Fixed Pattern Noise in the FOC - II

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ABSTRACT

Previous analyses by us have demonstrated the presence of 4- and 16-channel fixed pattern noise in flat-field images of P1, P2 and P3 FOC detectors. Several methods of removing this fixed-pattern noise have now been employed on nine PDA images from PFM2, including two images of approximately 10,000 counts. It is shown that the noise can be reduced from 1.5 to 0.5 percent using a "mean row" noise image in images having the same sample offset as the image used to create the correction image. For images with different sample offsets from the image used to create the correction image, the optimum procedure is the use of a simulated 4-channel noise image, although noise is only reduced in this case from 1.5 to 0.8 percent.

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FIXED PATTERN NOISE IN THE FOC II.

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Introduction

Preliminary analyses of fixed-pattern noise in the Faint Object Camera ground calibration images (Pickles, 1984; Bohlin and Blades, 1985) have verified the presence of distinct 4-channel and 16-channel noise patterns in the P1, P2 and P3 detectors. The images used in these studies, however, contained between 300 and 1000 counts per pixel, thus they were dominated by the random Poisson noise and conclusions concerning the fixed pattern noise could only be tentative. At the suggestion of D. Giaretta (1984), two long-exposure PDA images (≈10,000 counts each) were obtained with the P2 detector, as well as some “offset” images (successive images of approximately 1000 counts each, offset in either the line or sample direction by 7 pixels from the previously obtained image). Herein, we report the evaluation of these long-exposure and offset images and discuss several approaches for the removal of the fixed pattern noise.

Data Analysis

Nine images have been analyzed for the present study: two long-exposure images of 10,000 counts each, and seven offset images of approximately 1000 counts each. The offset images were acquired with increments of seven pixels in either the sample direction or the line direction between exposures. All exposures were acquired within a 24-hour period. Table 1 lists the images used in this analysis, the date of acquisition, starting line and starting sample numbers and exposure times.

As in the previous two studies, the rows of each raw image were averaged to create a “mean row”. Columns 100-200 of the “mean rows” of the long-exposure images are shown in Figure 1. A “noise image” was then created by dividing the raw image by a median filtered (5x5) version of itself. The mean row of this “noise image” is shown in Figure 2. It is immediately obvious that 4-channel noise is present at the 1.5 percent level rms scatter (3-5 percent level peak-to-peak) in this region of the image, and that the noise is predominantly enhancement of the intensity. Sixteen channel noise is also present, as shown in the Fourier transform of the mean row of image T8005 in Figure 3 (see also Bohlin and Blades 1985).

The four-channel noise is apparently coherent from image to image in the first 350
columns of each image, regardless of offset. Figure 4a shows overlaid mean rows of the noise patterns from T8001, T8006 and T8007 (columns 100-200) all of which have the same offset in the sample direction. The noise patterns are essentially identical in the images having the same sample offset. The 4-channel noise pattern is also aligned among the images with different sample offsets (T8001, T8002, and T8003 in Figure 4b), but differs in amplitude among the images.

The results for the right side of the image are somewhat different. For the images having the same sample offset, the noise patterns are identical in columns 400-500 of the image (Figure 5a). However, the images having different sample offsets show no correlation of their noise patterns in columns 400-500. The 4-channel noise does not align (Figure 5b). Shifting the offset images by the amount of their sample offset (Figure 5c) did not improve the alignment. The 16-channel noise, where present, is coherent among the images with the same sample offset. It is, however, offset among the images with different sample offsets.

Removal Techniques

The fixed pattern noise we have described here and in previous reports is apparently a fixed multiple of the number of counts in the image. As can be seen by comparing the noise patterns in T8001 (≈ 1000 counts) and T8019 (≈ 10,000 counts), the noise is 3-5 percent of the total number of counts. Three methods for removal of the fixed pattern noise were tested for this report, the first two methods having been described previously by Bohlin and Blades.

