Reduction of electrode position errors in clinical imaging

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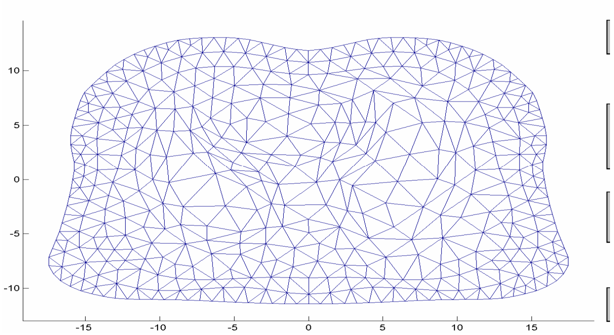
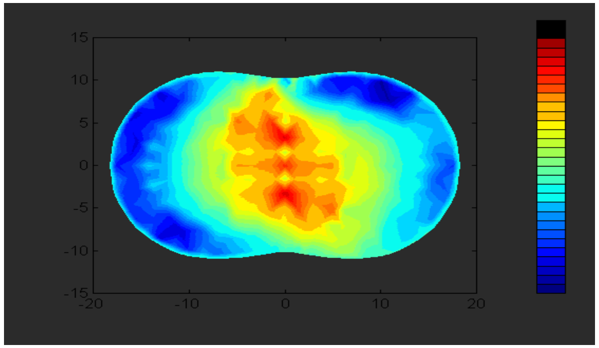
Overview

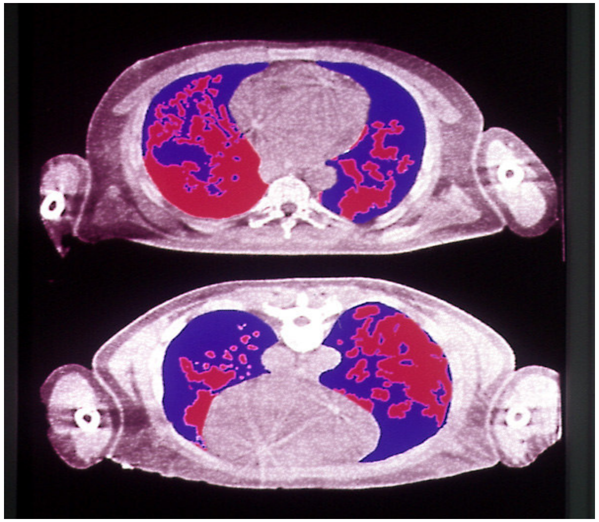
- <u>Research Aims</u>
- Outcome predictors for patient health
- Control variables for patient management
- Data fusion for better monitoring
- <u>Applied to Adult Intensive Care</u>
- Measuring/Monitoring respiratory and cardiovascular cyclical changes and trends
- Regional data on ventilation or perfusion insufficiency
- Inform diuretic and postural therapies.

EIT methodology

- Boundary measurements >> finite element model >>internal conductivity image.
- Resolution limited, better nearer the electrodes.
- Non-ionising, safe and fast (25/sec).
- Good tissue conductivity contrast
- Must choose the application : cf. X-ray image of lung fluid distribution

