Imaging with Electricity:

Biomedical Engineering Seminar
Carleton Univerity, Ottawa, ON, 22 Sep 2015

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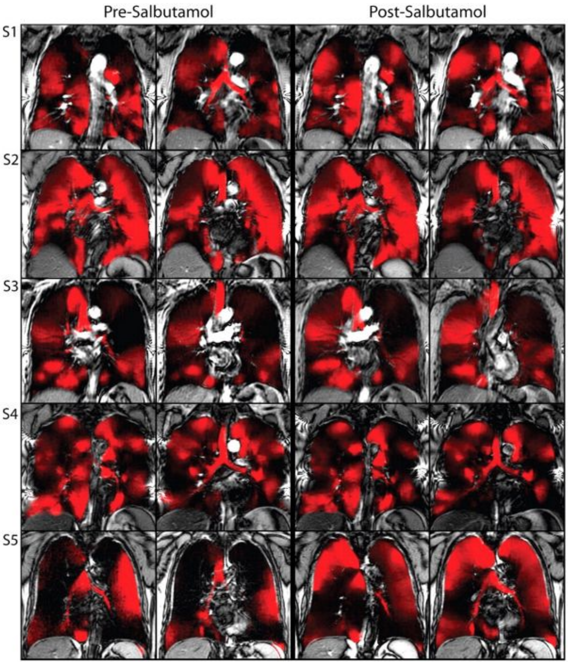
Lung Imaging

Lung Imaging

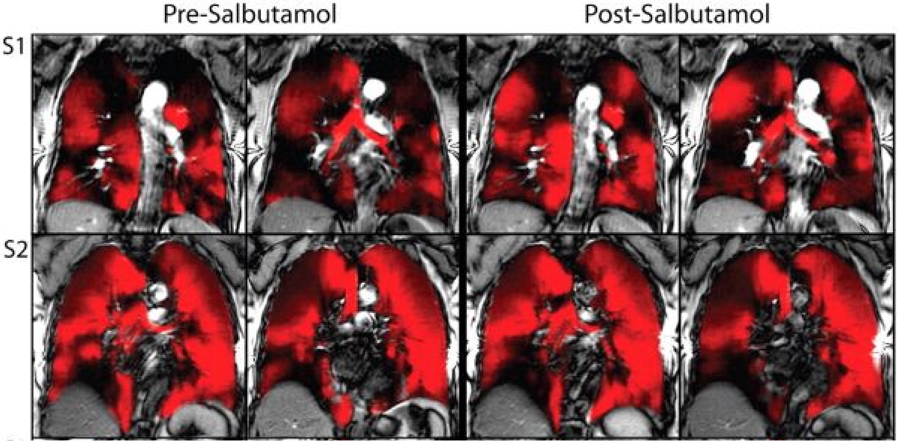
Source: Kirby et al, Radiology 261.1 (2011)

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

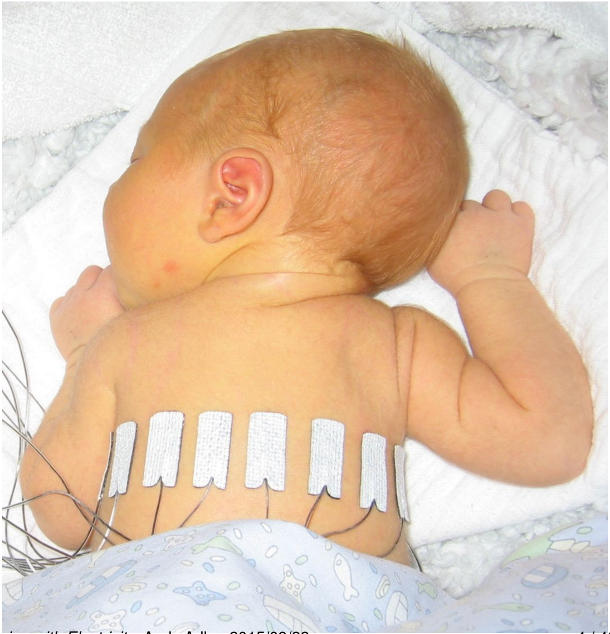
S1, S2: stage II disease,
S3, S4: stage III disease,
S5: stage IV disease.



Imaging ⇒ new clinical insights



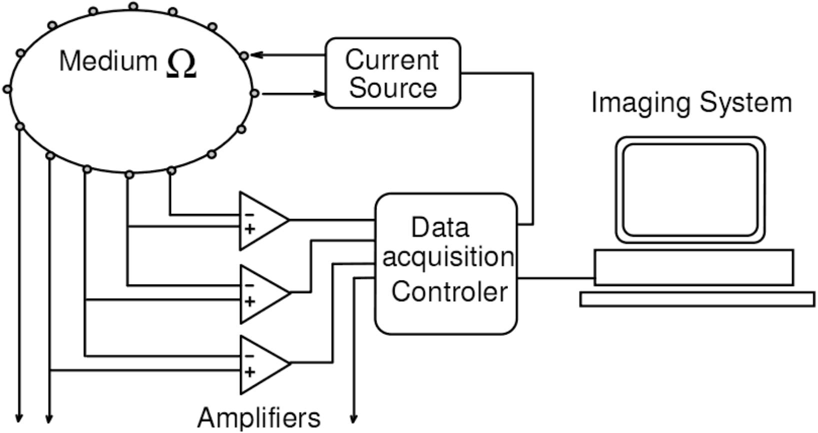
Electrical Impedance Tomography



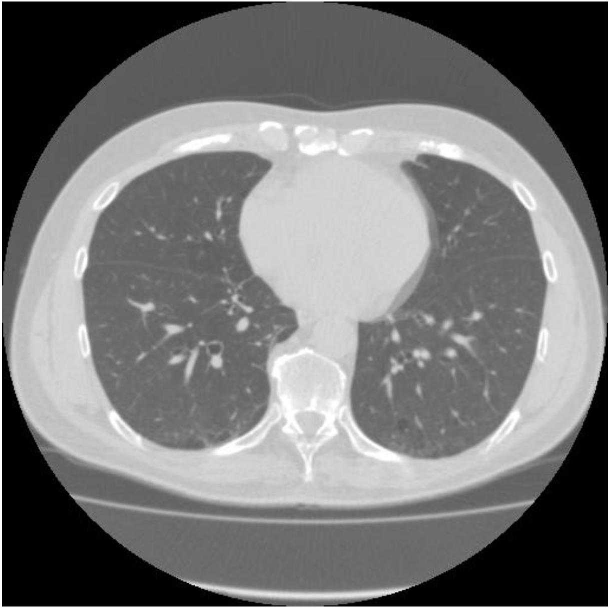
10-day old healthy baby with EIT electrodes

