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Developing a Wavelet CLEAN Algorithm for Radio-Interferometer Imaging

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Abstract. A new CLEAN-type algorithm searches for model components not in the dirty image but in the multi-resolution wavelet transform of the dirty image based on the dirty beam. A single-resolution prototype algorithm that searches for CLEAN components after convolution with the dirty beam has been tested and shown to be advantageous for the case of sparsely sampled and noisy u-v data, without specifying regions to be CLEANed.

1. Introduction

The image formed by simple Fourier transformation of the visibilities observed by radio interferometers has defects due to limited sampling of the u-v plane. Nonlinear deconvolution is required to correct these defects, CLEAN being the most popular algorithm (e.g., Cornwell, Braun, & Briggs 1999). However, it sometimes requires use of *a priori* knowledge of source structure, to avoid creating CLEAN components where the source 'should not' exist. This is the case partly because the standard CLEAN algorithm just takes the peak of the dirty image as the position of the next CLEAN component. For complex sources the peak brightness feature may be just a region of overlapping sidelobes plus noise; therefore choosing the area to be cleaned is crucial. In this paper an alternative CLEAN-type algorithm is proposed that uses wavelets to overcome the subjectivity of setting CLEAN boxes, so that reliable images can automatically be produced without *a priori* knowledge of source structure.

2. A prototype Wavelet CLEAN

If one can use not only the peak in the dirty map but also knowledge of the sidelobes to decide the position of CLEAN components, one may be able to establish an alternative CLEAN algorithm without CLEAN boxes, which leads to

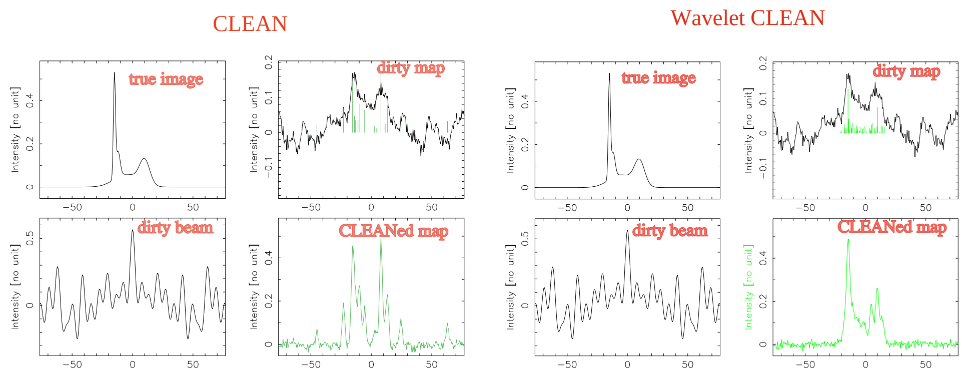

Figure 1. CLEAN and Wavelet CLEAN for 1-D model data.

a more efficient automatic imaging program not dependent on *a priori* knowledge of sources. Multi-dimensional wavelet expansion of the dirty image may provide the possibility of realizing such an algorithm, if one can construct a wavelet function based on the dirty beam.

Although such an ideal function for fast wavelet transformation is not known to date, as a first trial to demonstrate the power of the wavelet CLEAN, test have been conducted of a zero-order prototype that searches for CLEAN components not in the dirty image $I_d(x, y)$ or the residual image $I_r(x, y)$, but after convolution of those with the dirty beam $B(x, y)$. Convolving the dirty image with dirty beam $I_d(x, y) * *B(x, y)$ corresponds to a wavelet expansion of the dirty image at single resolution.

3. Sample images

Example 1-D deconvolution using CLEAN and the prototype Wavelet CLEAN for model data are shown in Figure 1. In both cases, the dirty map $I_d(x)$ is a convolution of the true image $I_{true}(x)$ with the dirty beam $B(x)$, with 10% gaussian noise added. For Wavelet CLEAN, the normal CLEAN procedure was performed not on $I_d(x)$ and $I_r(x)$, but on $I_d(x) * B(x)$ and $I_r(x) * B(x)$. Two hundred iterations were performed with a loop gain of 0.1 and no CLEAN boxes specified. The results show that the chance of picking wrong CLEAN components is significantly reduced for the Wavelet CLEAN. The two methods provided equally good results for a noise-free model image.

