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Combining Undersampled Dithered Data – A Review of the Options

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Abstract. Many imaging systems in astronomy have pixels which are too large to adequately sample the image falling on them. It is widely known that "dithering" – shifting by small amounts between exposures – can allow some of this lost information to be recovered. This technique is extensively used for HST WFPC2 and NICMOS imaging and is proposed for other systems.

Algorithms have been developed, by the authors and others, to allow the effective combination of such dithered, undersampled data. This paper describes a simple imaging model which allows the limits of dithered imaging to be readily appreciated and briefly reviews available software. The virtues and drawbacks of different methods are presented as a guide to workers with dithered data. An example using HST NICMOS data is given.

1. An Introduction to Undersampled Imaging

Imaging detector systems such as CCDs are often regarded as arrays of little square buckets which count up incoming photons which fall into the appropriate pixel area. An equivalent, more instructive view of the imaging process is to consider the image formation as a convolution of the optical image at the surface of the chip with the "pixel response function" (PRF, typically, but not always a square top-hat function the same size as the pixel) followed by a point-sampling of this new, smoother, continuous distribution. In the undersampled case this second sampling step is not done on a sufficiently fine grid to extract all the detail from the image. Dithered imaging can improve this sampling. However, the initial smoothing from the convolution with the PRF of the detector has already suppressed fine structure in the optical image – this is made worse by the noise – and this lost information cannot be fully recovered. For this reason large pixels with dithered imaging cannot fully replace a fully sampled imaging system.

2. Algorithms

Several methods have been proposed for the reconstruction of the true intensity distribution on the sky from dithered undersampled images. Reviews of the situation a few years back, biased towards the requirements of HST WFPC2 imaging are given in Hook & Adorf (1995) and Adorf & Hook (1995). These describe iterative methods, one (ACOADD) a simple multiple input channel generalization of the standard Richardson-Lucy restoration method and the second a "projection onto convex sets" (POCS) approach. ACOADD was originally developed for combining images with different PSFs but can also be used, with shifted PSFs and sub-sampled output images, for combining dithered under-sampled images. Its results are normally presented as restorations carried to convergence and subsequently convolved with a kernel function which suppresses spurious high spatial frequency information. This allows a choice of the effective output PSF within the constraints of artifacts on one side and destroying too much resolution on the other. The ACOADD method is available in the **stsdas.contrib** package within IRAF.

The requirements of the Hubble Deep Field imaging project late in 1995 led to the development of a direct, non-iterative linear approach to this problem which has become known as "drizzling" and widely used for HST and other data. The method is described in Fruchter & Hook (1997, 1998). It is available within the **dither** package in STSDAS and also from the Web[1]. Drizzling was used for the combination of all the imaging data from the Hubble Deep Field South observations in October 1998.

Recently Lauer (1998) has approached the problem in a different way and has derived a formally correct way of reconstructing an image from multiple dithered undersampled input images which has no loss of resolution at the Nyquist scale. This is achieved by suppressing artifacts caused by aliasing in Fourier space. This paper is also a detailed discussion of the subject in general. Although this approach may well be optimal in some cases, its recent appearance and the lack of a common-user software implementation at present mean that it cannot be included in the comparisons given below.

Both Drizzling and the Lauer method do not attempt to remove the effects of the optical PSF or the PRF of the detector. The images which they produce are hence free of the artifacts which arise when using non-linear methods to attempt to recover higher spatial frequency information which may not exist in the original data. On the other hand they fail to use such information when it does exist – typically in high contrast, high signal to noise regions of well-exposed images. In this regime non-linear restoration-based methods can be valuable.

3. Pros and Cons

The methods described above are in some respects complementary. To guide the prospective user, some of the most important advantages and disadvantages are tabulated here.

