Abstract

The inverse problem of electrocardiology aims to quantitatively reconstruct the electrical activity at the heart level given electrical information on the torso surface. The computed solution is sensitive to perturbations, thus small amounts of error can, in many cases, result in an unbounded solution. Creating a stable solution in the presence of input errors is critical. Also, for an electrical imaging procedure to be clinically accepted, its performance needs to be quantified and its sensitivity with respect to experimental and modeling errors needs to be analyzed.

The approaches for obtaining an electrical image of the heart has evolved over time from reconstructing a small number of dipoles to potential and activation time based inverse approaches. An extensive simulation study on an anatomically based porcine model was performed.

Three different cardiac sources were used to compute known potentials on the torso surface and at the heart level. Using the torso surface signals as input, potentials and activation times on the heart surfaces were reconstructed and then compared to the known cardiac sources.

We present comparisons between reconstructed solutions from an activation time formulation (Zero-crossing), two traditional potential spatial regularization methods (Tikhonov and Truncated SVD) and a potential temporal-spatial regularization method (Greensite). The algorithms were also subjected to individual experimental errors (e.g., geometrical, material conductivities and signal errors) and a combination of typical errors which could be encountered in a clinical or experimental situation.

The Inverse Problem of Electrocardiology Effects of Experimental Errors on Activation and Potential Inverse Formulations

L K Cheng, J M Bodley & A J Pullan
l.cheng@auckland.ac.nz
Bioengineering Research Group, The University of Auckland, New Zealand

The University of Auckland

www.cmiss.org

The Two Source Formulations

The inverse problem aims to quantitatively reconstruct the electrical activity of the heart from non-invasive electrical recordings. By reconstructing the problem in terms of dipoles, a unique solution does not result and there is little insight into the underlying electrical activity. By reconstructing epicardial potentials it is possible to obtain a unique solution but the problem also becomes ill-posed. Myocardial activation times provide more stable solutions and also provide a clinically useful representation of the cardiac events occurring within the heart.

Myocardial Activation Time Formulation

- Critical points and times were determined using the zero-crossing algorithm [3].
- With the initial estimate of the activation field, the solution is refined by minimising the differences between the computed and known torso surface potentials by adjusting the activation times.

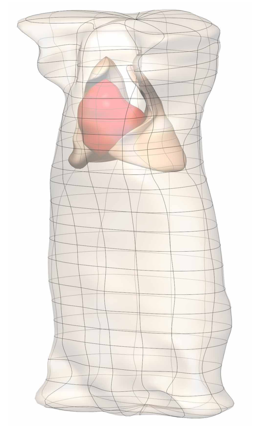
Epicardial Potential Based Formulation

- Three different potential based inverse procedures were used:
  - First order Tikonhov
  - Truncated SVD
  - Greensite's temporal and spatial regularisation method [2]
- Regularisation parameters were calculated using a number of established methods:
  - optimal criterion
  - CRESO criterion
  - L-curve
  - zero-crossing.
- Potential solutions were converted to activation fields by assigning the maximum negative slope as the activation time.

Solution Domain

A three-dimensional generic porcine model which consists of six boundary element surfaces: left and right endocardial, epicardial, left and right lung and skin surfaces.

