Supplement 1: Detailed Topography Processing Example

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Abstract This supplement is intended to provide a more detailed understanding of the methods used to process the topography data from the raw form off the detector to the final images displayed in this paper.

1. Introduction

Data acquired with a CCD detector generally requires processing before an analysis of the data can take place. Some of the issues that need to be addressed prior to the actual data analysis include dark current noise, system electrical noise, pixel gain differences, and geometric corrections.

2. Processing

2.1. Dark Current Subtraction

The first stage of image processing for most CCD based applications is the subtraction of dark current. Dark current is a quantum mechanical property of a CCD where charge will accumulate in a pixel well as a function of time. In order to remove the dark current an exposure is taken for the same length of time as a normal exposure but with no X-rays. In our case an image was selected from the sequence where there was no reflection visible. This not only removes the dark current but also any solvent-based background X-rays. Fig. 1 shows the background subtraction and the result.

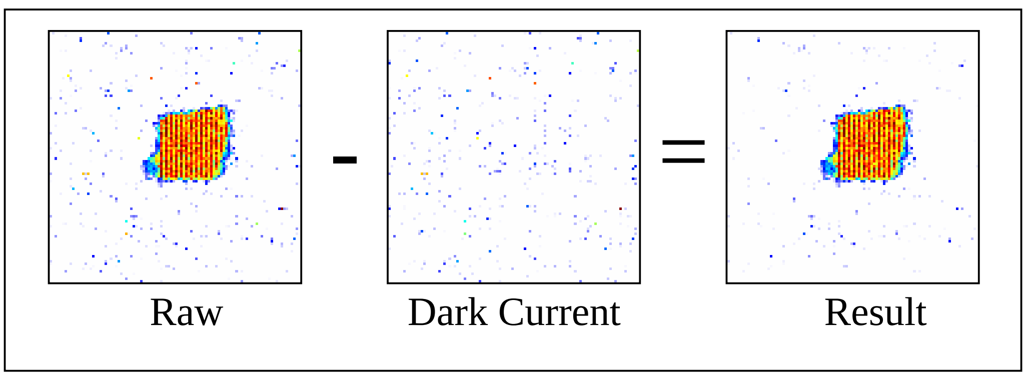

Figure 1 Dark current subtraction

2.2. Channel Separation

Further investigation of the result and raw images from Fig. 1 indicate a sensitivity difference between the odd and even pixel columns. It was decided to model this effect in terms of a linear gain and offset at the per pixel level as shown in equation 1. Before the optimisation can take place, the image must be divided into odd and even channels. This procedure is demonstrated in Fig. 2.

$$CorrectedPixelValue = gain \cdot (MeasuredPixelValue + offset) \tag{1}$$

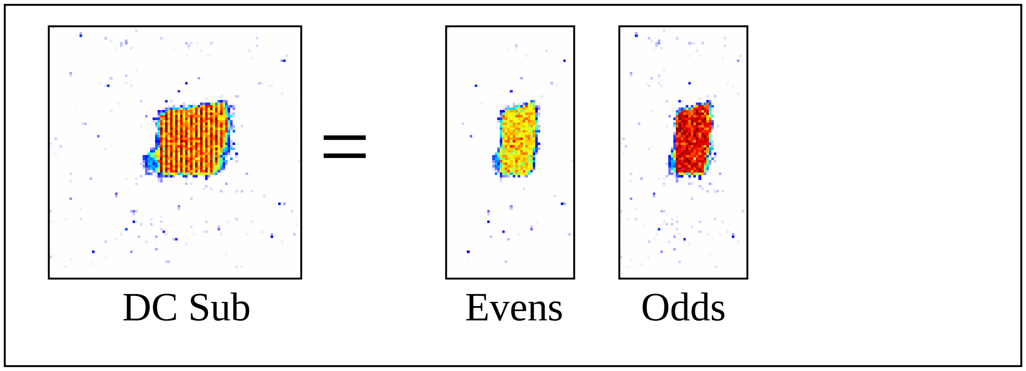

Figure 2 Splitting of odd and even channels

2.3. Channel Equalization with Genetic Algorithm

A genetic algorithm was used to determine optimal values for the gain and offset of equation 1. Genetic algorithms mimic the natural process of evolution to solve optimization problems. For this case, optimal values were chosen as the values which minimize the squared difference between the calculated intensity profiles of the odd frames vs. the even frames using equation 1. Fig. 3 shows the profiles before and after application of the genetic algorithm (Wormington *et al.*, 1999). The results for gain and offset are 1.2984 and -0.0752, respectively.

