Imaging with Electricity:

Biomedical Engineering Seminar
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Lung Imaging

Pre- and post-salbutamol 3He MR images (red) registered to two center coronal thoracic 1H MR images (gray scale) for five representative patients with COPD. S1, S2: stage II disease, S3, S4: stage III disease, S5: stage IV disease.

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Lung Imaging

Source: Kirby et al, Radiology 261.1 (2011)

Pre- and post-salbutamol $^3$He MR images (red) registered to two center coronal thoracic $^1$H MR images (gray scale) for five representative patients with COPD

S1, S2: stage II disease,
S3, S4: stage III disease,
S5: stage IV disease.
Imaging ⇒ new clinical insights
Electrical Impedance Tomography

10-day old healthy baby with EIT electrodes

Source: eidors3d.sf.net/data_contrib/if-neonate-spontaneous
Electronics – Block Diagram

- Medium $\Omega$
- Current Source
- Imaging System
- Data acquisition Controller
- Amplifiers
Current Propagation

Healthy Adult Male
CT slide at heart

Source:
eidors3d.sf.net/tutorial/netgen/extrusion
Current Propagation

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Finite Element Modelling
Finite Element Modelling

Simulated Voltages

Voxel Currents
Thorax Propagation

CT Slice with simulated current streamlines and voltage equipotentials
Thorax Propagation

CT Slice with simulated current streamlines and voltage equipotentials
Changing Conductivity

Heart receives blood (diastole) and is more conductive
Changing Conductivity

Heart receives blood (diastole) and is more conductive
Changing Conductivity
Application: Breathing

Chest images of tidal breathing in healthy adult
Application: Heart

EIT Signal in ROI around heart (and ECG)
Mechanical Ventilation

Mechanical Ventilator with EIT monitor

Source: Swisstom.com
Acute Respiratory Distress Syndrome (ARDS)
EIT + Lung State

Overdistension

Collapse
EIT + Lung State

Overdistension

Collapse

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EIT + Lung State

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EIT for Non-Invasive Blood Pressure

Fig. 1 Tracking the propagation of arterial pressure pulses by EIT: After placing several electrodes around the chest (1), impedance measurements are performed for each electrode pair (2) and used to construct a tomographic impedance image (3). A CT-scan of pig chest is provided as anatomical reference. Lower panel shows an example of pulse propagation during an entire cardiac cycle: a and b the filling of the heart is observed (black ROI). c The heart empties while the right lung (here on the left hand side) is starting to be perfused with conductive blood. d and e Both lungs are perfused (white ROI). Finally, f the cardiac cycle starts again.

Pulse transit time from heart to descending aorta using EIT

Neonatal Breathing

- Preterm newborns have complex, unstable physiology
- Ventilatory support is often essential
- Currently, no adequate monitors of breathing
- These data are from a lamb model of neonates

\[ \text{Figure 1. Exponential pattern of volume change during a SI, as measured by EIT, in global thorax and gravity-dependent} \]

Source: D. Tingay et al, In Press
EIT for Brain Imaging

Applications:

• Epileptic foci
• Stroke (Ischaemic vs. Haemoragic)
• Fast Neural Imaging

Fig. 2. Left: Finite element of the head used to produce images. Right: Example of EIT images produced in a saline filled tank

EIT for Cancer Imaging: Breast/Prostate

- Cancerous tissue has different electrical properties
- Image tissue
- Image increased vascularization

Source: Khan, Mahara, Halter et al, Conf. EIT, 2014
Non-medical applications

- Flow in pipes
- Mixing tanks
- Imaging metallic ores
- Hydro-geology

Figure shows resistivity in a cross-section of La Soufrière de Guadaloupe volcano.
Source: N. Lesparre et al, Conf. EIT, 2014
Why is EIT hard?
Inverse Problems . . . *Plato’s cave*
Plato’s cave ... Shadows on the wall

Source: iamcriselleeee.files.wordpress.com/2013/11/cave-2.jpg
Inverse Problems

Forward Problem:  \textit{Forms} \Rightarrow \textit{Shadows}

- Ill-conditioned
- Sensitivity to some movements is low
- Ill-posed
- Some movements don't change shadows
- Noisy
- Flickering light
Inverse Problems

Forward Problem:  $Forms \Rightarrow Shadows$
Inverse Problem:  $Shadows \Rightarrow Forms$

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Forward Problem:  \( \text{Forms} \Rightarrow \text{Shadows} \)
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Inverse Problems

Techniques: to calculate stable & meaningful parameters in the presence of inversion difficulties

Examples

- Image deblurring / restoration
- Medical imaging
- Geophysical imaging
- Model parameter fitting
- Reconstruction with incomplete/noisy data
Reconstruction in Pictures

