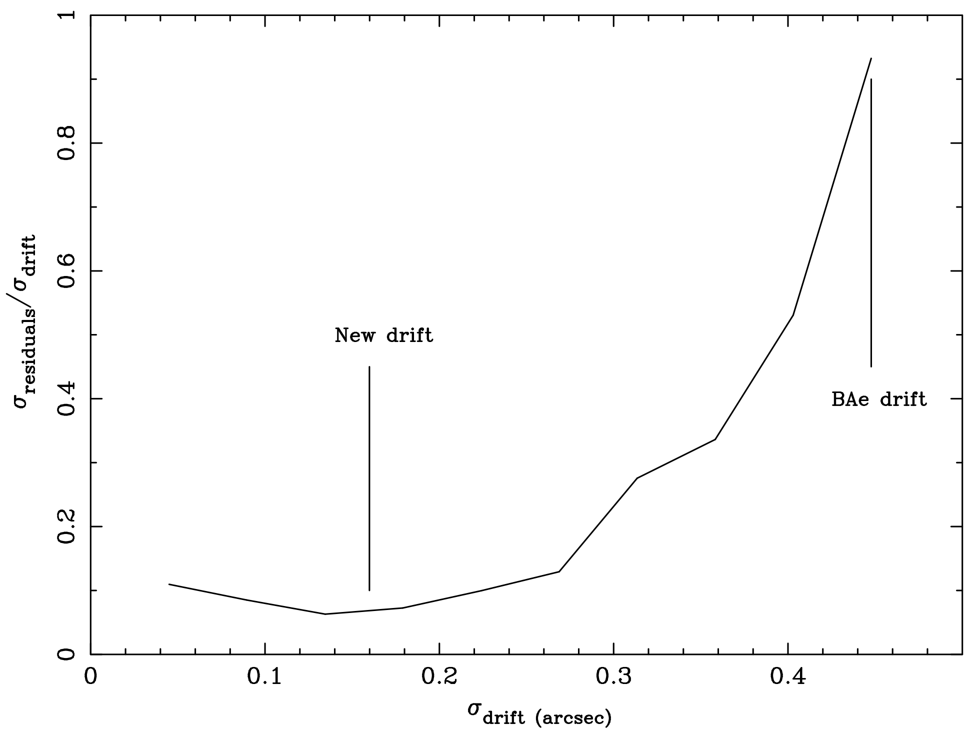

Figure 3: The performance of magnifier tracking as a function of drift. Here $\sigma_{\rm drift}$ is the standard deviation of the input x and y drift, and $\sigma_{\rm residuals}$ is the standard deviation of the residuals after the input drift has been subtracted from the tracking solution output in DD_TRH. The values for the BAe drift and the Elfving drift are marked.

to a FWHM of ~ 8 magnified pixels ($\sim 1''$) which can leads to large increase of the FWHM of the magnified PSF.

However, a newer tracking estimate obtained from ESA (from a private communication with Anders Elfving) shows the projected XMM drift to be of a much lower magnitude than the BAe estimate. The Elfving drift is plotted in Figure 1b and the residuals from a magnifier simulation using this data in place of the BAe `tdrift.dat` file is shown in Figure 4b.

The scatter in the residuals is $\sigma \simeq 0.01''$, which is very much less than the pixel size ($0.125''$), and comparable with scatter found in the working non-magnifier case, it can therefore be assumed that magnifier tracking is working optimally for this case.

To investigate the effect of drift magnitude on tracking quality, simulations were ran with drift files of different magnitudes. These were obtained by multiplying numbers in the BAe drift between 0.1 and 1.0. The input drift was subtracted from the output tracking solution obtained from DD_TRH to find the residuals (and therefore the error in tracking). The scatter in these residuals were then compared to the scatter in the input drift, their ratio being a measure of the improvement that using tracking gives of as opposed to switching off tracking in the magnifier mode.

The results are plotted in Figure 3, the values of σ for the BAe drift and the Elfving drift are marked on this plot. It is clear from this plot that there is very little improvement over using when tracking is for the BAe drift estimate. Using the Elfving drift estimate the tracking is considerably better, with a ten fold improvement over not utilising tracking.

If we impose the limit that the error in tracking (σ) must be less than $0.125''$ (1 pixel), the simulations show that this criterion is satisfied for $\sigma_{\rm drift} < 0.35''$ (compared to $\sim 0.45''$ for the BAe drift estimate).