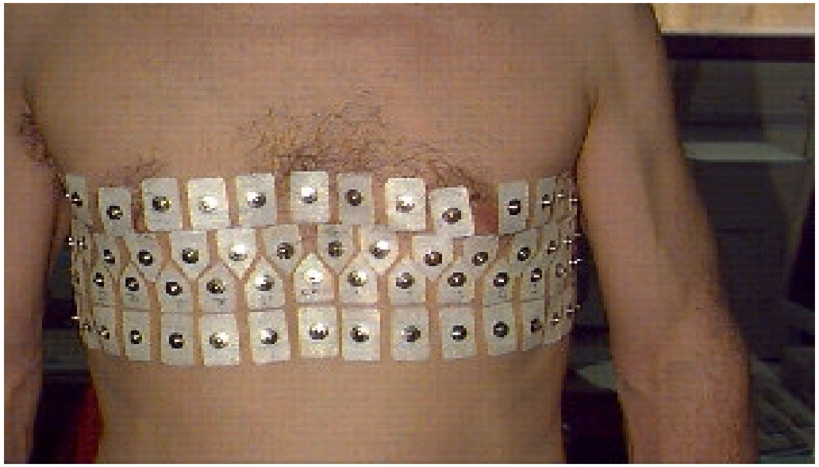


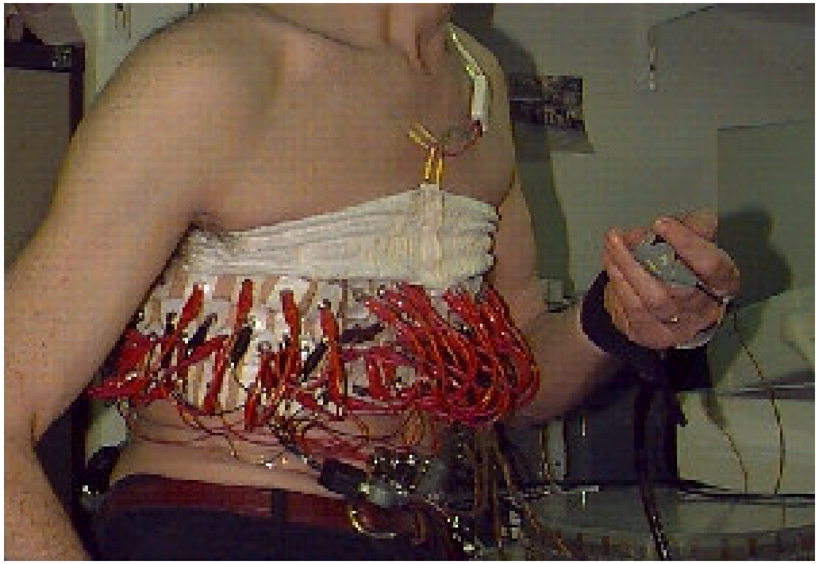




Practical difficulties

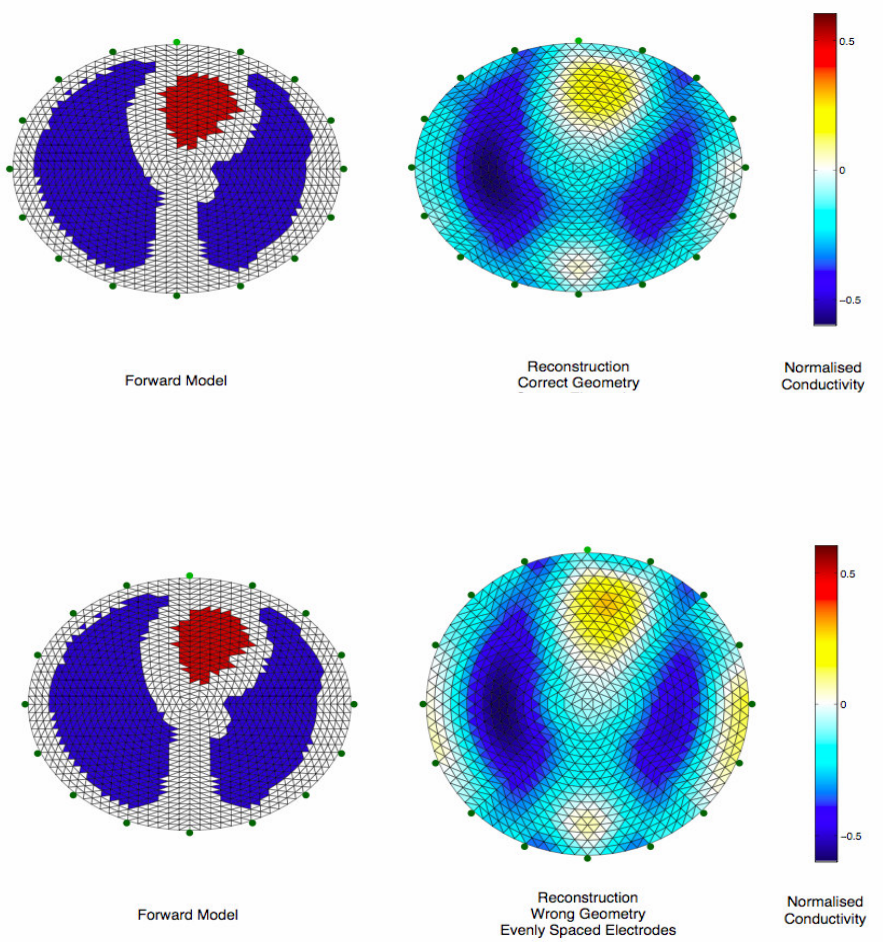
- The resolution of an image is related to the number of independent measurements; i.e. to the number of electrodes (N). Res ~N^2
- Solution- printed arrays, subsets.
- Problem then of knowing 3D positions.
- Equipment complexity = f(N)
- Acquisition speed = f(1/N) or increase complexity.





