

Interpreting Impedance Images ... *Interesting or Irrelevant?*

MIRAN Workshop, U. Manchester, UK:
Chest EIT: Vision, Status & Priorities
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EIT Images: *Interesting or Irrelevant?*

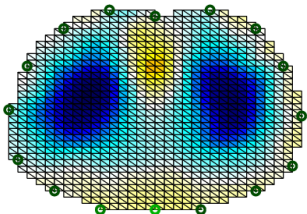
- Motivating Question:

What do we need from the engineers?

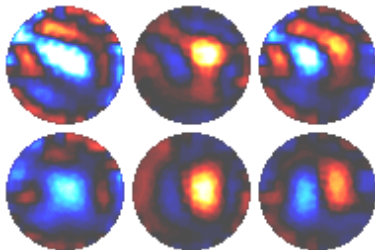
- Recent advances
- Requirements for clinical EIT
 - current work to address them
- What should be our priorities?

Recent Advances

GREIT

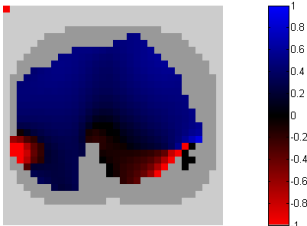


Electrode Errors

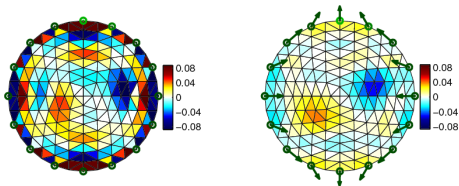


Lung Parameters

Alveolar Collapse (red): 2%
Alveolar Overdistension (blue): 37%
PEEP: 16 cm H2O



Electrode Movement



Requirements for clinical EIT

From “Whither EIT” *Phys. Meas.* (2012)

- Availability of EIT devices
- Standards
- Robustness
- Useful software
- Useful parameters
- Standardized procedures

Requirements: *availability*

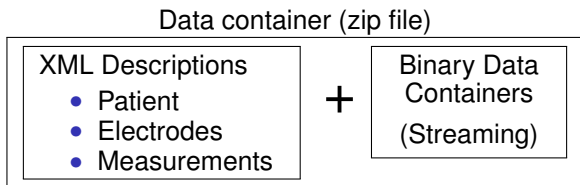
EIT devices must be readily available at a reasonable cost. Since EIT uses components common to consumer electronics, increases in volume should strongly reduce costs.

- Some progress
- Still a big problem

Requirements: *standard formats*

*EIT data and images must be accessible in standard formats.
For images, the natural format is a DICOM class.*

- It's not hard to do a DICOM class for EIT
- Work on a data format

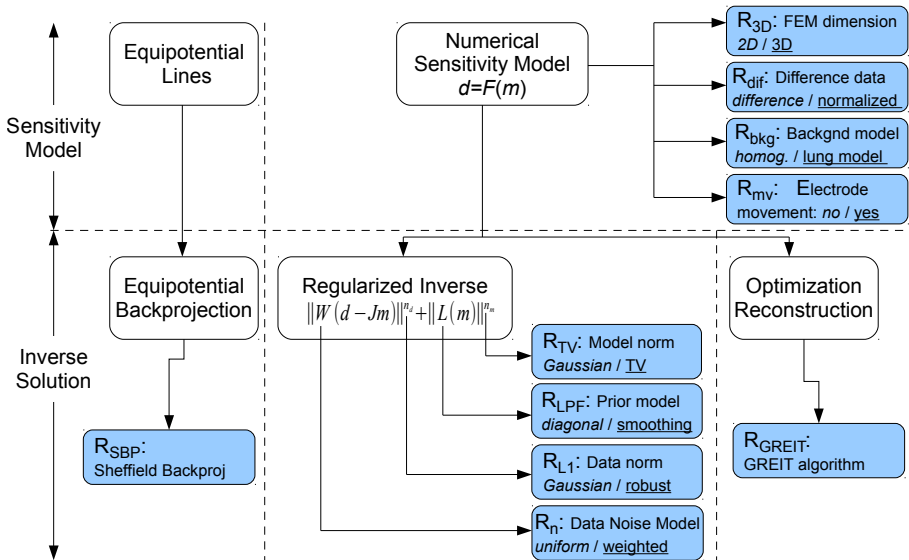


Requirements: *robustness*:

EIT systems must be robust against electrode contact problems and electrical interference. Systems must automatically compensate (if possible) for electrode errors or give appropriate warnings.

