Towards Non-Invasive Electrical Heart Imaging

L. K. Cheng & A. J. Pullan
Department of Engineering Science, The University of Auckland

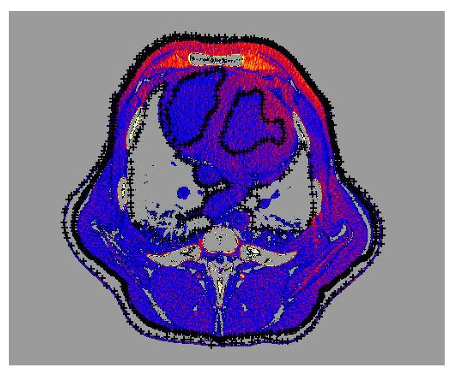
The University of Auckland

Abstract

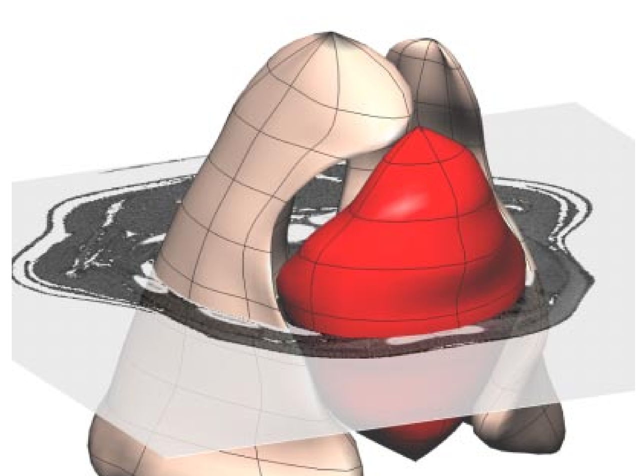
Before accurate, non-invasive, electrical images of the heart can be reconstructed several issues must be addressed. Geometric models must be created to match the subject, the appropriate resolution of the computational mesh must be determined and a continous potential field must be generated from discretely sampled ECG signals. We investigate each of these issues with reference to a porcine model. These procedures are now being used as part of an experimental program to validate inverse procedures.

Generic Geometric Model

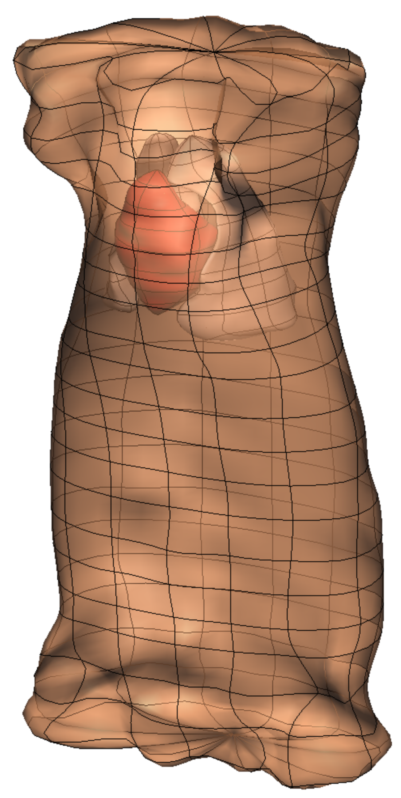
- Three-dimensional male and female human and porcine models have been constructed from CT and MRI images.
- The generic porcine model was created from 99 CT transverse slices at 5mm intervals. The images were then hand digitised and fitted using a non-linear fitting procedure [1].
- The model consists of 6 surfaces: skin, left and right lungs, left and right ventricular chambers and the epicardial surface.



Mid-sternum transverse slice with the torso surface, both lungs and both ventricular chambers digitised.



Generic porcine epicardial and lung surfaces with a CT image (from which the model was digitised) overlayed.



Full porcine model with outer torso layer, lungs and epicardial surfaces.

Computational Mesh Resolution

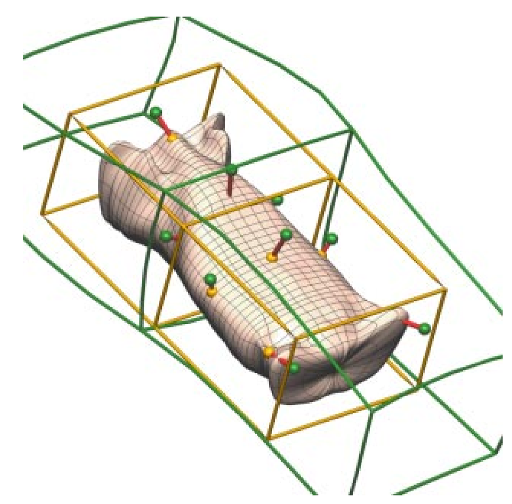
- When solving a problem with a discretisation process, it is necessary to have an appropriate computional mesh resolution to accurately represent the solution. This was determined by conducting a sequence of controlled simulations.
- For these simulations, two different cardiac sources were used: a constant current source (a moving dipole) and a surface activation profile [2].
- For a converged solution, the epicardium was refined to 5 mm average element size. The lungs and the ventricles 9 mm and the skin surface to an average element size of 18 mm.
- Numerical results were compared using multiple measures: RMS, relative RMS, Similarity Index as well as changes in maxima and minima.

