Non-Invasive Electrical Imaging of Heart: 3D Ultrasound based Heart Surface Reconstruction for Patient Specific Approach

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Abstract—**The objective of the present work is to develop a technique to make non invasive electrical imaging of heart (NEIH), as a routine clinical practice. NEIH gives the electrical activity of heart by reconstructing maps of epicardial potentials from measured body surface potentials. A new method is developed in which heart surface is reconstructed from 3D ultrasound data acquired from apical four chamber view. 2D images are then obtained from the 3D volume data. Segmentation is done manually by selecting the region of interest from 2D images. The heart surface is constructed from the segmented images by iso-surface extraction. Geometrical dimension is calibrated by computing a transformation between ultrasound wave depth and images in pixels/cm. Two heart surfaces are reconstructed, one for systolic the other for diastolic condition. The results demonstrate the feasibility of constructing dynamic patient specific model for use in NEIH.**

Keywords— **Electrical imaging of heart, epicardial potential, patient specific model**

I. Introduction

Non Invasive electrical imaging is an imaging modality whose goal is to display and interpret the electrical activity of the heart via measurements of the electrical potentials made on the body surface. In order to reconstruct epicardial maps from body surface maps both forward and inverse problems is solved for geometrical model of the torso volume[1][2][3]. The forward transfer matrix computed by solving the forward problem contains the geometrical and the conductivity information of the model. The accuracy of the reconstructed epicardial potential map is dependent on the forward transfer matrix and inverse method used.

The creation of a high quality model which includes all tissue regions with respective conductivities is a complex and time consuming procedure. The effect of using a homogeneous model is only on the magnitude values of potentials, but the topography of potentials remains the same. The geometrical error in the model has adverse effects on the computed potential maps. Hence a dynamic and patient specific geometrical model is required for exact computation of potential maps[4]. For a homogeneous patient specific model, the heart surface and body surface geometries only are required. This paper addresses the method for constructing a dynamic patient specific heart surface model from 3D ultrasound.

II. Methods

1) *Forward Problem*: Electrocardiographic forward problem in terms of epicardial sources is represented as

$$\nabla \cdot \sigma (\nabla \Phi) = 0 \quad \text{in } \Omega \tag{1}$$

$$\Phi = \Phi_0 \quad \text{on } \Gamma_E \tag{2}$$

$$(\sigma \nabla \Phi) \cdot n = 0 \quad \text{on } \Gamma_T \tag{3}$$

Where:

Φ_0 = electric potential on the epicardial surface boundary,

ΓE = boundary at the epicardial surface, and

ΓT= boundary at the torso surface [5][6][7].

2) *Data acquisition*: 3D US heart is captured using a 3D probe with Philips SONOS 7500 system for a 25 year old subject. 3D data is acquired for 15-20 seconds by aiming the heart for apical four chamber view. The acquired data is a rectangular volume which shows the 2D motion of heart when it is cut along any plane. The whole rectangular volume is sliced at equal intervals into 60 slices; each slice is a 2D movie file and is stored for further processing. Then every 2D movie lasting 3 seconds is separated into separate frames, with a frame rate of 30 frames per second which results in 24 frames per cardiac cycle. These frames are the images of heart at various instant of cardiac cycle. The images corresponding to the systolic and diastolic conditions is shown in Figs 1 and 2.

3) *Segmentation and surface reconstruction*: A systolic image and a diastolic image is selected from the set of images obtained for a particular 2D slice of movie. The images are selected manually guided by the cardiac cycle information available in each image. Also the interval between the systolic and diastolic image is kept constant in terms of number of frames in between the two images. With this two set of stacked images representing the volume is obtained. The heart is segmented from each image by region of interest processing done manually as shown in Fig 3. Then iso-surface is extracted from the segmented image set to form a heart surface mesh.

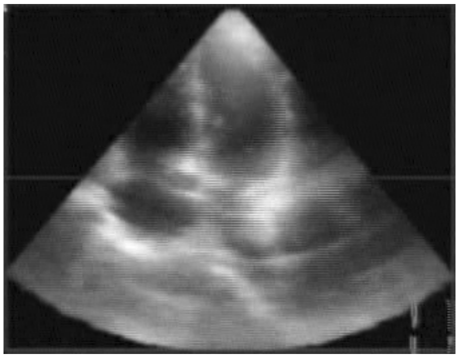

Fig 1. Ultrasound image of heart, systolic condition.