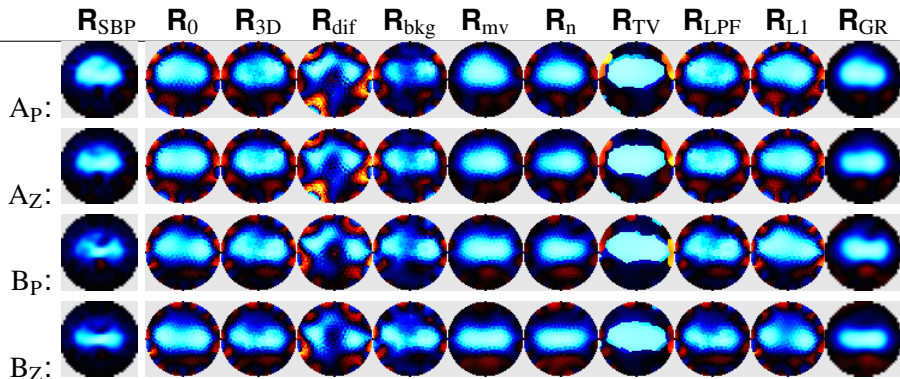
- Algorithm Evaluations
- Electrode error compensation
- Data quality measures
- Robust Algorithms

robustness: Algorithm Evaluations



Taxonomy of direct EIT reconstruction algorithms, classified in terms of the selection of forward and inverse model parameters.

robustness: Algorithm Evaluations



EIT images for all algorithms from two animals (A&B). For each animal, images of V_T at PEEP (\cdot_P) and ZEEP (\cdot_Z) are shown individually normalized to the maximum amplitude in each image (*Blue*: decrease in conductivity, *Red*: increase in conductivity).

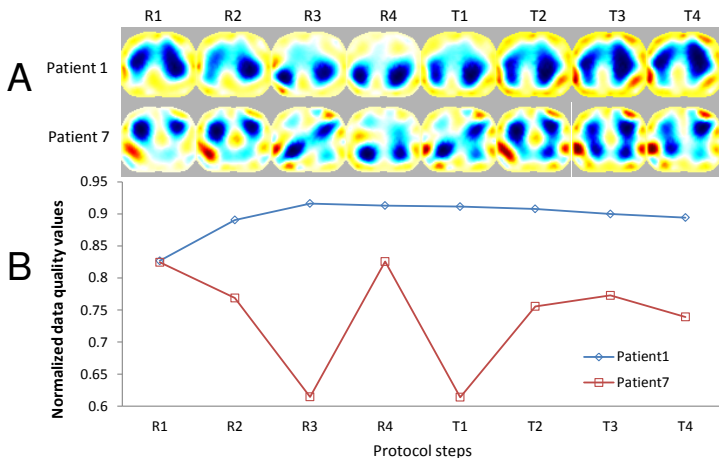
robustness: Algorithm Evaluations

Performance of different image reconstruction algorithms during mechanical ventilation with constant tidal volume and variable end-expiratory pressure and O_2 fraction – detection of global and regional tidal and end-expiratory lung volumes