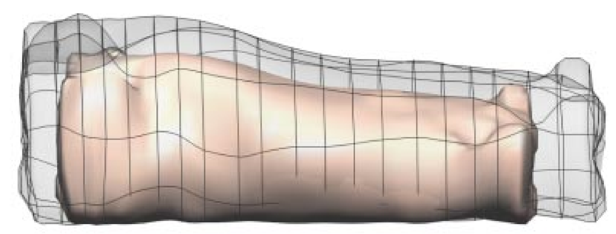
Patient Specific Models

When applying an inverse procedure to a specific subject, a patient specific mesh is required. The ability to model the geometry of the torso and position of the heart accurately are crucial for accurate results.

Torso Surface Customisation

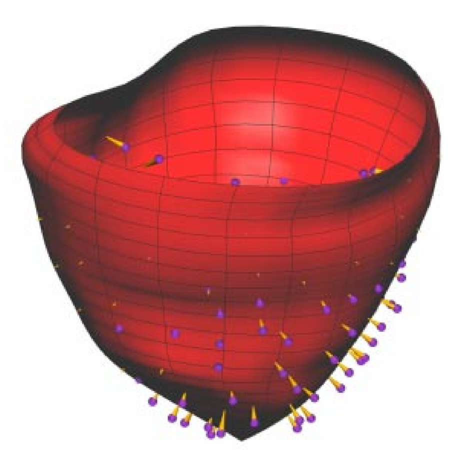
- Ideally, each subject will have MRI or CT information, and the non-linear fitting procedure [1] will be used to create a geometric model.
- Host mesh customisation is a faster but less accurate method by which a generic model can be transformed to a specific subject. This is for use when MRI or CT data is not available or as an initial mesh for the non-linear fitting procedure [1] when MRI or CT data is present.
- Using a small number of control points on both the generic model and the subject, a host mesh is deformed to minimise the differences.
- The slave mesh (the generic model) is embedded within the host mesh and moved accordingly.





Customising a smaller generic model (solid) to a larger specific subject (translucent) with the use of 9 control points. On the left, the generic mesh and data (gold) is customised to the measured data (green).

Heart Customisation

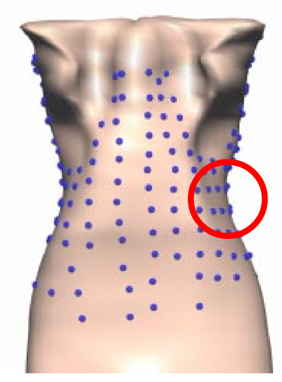


The generic porcine epicaridal surface with sock electrodes (purple spheres) projected orthogonally onto the surface (gold cones).

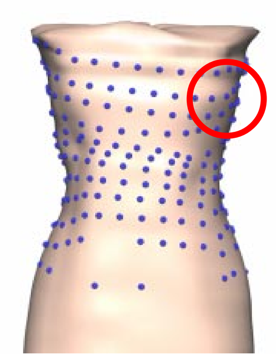
- Geometric locations of a few epicardial electrodes are obtained *in-vivo*.
- The remaining electrode postitions are obtained from an *ex-vivo* excised heart and transformed to match those measured *in-vivo*.
- The generic heart is then customised to match the recorded electrode positions.

