Electrical Impedance Tomography for Deformable Media

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Outline

• Electrical impedance tomography
• Image variability from boundary deformation
• Electrode displacement regularization
• Imaging of deformable media
• Conclusion
Electrical impedance tomography

EIT for deformable media

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Electrical impedance tomography

internal conductivity

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Electrical impedance tomography

applied current

internal conductivity

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Electrical impedance tomography

internal conductivity

boundary voltage

applied current

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Electrical impedance tomography

- inverse problem
  - non-linear
  - unstable
  - not unique

boundary voltage

internal conductivity

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Electrical impedance tomography

Inverse solution

1. Discretize

2.

3.

Boundary voltage

Internal conductivity

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Electrical impedance tomography

inverse solution
1. discretize
2. linearize
3.

boundary voltage

internal conductivity

\[ \text{boundary voltage} \times f(J) = \text{internal conductivity} \]
Electrical impedance tomography

inverse solution
1. discretize
2. linearize
3. regularize

$\mathbf{V} = \mathbf{f}(\mathbf{J}, \mathbf{R})$

boundary voltage
internal conductivity
Boundary deformation

The body is soft and is always in motion

- body motion causes EIT errors because:
  - the boundary deforms
  - the electrodes move

- monitoring may require movement e.g., breathing to monitor lung ventilation
Boundary deformation

adapted from http://www.brendoman.com/media/  (Oct. 12, 2006)
A study of deformation

Simulated EIT measurements to determine how much error is introduced from
1. boundary deformation
2. electrode displacement along boundary

• analysed results by
  1. inspection
  2. error measurement
Boundary deformation

forward model

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Boundary deformation

Correct

Incorrect

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Boundary deformation

Electrodes moved by approx. 1.50 cm

correct

incorrect

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Boundary deformation

Conductivity Variation vs. Number of Misplaced Electrodes

- Image error (conductivity variation %)
- # of electrodes shifted

- 3.00 cm
- 2.25 cm
- 1.50 cm
- 0.75 cm

EIT for deformable media
Displacement regularization

The proposed solution includes an electrode displacement parameter into the inverse problem:

• define the system model

• define the augmented regularization matrix

• define the augmented Jacobian matrix
Displacement regularization

boundary voltage

internal conductivity

image

\( \text{EIT for deformable media} \)

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Displacement regularization

boundary voltage

internal conductivity

electrode displacement

v

image

x
Displacement regularization

\[ x = f(J, R) v \]

\[ x = (J^T J + \lambda^2 R)^{-1} J^T v \]
Displacement
regularization

Building $R$ -- *a priori* claims

- conductivity distribution is smooth
- adjacent electrode displacements are correlated
Displacement regularization

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Displacement regularization

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Displacement regularization

EIT for deformable media

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Displacement regularization

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Displacement regularization

elements

elements

electrodes

electrodes

elements

electrodes

elements

electrodes

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Displacement regularization

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Displacement regularization

\[ R = \begin{bmatrix} \mu^2 & 0 \\ 0 & 0 \end{bmatrix} \]
Displacement regularization

Building $J$ -- sensitivity to input change
- conductivity change will affect boundary voltage
- displacements will affect boundary voltage
Displacement regularization

elements

electrodes
Displacement regularization

\[
\frac{\partial v}{\partial \sigma} \approx \frac{v(\sigma + \Delta \sigma) - v(\sigma)}{\Delta \sigma}
\]

electrodes

elements

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Displacement regularization

\( \frac{\partial v}{\partial \sigma} \quad \text{elements} \)

\( \frac{\partial v}{\partial r} \quad \text{electrodes} \)

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Displacement regularization

\[ J = \]
Algorithm performance

Results of a comparison to the standard algorithm
• no change in position accuracy
• marginal improvement in image resolution
• large improvement in artefact reduction
• calculates electrode displacements
Algorithm performance

under-regularized

regularized

under-regularized

regularized

artefact amplitude

deforation (% of diameter)
Imaging deformable media

Simulation

true
1%

standard

proposed

Phantom

5%

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Imaging deformable media

Phantom time series:
- 6 sec. increments
- periodic 5% deformation
Imaging deformable media

Human TLC-RC breathing: 1.2 sec. increments

10.8 sec  12 sec  13.2 sec  14.4 sec  15.6 sec  16.8 sec  18 sec

Human “paradoxical” breathing: 1.2 sec. increments

6 sec  7.2 sec  8.4 sec  9.6 sec  10.8 sec  12 sec  13.2 sec
Conclusion

This thesis
• studied & quantified the effect of boundary deformation
• proposes an algorithm that compensates & calculates electrode displacement
• provides evidence supporting the use of EIT for deformable media
Contributions

journal


conferences