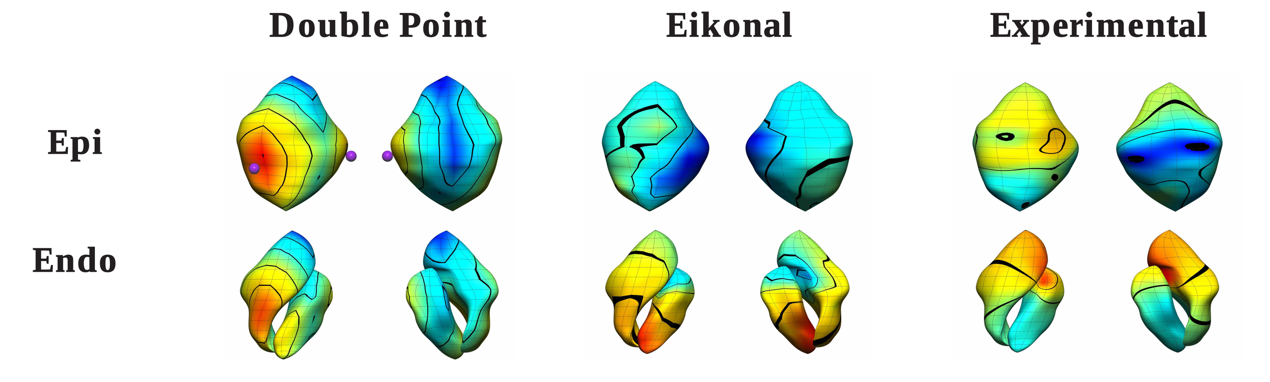
Generic porcine torso model containing six boundary element regions.



Cardiac Sources

Three distinct cardiac sources where used in an attempt to better understand the performance of the inverse procedures. They include activation fields derived from:

- initial activation seed points representing ectopic focii.
- an eikonal equation model of myocardial activation wavefront [6].
- experimental epicardial sock measurements [5].



The three cardiac sources (double point, eikonal and experimental) used as input for the inverse simulations

Experimental & Modelling Errors

Errors from experimental and modelling errors can be grouped into three main areas

- Geometric Errors: relative positions/sizes of heart and torso
- Material Property Errors: electrical conductivities and the transmembrane potential jump
- Signal Errors: correlated errors and Gaussian electrical noise

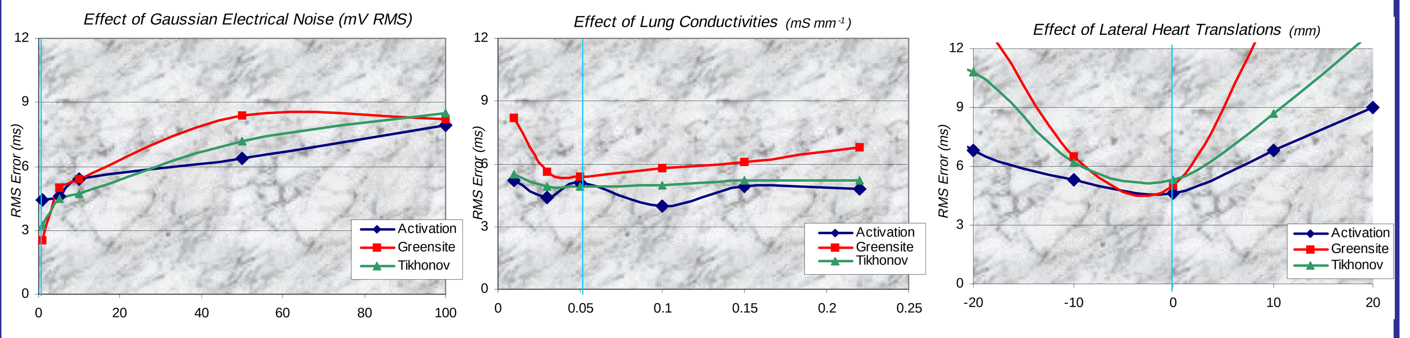
Effect of Individual Errors

- Errors were examined individually by perturbing the signal data, transfer matrix or material properties by a known amount.
- The relative positions and sizes of the heart and torso, material properties of the lungs and torso surface signals corrupted with correlated and uncorrelated noise.