In the first method, we created a “normalized noise image” (NNI) by dividing a raw image by a median filtered (5x5) version of itself. In this case we chose T8014 to create the NNI because it is a long-exposure image of 10,000 counts and the noise present should contain essentially no photon noise. Most of the reseau marks, but not all, were removed from T8014 using the RAL software tools before creating the NNI. The NNI was then divided into the test images listed in Table 1 (except, of course, T8014 itself). The results of correcting the test images by this method are shown in Figure 6a-h. Each Figure shows the mean row of the test image which has been normalized with a median filtered (5x5) version of that image at the top of the plot, and the mean row of the corrected test image (which has been normalized in the same way) in the bottom plot.

For the second test, we formed a mean row from the NNI created above from T8014. This mean row was then expanded into a full image. The resulting “mean row noise image” (MRNI) was then divided into the test images. The results of correcting the images in Table 1 by this method are shown in Figures 7a-7g.

The third approach was to create a “simulated noise image” (SNI), composed of an artificial noise pattern having factors of 1.03, 1.00, 0.99, and 1.00 repeated every four channels across the image. This 4-channel pattern was estimated using visual inspection.
of the actual noise pattern in columns 100-300 of the test images. No attempt was made to simulate the 16-channel noise pattern as it was not coherent between images of different offsets. All raw test images were divided by this simulated noise image. Figures 8a-8f show the normalized mean row from the raw data and the normalized mean row from the corrected data for each of these images. The correction appears to be quite good for columns to the left of column 350.

Discussion

A problem associated with our execution of the first test method is immediately apparent when examining Figure 6. The reseau marks that were not removed from the NNI introduce spikes in the corrected images. The only image which did not show evidence of this problem was T8001, in which the reseau marks happened to overlay precisely in location the marks in T8014. Aside from this difficulty, the first and second methods produced almost identical results, with the results of the second method having slightly less noise. The data presented demonstrate that those images having the same sample offset as T8014, the image used to create the NNI and the MRNI used in the correction, show a reduction in the amount of the rms noise from 1.5 to 0.5 percent after correction by the second method. The noise is reduced peak-to-peak from 5 percent to 1 percent. However, correction by the first or second method of T8002, T8003, T8004, and T8005, which are offset in the sample direction from T8014, yields less satisfactory results. Noise was reduced from 1.5 percent to 1.1 percent.

The noise can be reduced from 1.5 to 0.8 percent in columns 1-350 with the SNI 4-channel noise image, the third correction method we have created. Columns 350-512, however, show no improvement with this technique; in fact, the noise is sometimes enhanced. This method appears to be preferable, however, to the first and second methods for the images with a different sample offset from the image used to make the correction (i.e. in this test T8002, T8003, T8004, and T8005).

It is useful to compare in particular the noise patterns in the two long-exposure images, T8014 and T8019. With 10,000 counts per pixel each, they should exhibit essentially no photon noise. Noise in these two images is, therefore, some combination of fixed pattern noise and pixel-to-pixel variations in sensitivity. If the noise in these two long-exposure images is almost entirely fixed pattern noise, the normalized noise images from these two images should be essentially identical and the correction of T8019 with the noise pattern from T8014 would produce the optimum correction result among all of the tests performed. On the other hand, if pixel-to-pixel variations make a significant contribution to the noise in these images, we would not expect the noise patterns to be a close match, because they are offset from each other in both the sample and line directions. In Figure 6h (bottom) is plotted the mean row of the normalized noise from image T8019 divided by the normalized
noise from T8014 (NNI). While the remaining noise after the division is certainly less than that left in images T8002 (Figure 6b), T8002 (Figure 6c), T8004 (Figure 6d), or T8005 (Figure 6e), it is still much greater than the remaining noise in T8001, T8006, and T8007 (Figures 6a, 6f, and 6g), all three of which have the same sample offset as T8014, but different line offsets. The conclusion we have reached after examination of this data is that the pixel-to-pixel variations in sensitivity are comparable in amplitude to the fixed pattern noise and render correction for fixed pattern noise based on an image taken at a different sample offsets inapplicable. There is no correlation, however, between different line offsets and the coherency of the noise patterns among the images.

