A comparison of SDI CLEAN and multi-resolution CLEAN for deconvolution in imaging of extended and diffuse sources.

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3rd July 2005

Abstract

This report gives a practical, working comparison between Steer-Dewdney-Ito (SDI) CLEAN and multi-resolution CLEAN algorithms for deconvolution of the dirty image during imaging of extended and diffuse sources such as gas clouds and nebulosities. For a qualitative comparison, real data from the GMRT observations of the supernova remnant IC443 at 243 MHz and 610 MHz by Prof. Mitra was used. For a quantitative comparison between the two methods, a simulated source was created using tasks existing in `AIPS` and imaged. The quantitative comparison was not completed within the authors's stipulated time period at NCRA and is planned to be completed at later stage.

1 Introduction

The image of a source is constructed by Fourier transforming the visibilities in the U-V plane. In the ideal case, the transform is unique. Hence the image created is the correct map of the source. However in earth rotation aperture synthesis, it is not possible to sample the visibilities over the entire U-V plane. The visibilities which are not measured are set to zero in the data. This gives rise to spurious sidlobes in the source map. This so-called *Dirty Map* is CLEANed with the *Dirty Beam*[1], by the CLEAN algorithm described by Högbom [1]. CLEAN assumes a largely empty field of view with a few scattered point sources. Although very successful in deconvolution of fields eith point objects, standard CLEAN algorithm fails to produce smooth maps of extended sources.

1.1 Problems of Imaging of Extended Sources

The standard algorithm of CLEAN detects maxima over the specified area and considers them to be point sources. Applying this algorithm on diffuse sources produces maps with

[1]The *Dirty Beam* is the Fourier transform of the sampling function in the U-V plane

series of spikes and point-like features in places where smooth features are expected. Missing visiblity values result in presence of negatives in the theoretical beam. In extended sources, these negatives can result in loss of features and flux information. To get around these problems in the standard algorithm, variations like *Multi-resolution CLEAN* and *SDI CLEAN* were developed.

1.2 Variations of the CLEAN algorithm

1.2.1 Multi-resolution CLEAN

Since CLEAN is effective with compact structures only, extended structure is obtained by cleaning a low resolution version of the image. Fewer components are required to describe the structure in low resolutions because the beam is very wide. The more intricate features can be obtained by running CLEAN on a higher resolution image, where the beam is very narrow. In practice, multiple maps are created by 'CLEAN'ing the image at various resolutions and a final image is obtained by adding these maps.

Traditionally, observers used a simple trick to overcome the problem of the standard CLEAN algorithm. First, they would CLEAN the map with a high resolution *Dirty Beam* to remove all the point sources in the field. The visibility values corresponding to those sources were subtracted from the data. Then the remaining data would be CLEANed with a low resolution *Dirty Beam* to extract the diffuse emission. The high resolution and low resolution maps would then be added together to give the complete map.

The multi-resolution CLEAN algorithm is only a formalized version of this method. During each cycle, the algorithm checks the peak flux in each *Dirty Map* (at various resolutions). The peak flux weighted by a multiple of the beam ratio forms the criteria for selecting the next *Dirty Map* to be CLEANed. The algorithm also specifies decreasing gain factors for lower resolutions to stop the low resolution beams from CLEANing the strong high resolution features.

1.2.2 SDI CLEAN

As described earlier, the original CLEAN algorithm works well on compact sources but not on extended sources. When the algorithm is applied to extended sources, the final image develops 'ripples' kind of structures which are obviously spurious. Hence the CLEAN algorithm cannot be directly applied to extended sources. Steer, Dewdney and Ito [2] modified the CLEAN algorithm to suit the CLEANing of the extended sources better.

In SDI CLEAN the maxima is detected over a specified area and all points above or equal to a fraction of the maxima are taken as CLEAN components. Thus unlike the normal CLEAN algorithm, SDI CLEAN takes care of the extended features present in the *Dirty Map* and produces an image much nearer to the actual object.

Another issue that is tackled in SDI CLEAN is the case in which both point sources and extended sources being present in the *Dirty Map*. Before beginning an iteration it checks the number of pixels that are greater in brightness than the user-specified fraction of the maxima. If this number is greater than a user-specified value only then it continues with SDI CLEAN , else it switches over to the normal CLEAN algorithm thus taking care of the point sources as well.

2 Supernova remnant IC443

The supernova remnant IC443 in Gemini has the right structural features to make its imaging an excellent testing ground for the CLEAN algorithms. It has a mixture of large ($\sim 1^\circ$) nebulosity with a good amount of fine features, three significantly bright point sources (two of which form a close double pair) and a few more faint point sources. The IC443 observation data was provided by Prof. Mitra. The observations were made with the GMRT simultaneously at 610MHz and 243MHz in 2003 using the co-axial feeds and measuring the orthogonal polarisations.

2.1 Flagging and calibration

The data was flagged and calibrated in iteratively with 3C147, 3C48, 3C286 as bandpass calibrators and 0632+103 as the phase calibrators. Two antennae had a power failure for a certain period of time during the 10 hour observation. Some others had highly unstable gains.

After bandpass calibration, twenty relatively interference-free channels were averaged to increase the signal-to-noise ratio (SNR). After this the bright point sources in IC443 were used to iteratively self-calibrate the data. Some final flagging was performed to remove ripples seen around the point sources. After this stage, the data wasn't further flagged or calibrated so that comparisons between the different results could be interpreted as being due to the CLEANing methods.

After creating a few images, small differences between the results of multiresolution CLEAN and SDI CLEAN were noticed and are discussed below.

3 Discussion and Comparison

The working comparison of the two algorithms is given below.

1. Multiresolution CLEAN is better than SDI CLEAN for diffuse emission which has very low flux density ($\sim$noise level).

2. Multiresolution CLEAN requires a considerably longer time to complete than SDI CLEAN.

3. However, multiresolution CLEAN requires less manual intervention than SDI CLEAN. Multiresolution CLEAN requires manual intervention at the start of the CLEANing, SDI CLEAN, throughout.

4. Without manual intervention, both the algorithms require very specific values of control parameters to converge to an 'astronomically satisfactory' image. Setting the values of the parameters is a 'trial and error' process. However with manual intervention (setting up CLEAN boxes, forcing a particular field or a particular algorithm), the algorithms can be made to converge to a satisfactory image for a wide range of parameters.

4 Further Work

The authors intend to do a quantative comparision between the two algorithms. Simulated data will be used for this purpose. Extended emission will simulated by closely placed gaussian sources. Both Multi-resolution and SDI CLEAN will be used on this simulated source field. The image hence obtained will be subtracted from the original image and rms leftover intensity will be calculated. The algorithm that gives a lesser rms value will be considered better in deconvolving the field. The above process will be repeated for a range of parameters and rms will be calculated. Thus, stability of these algorithms over parameters will be checked.

5 Acknowledgements

We would like to thank the Homi Bhabha Centre for Science Education and the NIUS programme for this wonderful opportunity to learn basic radio astronomy. We would also like to thank Prof. Nityananda, Prof. Rao and Prof. Mitra for guiding us through the theory and the imaging project.

References

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[2] Steer D., Dewdney P. & Ito M., 1984, A&A, 137, 159.