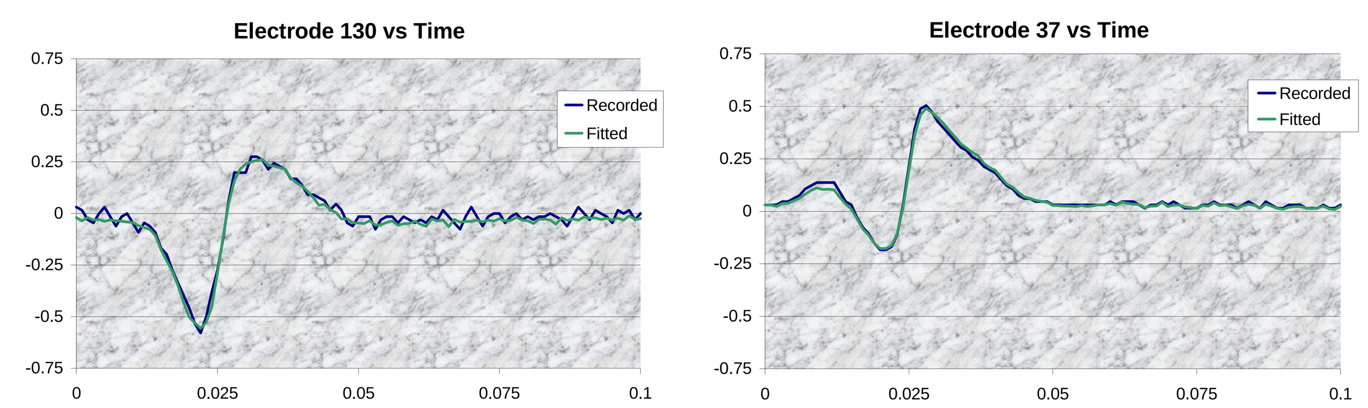
Signal Interpolation

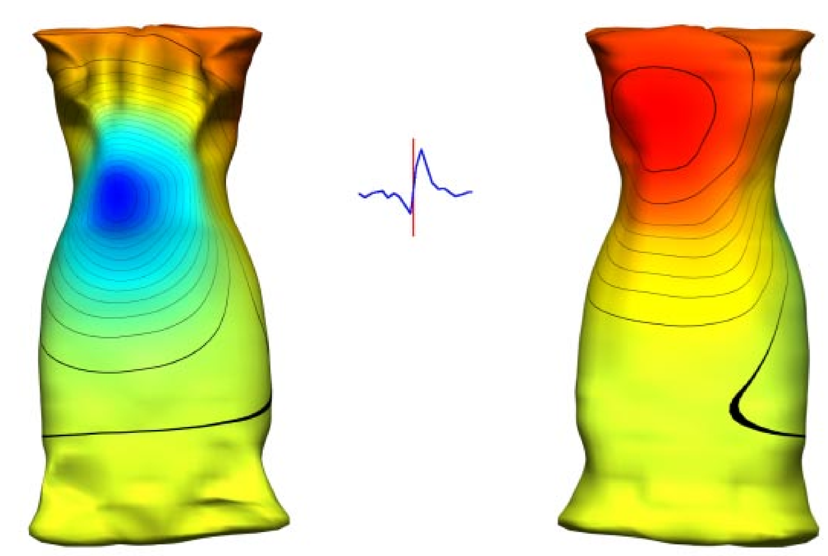
- Experimentally, data is acquired at discrete, non-uniform locations. These must then be manipulated to a form which can be used in inverse procedures.
- Traditionally, this is achieved by cubic-splines or triangulation. These techniques force the field to pass directly through each noisy data.
- Finite element field fitting creates a continuous potential field and has the advantage of smoothing out noisy data. Sobolev smoothing parameters are used to provide a penalty against excessive curvature in the field.



The blue spheres represent the 256 electrodes on the anterior (left) and posterior (right) surface of the model. The red circles show the location of electrodes 37 and 130. Electrode 37 is located on the right upper posterior while electrode 130 is on the anterior over the heart. Below is a comparison between experimentally measured and fitted signals.

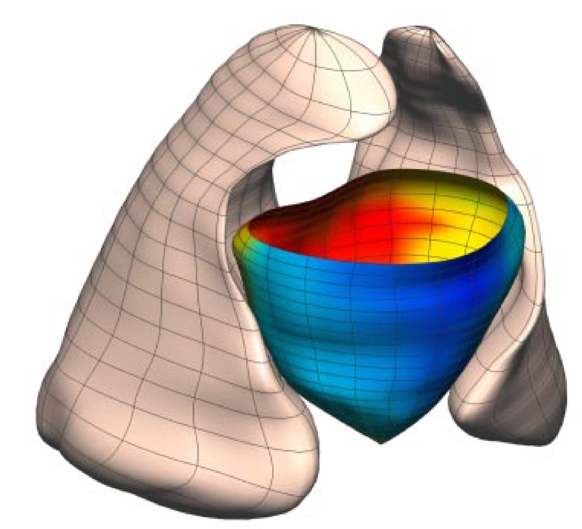






Potentials on the torso surface created by finite element field fitting from 240 electrode locations. Blue indicates minimum and red indicates maximum potential. An electrode recording is displayed with the red marker indicating the current time in the cardiac cycle.

Full Procedure



A non-invasive electrical image of the heart. Red indicates earliest and blue latest activation times.

Preliminary results of applying the overall procedure to data obtained from the experimental program is shown. An electrical image of the heart was obtained non-invasively with the algorithms developed by [3].

References

[1] C. P. Bradley, A. J. Pullan, and P. J. Hunter, "Geometric modelling of the human torso using cubic Hermite elements," Ann. Biomed Eng., vol. 25, 1997.
[2] K. A. Tomlinson. *Finite element solution of an eikonal equation for excitation wavefront propagation in ventricular myocardium.* PhD thesis, The University of Auckland, New Zealand, 1999.
[3] G. Huiskamp and F. Greensite, "A new method for myocardial activation imaging," *IEEE Trans. Biomed. Eng.*, vol. 44, 1997.