Imaging electrode movement and conductivity changes in EIT

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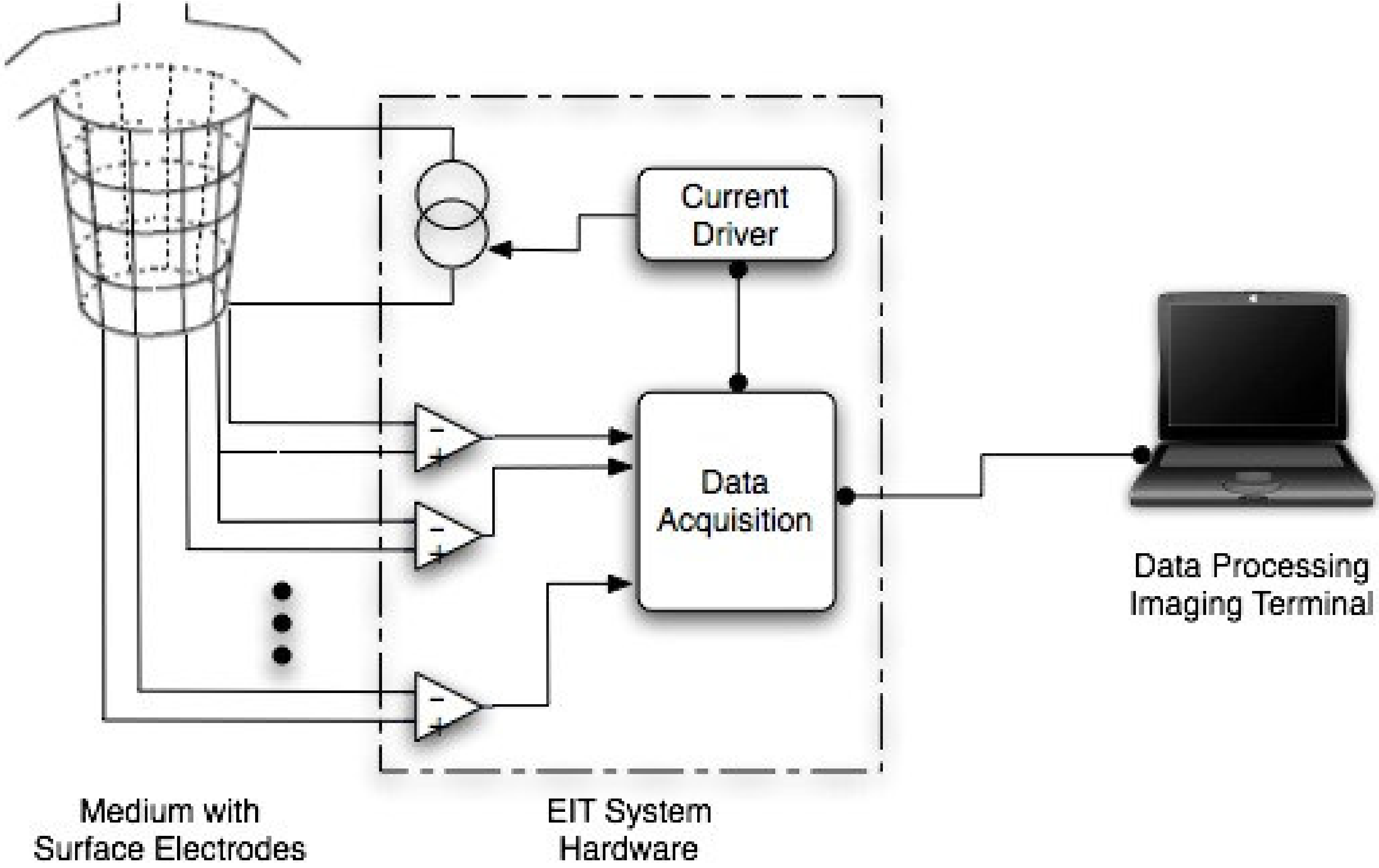
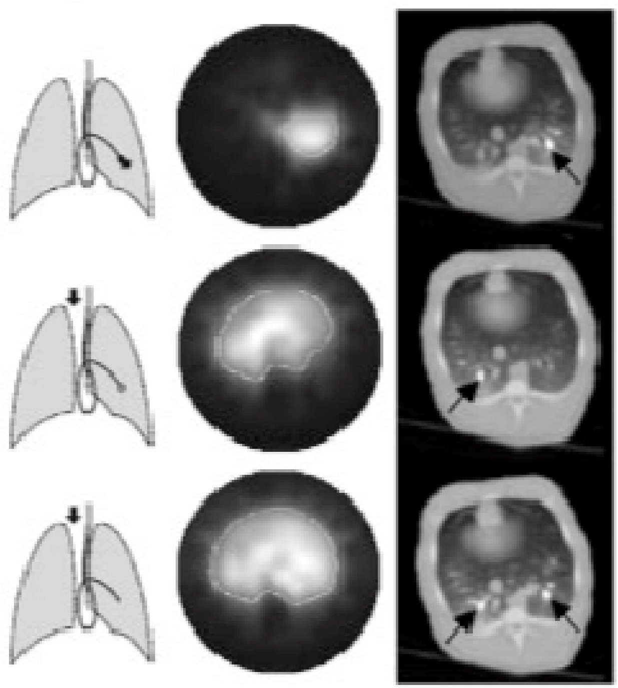
Summary