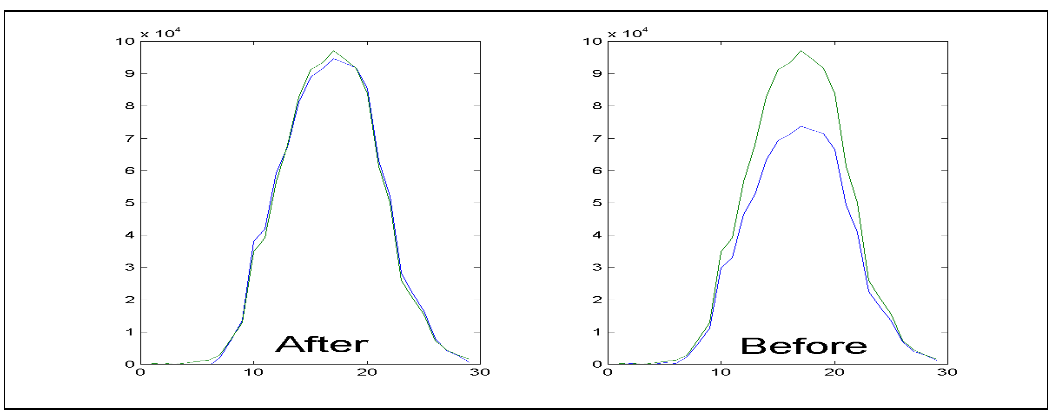

Figure 3 Channel balancing calculation to balance intensity profiles

2.4. Correction and Recombination

The above correction is applied to the even channels and then the separated channels (even, odd) are recombined. This process is illustrated in Fig. 4. The corrected pixel values are constrained to the proper dynamic range (here: 8-bit): Values below zero were set to zero and values above 255 were set to 255 for this example.

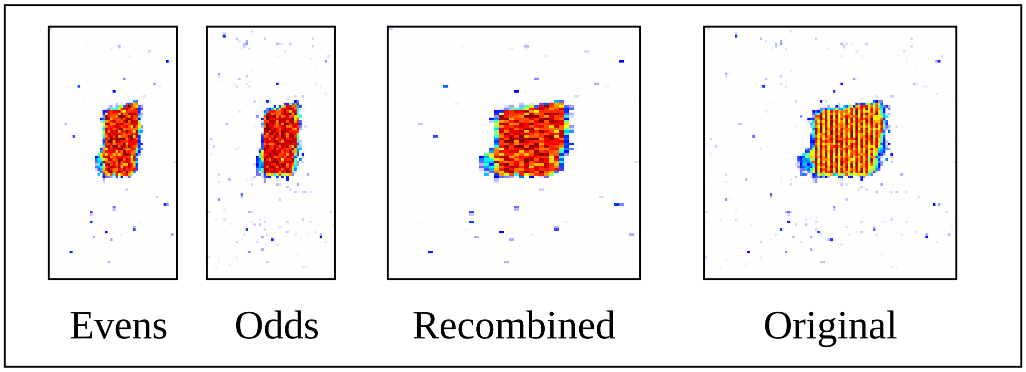

Figure 4 Results for genetic algorithm channel balancing

2.5. Speckle Noise

A median filter with a box size of 3x3 pixels is used to remove speckle or random noise from the image. This is a common method and has been described elsewhere. The result is shown in Fig. 5. The maximum pixel value for the frame is saved for a later step in the data processing.

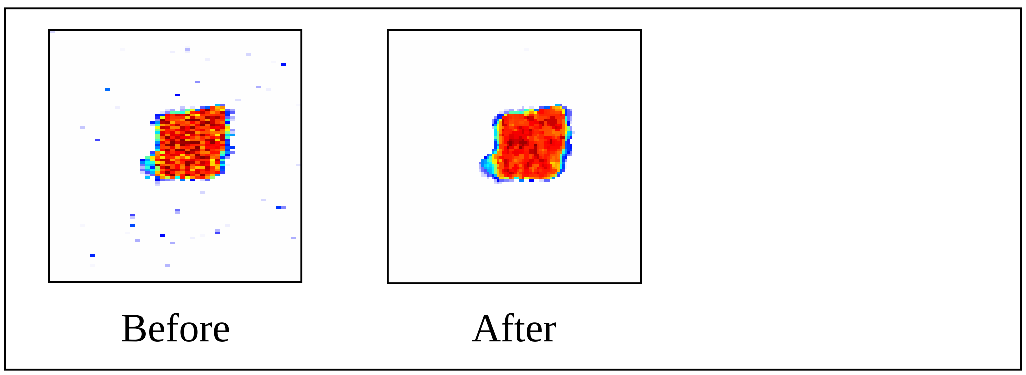

Figure 5 Median filter results showing before and after processing with the median filter

2.6. Resolution Enhancement

Wavelets are used to enhance the resolution of the images. In a 2D wavelet transform and image is decomposed into 4 sub channel images. They are labelled LL, LH, HL and HH. The labelling describes the way the wavelet filters were applied to the image. Here we take the image we recorded and effectively use it as the LL coefficients and using null matrices for the other three coefficient matrices to arrive at an approximation of what the original image may have looked like if it was recorded in a high spatial frequency. This is a reasonable approximation because generally most of the energy in the 2D wavelet decomposition is located in the LL channel. The results are shown in Fig. 6. Overall the intensity values are lower by about 25%. This is due to the redistribution of energy to fill the 3x additional coefficients in this level so that the total energy is constant (sum of all coefficients). There is a ripple visible at sharp edges mainly across the bottom edge. This would have been eliminated if the other (high frequency) coefficient matrices were available during the reconstruction. A Daubechies order 6 wavelet (Daubechies, 1992) from the Matlab Wavelet Toolbox (The Math Works Inc., 1992) was used to perform this calculation.