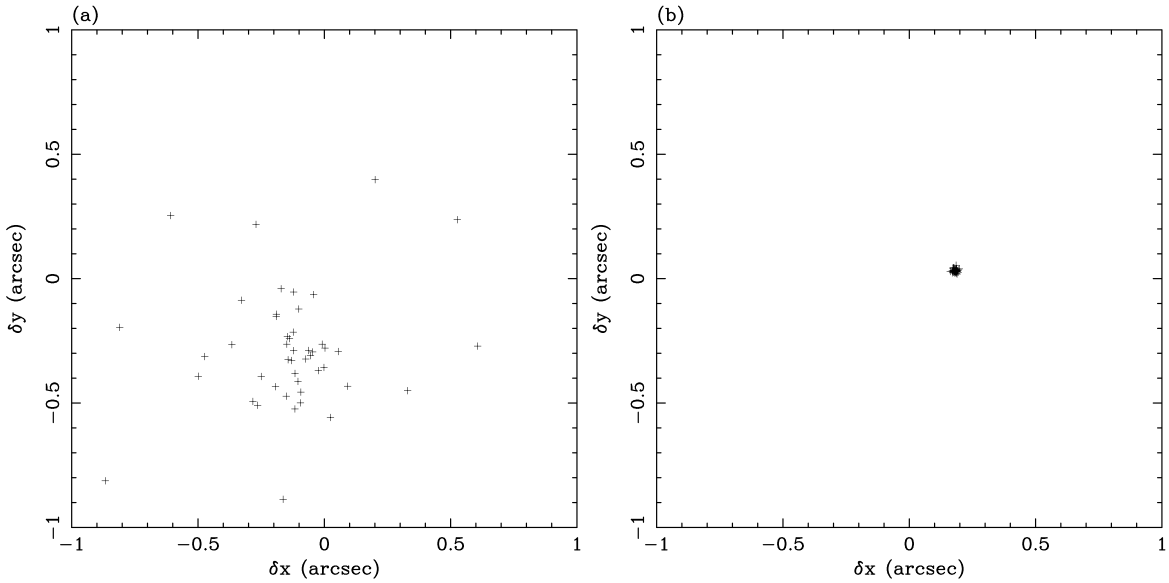

Figure 4: x and y residuals found by comparing the tracking history output from `DD_TRH` and the input `tdrift.dat` file. a) shows magnifier tracking using the BAe tracking estimation and b) shows the residuals when using the Elfving drift. Note that the offset from zero is a systematic error from the location of stars in the reference frame.

4 Worst case scenario solutions

The variation in guide star counts shown in Figure 2, will make identification of the failure of magnifier tracking easy to identify during OM calibration. Should the tracking be worse than the expected Elfving drift and magnifier tracking fails, then the following solutions may be possible to obtain better quality tracking than the current algorithms allow:

4.1 "Brute force" centroiding

A new "brute force" centroiding routine has been written for magnifier tracking (although is not currently implemented in the current software release). In this algorithm, rather than attempting to be adaptive and centroid only only the counts from the star as in `buildstar1()`, the centroid of the whole 32×32 TSW is calculated. Using this far simpler approach tracking with the BAe drift is much improved over the with the normal centroiding algorithm.

Simulations ran using this new algorithm show that for a similar run using the Sun simulator and the BAe drift the improvement is good, running the same simulation that gives a standard deviations of the residual of $0.45''$ for the normal centroiding algorithm, gives $0.05''$ with the new algorithm.

However this approach will fail in the high background case, where the surrounding background will contribute a significant amount of to the centroiding, causing the centroid to be biased towards the centre of the TSW rather than than the centre of the star. This is the exact problem that the adaptive algorithm used in `buildstar1()` attempts to avoid.

4.2 Binning of tracking windows

The failure of the adaptive centroiding algorithm is due to the large PSF caused by the combination of the magnifier and the large drift. However this routine appears to be robust when the magnifier is not used. If the TSW was binned 2×2 or 4×4 pixels, this would most likely result in the `buildstar1()` qalgorithm functioning correctly, as the input would more closely mimic that of non-magnified tracking. As the PSF is greatly oversampled, this loss in resolution would not significantly affect the centroiding accuracy.

This option would significant code changes, especially if the more common mode of unmagnified tracking is to be unaffected by these changes. However it remains a second possiblity and has the benifit that the issues with the alternative centroiding algorithm would not occur.

Currently no code exists to implement this feature, however it is not considered to be a major code change to implement this feature.

5 Synopsis

Guide star selection: A new set of parameters have been selected and implemented for guide star selection in the magnified case. These parameters are only used when the magnifier is being used and therefore normal tracking and guide star selection should be unaffected. It should be noted that these parameters have not yet undergone significant testing. They will be fully tested and this testing will be described in a future document.

Errors in tracking: This error is very dependent on the magnitude of the attitude drift. Until the XMM is launched this motion will be unknown, however taking the Elfving drift as the new baseline estimate, the magnifier tracking problem will not occur. In fact the drift has to be only marginally better than that given in the original BAe drift estimate for magnifier tracking to function correctly. In the case of the drift being worse than expected two new algorithms are suggested that will improve tracking in these situations.