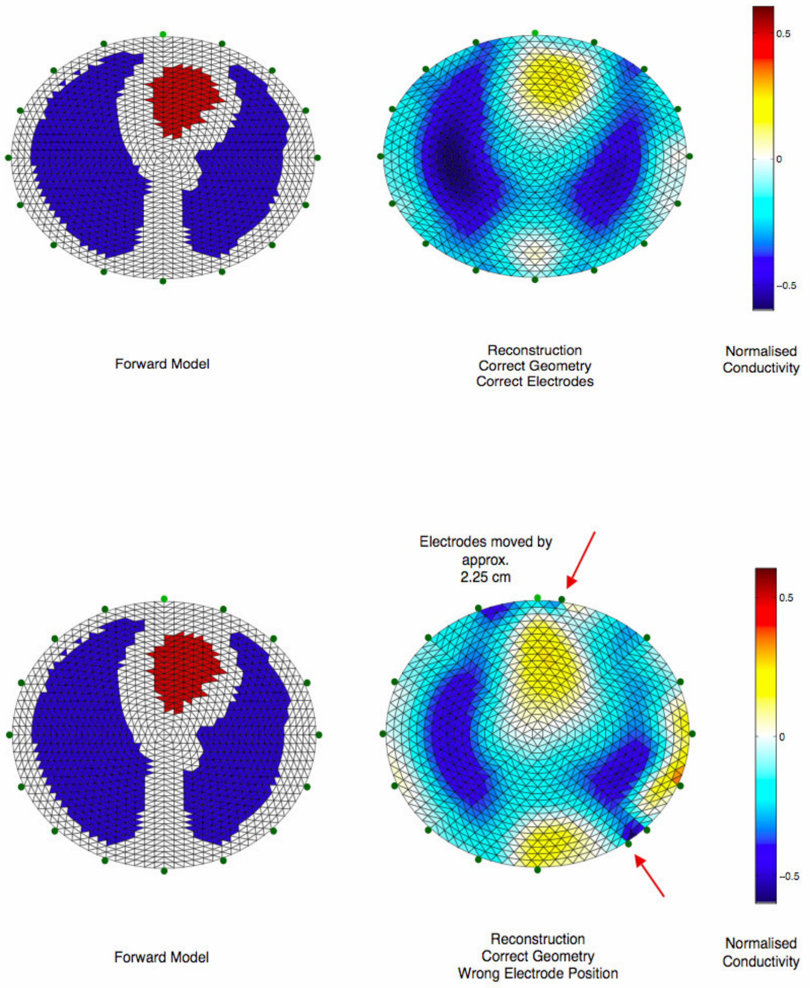
Simulation reconstruction 1

- 2304 element forward model, a 30 cm major-axis ellipse with 1.2 major/minor axis ratio
- Circular, 30 cm diameter, inverse model reconstruction with no electrode displacement
- The resulting conductivity distribution has broadened with a larger statistical variance of 0.1362 compared to the reference distribution 0.1088, an increase of approximately 25%



