Wide–band, Wide–field Imager MFImage

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***Abstract*—This memo describes the Obit wide–band, wide–field imager MFImage as well as its data products.**

***Index Terms*—Radio interferometric imaging**

I. Introduction

MODERN radio interferometer arrays such as EVLA and MeerKAT obtain much of their sensitivity using a wide bandwidth. At low frequencies and with greater sensitivity there are always many sources scattered across the field of view whose sidelobes must be removed by deconvolution. This memo discusses a wide–band, wide–field imager, MFImage developed in the Obit package [1] [1].

II. Wide–field imaging

Many radio interferometers use Earth rotation systhesis, observing over a time period during which the rotation of the Earth extends the uv coverage, and in which a 2-D antenna array partially fills a 3-D uvw space. Wide–field imaging in this regime becomes a 3-D problem as the response to the sky is given by [2]

$$V(u, v, w) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} I(l, m) e^{-2\pi i[ul+vm+w(\sqrt{1-l^2-m^2}-1)]} \frac{dl dm}{\sqrt{1-l^2-m^2}}$$

where l and m are direction cosines on the sky. The fundamental problem is that the 3-D uvw coverage results in “resolution” in the “w” direction, perpendicular to the sky. The curvature of the sky means that its image may not be well focused on a single tangent plane away from the delay tracking center. There are several solutions to this problem but the one considered here is “tiling”, AKA “Mosaicing” [3] in which the region of the sky of interest is tiled with 2-D facets which are close enough to the celestial sphere that images on them are well focused.

The traditional approach to this has been to make the facets tangent to the celestial sphere at their midpoints but this leads to a slow deconvolution as the response to a source in one facet is not easily predicted in another and the facets need to be CLEANed one per major cycle. A major improvement is the scheme of [4] which describes a zero cost option to rotate the facets to a common plane. The enhancement of [5] is to align the facet grids to allow many facets to be CLEANed in parallel.

Faceted imaging has a number of operational advantages. First, it is trivial to parallelize as each facet uses the same data with a slightly different rotation matrix. Second, after the initial set of facets are made, the location of interesting emission is known and only a subset of the facets may be needed in a given major CLEAN cycle. When the deconvolution is finished, the facets are combined onto a single plane.

III. Wide–bandwidth imaging

Large fractional bandwidths introduce their own complications. First, the sky itself generally doesn’t have the same brightness distribution across the band. Furthermore, the gain pattern of the array elements will generally scale in size with frequency with a larger field of view at lower frequencies. Variations in sky brightness distributions and antenna gain must be taken into account with sufficiently large fractional bandwidths.

IV. MFImage

Obit wide–field, wide–band imager MFImage uses tiling with multiple factet as needed for a given field of view with optional outlying factets to cover nearby strong sources selected from a catalog. The bandpass is divided into subbands whose fractional bandwidth is sufficiently small that bandwidth effects can be ignored. Each subband has multiple channels with fine enough frequency resolution to avoid bandwidth smearing.

MFImage loops over pointings in a dataset performing a number of operations:

1) Select, apply calibration and editing and optionally time average the visibility data in a baseline dependent fashion to reduce the data volume while minimizing time smearing [6].
2) Image Stokes I and deconvolve using CLEAN, optionally with multiple resolutions. Subband images are made independently but CLEANed jointly driven by a weighted average of the subband images. CLEAN windows may be automatically selected.
3) Perform up to a given maximum number of phase self-calibrations if a peak in the image exceeds a given threshold. A new imaging/deconvolution is performed after each self calibration.
4) Perform up to a given maximum number of amplitude and phase self-calibrations if a peak in the image exceeds another given threshold. A new imaging/deconvolution is performed after each self calibration.
5) Facet images have CLEAN components which were subtracted restored with a Gaussian and are combineded into a common plane in each subband.
6) A spectrum is fitted in each pixel using the subband images fitting only the number of terms allowed by the SNR in the subband images. Fitting is weighted by $1/\mathrm{RMS}^2$ in each of the subband planes. If the fit

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[1] http://www.cv.nrao.edu/∼bcotton/Obit.html

is not statistically improved with a spectral index[2] (or curvature) term this term is not included in the fit and a default spectral index (curvature) value, generally 0, is used.
7) Optional imaging of Stokes, Q, U and V.
8) Optional primary beam correction.

MFImage is described in more detail in [7].

V. Data products

A. Data Cube

The principal product of MFImage is a complex (i.e. non-standard) image cube containing a number of parts.

1) A plane in which the pixel values are the flux densities at the image reference frequency.
2) A spectral index plane with either the fitted spectral index or the default value.
3) Optional curvature plane(s). Controlled by parameter *nterm* but more spectral terms than spectral index is seldom useful.
4) A cube of ∼constant fractional bandwidth subband images, the width is set by parameter *maxFBW*. Note: these are not equally spaced in frequency.

One of the complications of the SNR dependent fitting is that there may be discontinuities in the total intensity image at places where the number of fitted spectral terms changes, i.e. between regions with only a total intensity and those with total intensity and spectral index. For this reason, it is also possible to derive images without spectral index (or curvature) terms in the fit in which case the image is the weighted average of the subband images. This is done using ObitTalk function *ImageMF.PFitSpec* or *ImageMF.PFitSpec2*.

When a significant fraction of the total band has been flagged due to RFI, comon at low frequencies, the effective frequency is subject to the RFI environment at the time of the observations. Without primary beam correction, antenna gain variation with frequency will also modify the effective frequency as a function of distance from the pointing center.

B. Descriptive parameters

The details of the structure of the output cube, e.g. number of spectral term planes, subband planes and frequencies defining them are given by keywords in the image header:

1) "Frequency" axis label. The coordinate label for the third axis is "SPECLNMF" indicating that this image is of the type produced by MFImage and that any CLEAN component table ("AIPS CC") has a tabulated spectrum on each entry. The coordinate value on this axis is the reference frequency.
2) NTERM, the number of spectral terms, i.e. total intensity, spectral index, curvature ... planes at the beginning of the cube.
3) NSPEC, the number of subband image planes following the spectral planes.
4) FREQnnnn the frequency (Hz) of the center of subband nnnn (1-rel).
5) FRELnnnn the frequency (Hz) of the lower edge of subband nnnn (1-rel).
6) FREHnnnn the frequency (Hz) of the upper edge of subband nnnn (1-rel).
7) ALPHA, default spectral index.
8) RFALPHA, the frequency (Hz) at which ALPHA is measured.

C. CLEAN Components

The CLEAN components from the individual facets obtained during the deconvolution are combined into single "AIPS CC" table with a 3-D spatial location and a tabulated spectrum. The details of these tables are described in [8].

D. Output UV data

The input data after selection, calibration and editing applied and any averaging is written into the output uv data file. This file also has any self-calibration tables ("AIPS SN") attached. If an amplitude and phase self calibration was performed, then the last phase self–calibration solution table has been applied to the data in the output UV data.

[2] Spectral index, α, is given by $S_\nu = S_{\nu_0}(\nu/\nu_0)^\alpha$ where ν is frequency and ν_0 is the reference frequency.

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