- Electrical impedance tomography (EIT)
- Inverse problems
- Electrode movement in soft-field applications
- Methods of data acquisition
- Imaging algorithm with movement estimation
- Results
- Discussion

Electrical impedance tomography

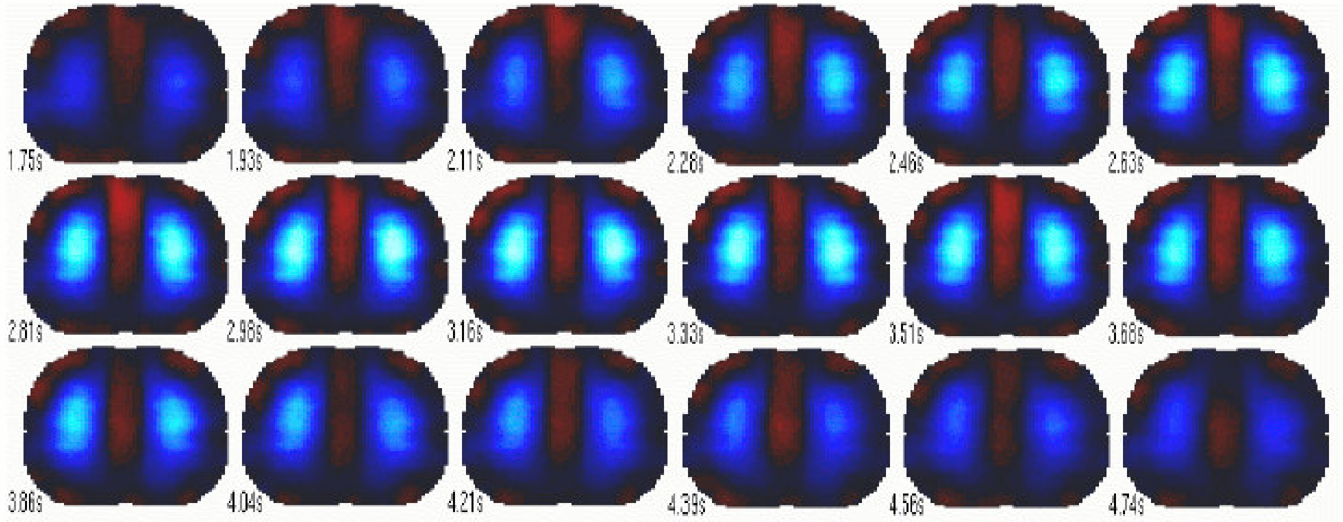


EIT: lung ventilation

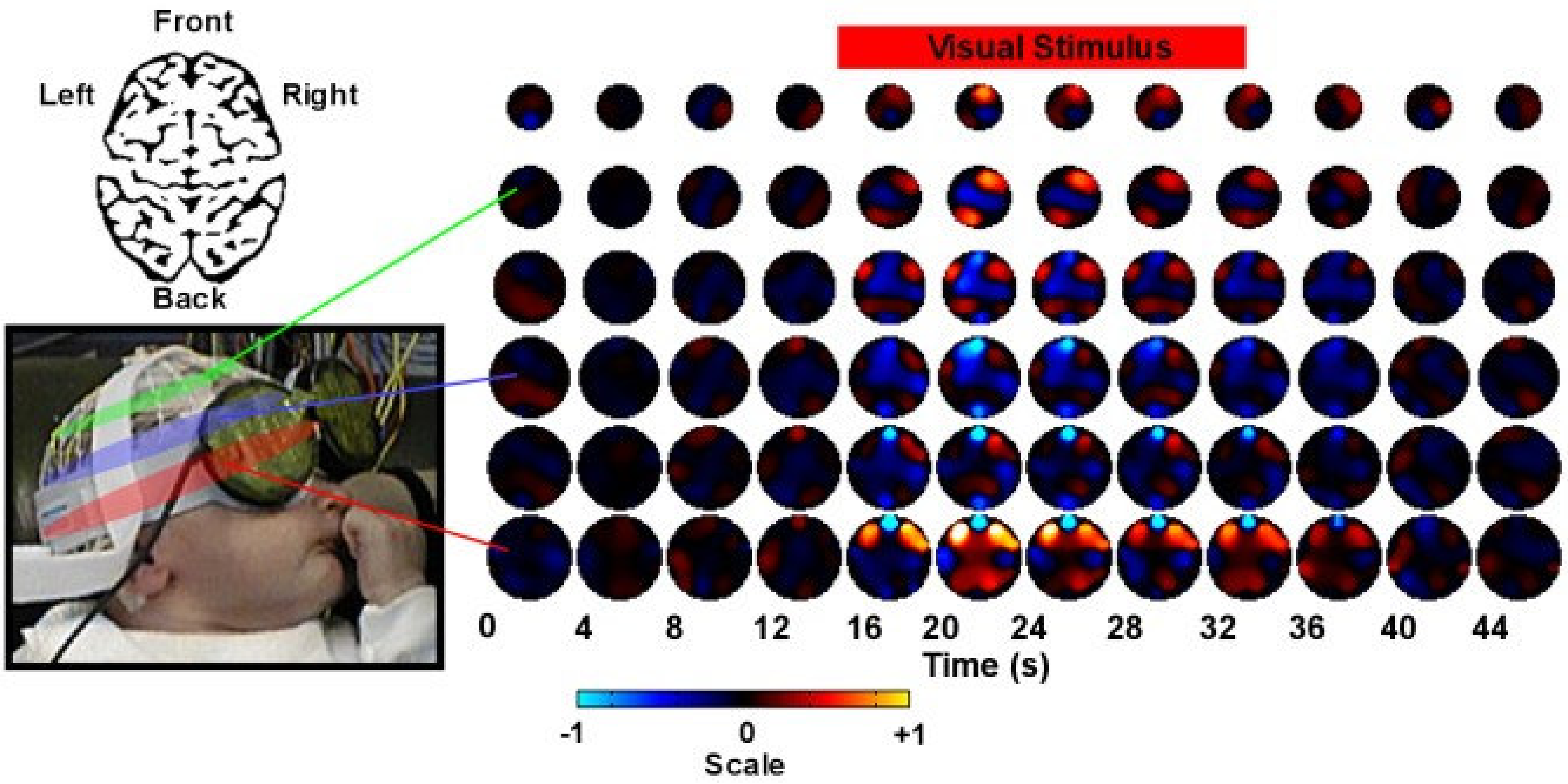


Left: Lung perfusion imaging using a conductive contrast in normal bovine subject. Images are compared with electron beam computerized tomography.
(Frerichs *et al.* 2002)

Right: Lung ventilation imaging of normal human subject.
(Adler *et al.* 1994)



EIT: encephalic imaging



A visual evoked response of a neonate.
Activity is reported as due to changes in blood flow.
(London EIT Group, 2006)