Source: eidors3d.sf.net/data_contrib/if-neonate-spontaneous

Electronics – Block Diagram



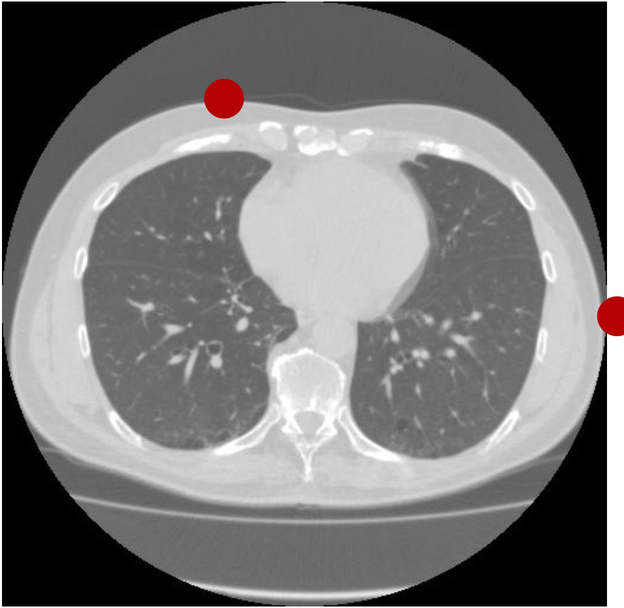
Current Propagation



Healthy Adult Male
CT slide at heart

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

Current Propagation



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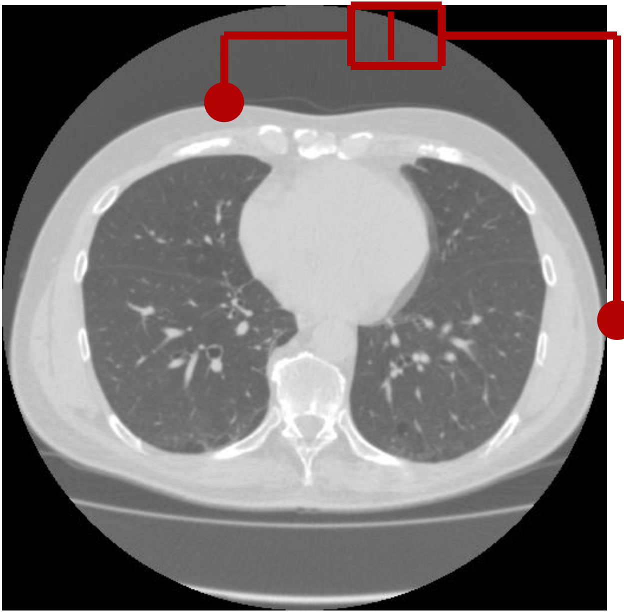

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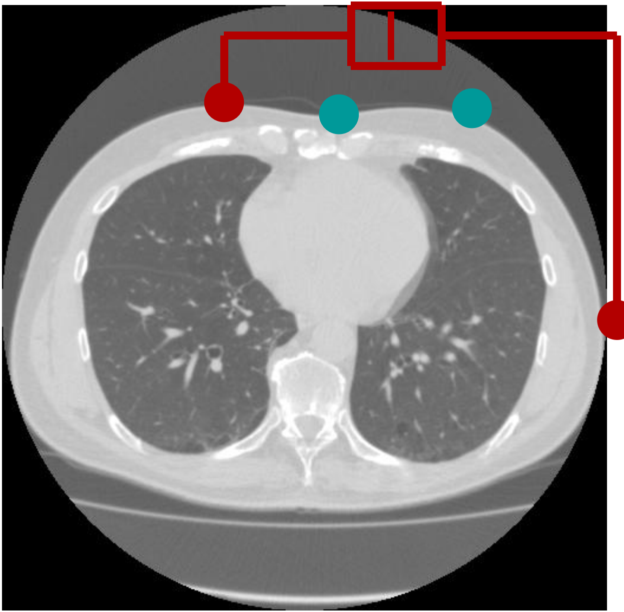

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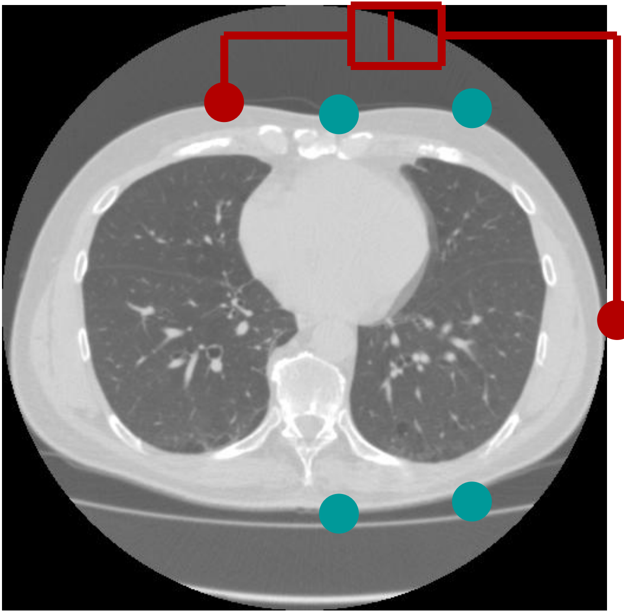

Healthy Adult Male
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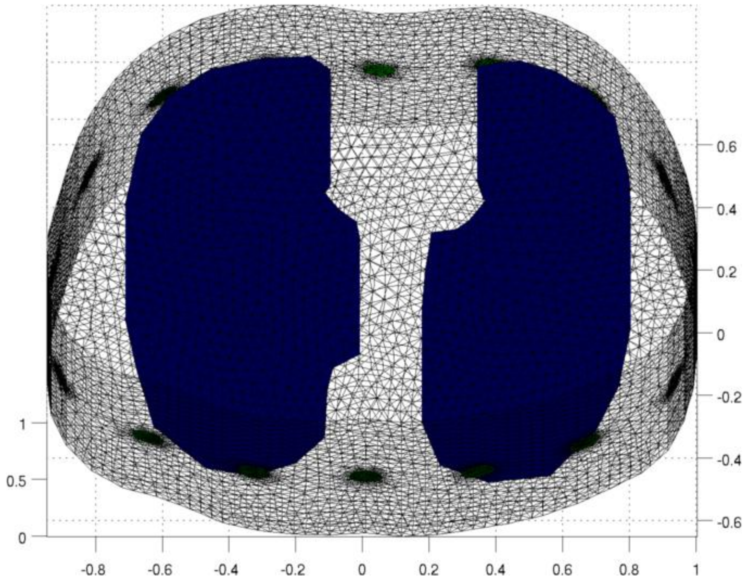
Finite Element Modelling