Expected finding	R_{SBP}	R_0	R_{3D}	R_{dif}	R_{bkg}	R_{mv}	R_n	R_{TV}	R_{LPF}	R_{L1}	R_{GR}
V_T is independent of PEEP											
$V_{T,E,Z,21} = V_{T,E,P,21}$	0.021*	0.332	0.175	0.203	0.387	0.014*	0.001*	0.845	0.172	0.000*	0.006*
$V_{T,E,Z,100} = V_{T,E,P,100}$	0.009*	0.041*	0.027*	0.052	0.062	0.008*	0.009*	0.208	0.027*	0.001*	0.008*
V_T is independent of $F_{I}O_2$											
$V_{T,E,Z,21} = V_{T,E,Z,100}$	0.031*	0.015*	0.018*	0.001*	0.008*	0.044*	0.035*	0.111	0.017*	0.000*	0.041*
$V_{T,E,P,21} = V_{T,E,P,100}$	0.003*	0.007*	0.006*	0.026*	0.009*	0.003*	0.001*	0.134	0.005*	0.000*	0.002*
V_T is reproducible											
$V_{T,E,Z1} = V_{T,E,Z2}$	0.002*	0.006*	0.004*	0.000*	0.003*	0.003*	0.001*	0.018*	0.004*	0.001*	0.002*
$V_{T,E,P1} = V_{T,E,P2}$	0.000*	0.000*	0.000*	0.001*	0.000*	0.000*	0.000*	0.002*	0.000*	0.000*	0.000*
CoG is PEEP dependent											
$CoG_{E,Z,21} > CoG_{E,P,21}$	0.069	0.097	0.094	0.156	0.138	0.064	0.050	0.090	0.094	0.138	0.051
$CoG_{E,Z,100} > CoG_{E,P,100}$	0.024*	0.032*	0.032*	0.049*	0.045*	0.025*	0.022*	0.030*	0.032*	0.056	0.022*
CoG is $F_{I}O_2$ dependent											
$CoG_{E,Z,21} < CoG_{E,Z,100}$	0.006*	0.007*	0.006*	0.015*	0.010*	0.006*	0.006*	0.007*	0.006*	0.014*	0.006*
$CoG_{E,P,21} < CoG_{E,P,100}$	0.552	0.526	0.529	0.458	0.539	0.526	0.581	0.556	0.528	0.493	0.530
CoG is reproducible											
$CoG_{E,Z1} = CoG_{E,Z2}$	0.007*	0.016*	0.020*	0.192	0.017*	0.039*	0.010*	0.017*	0.018*	0.008*	0.017*
$CoG_{E,P1} = CoG_{E,P2}$	0.001*	0.001*	0.002*	0.002*	0.001*	0.008*	0.006*	0.002*	0.002*	0.000*	0.007*

E, Measures by EIT; V_T , tidal volume; PEEP (P), positive end-expiratory pressure; ZEEP (Z), zero end-expiratory pressure; $F_{I}O_2$, fraction of O_2 in inspired gas; 21, $F_{I}O_2$ equal to 21%; 100, $F_{I}O_2$ equal to 100%; indices 1 and 2 identify the first and the second measurements at identical ZEEP or PEEP levels; Up, upper or nondependent lung regions; Lo, dependent lung regions

robustness: Data quality measures

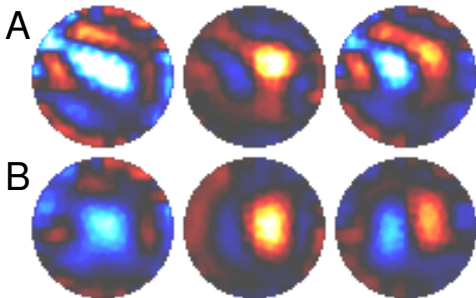


Clinical data and data quality metric for each stage of the protocol (R1–R4 — recruitment: PEEP \uparrow , T1–T4 — titration: PEEP \downarrow).

A: EIT images (one-step Gauss-Newton solver with a 2D forward model), B: Calculated data quality.

robustness: Electrode error compensation

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



EIT images in anaesthetised, ventilated dog

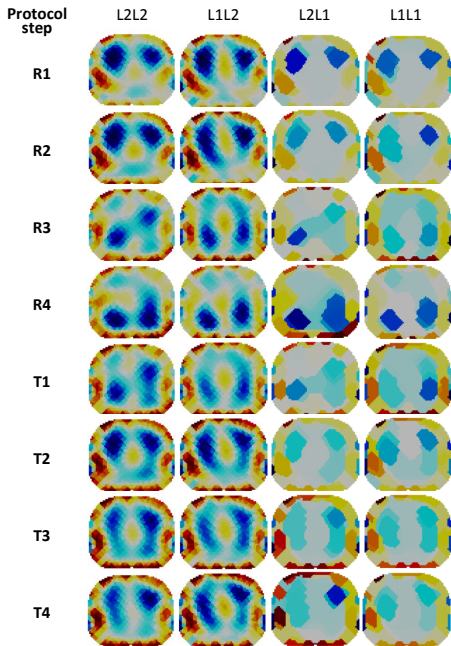
A: uncompensated, *B*: compensated. *Left*: ventilation *Centre*: saline (right lung) *Right*: ventilation and saline

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

robustness: Robust Algorithms

- ℓ_1 norm for the image prior allows “blocky” reconstructions
- ℓ_1 norm for the data mismatch gives improved robustness to outliers

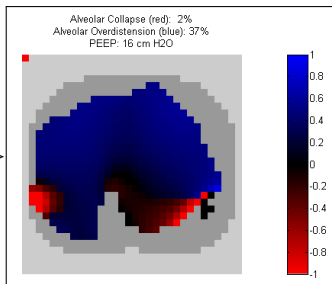
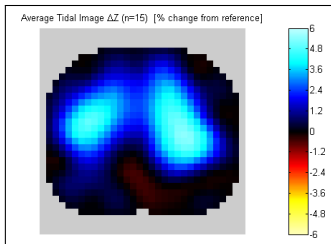
Figure: Reconstructions with mixed (data/image) norms for clinical data for each stage of the protocol (R1–R4 — recruitment: PEEP \uparrow , T1–T4 — titration: PEEP \downarrow).