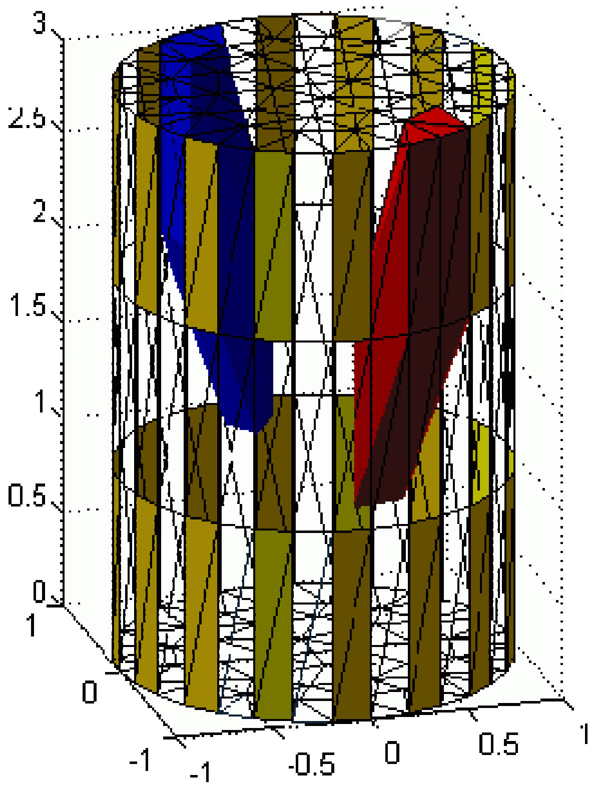
EIT numerical methods

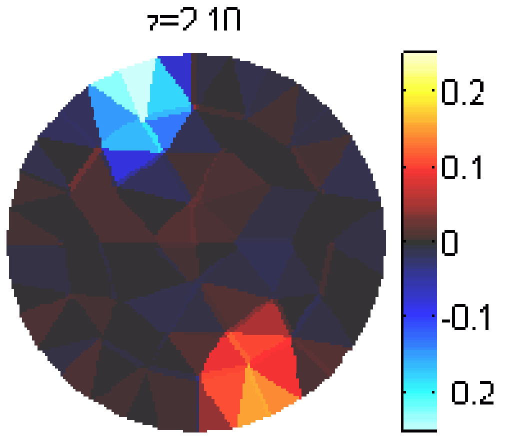
- Finite Element Method (FEM) simulation software to model the forward and inverse problem

- EIDORS is *Electrical Impedance & Diffuse Optical Reconstruction Software* http://www.eidors.org

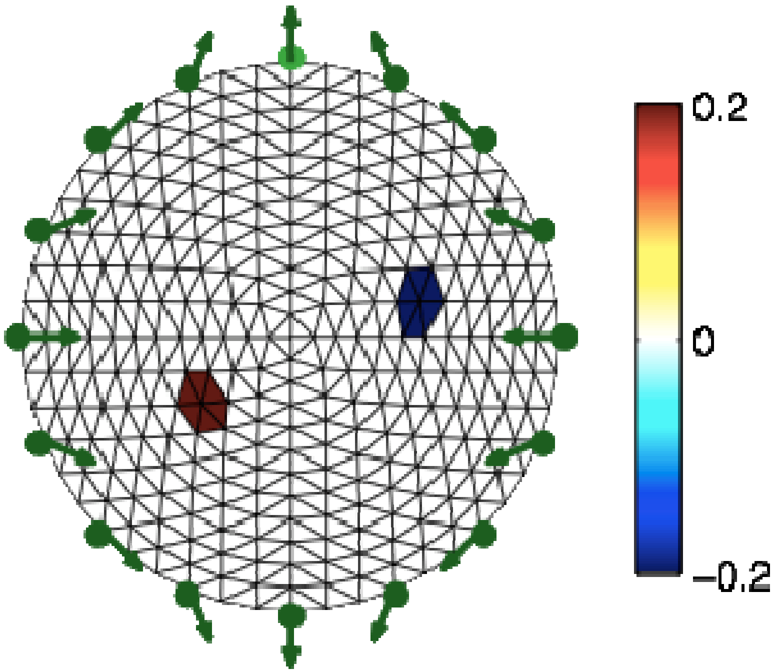
- *forward*: voltages from conductivity *inverse*: conductivity from voltages