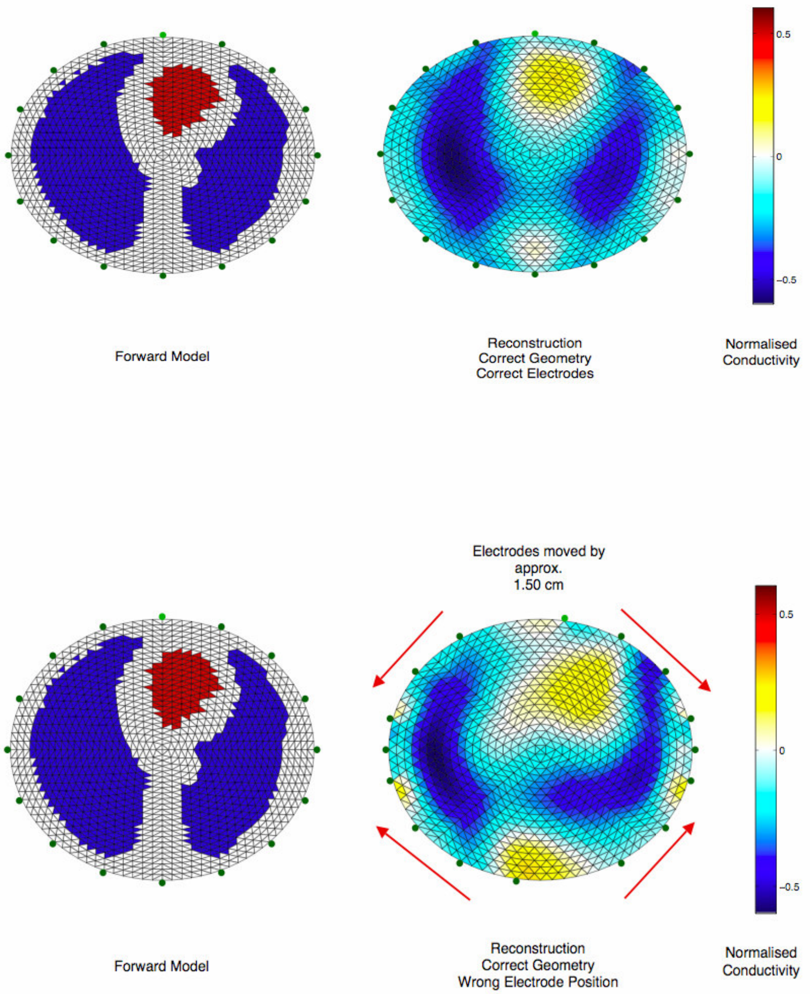
Simulation reconstruction 2

- Elliptical boundary reconstruction with electrodes 2 and 8 displaced counterclockwise by 2.25 cm
- These displacements severely affect the reconstruction. The left lung's northern lobe has strongly deteriorated. Large, positive artefacts appear in the south and west boundaries and small but strong negative artefacts appear adjacent to the displaced electrodes. The western semicircle remains relatively unaffected by the displacement of these two eastern electrodes.



