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Undistorting FUSE Using Wavelets

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Abstract. This paper describes a method for determining the geometric distortion of the *FUSE* detectors using data from the in-orbit stimulation lamp exposures. A wavelet approach is used to smooth the image, while enhancing the shape of the shadows cast by the QE and plasma grids suspended above the detectors. By tracing pixel-by-pixel the horizontal and vertical shadows and by using interpolation for the regions between them, a two-dimensional map of the geometric distortion can be created.

1. Geometrical Distortions in the FUSE Detectors

The Far Ultraviolet Spectroscopic Explorer (*FUSE*) employs two microchannel plate (MCP), double-delay line detectors on which up to six individual spectra are simultaneously projected. Segment 1A of detector 1 is shown in Figure 1. The horizontal and vertical lines are shadows cast by the quantum efficiency (QE) and plasma grid wires suspended above the detector and illuminated by an on-board stimulation or "stim" lamp. In addition to the large scale distortions caused by the detector electronics, the distortion map clearly shows an ~ 85 pixel periodic distortion running vertically across the detector, which is due to the differential non-linearity (DNL) of the detector electronics.

2. Wavelets

The fundamental idea behind wavelets is to analyze according to scale (see e.g., Chui 1992). Wavelets are functions that satisfy certain mathematical requirements and are used in representing data or other functions. This idea is not new. Approximation using superposition of functions has existed since the early 1800's, when Joseph Fourier discovered that he could superpose sines and cosines to represent other functions. However, in wavelet analysis, the scale that one uses in looking at data plays a special role. Wavelet algorithms process data at different scales or resolutions. If we look at a signal with a large "window," we would notice gross features. Similarly, if we look at a signal with a small "window," we would notice small discontinuities. The result in wavelet analysis is to "see the forest and the trees."

For many decades, scientists have wanted more appropriate functions to approximate choppy signals than the the sines and cosines that comprise the bases of Fourier analysis. By their definition, these functions are non-local (and

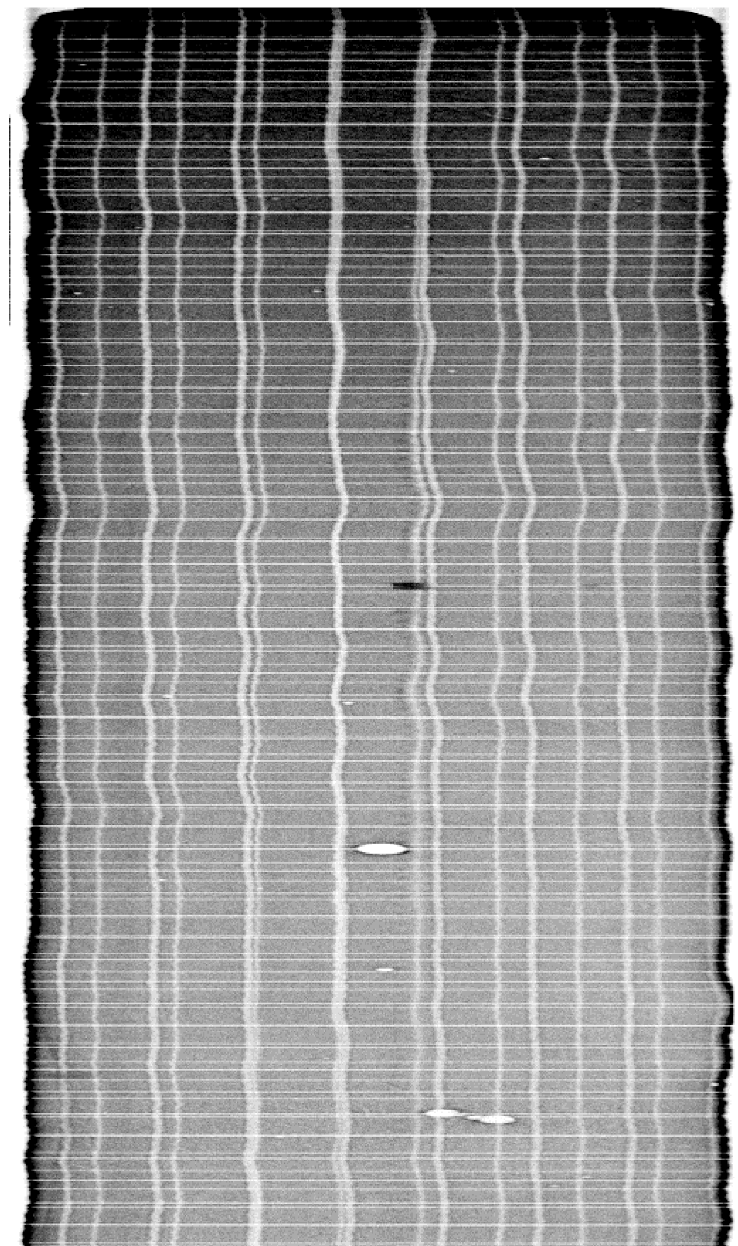

Figure 1. A negative rotated image of detector 1A showing the vertical distortion. The image is a sum of 28 stimulation lamp exposures and is compressed from its original size of 16384×1024 pixels.

stretch out to infinity), and therefore do a very poor job in approximating sharp spikes. With wavelet analysis, we can use approximating functions that are contained neatly in finite domains and hence, well-suited for approximating data with sharp discontinuities. The wavelet analysis procedure is to adopt a wavelet prototype function, called an "analyzing wavelet" or "mother wavelet." The original signal or function can be represented in terms of a wavelet expansion (using coefficients in a linear combination of the wavelet functions), data operations can be performed using just the corresponding wavelet coefficients.