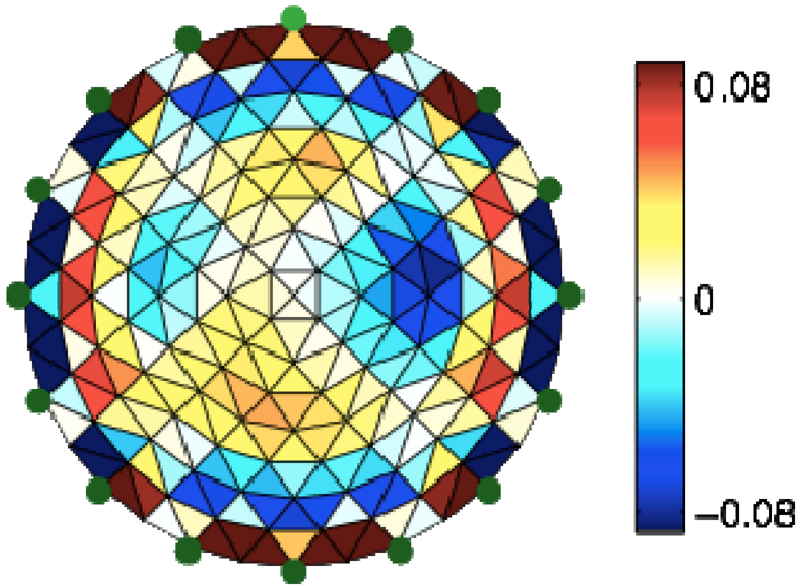
- Avoid the *inverse crime*





EIT electrode movement





Left: Simulation of electrode movement of 1% medium diameter.
Right: Reconstruction of image assuming fixed electrode position.

EIT regularization algorithm

- Since EIT is *ill-posed* we must struggle with extraneous solutions due to non-uniqueness (*i.e.* the system is underdetermined)
- We solve the inverse problem by *regularization* of the observed data using *a priori* information about the nature of the EIT system & our medium
  - A smoothness constraint to spatial variation of *conductivity* & neighboring electrode *movement*
  - Model *noise* as an additive white Gaussian process

EIT regularization algorithm

- The forward solution is modelled as a linear operator

$$\mathbf{z} = \mathbf{J}\mathbf{x} + \mathbf{n}$$

- Our reconstruction model quantifies the *sensitivity* of the voltage measurement due to *conductivity* and *movement* variations

$$\mathbf{J}_{i,j} = \frac{F_i(\mathbf{x}_j + \Delta\mathbf{x}_j)}{\Delta\mathbf{x}_j}$$

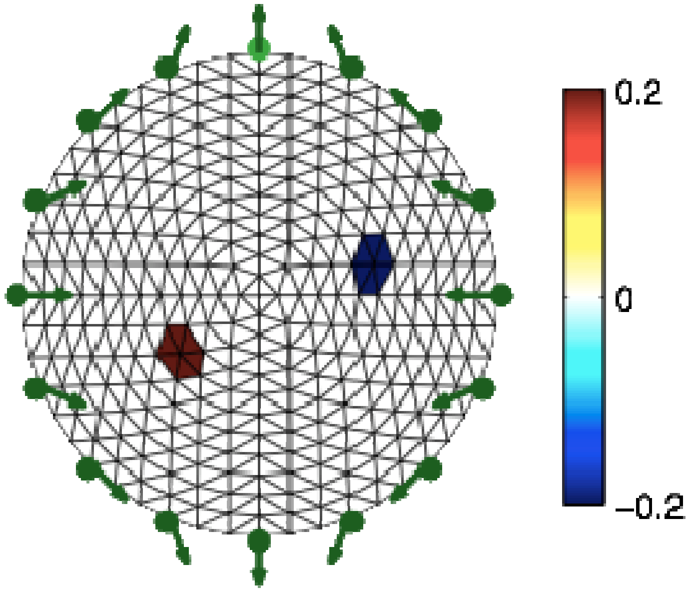
EIT regularization algorithm

- The inverse solution estimates $\mathbf{x}$ using a one-step regularized inverse based on
  - noise model $\mathbf{W}$
  - conductivity prior $\mathbf{R_c}$
  - movement prior $\mathbf{R_m}$

$$\hat{\mathbf{x}} = \left(\mathbf{J}^t\mathbf{W}\mathbf{J} + \lambda^2(\mathbf{R}_c + \mu^2\mathbf{R}_m)\right)^{-1}\mathbf{J}^t\mathbf{z}$$

Image & movement results

Forward simulation:
1. 576 element planar FEM with 2 contrasts of opposing conductivity
2. Elliptical deformation of medium of 1% diameter (shown x20)
3. AWGN of 20dB SNR



Standard reconstruction:
1. 256 element planar FEM rotated by 45 degrees
2. Hyperparameter $\lambda = 10^{-2}$