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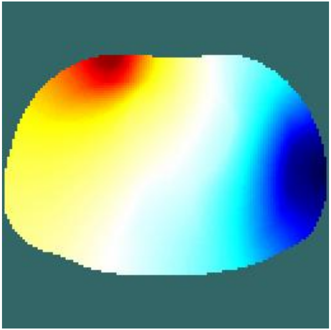
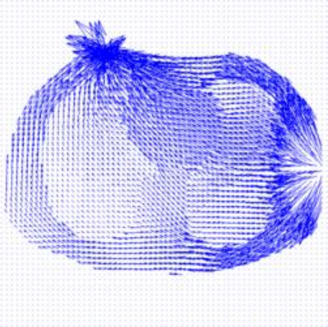
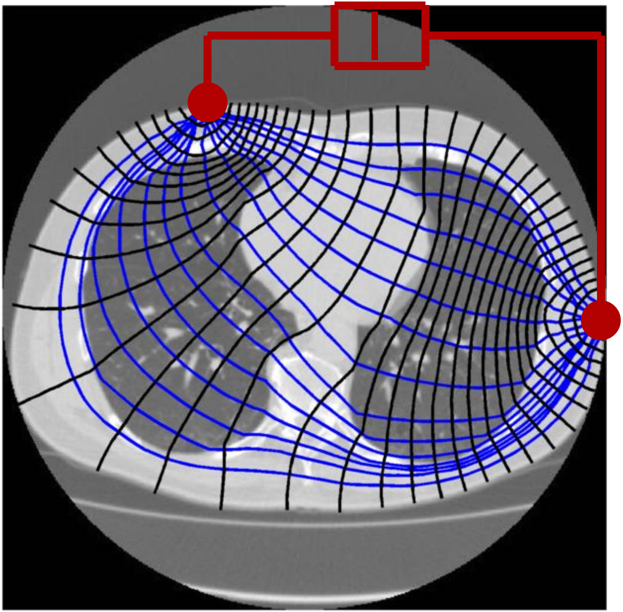


Simulated Voltages



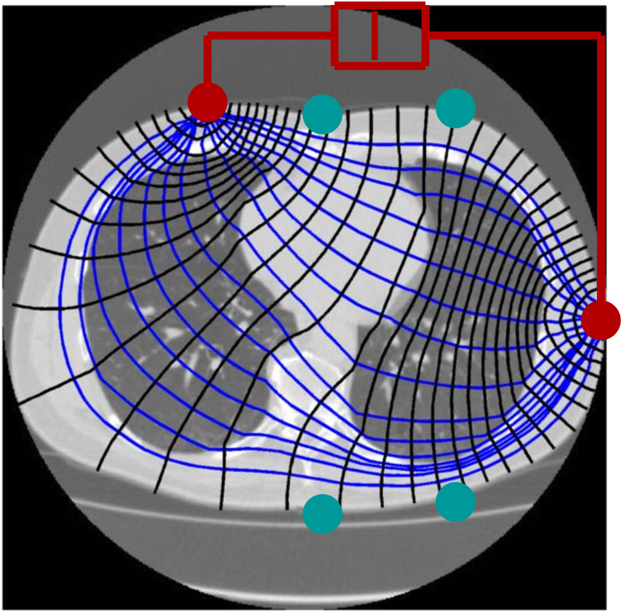
Voxel Currents

Thorax Propagation



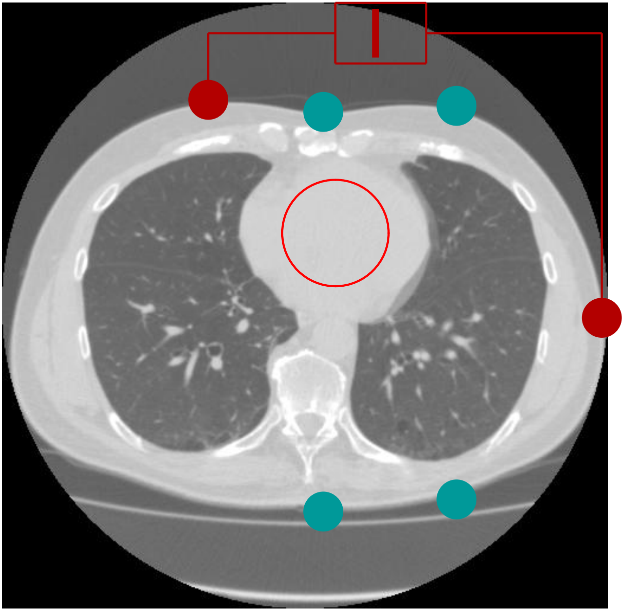
CT Slice with simulated current streamlines and voltage equipotentials

Thorax Propagation



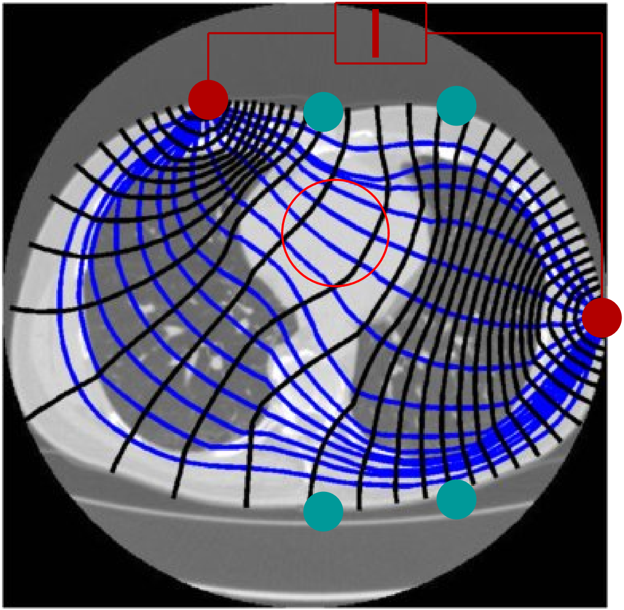
CT Slice with simulated current streamlines and voltage equipotentials

