On the fly bad pixel detection for the Chandra X-Ray Observatory's Aspect camera

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Abstract. The Chandra X-Ray Observatory uses an optical CCD in its aspect camera. As with all space-based CCD detectors, radiation damage will accrue with time and substantially increase the dark current of individual pixels, resulting in "warm pixels". In order to obtain the most accurate aspect solution possible, it is necessary to identify and compensate for these regions when processing the guide star images. If a warm pixel is included in a guide star image, it will bias the centroid location for that image. As the spacecraft dithers, this bias will introduce a wobble to the star location that translates to a wobble in the aspect solution. Special dark current calibration observations can be taken to provide a full-frame dark current map, however, it is not operationally feesible to obtain a new map for each observation.

The CXC data systems group has developed software to analyze the star image data and identify warm pixels as part of standard processing. This "on the fly" determination allows us to adjust for variations in CCD conditions between dark current calibration observations and provides useful information for identifying bad regions on the Aspect camera CCD.

1. Motivation

In order to achieve the unprecedented accuracy of Chandra's aspect solution, it is necessary to get the most accurate star centroid locations possible. As the aspect camera CCD is exposed to radiation, warm pixels will develop. These warm pixels can effect the centroid locations of the stars by creating a bias in that direction. If the pixel is very warm, this bias can be quite pronounced and create relatively large centroid errors. It is possible to correct for these warm regions during processing by applying a background subtraction using a dark current map. These dark current maps show the expected number of counts to be registered by each CCD pixel when no source photons fall on it. They are generated through special dark current calibration observations. Since it is not feesible to conduct a dark current calibration for each observation, a mechanism is needed to identify and correct for new warm regions as they evolve. This can be accomplished by anayzing the outermost pixels of the guide star images themselves.

2. Accumulate Pixel Data

Chandra's Aspect camera is a 1024 x 1024 pixel CCD. To save bandwidth, only a small subset of 4x4, 6x6 or 8x8 pixels centered on each star/FID is telemetered to the ground.

If the spacecraft did not dither, the same set of pixels would be seen in each image and we would have only a few pixels to analyze. However, spacecraft dither will cause the star image to move along the CCD. The on-board computer tracks this motion and adjusts the set of pixels used so that the star remains centered in the field. As a result, a much larger sampling of pixels will can obtained.

For this analysis, we want to collect data from pixels with little or no counts from the source. The typical star image will have a FWHM of 1.8 pixels. This means that the 4x4 images can have no pixels uneffected by the source image and are ignored. For all other images, the outer rim of pixels should contain background counts only. These are the pixels used in the analysis.

Background subtracted image values are accumulated for each pixel matching the above criteria. For each pixel, we also determine the average total image counts of all images containing that pixel.

3. Determine Dark Current Level and Threshold

To determine if a pixel is warm, it must consistantly show a number of counts above some threshold. Each pixel will show random fluctuations in counts from background radiation. They may also show higher count levels from extended source emissions or from elevated background levels in the vicinity of the star. Stars located near the outer ends of the CCD will have elongated PSFs which could cause source photons to land in the outer rim pixels. Since there several factors that effect the number of counts seen in these 'background' pixels, we cannot simply apply a static threshold to all pixel data to determine if it is warm. We use a two-tiered method for calculating the dark current threshold level to apply. The dark current threshold is defined to be the greater of:

1. An absolute threshold level
2. A fraction of the average total image counts

The dark current value for each pixel is determined by a percentile method.

$$Dark\_current_p = pixel\_value[N * numvals] \tag{1}$$

where

N = Percentile level, typically 0.10
numvals = Number of pixel values accumulated
pixel_value = sorted array of pixel values

Any pixel whose dark current level is above the dark current threshold is considered 'BAD'. Its location and dark current level are stored.

4. Application to Data

Once the warm pixels have been identified, this new information must be applied to the star images in order to remove the effects these pixels will have on the image centroids.

The dark current map is updated to reflect the elevated dark current levels for all bad pixels found. Since the image data we use has already been background subtracted, this correction is additive.

$$Dark\_current[pixel\_row, pixel\_col] += Dark\_current_p \tag{2}$$

The raw image data is then re-run through the background subtraction process. With the proper dark current subtracted, the centroids will not be biased by the elevated counts, and a more accurate centroid can be obtained.

5. Results

When a warm pixel contaminates a star image, it produces an offset to the image centroid in the direction of that pixel. As spacecraft dither moves the image along the CCD, the direction of this offset changes, creating a periodic wobble in the star locations. This wobble is apparent in the aspect solution. The effect is reduced by the use of multiple guide stars and smoothing techniques, but it can still have a noticable impact on pointing accuracy.

Figures 2&3 show a series of plots that characterize the accuracy of a star's centroids. The plots show the difference between the star centroid and that star's 'expected' location. Since a guide star's actual position is well known, one can use the spacecraft motion described by the aspect solution to predict where that star should fall on the CCD as a function of time. By comparing these values with the locations described by the star centroids, one can gain a sense of the accuracy of these centroids.

The two spatial plots at top show the same data at different scales. These show the distribution of the centroid offsets in the spacecraft Y and Z axes from expectations. With good centroids and a good solution, this distribution should be centered on 0.0 with a small random spread. The other plots show the offsets for each axis as a function of time. These allow the periodic nature of the effect to be seen.

Figure 2 shows the results of a run containing 2 bad pixels. The warm pixel detection was turned off during processing. The spatial plots show a significant elongation in the Z direction. This is a result of the warm pixels moving in and out of the image field as the star dithers on the CCD. The plots of offset vs. time show the periodic nature of the effect. The RMS of the offsets is indicated on these plots.

Figure 3 shows the same data when warm pixel detection is applied. Notice the spatial plot shows significant improvement in the distribution. The plots of offset vs. time also show significant improvement, especially in the Z axis. The RMS has dropped from 0.24 arcsec to 0.09 arcsec. The remaining periodicity is most likely due to pixels that are warm, but not yet above the threshold level.

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Figure 1. Reconstructed star location without bad pixel correction.

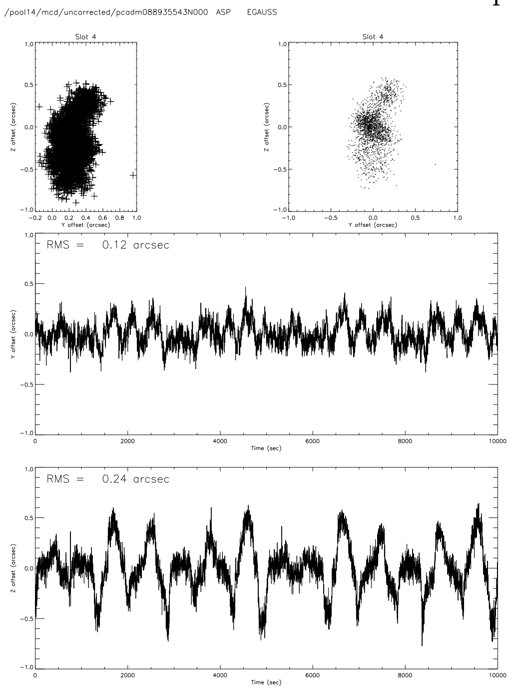

Figure 2. Reconstructed star location with bad pixel correction.