- Forward Problem

\[ \text{Measurements (difference)} = \text{Image (difference) Jacobian} + \text{noise} \]
Reconstruction in Pictures

- Forward Problem

\[
\text{Measurements (difference)} = \text{Jacobian} \times \text{Image (difference)} + \text{noise}
\]

- Linear Solution: Minimize norm

\[
\text{Regularized linear inverse model} - \times \text{Norm weighted by measurement accuracy} + \text{Penalty Function}^2
\]
Idea #1: Reconstruction with Data Errors

“Traditional” Solution

Error Here
Replace With zero

Electrode errors: “Zero bad data”
Idea #1: Reconstruction with Data Errors

“Traditional” Solution

Error Model Solution

Low SNR here
Replace With zero
Electrode Error compensation

- Offline compensation using “jack-knife” approach (2005)

A

B

EIT images in anaesthetised, ventilated dog
A: uncompensated, B: compensated. Left: ventilation Centre: saline (right lung) Right: ventilation and saline

- Automatic detection (via reciprocity comparison) (2009)
- New work to speed online calculation & use data quality
Idea #2: Electrode movement

Sensitivity to sensor movement

\[ = \times + \text{noise} \]

- Jacobian now includes measurement change due to movement
- “image” now includes x,y sensor movement
**Idea #2: Electrode movement**

Sensitivity to sensor movement

\[ \text{Jacobian now includes measurement change due to movement} + \text{noise} \]

“Image” now includes x,y sensor movement

Adapted penalty function

\[ \text{Penalty: Image and movement - Expected image} \]

\[ = \underbrace{\begin{pmatrix} 1 & -\frac{1}{2} \\ -\frac{1}{2} & 1 & -\frac{1}{2} \\ -\frac{1}{2} & 1 & -\frac{1}{2} \\ -\frac{1}{2} & 1 & -\frac{1}{2} \end{pmatrix}}_{\text{Expected movement}} \quad \times \quad 2 \]

“Unlikelyhood” of movement and image co-variance

“Unlikelyhood” of movement

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Electrode movement compensation


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Idea #3: Data Quality
Idea #3: Data Quality

Depth Sounder – with analog and digital gauges
What’s the problem?

With strong priors and complex algorithms, algorithms give us pretty pictures, even when they are irrelevant.

Question:
- how can we know when to trust a pretty picture?
- how can we know when the data are junk?
Data Quality Measure: Concept

- **Concept**: High Quality Data are Consistent

- **Idea**: Use IP to predict each data point from all others

\[
\begin{align*}
&\text{Original} \quad d \\
\Rightarrow &\quad \text{Remove } i \quad d^{(i)} \\
\Rightarrow &\quad \text{Solve} \quad \hat{m}^{(i)} \\
\Rightarrow &\quad \text{Predict} \quad \hat{d}^{(i)}
\end{align*}
\]

- Calculate error

\[
\epsilon_i = d_i - \hat{d}_i^{(i)}
\]
Example: Data quality measures

Clinical data and data quality metric for each stage of the protocol (R1–R4 — recruitment: PEEP↑, T1–T4 — titration: PEEP↓).

A: EIT images  B: Calculated data quality.
Perspectives

- Data analysis is hard
- powerful algorithms are useful
- we live in a world of big data
- complex systems fail in complex ways
- users like pretty pictures

So ... the situation will get worse
Solutions?

⇒

Thus, we need

• Open Data
• Open source analysis
Solutions?

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Solutions?

⇒

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Solutions?

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For EIT ...
EIDORS: Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software

Project Goal

Provide free software algorithms for forward and inverse modelling for Electrical Impedance Tomography (EIT) and Diffusion based Optical Tomography, in medical and industrial settings, and to share data and promote collaboration between groups working these fields.

Requirements

- Matlab (>= 7.0) or Octave (>= 3.4)
- Netgen Mesher (optional)

Getting Started

To try the EIDORS software, follow these steps:

1. Download the software (release or developer version):
   - Release Version: EIDORS 3.5 (14 Jul 2011)
   - Developer Version:
For EIT . . .
Thank you . . .

Imaging with Electricity

*Abstract:* We use body surface electrical current stimulation and measurements to generate images of the internal electrical properties. This principle is used in geophysics, process monitoring, and medical imaging. Currently, the most successful medical application of electrical impedance tomography (EIT) is for imaging the thorax, where the movement on conductivity contrasting air and blood can be imaged over time. The generation of EIT images requires solving an inverse problem, which is ill-conditioned because of the diffuse nature of current propagation. The technology is thus sensitive to electrode properties, data quality, and patient movement. To address these issues, several innovative strategies to analyze and interpret these data have been developed. This talk will explain our recent progress in imaging the chest with EIT, and the image generation and interpretation strategies that are required.