3. Method

A wavelet approach was chosen for determining the two dimensional geometric distortions, because wavelet methods are typically quite efficient, which is important when dealing with large images, such as those produced by *FUSE*. Our approach is similar to that of Starck & Murtagh (1994) and uses a B-spline of degree 3 (B_3-spline) for our "mother wavelet." The B_3-spline leads to a convolution with a 5×5 kernel in two-dimensions.

At the smallest wavelet scale, the image mostly contains noise, and a B_3-spline does a good job at producing a smoothed image without degrading the resolution. The B_3-spline at the next larger scale is a good approximation to the cross-section of the grid wire shadows, which results in the shadow minimum being well localized in the low signal-to-noise data. Once the shadow's minimum is known, it is easy to trace the grid wire from one end to the other. The distortion is then just the difference in position of the measured minimum and the true minimum, which we approximate by assuming the grid wires are straight.

In the case where two wires are close together and their shadows start to merge (see Figure 1), we use a modified B_3-spline. We pad either end of the kernel with one or more zeros to bias the wavelet in that direction. This modified wavelet enhances one side of the shadow in relation to the other and enables us to bias our trace toward one wire or the other.

4. Results

Figure 2 shows segment 1A after correcting for the geometric distortion. The corrected image is nearly perfectly rectangular and the grid wires are evenly spaced. We have also aligned the six spectra across the two segments of each detector and removed the large scale wavelength distortions.

Some notable features of the wavelet method outlined here are: 1) the sensitivity to distortions on scales of < 10 pixels, 2) the sub-pixel accuracy of the distortion map after smoothing is applied, and 3) the ability to deconvolve and trace two wires whose shadows are nearly merged.

References

Chui, C. K. 1992, An Introduction to Wavelets (Boston: Academic Press)

Stark, J.-L. & Murtagh, F. 1994, A&A, 288, 342

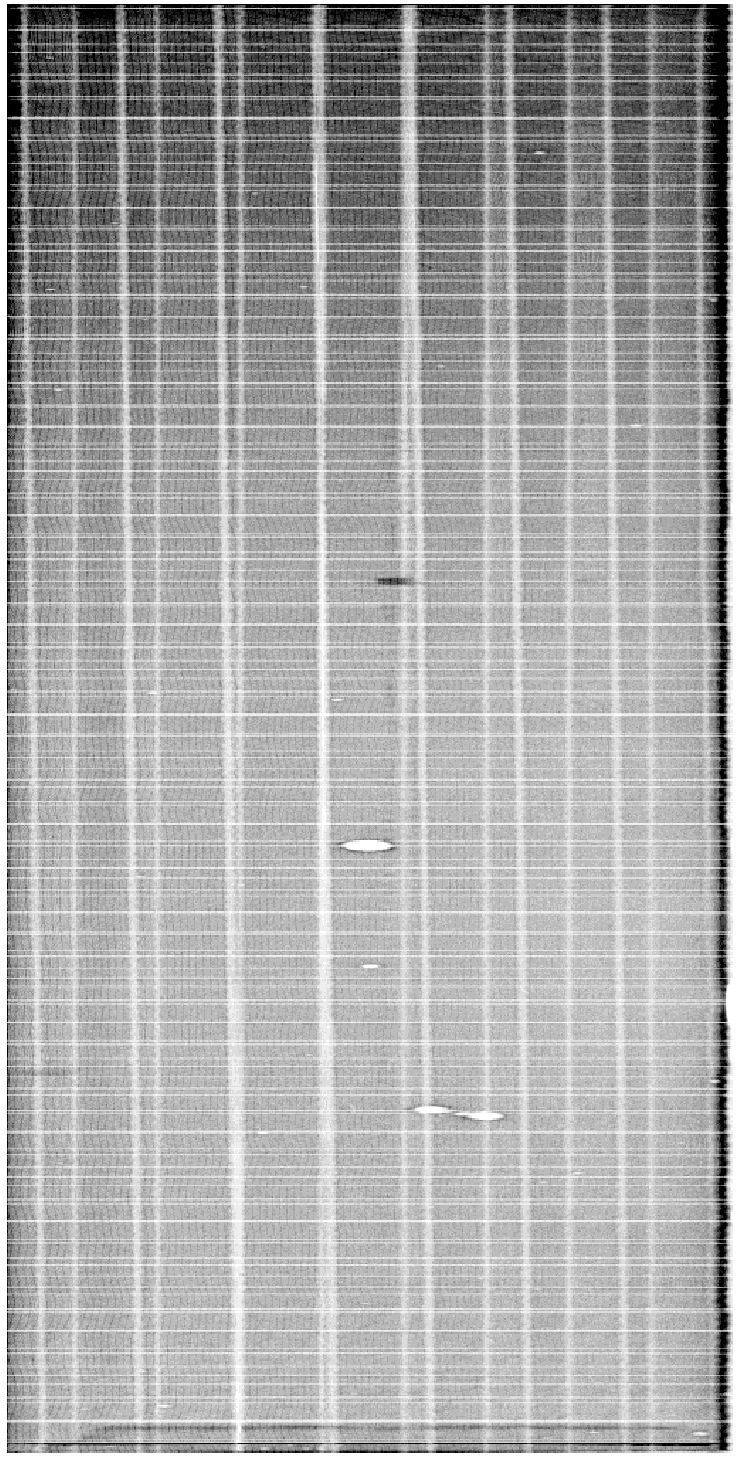

Figure 2. A negative rotated image of detector 1A after removing the geometric distortion. See the caption of Figure 1.