Changing Conductivity



Heart receives blood (diastole) and is more conductive

Changing Conductivity



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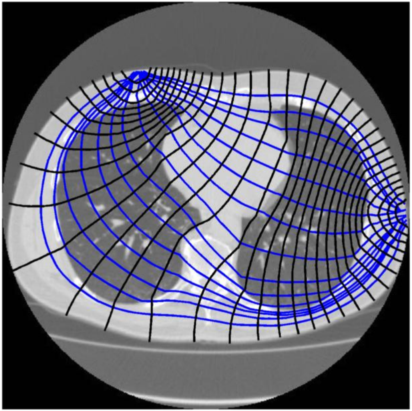
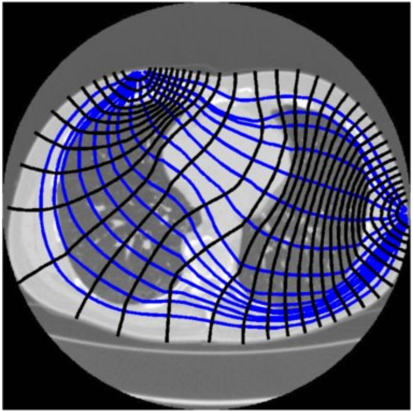
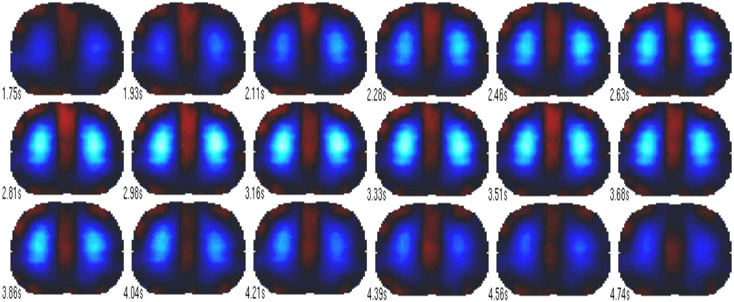


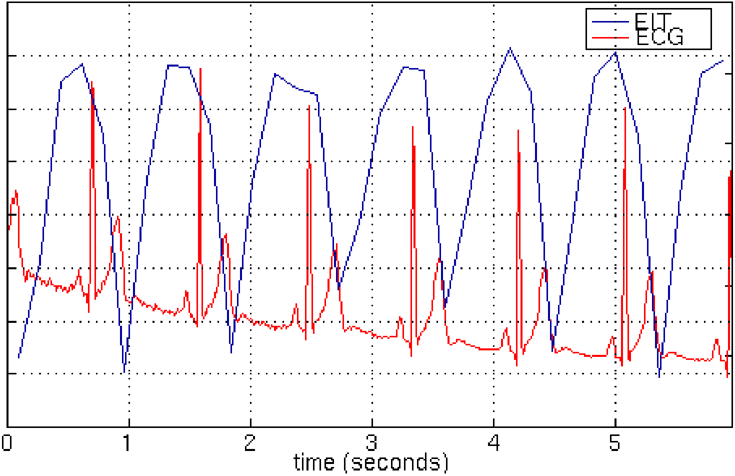


Application: Breathing



Chest images of tidal breathing in healthy adult

Application: Heart



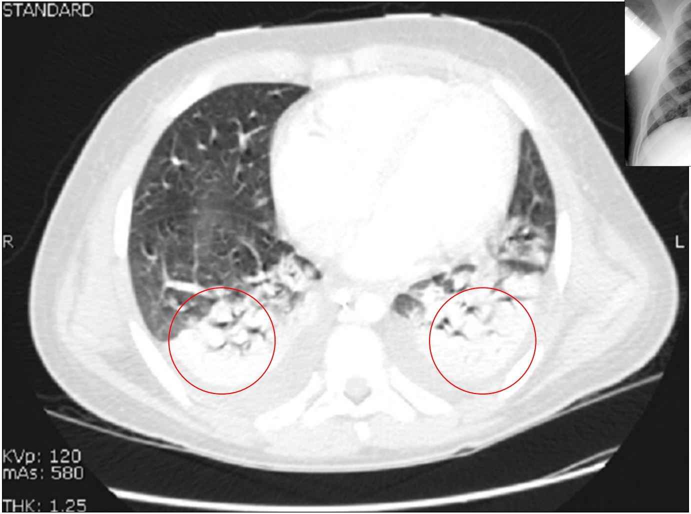
EIT Signal in ROI around heart (and ECG)

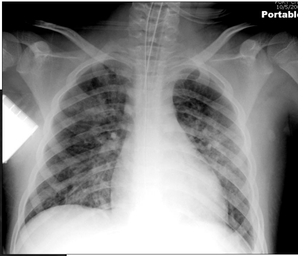
Mechanical Ventilation

Mechanical Ventilator with EIT monitor

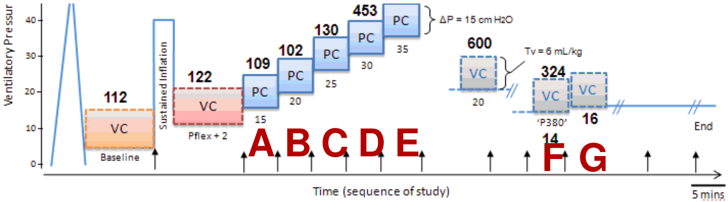
Source: Swisstom.com

Acute Respiratory Distress Syndrome (ARDS)





EIT + Lung State



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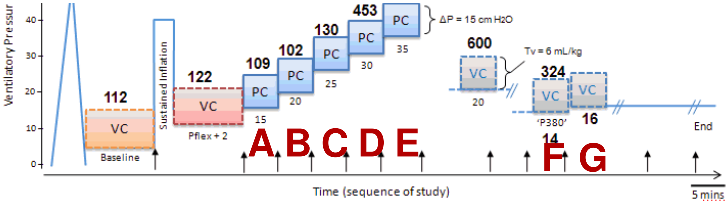
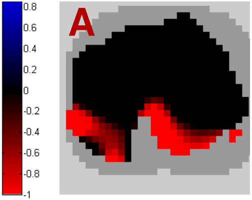
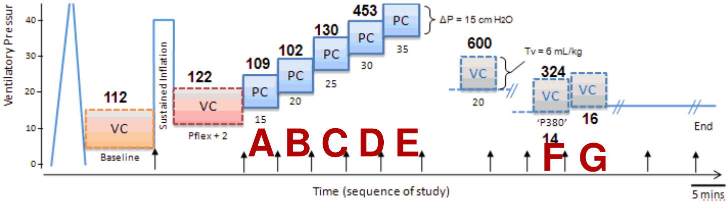


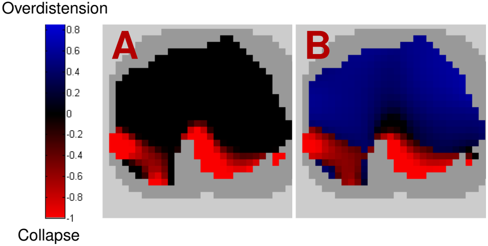
Overdistension



Collapse

EIT + Lung State





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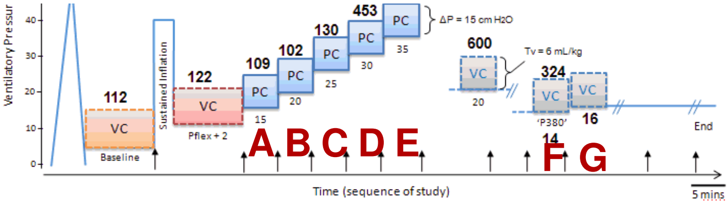