Requirements: *useful software:*

Software must have an intuitive interface focused on the clinical user. EIT parameters should be related to those commonly used: pressures, volumes, time, or fractions (not ΔZ). Analysis must be on-line (not retrospective).

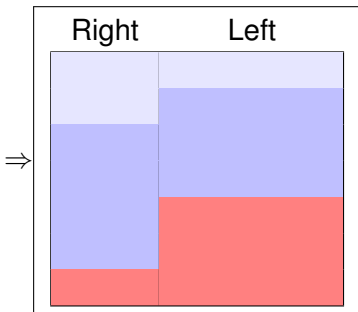
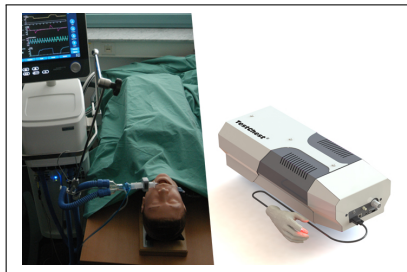
- Agreement that we need *overdistention* and *collapse* fractions.



Requirements: *standardized procedures:*

Standardize EIT protocols (e.g. duration of PEEP steps, magnitude of steps, type of ventilation, EIT frame rates, additional measurements). . . automated approaches for data analysis and interpretation should be included.

- Which information from EIT impacts care?
How to present information?



Thoughts (from “Whither EIT”)

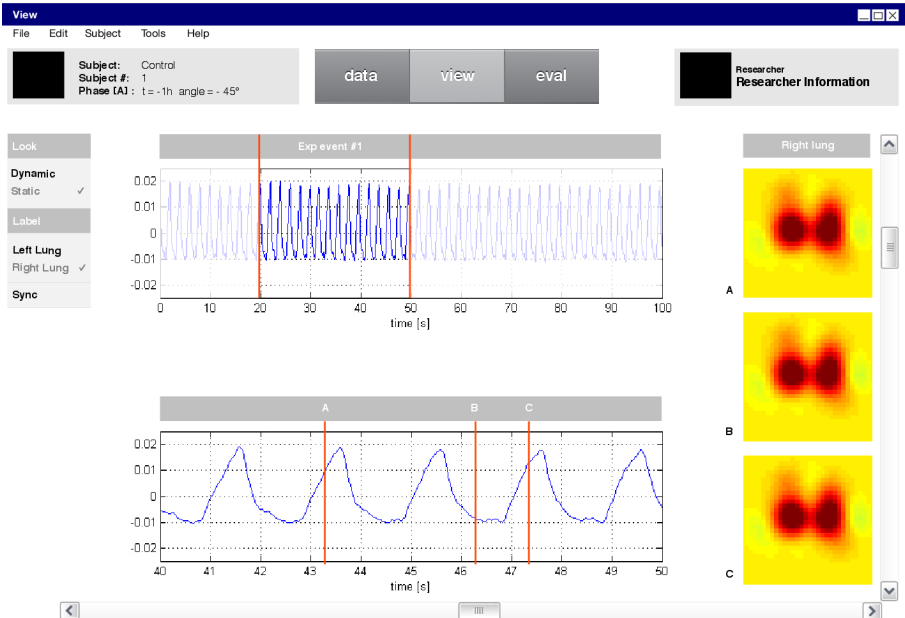
- EIT is at a critical time.
 - a large and growing clinical interest
 - commercial devices on the market.
- Risk: enthusiasm dissipates, as new clinical researchers unable to reliably use EIT,
 - unable to usefully interpret the images generated
 - images ruined by errors.
- Is EIT “another technology too complicated for the clinic”?