Conclusions

The general noise pattern displayed by the test images is that of 4-channel noise, the noise being the greatest on one side of the image and decreasing toward the opposite side. Sixteen-channel noise, if present, is most noticeable on the side of the image where the noise is the greatest. The four channel noise has been a fixed multiple of the number of counts in the image in all test performed by us and is coherent from image to image regardless of offset in this data set of images acquired within a short time period.

Data presented herein indicate that the pixel-to-pixel variations in sensitivity are comparable to this fixed pattern noise. For this reason, an image cannot be used to create a noise correction for an image acquired at a different sample offset. Our recommendation is that a "mean row noise image" (MRNI) be used to correct the raw data images for 4-channel fixed pattern noise, if one is available with the same sample offset. Otherwise, a "simulated noise image" (SNI) as described above gives acceptable results.
References


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Figure Captions

Figure 1a: Columns 100-200 of the mean row of image T8014 plotted against the number of counts.

Figure 1b: Columns 100-200 of the mean row of image T8019 plotted against the number of counts.

Figure 2: Columns 100-200 of the mean row of the noise image created from T8019 by dividing the raw image by a median filtered image.

Figure 3: Fourier transform of the mean row if image T8005 (columns 50-450 only).

Figure 4a: A composite plot of columns 100-200 of the mean rows of T8001 (solid line), T8006 (dotted line) and T8007 (dashed line) plotted against number of counts.

Figure 4b: A composite plot of columns 100-200 of the mean rows of T8001 (solid line), T8002 (dotted line) and T8003 (dashed line) plotted against number of counts.

Figure 5a: A composite plot of columns 400-500 of the mean rows of T8001 (solid line), T8006 (dotted line) and T8007 (dashed line) plotted against number of counts.

Figure 5b: A composite plot of columns 400-500 of the mean rows of T8001 (solid line), T8002 (dotted line) and T8003 (dashed line) plotted against number of counts.

Figure 5c: A composite plot of columns 400-500 of the mean rows of T8001 (solid line), T8002 (dotted line) and T8003 (dashed line), the data for T8002 and T8003 having been shifted by the amount of their respective sample offsets from T8001. The vertical axis is number of counts.

Figures 6, 7 and 8 are sets of composite plots, each showing the normalized mean row for two images, a raw image (top) and a corrected image (bottom). The top plot has been offset by 0.1 for purposes of display. Figure 6 shows the raw data corrected using the noise image from T8014, created by dividing the raw T8014 image (with the majority of the reseaux removed) by a median filter image of T8014. Figure 7 shows the raw data corrected with a “mean row image” of the noise from T8014. In this case the mean row of T8014 is expanded into a full image in which every row is the “mean row”. Figure 8 shows the raw data corrected using a simulated noise image with 4-channel noise at the 3 percent level.

Figure 6: a) T8001, b) T8002, c) T8003, d) T8004, e) T8005, f) T8006, g) T8007, h) T8019.

Figure 7: a) T8001, b) T8002, c) T8003, d) T8004, e) T8005, f) T8006, g) T8007, h) T8019.

Figure 8: a) T8001, b) T8002, c) T8003, d) T8004, e) T8005, f) T8006, g) T8007, h) T8014, i) T8019.
Figure 1a
Mean row of images T8001, T8006, T8007; columns 100-200
Figure 4b
-14-
Figure 5a
Figure 5b

-16-
Mean row T8001, T8002, T8003, shifted; columns 400-500

Figure 5c
Figure 5d
-21-
Figure 6h
T8004: Raw Noise (top) and Type 2 Corr

Figure 7d
Figure 8b
T8004: Raw Noise (top) and Simulated Noise Corr
Figure 8e
Figure 8h
Figure 8i