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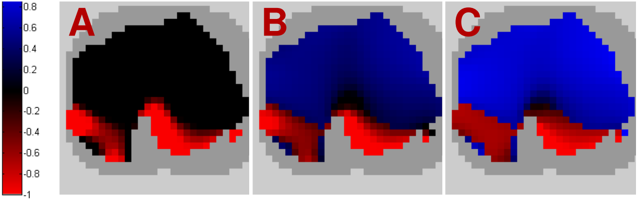

Collapse

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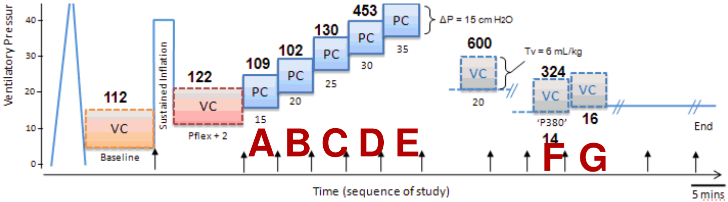

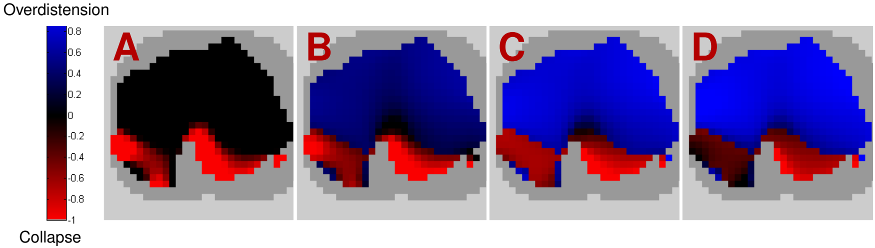

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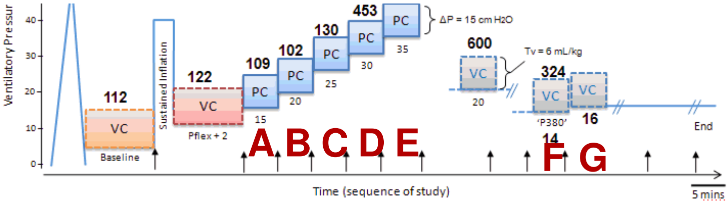

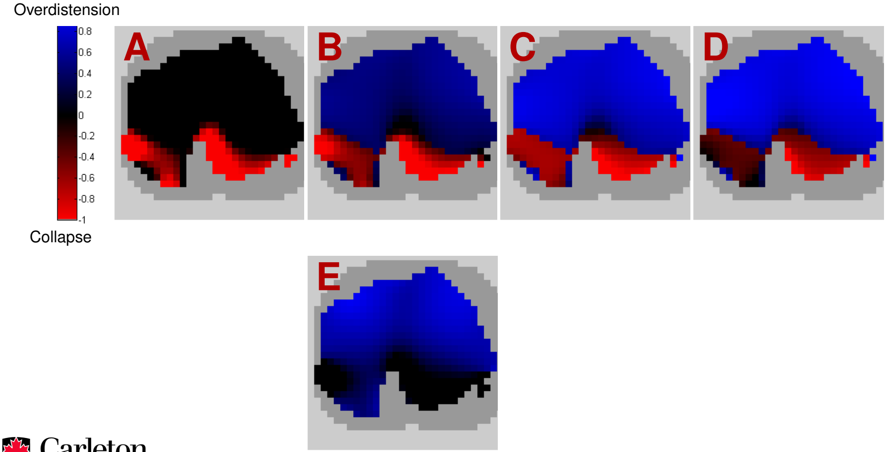

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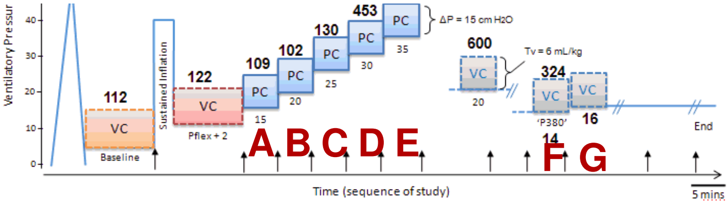

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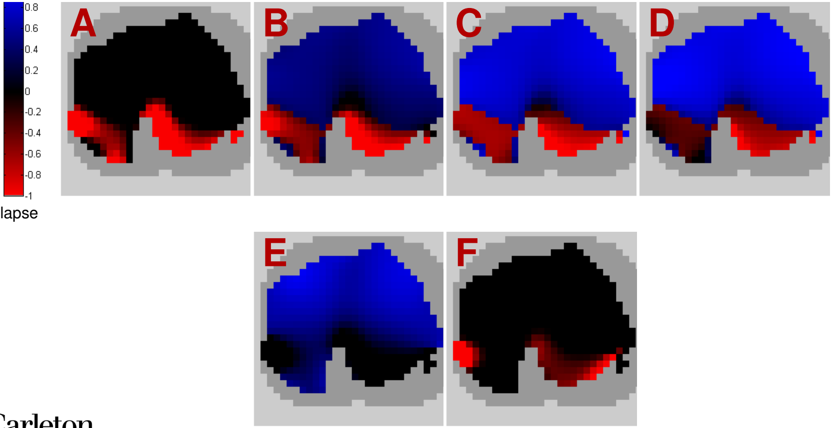

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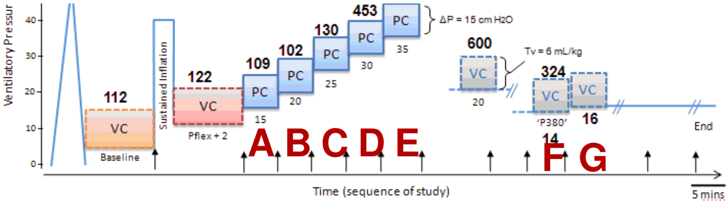
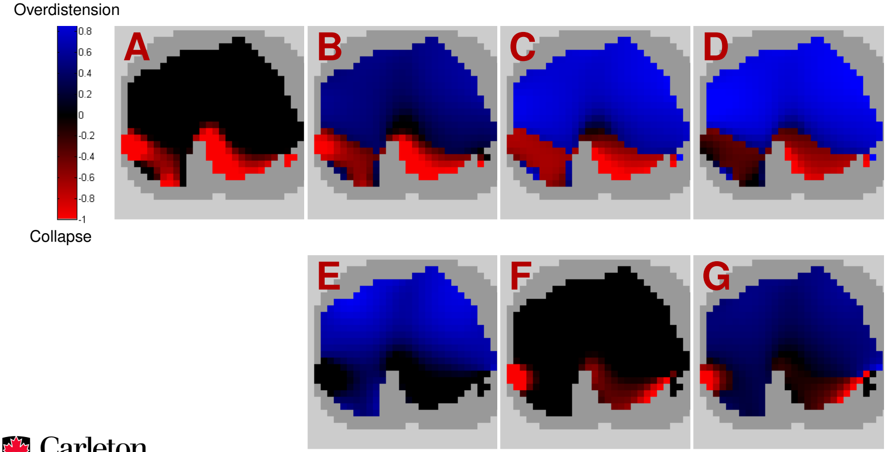