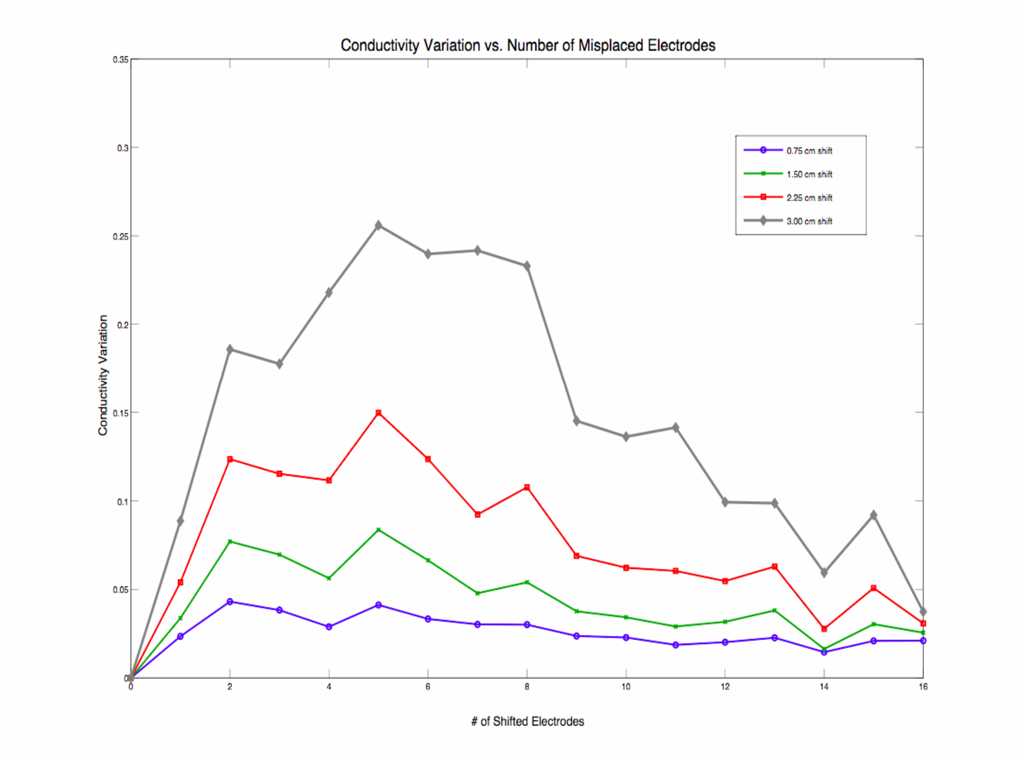
Simulation reconstruction 3

- All electrodes migrate by 1.50 cm towards the east-west
- Strong contrasts in conductivity concentrate near the poles of migration whereas light contrasts in conductivity appear between the largest electrode gaps.



Simulation reconstruction 4

Conductivity variation $v\sigma$-- versus number of displaced electrodes plotted for four size categories of displacements: 0.75 cm (blue circle), 1.50 cm (green x), 2.25 cm (red square) and 3.00 cm (grey diamond).



Use 3D electrode arrays &
find electrode positions in space

Solutions:-

1. Small fixed-geometry arrays
2. General population shapes
3. Optical referencing
4. EIT data referencing

Referencing may become as complex as the problem it is solving.

Solutions 1 and 2

- Application to breast imaging for tumour detection; conformable tissue; solution 1

  Jossinet, RPI, Dartmouth College
- Early work in Sheffield, RPI, OBU and many others; solution 2:

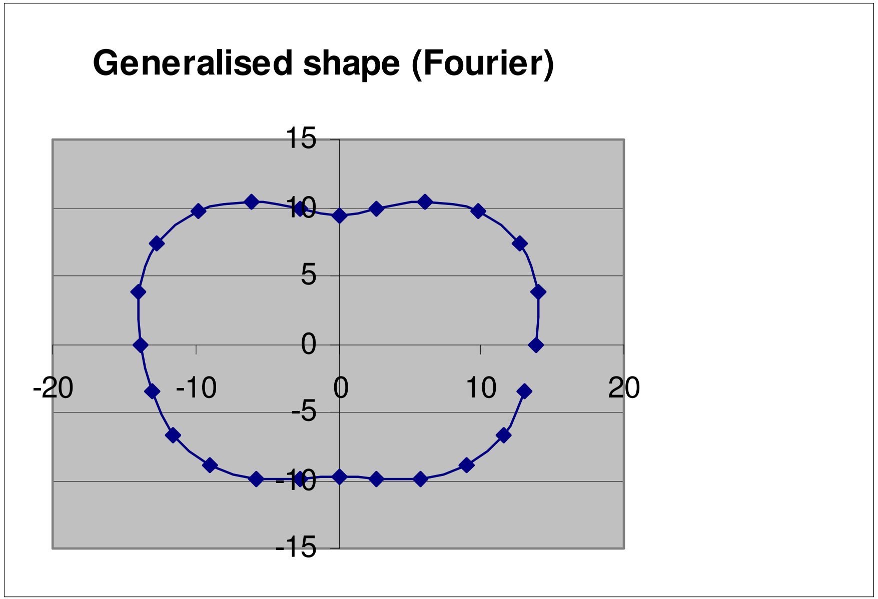
  Circles

  Ellipses with a/b = 1.2 …. 1.5

  Fourier components :

  $$R(\theta) = 12.5 + 0.4 \sin\theta + 2.2 \cos 2\theta + 0.5 \sin 3\theta - 0.75 \cos 4\theta$$
- SizeUK etc (11000 subjects)