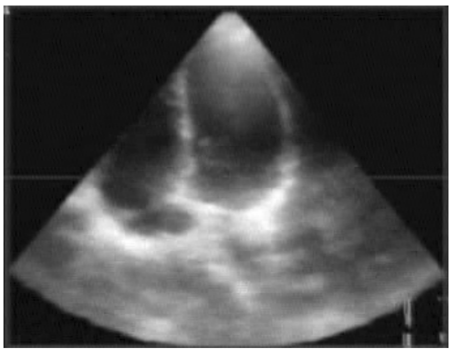

Fig.2.Ultrasound image of heart, diastolic condition

4) *Simulations*: Equation (1) along with (2) and (3) is solved by Finite Element Method[8][9]. Two finite element models are constructed from the heart surface and body surface mesh data. The body surface mesh data is available with SCIRun dataset [10]. Tetrahedral mesh is generated within the volume bounded by the two surfaces using the mesh generation software TetGen. Forward problem is solved for both the models using SCIRun with same set of epicardial map for both heart surfaces.

III. RESULTS

The heart surface was reconstructed from segmented images. Fig 4 shows the reconstructed placed inside the body surface mesh. Two models are considered for simulation, model 1 with heart surface reconstructed from systolic image set and model 2 with heart surface obtained from diastolic image set. Forward problem results are shown in Figs 5 and 6.

IV. DISCUSSION

Fig 1 and 2 shows the feasibility of segmenting heart surface from 3D US images, also the change in geometry of the heart from systole to diastole is seen clearly. This change in geometry demands the requirement of dynamic patient

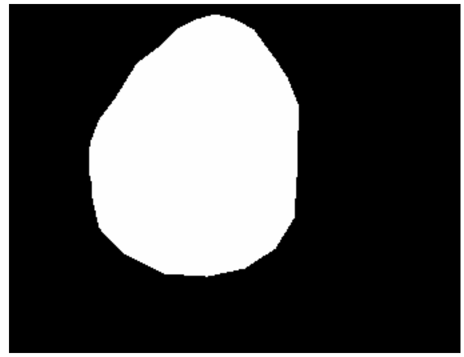

Fig 3. Region of interest segmented image.

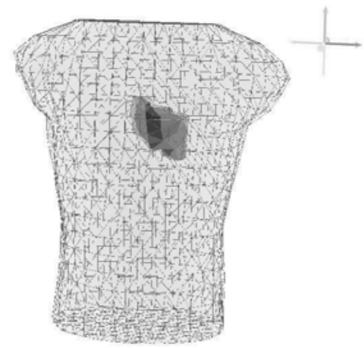

Fig 4. Reconstructed heart placed within the body surface

Fig 5. Body surface potential map computed with model 1.

Fig 6. Body surface potential map computed with model 2

specific model. Fig 5 and 6 shows the difference in body surface potential map due to the change in heart geometry. The quantitative analysis of the accuracy of reconstruction is difficult because complete automatic segmentation is not available and error incurred due to manual segmentation is unavoidable.

V. Conclusion

Patient specific models can be constructed from heart surface reconstructed by the proposed method and body surface reconstructed using stereovision technique.

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References

[1] D.H.Brooks,R.S. MacLeod, R.S: (1994) Imaging the electrical activity of the heart: direct and inverse approaches, *Proceedings. ICIP-94., IEEE International Conference,* 3,548-552.

[2] R.M.Gulrajani, R. M: (1998) The forward and inverse problems of electrocardiography, *IEEE Engineering in Medicine and Biology.,* September/October, 84-101.

[3] R.M.Gulrajani: (1997) The forward problem of electrocardiography: from heart models to body surface potentials, *Proceedings of the 19th Annual International Conference of the IEEE*, 6, 2604 -2609

[4] N.K.Suresh Kumar, M Ramasubba Reddy:(2004) Non-invasive Elelectrical imaging of heart – a patient specific approach, *International Journal of Bioelectromagnetism*, Vol 6, No 1

[5] Jaakko Malmivuo, Robert Plonsey: Bioelectromagnetism, Oxford University Press, New York, 1995, chapter 7
[6] Robert plonsey: Bioelectric phenomena, McGraw-Hill Book Company, New York, 1969, Chapter 5.

[7] J.D.Bronzino,: Biomedical Engineering Handbook, CRC Press, 1999, Chapter 9.

[8] R.S.MacLeod, C. R. Johnson and P.R. Ershler: (1991) Construction of an inhomogeneous model of the human torso for use in computational electrocardiography, Proceedings *of the Annual International Conference of the IEEE,* 13,688-689.

[9] C.R.Johnson, R.S. MacLeod: (1991) Computer models for calculating transthoracic current flow, *Proceedings of the Annual International Conference of the IEEE,* 13,768-769.

[10] SCIRun: A Scientific Computing Problem Solving Environment. Scientific Computing and Imaging Institute (SCI), http://software.sci.utah.edu/scirun.html, 2002.