Effect of Combined Errors

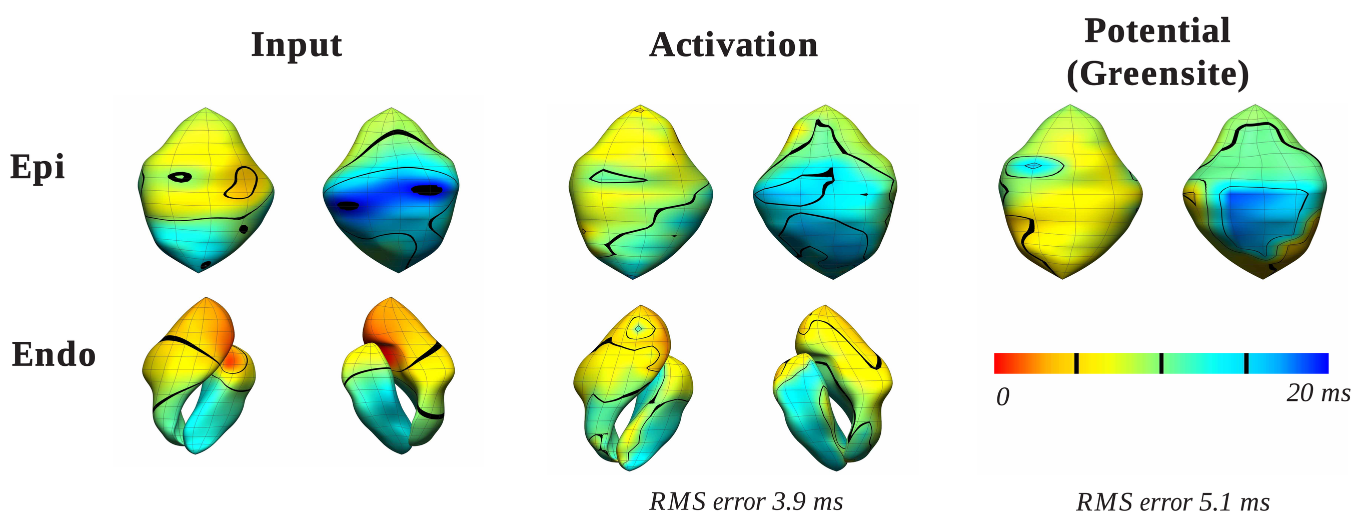
Typical errors which could be encountered in a clinical or experimental situation were obtained by combining a number of individual errors (heart translation, heart rotation, electrode displacement, electrical noise, etc.).

Effect of Individual Errors with Double Point Cardiac Source



Effect of Gaussian electrical noise, lung conductivities and lateral heart translations on activation, Greensite and Tikhonov inverse solutions

Effect of Typical Errors with an Experimentally Derived Cardiac Source



Anterior and posterior views of the input, activation based and potential based inverse solutions displayed as activation fields on the epicardial and endocardial surfaces. The potential based approach used Greensites method with the regularisation parameter determined using the zero-crossing method.

Conclusions

- The activation based formulation was more stable than all the potential based approaches when any error was introduced into the system.
- The preferred epicardial potential approach was Greensite's method which regularized both in the temporal and spatial domains.
- The relative size and position of the heart and torso had the largest effect on inverse solutions.
- The material properties had negligible effect on the computed solutions.

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, pp. 96–111, 1997.

2 F Greensite and G Huiskamp. "An improved method for estimating epicardial potentials from the body surface", *IEEE Trans. Biomed. Eng.*, 45:98–104, January 1998.

3 G Huiskamp and F Greensite. "A new method for myocardial activation imaging", *IEEE Trans. Biomed. Eng.*, 44:433–446, 1997.

4 P R Johnston and R M Gulrajani. "A new method for regularization parameter determination in the inverse problem of electocardiography", *IEEE Trans. Biomed. Eng.*, 44(1):19–39, January 1997.

5 M P Nash, C P Bradley, L K Cheng, A J Pullan and D J Paterson. "An *in-vivo* experimental-computational framework for validating ECG inverse methods", *Intl. J. Bioelectromagnetism*, 2(2), September 2000.

6 K A Tomlinson, A J Pullan and P J Hunter. "Modeling mycardial excitation wavefront propagation in ventricles by finite element solution of an eikonal equation.", In *Proceedings of the First Joint Meeting of BMES & IEEE/EMBS*, page 192, Atlanta, GA, October 1999.