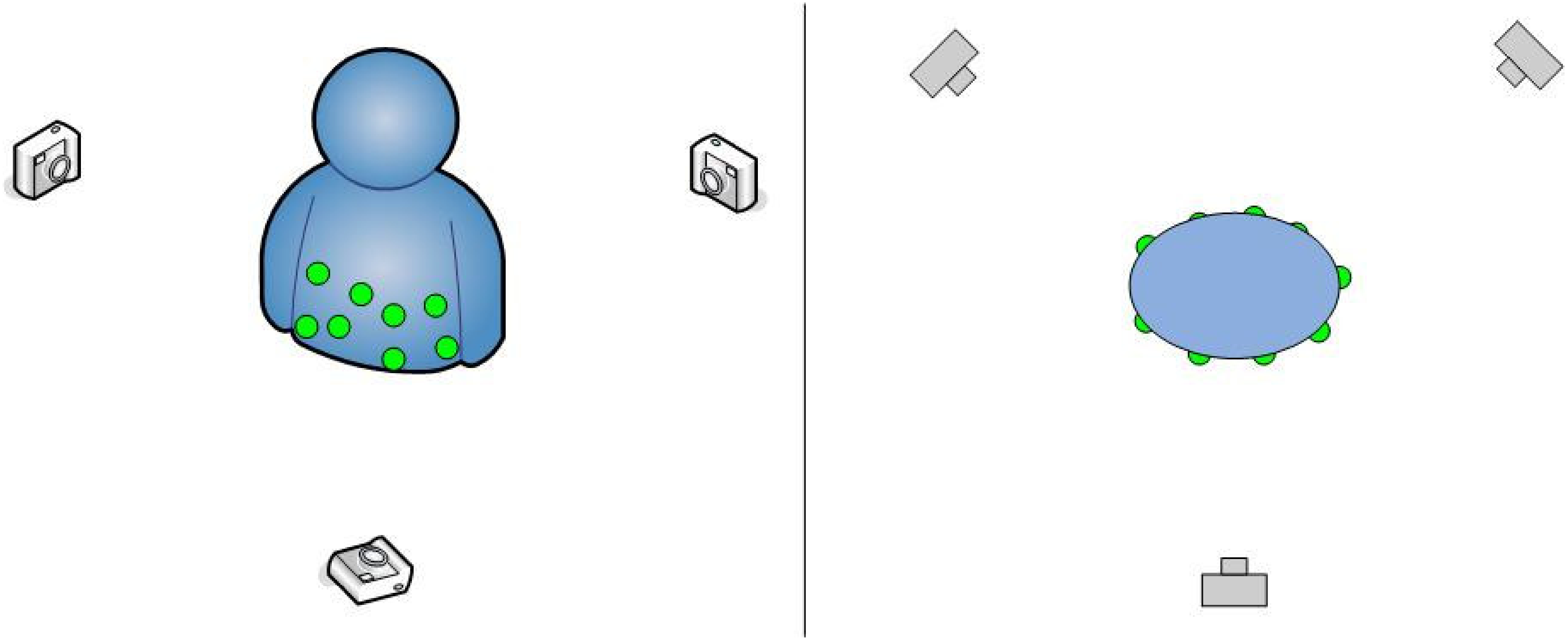
http://www.scientific-computing.com/minisite/issue102/1.html



Solution 4, use of EIT data for shape

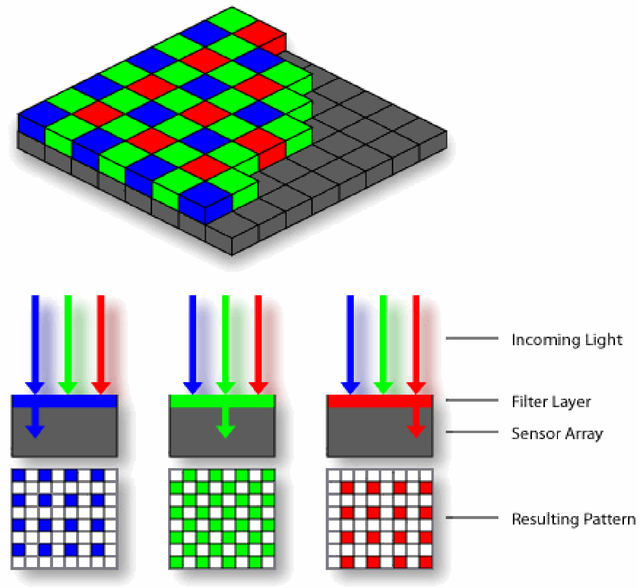
- 1996 Adler: yes, movement contributes to images
- 1996 Gersing: measured a shape effect in EIT data
- 1998 Blott: compensation using reconstruction of electrode position
- 1998 Lionheart: analytical electrode position finding possible for isotropic conductivities
- 2005 Soleimani: reconstruction of 3D electrode positions
- 2005 Zhang & Patterson: movement “artefact” on EIT data

