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Filtering of Signal Dependent Noise Applied to MIPS Data

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Abstract. Linear filtering and usual nonlinear median filtering are not effective for signal-dependent noise removal. We apply here an approximate decoupling of signal and noise by means of a nonlinear transform. The transform is followed by a linear filter and the corresponding inverse transform. This procedure allows us to mitigate the signal-dependent noise in the images obtained by the Multiband Imaging Photometer for *Spitzer* (MIPS), 70μm imaging band.

1. Introduction

Extraction and detection of point sources is of a paramount importance in astronomy. Thus one of the ultimate goals of processing astronomical images is to secure more reliable point source identification. In general, to achieve that it is necessary first to smooth images in order to reduce the noise. Linear filtering, or even nonlinear median filtering are not useful for signal dependent noise removal, due to the nonlinear coupling of signal and noise. Therefore, the first step would be to decouple the noise from signal, which is done by applying a nonlinear transformation. This transformation is followed by a linear filter and a nonlinear inverse transformation thus leading to the removal of the signal dependent noise (Arsenault & Denis 1983; Kotropoulos, Papas, & Pitas 2001). It is argued that since real images have different types of noise, a combination of filtering techniques should be used.

2. Homomorphic Image Processing

There are many different ways of including noise into image processing procedures, depending on how the noise is defined. The most common approach is based on the the so called additive noise model

$$I(x,y) = s(x,y) + N(x,y) \tag{1}$$

where $I(x,y)$ is the observed image, $s(x,y)$ denotes the signal and $N(x,y)$ is Gaussian white noise.

A more complicated model considers the so called multiplicative noise

$$I(x,y) = s(x,y)N(x,y) \tag{2}$$

We consider here a more general model which describes the signal-dependent noise and reduces to the aforementioned equations in more simple situations. The model is described by the following equation

$$I(x, y) = f(s) + g(s)N(x, y) \tag{3}$$

The functions f, g are nonlinear. We assume that $N(x, y)$ is uncorrelated with the signal s. Multiplicative noise is of course a special case of (3). Photoelectron noise can also be described as a special case of (3)

$$I(x, y) = \alpha s^p + \beta s^q N(x, y) \tag{4}$$

The desirable decoupling can be obtained (Arsenault & Denis 1983; Kotropoulos et al. 2001) by applying to the observed image (4) a nonlinear transformation $G(I)$ which is chosen in such a way that

$$G(I) = G[f(s) + g(s)N(x, y)] \sim V(s) + N(x, y) \tag{5}$$

Strictly speaking, the exact separation can be achieved only for multiplicative noise, when $G(s) = \gamma H(s)$, where γ is a constant. For the photoelectron noise (4) it can be done approximately by choosing $G(I)$ in the following form

$$G(I) = [(p\alpha^{-p/q} - p/q)/(\beta(p - q))]I^{(p-q)/p}, \tag{6}$$

Then the expression (5) becomes

$$G(I) \sim G(f(s)) + N(x, y) \tag{7}$$

To process the images below, the following values of the parameters were used $\alpha = \beta = 1, p = 0.75, q = 0.45$.

3. Linear Filtering of the Transformed Image and the Restoring Tranformation

The removal of the noise $N(x, y)$ here can be done by a linear filtering and the choice of the appropriate filter depends on the probability density function (PDF) of $N(x, y)$. For example, if the noise has a Gaussian distribution the simple arithmetic mean will do the job. If the noise is a mixture of positive and negative spikes, the median filters will be more effective. After linear filtering the image must be restored by the following nonlinear transform $T(G(f(s))) = s$. For the model (3) it takes the following form

$$T(z) = (z\beta(p - q)/(\alpha p))^{1/(p-q)} \tag{8}$$

4. Mosaics

A mosaic of astronomical observation request AOR3865856 is presented in Figure 1. The image was obtained by MIPS in the 70μm imaging band. The mosaic size is 0.9 deg x 0.5 deg. The effective exposure time for one AOR is 30 sec. The basic calibrated data (BCD) is from SSC pipeline version 10.0. The mosaic image is made by MOPEX (Makovoz & Khan 2005).