EIT for Non-Invasive Blood Pressure

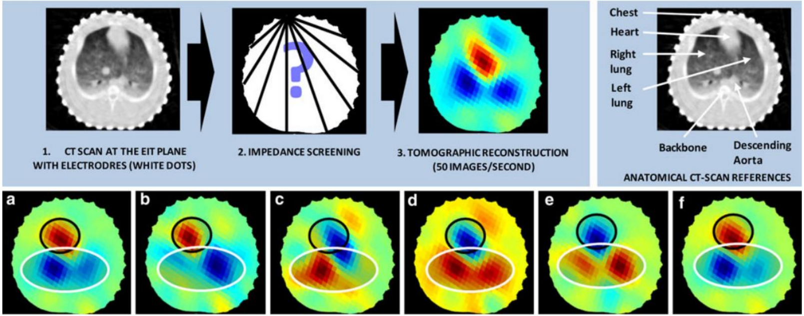


Fig. 1 Tracking the propagation of arterial pressure pulses by EIT: After placing several electrodes around the chest (*1*), impedance measurements are performed for each electrode pair (2) and used to construct a tomographic impedance image (3). A CT-scan of pig chest is provided as anatomical reference. *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

Source: Sola *et al, Med. Biol. Eng. Comput.*, 2011

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

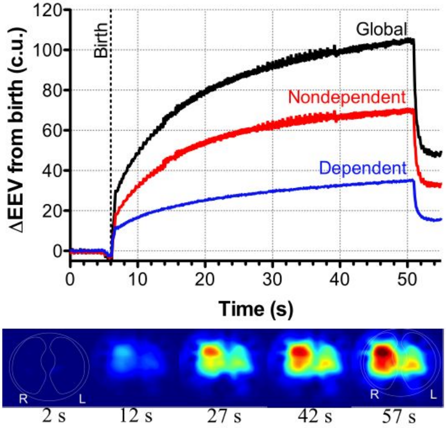


Figure 1. Exponential pattern of volume change during a SI, as measured by EIT, in global thorax and gravity-dependent

Source: D. Tingay *et al*, In Press

EIT for Brain Imaging

Applications:

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

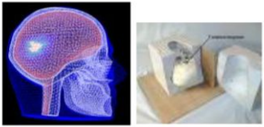
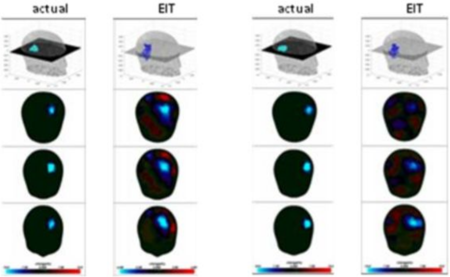


Fig. 2. Left : Finite element of the head used to produce images. Right: Example of EIT images produced in a saline filled tank

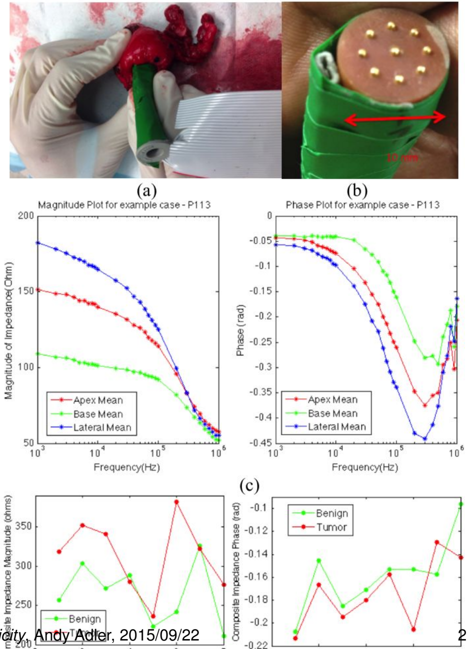


Source: Holder, www.ucl.ac.uk/medphys/research/eit/pubs/brain_EIT_overview.pdf

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 metalic ores
- Hydro-geology

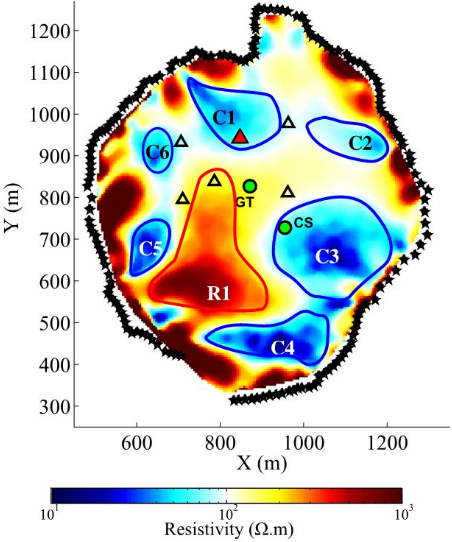


Figure shows resistivity in a cross-section of La Soufrière de Guadaloupe volcano.

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: *Forms* $\Rightarrow$ *Shadows*

Inverse Problems

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

Inverse Problems

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

- Ill-conditioned
  Sensitivity to some movements is low

Inverse Problems

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

- Ill-conditioned
  Sensitivity to some movements is low
- Ill-posed
  Some movements don't change shadows

Inverse Problems

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

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

Inverse Problems

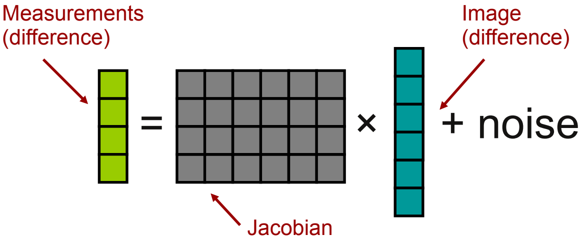
Techniques: to calculate stable & meaningful parameters in the presence of inversion difficulties

Examples

- Image deblurring / restoration
- Medical imaging
- Geophyical imaging
- Model parameter fitting
- Reconstruction with incomplete/noisy data