Solution 3, addition of optical position data



Camera practicalities 1

- Green coloured LEDs
- Pixel number (8 million = 2450 x 3270)
- USB/Firewire control
- USB/Firewire data load
- Frame rate 1.4/second
- RAW (not .jpg) output
- Bayer filter. See also FoveonX3 and triple-CCD cameras. (Price high)



Camera practicalities 2

- Use circular emitters to overcome circle of confusion constraint
- Image area ~ 24cms x 32cms so 1 pixel is approx 0.1mm x 0.1mm, but Bayer filter increases this

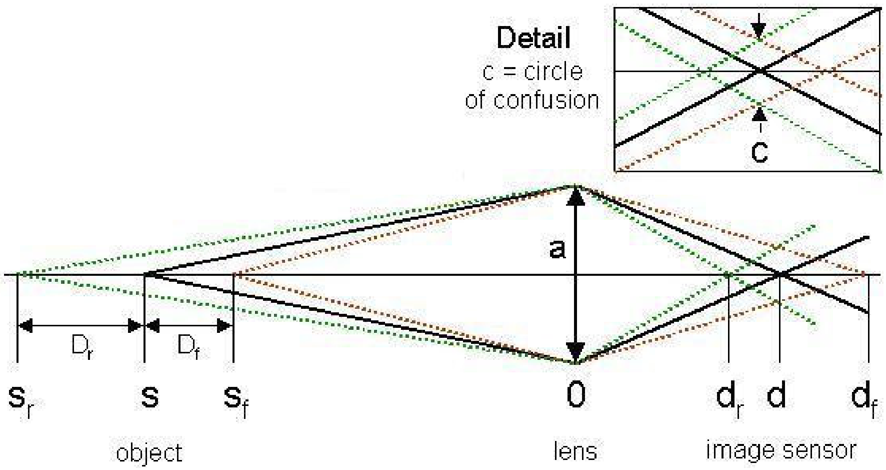


Image representation 1

The **camera projection matrix *P*** is the product of the camera calibration matrix (the intrinsic parameters) with the equation for the extrinsic parameters (R and C° which relate the orientation and position of the camera centre in the world coordinate frame). The general mapping equation for an ideal camera is:

$$x = \begin{bmatrix} f/m_w & s & p_x/m_w \\ 0 & f/m_h & p_y/m_h \\ 0 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} R & -RC^{\circ} \end{bmatrix} \cdot \begin{pmatrix} X \\ Y \\ Z \\ 1 \end{pmatrix} = KR\left[I \middle| -C^{\circ} \right] X$$

where

f is focal length

p is the frame offset

m_h m_w allow for non-square pixels

R is camera rotation matrix

C is camera position vector

Image representation 2

- Real cameras introduce errors, principally radial distortion
- As lens distortion occurs during the projection from world points to image points, it can be corrected by introducing a correction to the camera calibration matrix K

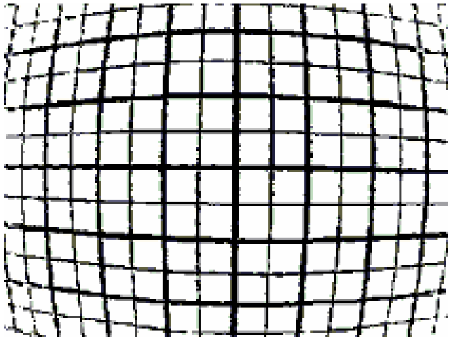
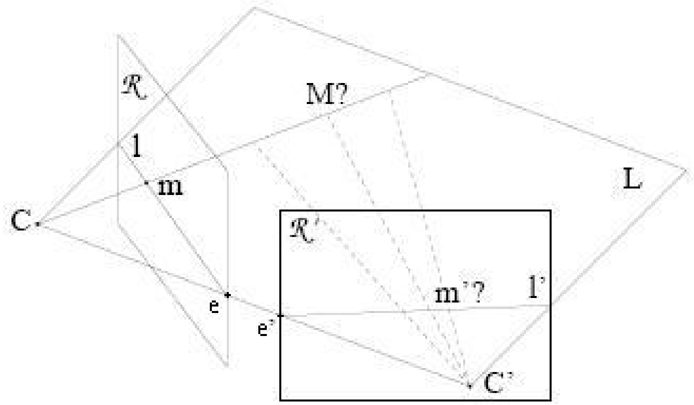


Image representation 3

- Every point on the plane *L* projects to the **epipolar lines** *l* and *l'* respectively. Note that every epipolar line *l*, corresponding to different planes *L*, passes through the epipole *e*. The two rays *Cm* and *C'm'* intersect at the point *M* and are coplanar.
- We know that M lies on the ray *Cm* and that this ray is projected to the line *l'* on the second image plane. We therefore have to look for the point *m'* on the line *l'* only, facilitating the search.