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[1] `http://www.stsci.edu/~fruchter/dither/`

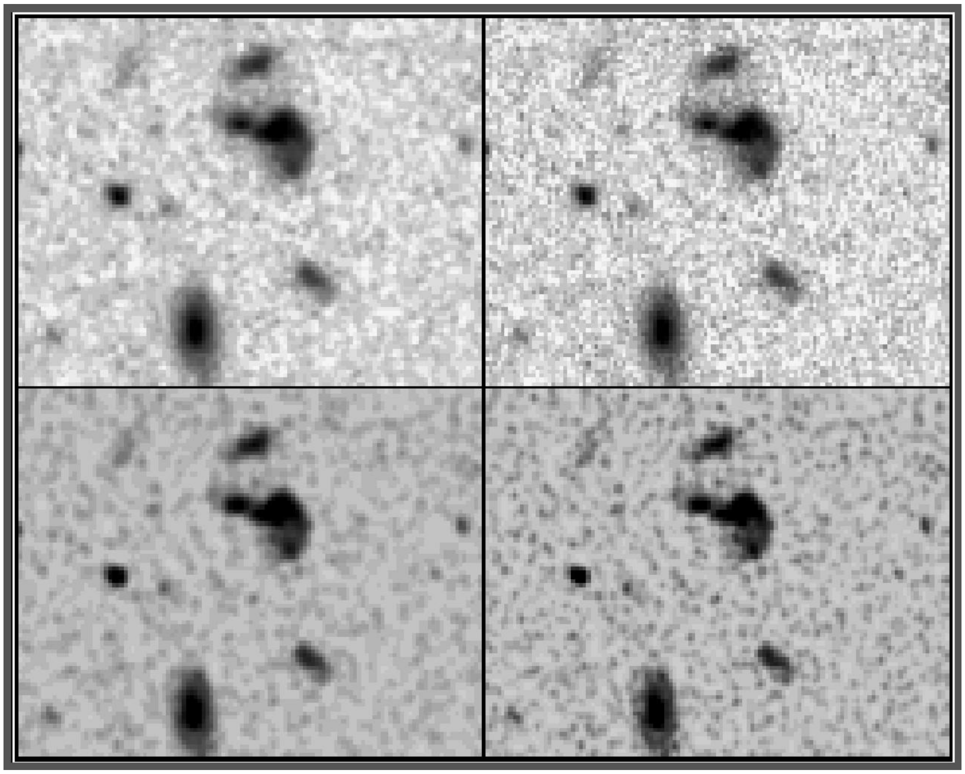

Figure 1. A comparison of combinations of deep HST NICMOS Camera 3 data. There were 9 evenly-spaced dither positions. The upper combinations were done with Drizzle and the lower ones with ACOADD. The upper left had $pixfrac = 1.0$ and the upper right $pixfrac = 0.5$. The lower left was smoothed with a Gaussian of $\sigma = 1.0$ output pixels and that at the lower right with $\sigma = 0.7$. Data courtesy Mark Dickinson (STScI).

3.1. Multichannel Lucy Restoration (ACOADD):

- + can attempt reconstruction of higher spatial frequency information (super-resolution)
- + can create output images with a specified resolution
- + can combine images with different PSFs
- − may introduce photometric bias of point-sources and other artifacts
- − cannot handle geometric distortion
- − creates output images with strongly correlated noise
- − requires good knowledge of the PSF
- − is computationally intensive and iterative

3.2. Drizzling

- + is photometrically faithful and introduces minimal artifacts
- + produces noise correlations only on small scales and in predictable ways
- + can handle arbitrary geometric distortions

- + can handle pixel weighting in a fully flexible way
- + is relatively fast and efficient for large images
- – requires images with matched PSFs
- – cannot achieve super-resolution
- – produces output images have a small amount of space-variant smoothing

4. An Example

To illustrate the relative merits of the two methods compared above, some deep HST NICMOS camera 3 imaging at 9 dither positions were combined using both ACOADD and Drizzle as the combination engine. The results are shown in Fig. 1 for two different parameters in each case. For all images the output image had a pixel spacing which was three times as fine as that of the input. The contrast and slight resolution enhancement offered by ACOADD is clear as is the strongly correlated noise speckling in the background.

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