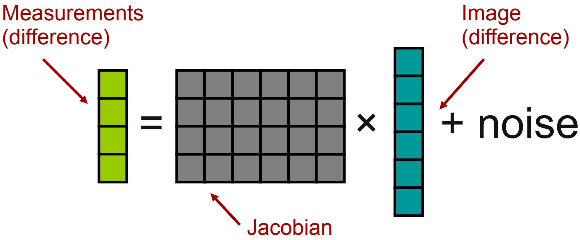
Reconstruction in Pictures

- Forward Problem

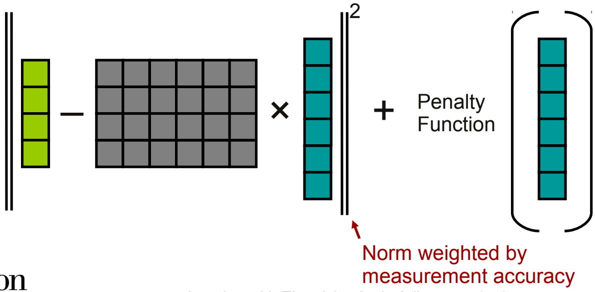


Reconstruction in Pictures

- Forward Problem

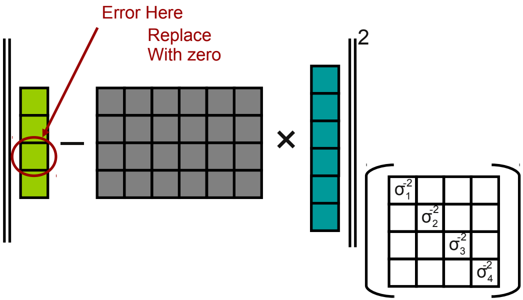


- Linear Solution: Minimize norm



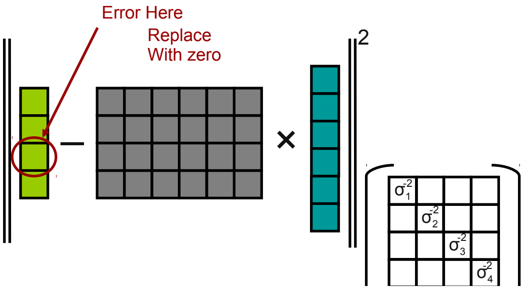
Idea #1: Reconstruction with Data Errors

"Traditional" Solution

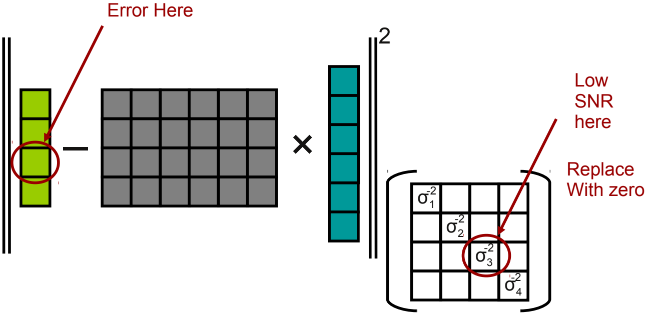


Idea #1: Reconstruction with Data Errors

"Traditional" Solution

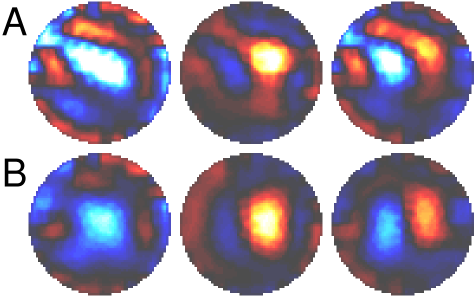


Error Model Solution



Electrode Error compensation

- Offline compensation using "jack-knife" approach (2005)

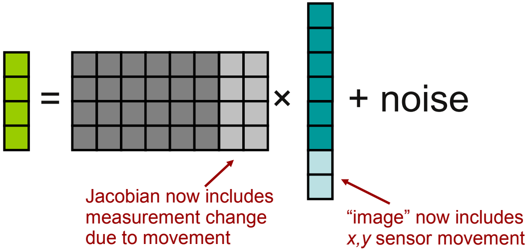


EIT images in anaesthetised, ventilated dog
A: uncompensated, *B*: compensated. *Left*: ventilation *Centre*: saline (right lung) *Right*: ventilation and saline

- Automatic detection (via reciprocity comparison) (2009)
- New work to speed online calculation & use data quality