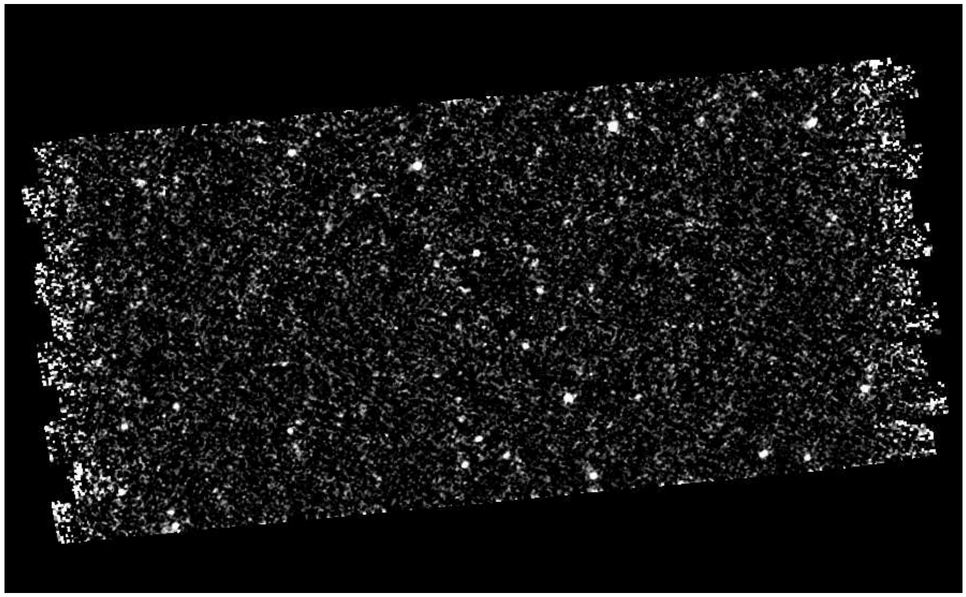

Figure 1. AOR3865856 mosaic.

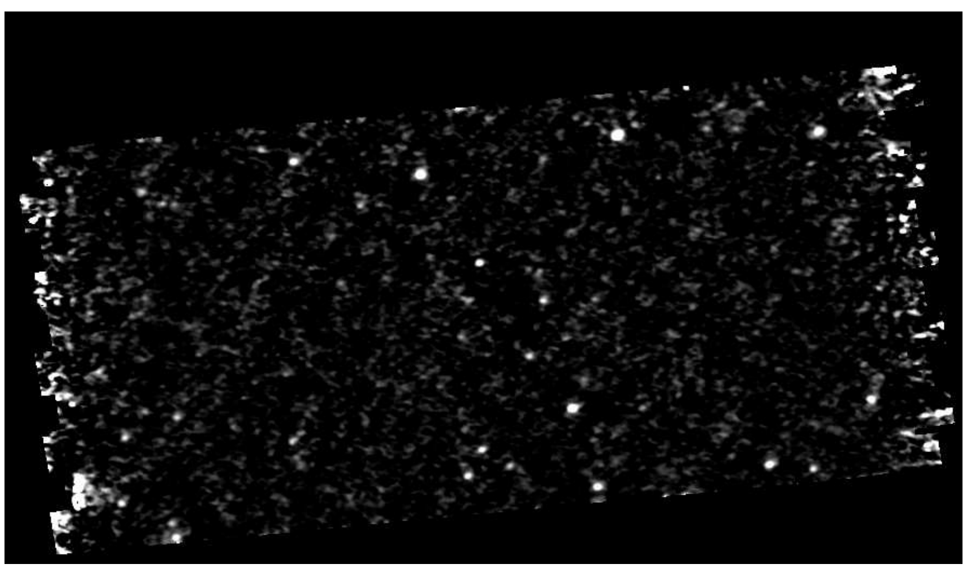

Figure 2. AOR3865856 mosaic after a linear filtering.

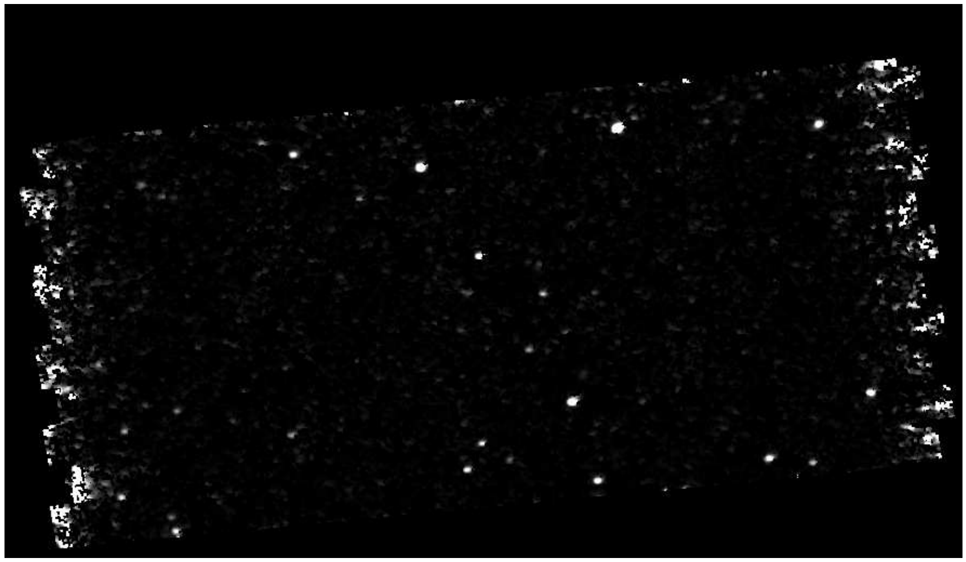

Figure 3. AOR3865856 mosaic after the homomorphic filtering.

5. Conclusion

The signal to noise ratio (SNR) obtained by applying the homomorphic filtering is higher than SNR obtained after direct linear filtering. This leads to a more reliable point source extraction. It also indicates presence of a signal-dependent noise. In reality, the additive, multiplicative and signal-dependent noises are all present which calls for consecutive application of a few different filtering procedures. The filtering procedure applied here, together with the nonlinear denoising and segmentation methods described in Pesenson et al. (2005), are complementary to each other, which makes them especially comprehensive.

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