Electrode Placement Strategies for EIT

Brad Graham
School of Information and Technology, University of Ottawa
Ottawa Canada
graham.bm@sympatico.ca

Andy Adler
Department of Systems and Computer Engineering, Carleton University
Ottawa Canada
adler@sce.carleton.ca
Goal of this work

- Many ways to place electrodes in 3D
- How much difference do the variations make with respect to performance?
- What is the most important factor?
- Is any EP strategy clearly superior to the others?
Constraints

- Desire to validate simulated results with available equipment
  - GOE MF II Type Tomography System
  - 16 Electrode machine intended for 2D planar arrangement with adjacent drive protocol
Reconstruction Algorithm

\[
x = (H^TWH + \lambda^2 R)^{-1} H^T W z
\]

\( R \) is diag \((H^TH)\), the prior used in NOSER\(^3\)
\( \lambda \) is selected with \textit{BestRes}\(^1\)
\( W \) models the system noise\(^1\), we assume that all measurements have equal noise variance
\( x \) and \( H \) are in a nodal basis
Model is solved using the Nodal Inverse Solver of [5]
\( z \) is difference data
2 Electrode Arrangements

Aligned

Offset
Electrode Sequencing

• The 2 arrangements combined with sequencing gave us 7 EP strategies to evaluate
  – Planar
  – Planar-Offset
  – Planar-Opposite
  – Zigzag
  – Zigzag-Offset
  – Zigzag-Opposite
  – Square
Planar Planar-Offset

Planar

Planar-Offset
Planar-Opposite

ZigZag-Opposite
Square
Simulated Data

• Impulse Contrast located at r/2 and moved through 28 vertical locations

• Led to 28 reconstructions per EP Strat
Eval Criteria

- Resolution
- Radial Position Error (PE)
- Vertical PE
- Image Power
- Qualitative (artefacts)
- Immunity to Noise
- Immunity to systematic Electrode Placement Errors
  - Offset Error
  - Layer Separation Error
Resolution – no noise
Radial PE – no noise
Vertical PE – no noise
Image Power– no noise
Qualitative Evaluation - 1

- Planar
- Planar-Opposite
- Planar-Offset
- Square

- Sperical Shaped reconstruction
Qualitative Evaluation - 2

- Zigzag
- Vertically elongated shape
Qualitative Evaluation -3

- Zigzag-Opposite
- Artefacts reaching to electrodes
Qualitative Evaluation -4

- Zigzag-Offset
- Banana shaped artefact
Results - Noise

- AWGN Added in 6 steps from 0.1 to 0.6%
- Zigzag, Zigzag-offset failed for noise > 0.2%
- Square failed for noise > 0.3%
- The 2 Opposite EP Strategies worked up to 0.6% but with degraded resolution and PE
- Planar, Planar-Offset very robust to noise
  – performance degraded slowly
Offset Error

• Data simulated with aligned arrangement, reconstructed using offset arrangement

• Data simulated with offset arrangement, reconstructed using aligned arrangement
Results – Offset Error

- All strategies showed degraded resolution with Zigzag-Opposite being worst
- Planar-Opposite: conductivity increases were reconstructed as conductivity decreases
- Planar, Planar-Offset, Zigzag all produced good images without shape artefacts
  - …all were rotated in position by about 20 deg
Layer Separation Error

• Data was reconstructed with electrode planes 11 cm apart

• Data was simulated with electrode planes separation from 11 cm to 20 cm in 9 steps
Results - Layer Separation Error

• Radial PE, Vertical PE and Image power not significantly affected
• All strategies produced vertical elongation artefacts
• Square and opposites most affected
• Zigzag, Zigzag-offset less so
• Planar, Planar-Offset least affected
Significant Observations

• Made many observations; here we cover the important ones
• Planar produces largest signal, most spherical image (least artefacts) for contrasts in the middle section
• Most robust to noise
• Robust to Layer Sep error and Offset error
## Summary

<table>
<thead>
<tr>
<th></th>
<th>Res</th>
<th>VPE</th>
<th>RPE</th>
<th>Qual</th>
<th>Noise</th>
<th>Offset Error</th>
<th>Layer Sep Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planar</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Planar-Offset</td>
<td></td>
<td></td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Planar-Opposite</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>Zigzag</td>
<td></td>
<td>--</td>
<td></td>
<td>-</td>
<td>--</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Zigzag-Offset</td>
<td></td>
<td>--</td>
<td></td>
<td>--</td>
<td>--</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Zigzag-Opposite</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>--</td>
</tr>
<tr>
<td>Square</td>
<td></td>
<td>--</td>
<td></td>
<td>+</td>
<td>-</td>
<td></td>
<td>--</td>
</tr>
</tbody>
</table>
Conclusion

- Planar and Planar-offset strategies are the most robust to noise and systematic electrode errors
- *in vivo* placement may be most important issue
- We recommend the Planar EP Strategy
Recommended 3D electrode placement