New Methods for Precision Radio Imaging

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Future Radio Arrays

- Planned radio telescopes like the Square Kilometer Array (SKA) will implement a ”Large N” design
  - Many small radius telescopes spread over hundreds of kilometers
- These arrays have advantage of naturally wide field-of-view (FOV)
  - Can cover large areas of the sky in a single observation

Image courtesy of: skatelescope.com
Wide FOV

- A wide FOV is advantageous for many radio astronomy applications.
- Introduces a fundamental problem.
- Sky is virtually full of radio sources at sensitivity of SKA.
  - These sources add noise to the FOV center.

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Time and Frequency Averaging

- Distant sources are often suppressed through time/frequency averaging.
  - Average observations over frequency channels/small window of time.
- This "smears" distant sources, which reduces the effects that they have on the center of FOV.
- This method does not remove the flux density of the source, just spreads it out.
- This actually increases the noise in the region where the source used to be.
Field of View Control

- One method that does not suffer from the drawbacks of time/frequency averaging is using convolution functions in the $u,v$ plane.
- As the earth rotates, the baselines of an array move through the $u,v$ plane.
  - More telescopes, more coverage.
- The observed data is a sample of the visibility function, which is Fourier transformed to form the image plane.
- We use the relationship between the $u,v$ plane and the image plane to strategically convolve the data.
Experimental Data

• To test the field-of-view method, data from the MERLIN array in England was used.
• Used 4 elements of the array, resulting in 6 baselines.
• This work builds upon theoretical work done by previous REU students (Dylan Nelson, 2006).
  - Showed that simulated data sets responded positively to field-of-view control via \( u,v \) convolution.
Convolution Functions

- Jinc function was used as a convolution function.
- Transform is a window function.
- Favorable properties in image plane, but is intense computationally.
Convolution Functions

- A Gaussian function was also used.
- Transform is a Gaussian.
- Easier to compute than the Jinc, and allows for partial attenuation of distant sources.

\[
\tilde{w}(q) = e^{-\frac{\pi q^2}{s^2}} \quad W(r) = e^{-\pi \alpha^2 r^2}
\]
Jinc Results

Without Convolution Function

With Jinc Convolution Function

Ratio of sources: .7566 ± .0153

Ratio of sources: .0018 ± .0061
**Gaussian Results**

**Without Convolution Function**

Ratio of Sources: \(0.7566 \pm 0.0153\)

**With Gaussian Convolution Function**

Ratio of Sources: \(0.1840 \pm 0.0063\) (Source partially attenuated as predicted)

Theoretical attenuation curve, with measured point.
Comparison with Freq/Time Avg.

Data set time and frequency averaged to mimic size of Jinc convolution function.

With Jinc convolution function
Flagging Tests

• After preliminary tests were successful, the robustness of the algorithm was tested.
• Data was systematically flagged to test the point at which the algorithm stopped producing predicted results.
• Abundant flagged data makes the convolution incomplete.
• Flagging schemes:
  – Frequency flagged at regular intervals (1/16 - 1/4\textsuperscript{th} of total)
  – Time flagged at regular intervals (1/16 - 1/4\textsuperscript{th} of total)
  – Time/Frequency flagged only on shortest/longest baseline (1/16 -1/4\textsuperscript{th} of baseline total)
  – ”Worst Case” - Frequency and time flagged at random intervals accross all baselines (~1/2 of total)
Flagging Results

Ratio of Sources

<table>
<thead>
<tr>
<th>Test</th>
<th>Jinc</th>
<th>Gaussian</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4 Frequency</td>
<td>0.0356</td>
<td>0.1930</td>
</tr>
<tr>
<td>1/16 Frequency</td>
<td>0.0387</td>
<td>0.1871</td>
</tr>
<tr>
<td>1/4 Time</td>
<td>0.0456</td>
<td>0.1919</td>
</tr>
<tr>
<td>1/16 Time</td>
<td>0.0431</td>
<td>0.1881</td>
</tr>
<tr>
<td>Shortest Baseline</td>
<td>0.0352</td>
<td>0.1713</td>
</tr>
<tr>
<td>Longest Baseline</td>
<td>0.0398</td>
<td>0.1829</td>
</tr>
<tr>
<td>Worst Cast</td>
<td>0.0483</td>
<td>0.1944</td>
</tr>
<tr>
<td>Without Flagging:</td>
<td>0.0017</td>
<td>0.1844</td>
</tr>
</tbody>
</table>

- Nearly all tests reacted predictably.
- Exceptions are shortest/longest baseline for the Gaussian case.
- However, spread between all flagging scenarios is small.
- Jinc function is much more sensitive to large portions of flagged data.
- Regularity of flagging may affect Jinc function.
Conclusions and Future Work

- Both functions used for $u, v$ convolution produced superior results compared to frequency and time averaging.
- Both functions underwent various flagging schemes, and delivered results which illustrates the robustness of the algorithm.
- $u, v$ convolution is a viable option for actual observational data.
- Future work:
  - More realistic flagging testing. Current work may be compromised by regularity of flagging.
  - Testing of method on data set from a larger array – tests not only program but reaction of function.
  - Other functions should be tested, functions that require less support in $u, v$ plane.
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