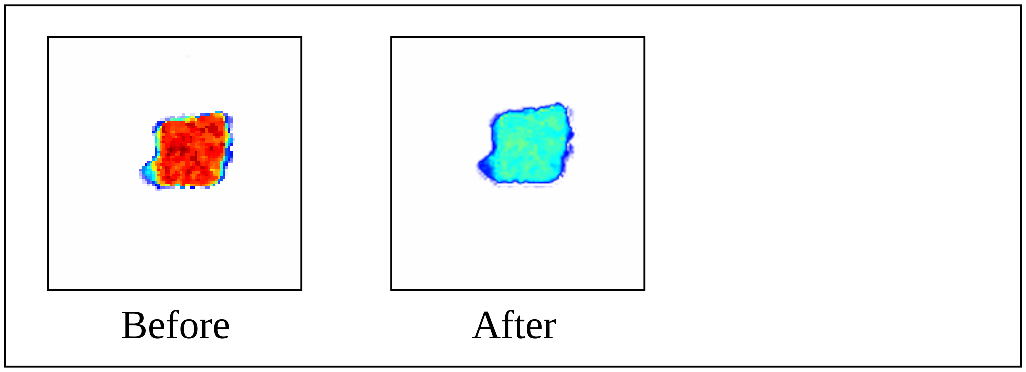

Figure 6 Application of inverse wavelet transform for resolution enhancement

2.7. Remove High Frequency Noise

To clean up the high frequency noise (*ripple* effect) generated by the wavelet transform (Section 2.6) a 5x5 median filter was applied to the image data. The effect of this process is shown in Fig. 7.

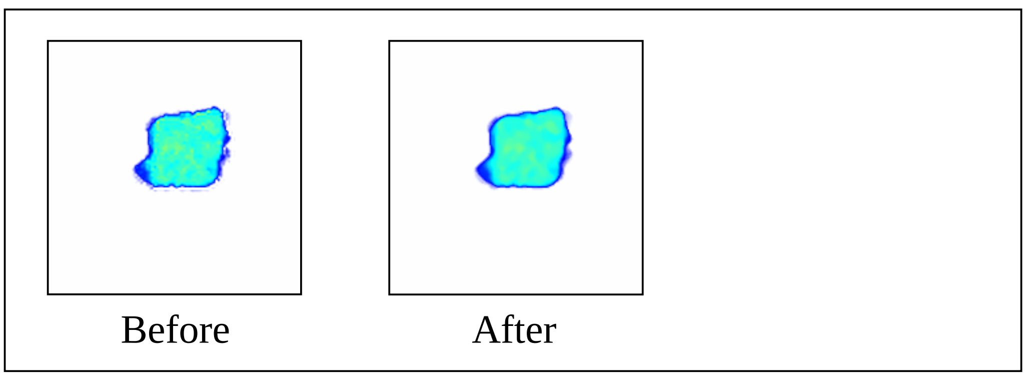

Figure 7 Application of median filter

2.8. Restore initial bit-depth

For further analysis the intensity data is rescaled back to the full dynamic range of the original image. This is accomplished by using the maximum value obtained in step 2.5 as a marker for the maximum value that should be in this image. After stretching the values in the image are restored to the original minimum and maximum values determined by the ADC.

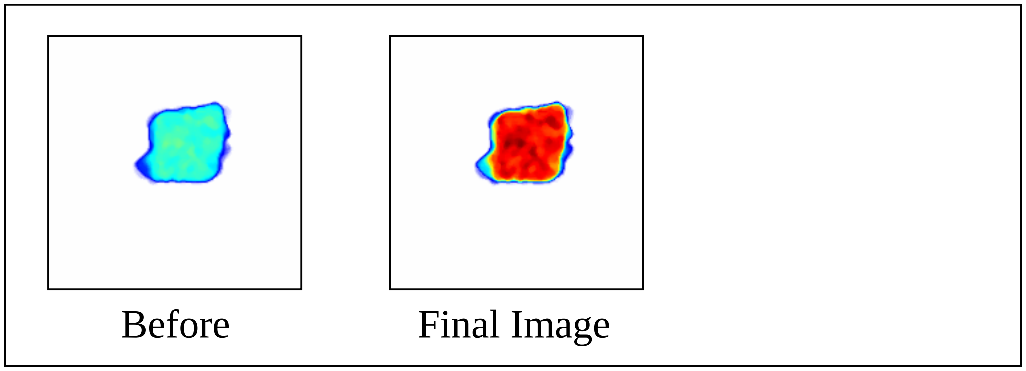

Figure 8 Final image, after stretching.

References

Daubechies, I. (1992). Ten lectures on wavelets, SIAM Rev ed. Philadelphi, PA.

The Math Works Inc. (1992). MATLAB Reference Guide, Natick, MA.

Wormington, M., Panaccione, C., Matney, K. M. & Bowen, D. K. (1999). Phil. Trans. R. Soc. Lond. 357, 2827-2848.