An example of two-dimensional Wavelet CLEAN for 5 GHz VLBA data is shown in Figure 2, which also illustrates the order of computations for the procedure. The observed source is the radio quasar 0108+388, which consists of only a few major bright components at 5 GHz at VLBA resolution. One hundred iterations were taken with a gain of 0.3 and no CLEAN boxes specified. The positions of CLEAN components at each iteration for both CLEAN and Wavelet CLEAN are shown in Figure 3. The plot suggests that the positions found by standard CLEAN are fluctuating during the iteration while those of Wavelet CLEAN are rather stable around the peak positions in the original dirty image.

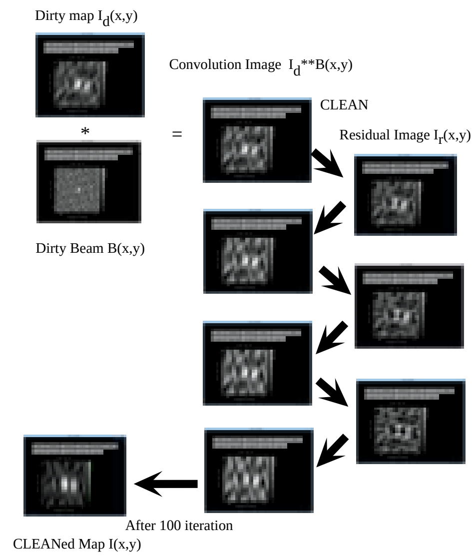

Figure 2. 2-D experiment of Wavelet CLEAN with real data.

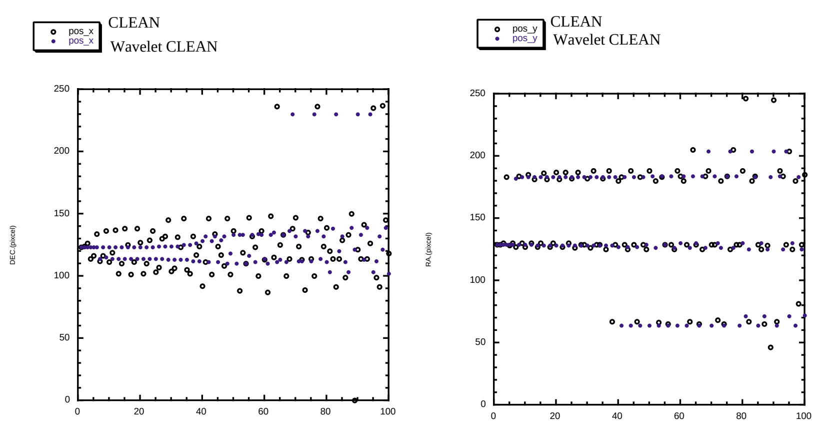

Figure 3. Positions of CLEAN components at each iteration of Figure 2.

4. Discussion

For the case of sparsely sampled and noisy u-v data, and without specifying regions to be CLEANed, the Wavelet method is shown to be advantageous. In fact taking the convolution of the dirty image with the dirty beam was discussed briefly in the original proposal of the CLEAN algorithm by Högbom (1974). In the original CLEAN algorithm the convolution was not performed because in Fourier space it differs from the original dirty image by only a multiplicative factor, and the author felt it was unnecessary. Nevertheless, a difference between CLEAN in two different image domains can be observed. The improvement of this prototype Wavelet CLEAN, which does convolve with the dirty beam, can be attributed to a suppression of noise and aliasing in the dirty image by use of information in the sidelobes of the whole image domain. So far this method has the advantage for compact sources with several components. Although the possible extension of the algorithm for multi-dimensional imaging of extended radio sources, introducing wavelet functions based on the dirty beam, remains to be studied, the current analysis of the prototype provides the basic concept.

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