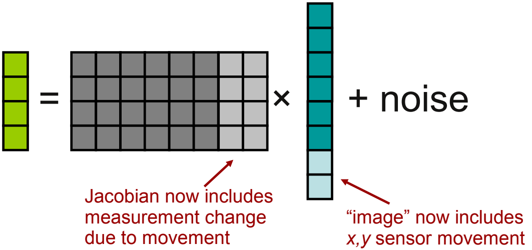
Idea #2: Electrode movement

Sensitivity to sensor movement

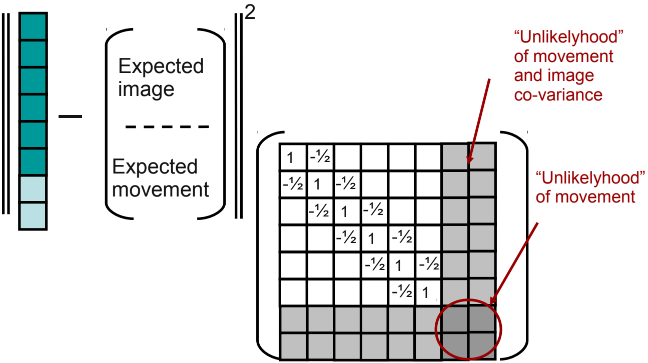


Idea #2: Electrode movement

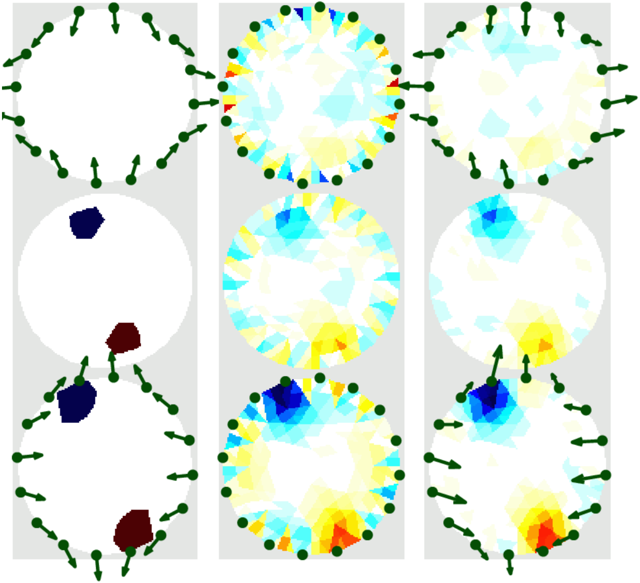
Sensitivity to sensor movement



Adapted penalty function



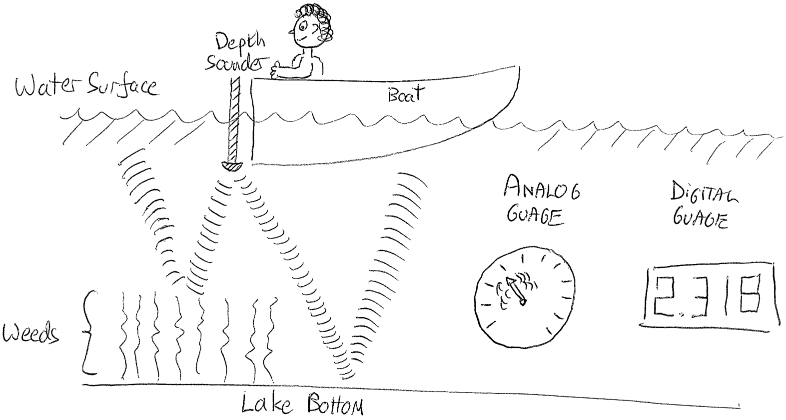
Electrode movement compensation



mez-Laberge *et al*, Phys. Meas., 2006

Idea #3: Data Quality

Idea #3: Data Quality



Depth Sounder – with analog and digital guages

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

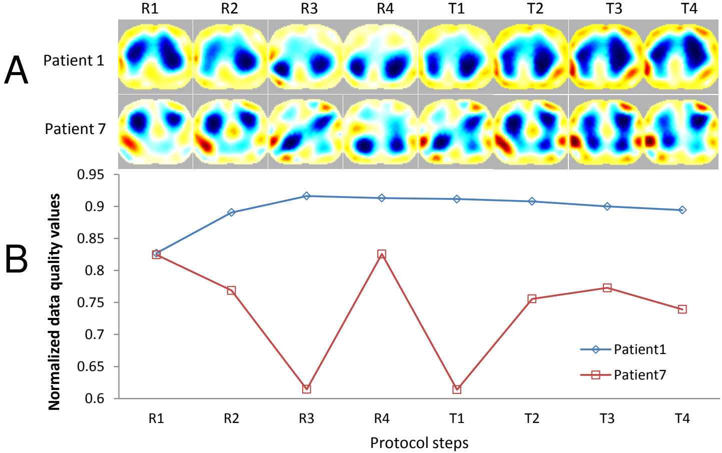
- *Concept:* High Quality Data are Consistent
- *Idea:* Use IP to predict each data point from all others

Original d	$\Rightarrow$	Remove i $d^{(i)}$	$\Rightarrow$	Solve $\hat{m}^{(i)}$	$\Rightarrow$	Predict $\hat{d}^{(i)}$

- 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?

Solutions?

Solutions?

$\Rightarrow$

Solutions?

$\Rightarrow$

Solutions?

$\Rightarrow$

Thus, we need

Solutions?

$\Rightarrow$

Thus, we need

- Open Data

Solutions?

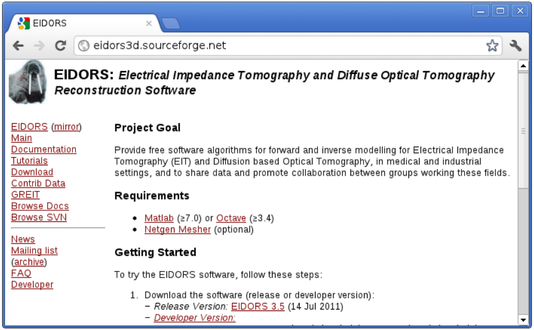
$\Rightarrow$

Thus, we need

- Open Data
- Open source analysis

For EIT . . .

For EIT . . .



EIDORS
eidors3d.sourceforge.net
EIDORS: Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software
EIDORS (mirror)
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Developer
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:

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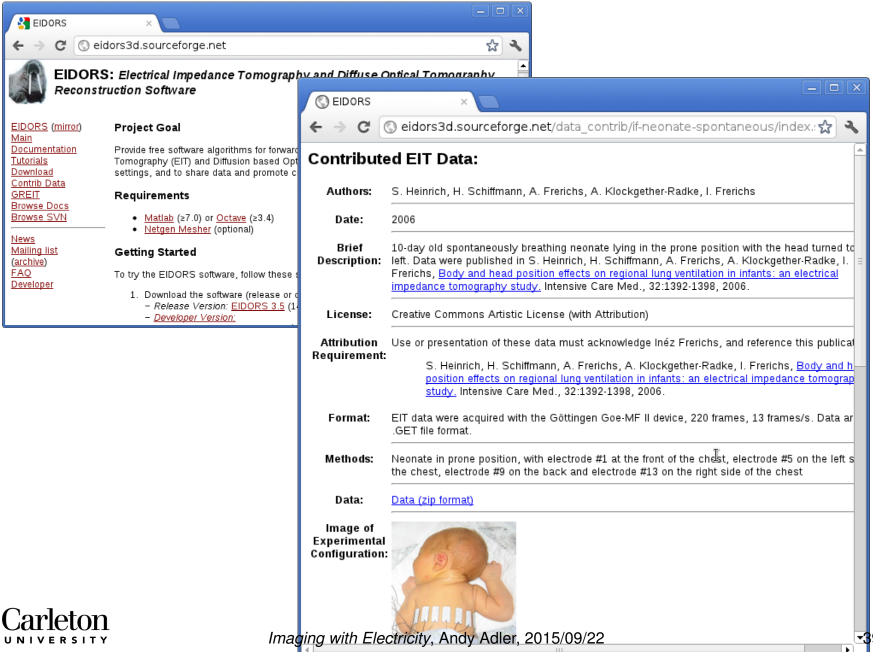
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– Release Version: EIDORS 3.5 (1
– Developer Version:
EIDORS
eidors3d.sourceforge.net/data_contrib/if-neonate-spontaneous/index.
Contributed EIT Data:
Authors: S. Heinrich, H. Schiffmann, A. Frerichs, A. Klockgether-Radke, I. Frerichs
Date: 2006
Brief Description: 10-day old spontaneously breathing neonate lying in the prone position with the head turned to left. Data were published in S. Heinrich, H. Schiffmann, A. Frerichs, A. Klockgether-Radke, I. Frerichs, Body and head position effects on regional lung ventilation in infants: an electrical impedance tomography study. Intensive Care Med., 32:1392-1398, 2006.
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Attribution Requirement: Use or presentation of these data must acknowledge Inéz Frerichs, and reference this publicat
S. Heinrich, H. Schiffmann, A. Frerichs, A. Klockgether-Radke, I. Frerichs, Body and h position effects on regional lung ventilation in infants: an electrical impedance tomograp study. Intensive Care Med., 32:1392-1398, 2006.
Format: EIT data were acquired with the Göttingen Goe-MF II device, 220 frames, 13 frames/s. Data ar .GET file format.
Methods: Neonate in prone position, with electrode #1 at the front of the chest, electrode #5 on the left s the chest, electrode #9 on the back and electrode #13 on the right side of the chest
Data: Data (zip format)
Image of Experimental Configuration:

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.