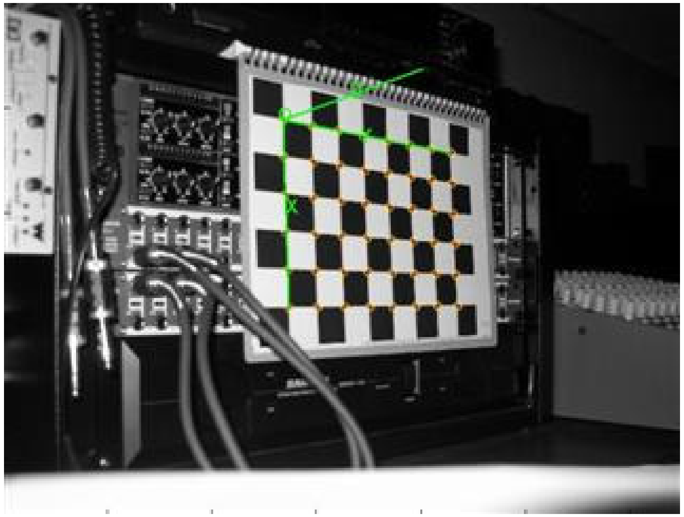


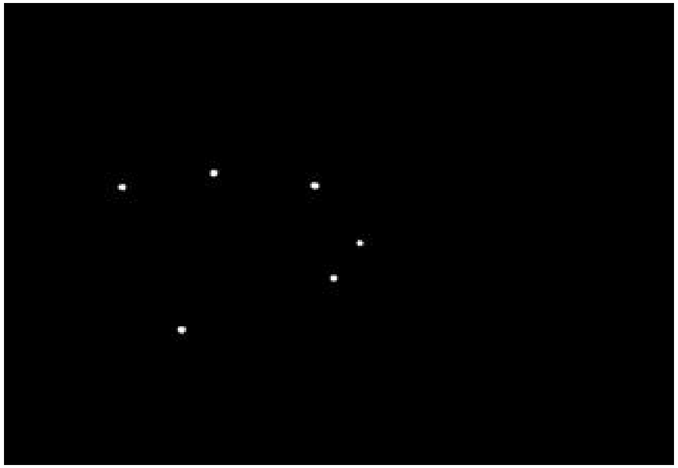
MATLAB toolboxes

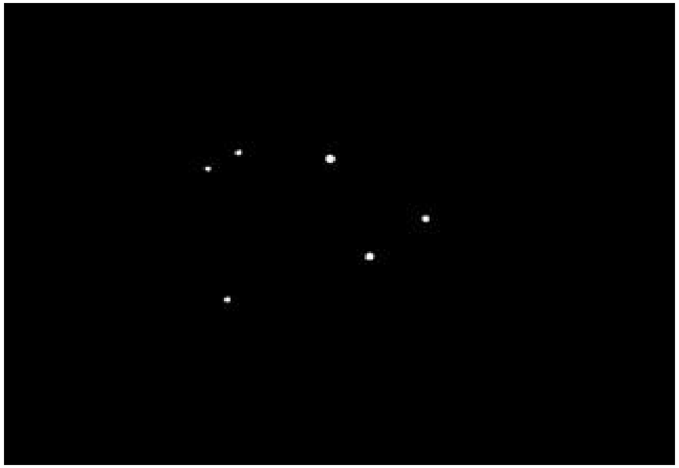
- Image Acquisition
- Camera Calibration for MATLAB (Intel)
- Image Processing

  -Posterise

  -Centroid







Results

- Markers found with accuracy 0.1 - 0.3mm
- Small number correlated manually
- Larger number can be correlated by selective illumination
- LEDs are directional –reflectors may be better

Discussion points

Patients sitting (360 view, 3 cameras) ok

Patients lying (230 view, 2-3 cameras)-

remember hidden positions

or use subset of electrodes

Patients being turned

as above

use only arrays on the sides (c.50degrees each side)