So, we need good advice (for beginners) on how to

- conduct
- analyse

simple EIT experiments/clinical protocols

Concept for Graphical Analysis tool (View Screen)



Concept for Graphical Analysis tool (*Eval Screen*)

Evaluate

File Edit Subject Tools Help



Subject: Control
Subject #: 1

data

view

eval

Researcher
Researcher information

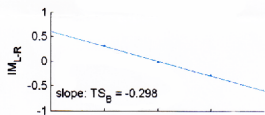
Evaluate

Design

B: Left

B: Horizontal

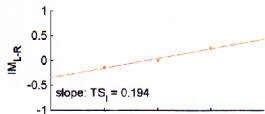
B: Right



I: Left

I: Horizontal

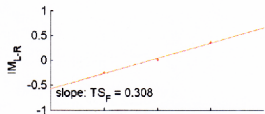
I: Right



F: Left

F: Horizontal

F: Right



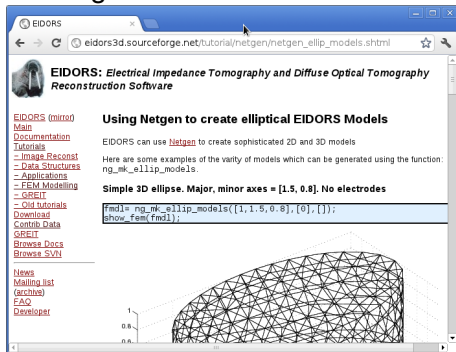
Recommendations: “Whither EIT”

- think about the physiology;
 - e.g. EIT measure “my patient’s lungs are 30% collapsed” provides insights which lead to interventions
- analyze EIT images in creative ways
 - exploit the parameter “time” and many of sophisticated signal processing algorithms to generate new parameters.
- To solve these problems, we must work in *interdisciplinary teams* (clinical, engineering and mathematical experts).

Requirements: *collaboration*

EIDORS \Rightarrow ...

Sharing Code



The screenshot shows the EIDORS website with a sidebar menu on the left containing links like 'Main', 'Documentation', 'Tutorials', 'Image Reconst', 'Data Structures', 'Applications', 'FEM Modelling', 'GREIT', 'Old tutorials', 'Download', 'Contrib Data', 'SREIT', 'Browse Docs', and 'Browse SVN'. The main content area is titled 'Using Netgen to create elliptical EIDORS Models' and includes a code block for creating a simple 3D ellipse model.

EIDORS: Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software

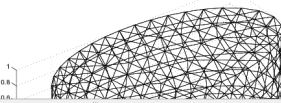
Using Netgen to create elliptical EIDORS Models

EIDORS can use [Netgen](#) to create sophisticated 2D and 3D models

Here are some examples of the variety of models which can be generated using the function: `ng_mk_ellip_models`.

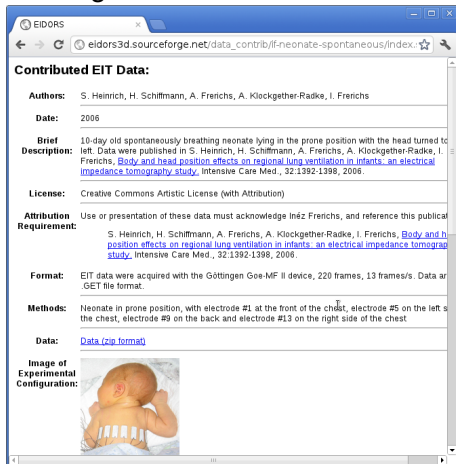
Simple 3D ellipse. Major, minor axes = [1.5, 0.8]. No electrodes

```
fmdl = ng_mk_ellip_models([1, 1.5, 0.8], [0], []);  
show_fem(fmdl);
```



A 3D wireframe model of a human torso, showing the elliptical shape defined by the code. The axes are labeled as 1, 0.8, and 0.6.

Sharing Data



The screenshot shows the 'Contributed EIT Data' page on the EIDORS website. It lists a specific dataset with details on authors, date, description, license, attribution requirements, format, methods, and data availability.

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.

License: Creative Commons Artistic License (with Attribution)


Attribution Requirement: Use or presentation of these data must acknowledge Inéz Frerichs, and reference this publication: 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.

Format: EIT data were acquired with the Göttingen Goe-MF II device, 220 frames, 13 frames/s. Data are .GET file format.

Methods: Neonate in prone position, with electrode #1 at the front of the chest, electrode #5 on the left side of 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:



A photograph of a neonate lying in a prone position, with several EIT electrodes attached to their back and chest.