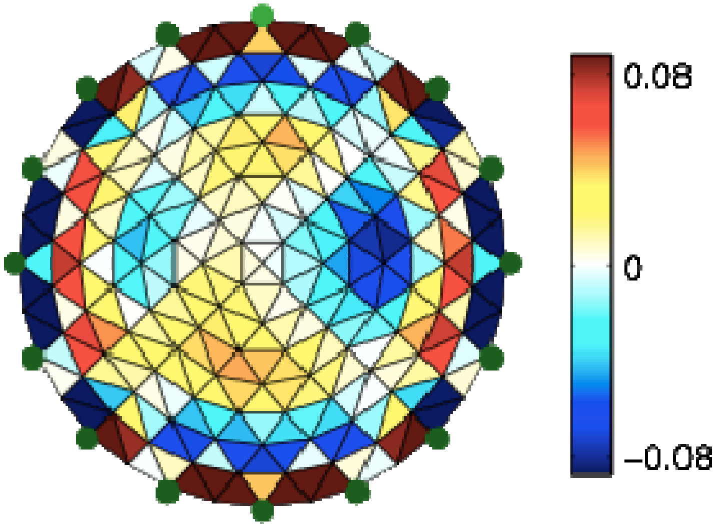
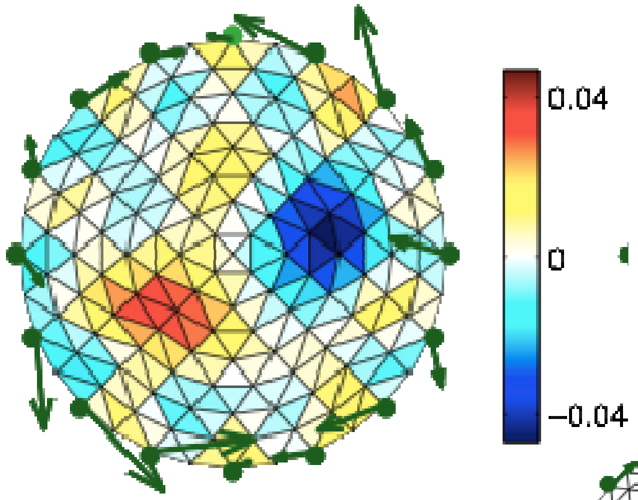


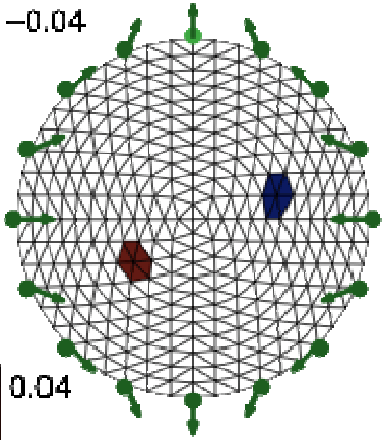
Image & movement results

Proposed reconstruction method:

1. Hyperparameters $\lambda = 10^{-2}$ and $\mu = 1$

2. Expected movement is 40%





Proposed reconstruction method:

1. Hyperparameters $\lambda = 10^{-2}$ and $\mu = 20$

2. Expected movement is 2%

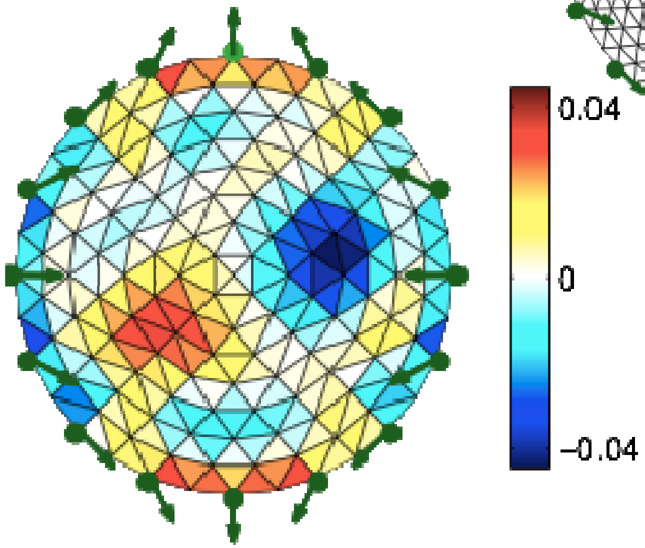


Image & movement results

Forward simulation:

1. 828 element 3D FEM
2. "Ellipse-twist" deformed
3. AWGN of 20dB SNR
4. Green plates are electrodes
5. Two contrasts of opposing conductivity

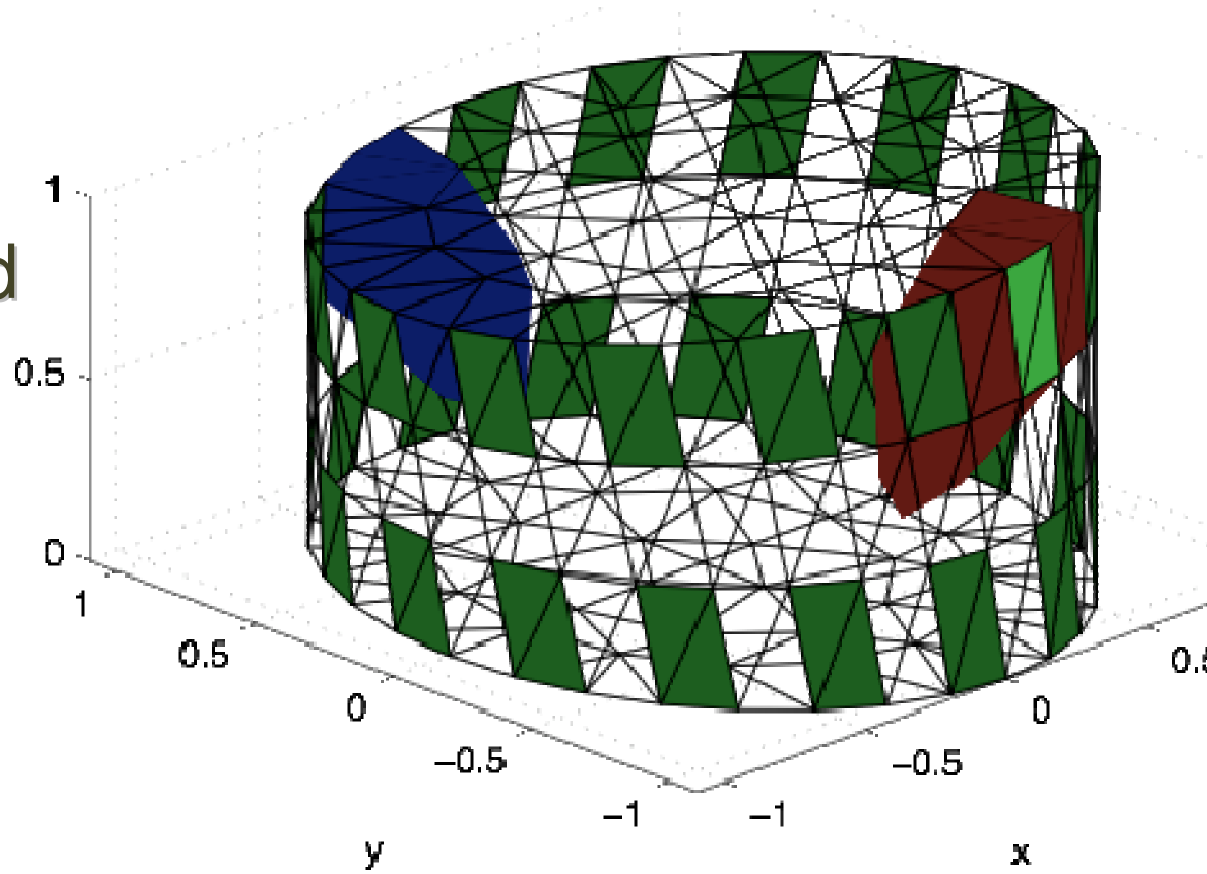
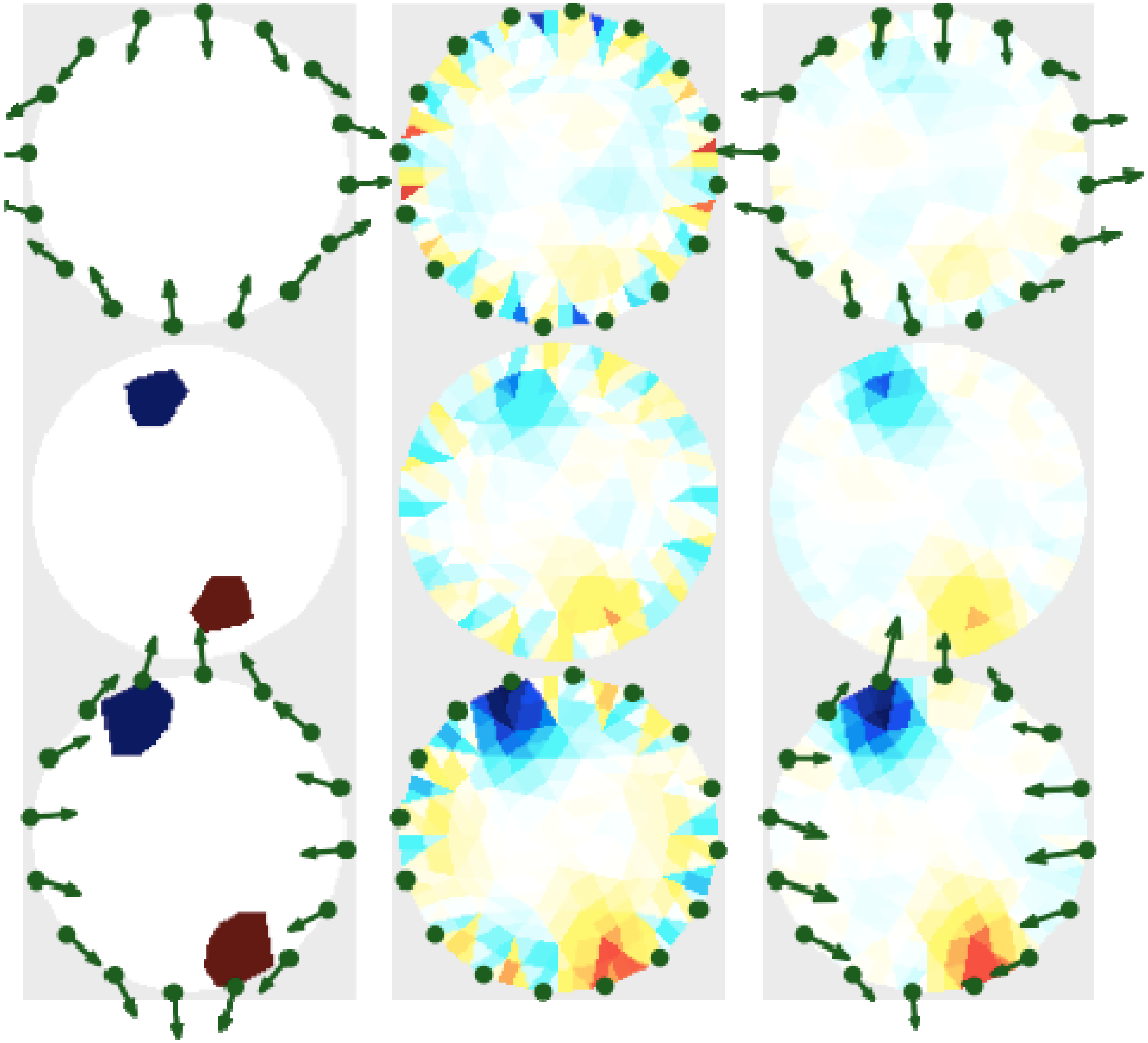


Image & movement results

1st column:
Forward simulation

2nd column:
Standard reconstruction
$\lambda = 3 \times 10^{-3}$

3rd column:
Proposed reconstruction
$\lambda = 3 \times 10^{-3}$ $\mu = 20$



Discussion

- Benefits:
  - Estimating the electrode position resulted in a reduction of 70% of the artefact power for movements of 1% in 2D and 3D simulation
  - Results show reasonable estimates of actual electrode displacements (although not quantified)
  - Movement reconstructions have been tested on phantom data and show comparable results

Discussion

- Limitations:
  - Reconstruction requires manual adjustment of regularization hyperparameters λ μ
  - Noise priors used are simplistic and could be refined to represent true EIT noise
  - Electrode movements are modelled as translational only (no rotation or strain)