Total Cardiac Vector Reconstructor (TCVR)

A reconstruction algorithm to compute the path of the current density of the heart using EIT and ECG data

Christopher Wilcox

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1 Introduction

The primary purpose of this project is to reconstruct the path of the Total Cardiac Vector (TCV) using the ACT 5 Electrical Impedance Tomography (EIT) system. This system collects both EIT and Electrocardiography (ECG) data which will both be utilitized in the reconstruction. The TCV is defined to be the integral of the current density of the heart governed by the cardiac cycle, $J^H(\vec{x}, t)$, over the heart region H when $J^H(\vec{x}, t)$ is defined as the series of K dipoles originating at points $\{\vec{Q}_k\}_{k=1}^K$:

$$J^H(\vec{x}, t) = \sum_{k=1}^{K} \vec{m}_k(t)\delta(\vec{x} - \vec{Q}_k) \tag{1.1}$$

The TCV, denoted by $\vec{M}(t)$ is mathematically defined as:

$$\vec{M}(t) := \int_H J^H(\vec{x}, t)dH \tag{1.2}$$

2 Project Description

The reconstruction algorithm works by taking the measured ECG and EIT voltages measured on a set of L electrodes by the ACT 5 EIT system. Using the measured ECG voltages, $\vec{V}(t)$, the TCV is reconstructed by minimizing the l2 error norm between the measured voltages and predicted voltages, $U(t; \sigma_0(t))$, generated using the Finite Element Method (FEM) by simulating forward data on the elementary basis vectors in $\mathbb{R}^3$:

$$E(\vec{M}) = ||\vec{U}(t) - \vec{V}||_2 \tag{2.1}$$

The predicted voltages, $\vec{U}_0$, is the resulting vector of the mapping G, that takes the source $\vec{M}(t)$ to the voltages, $\vec{U}(t)$. The columns of G are computed by simulating ECG voltages from a dipole of unit magnitude pointed in the elementary basis vectors. Using the measured EIT voltages, the conductivity is reconstructed at each sample and used in the algorithm to improve the accuracy of the reconstructor. The algorithm is written in Matlab and the FEM is solved using piecewise linear basis functions. Some issues to the project included the ability to quickly compute the dipole source origin as well as quickly simulate forward data using a variable conductivity distribution. As this project is updated, these challenges will be addressed.

3 How to Use

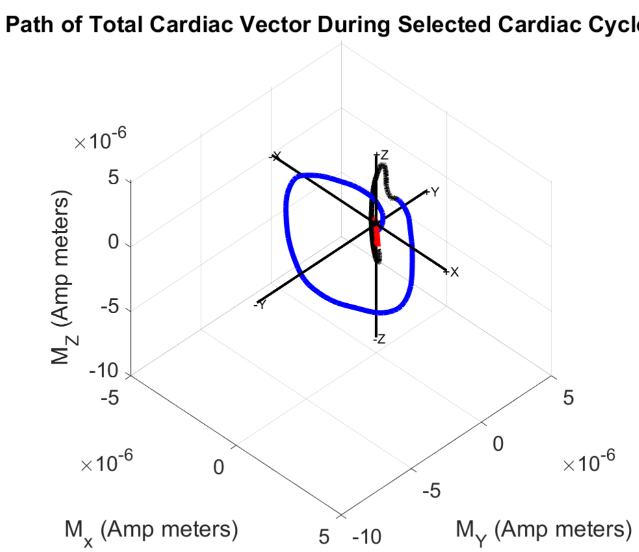
The main program of this project is TCVR.mat. To run this file, the supplemental files provided in the include folder are needed. These include the files needed to construct the source to voltage map, G, using the Finite Element Method and determine the dipole source origin. The ECG data needs to be filtered before using with this reconstruction algorithm. This is done by the file FilterECGData.mat using an Adaptive Filter Algorithm implemented by Nilton Barbosa da Rosa Jr. at Colorado State University. When using this algorithm with EIT data, the ToDLeR conductivity reconstruction algorithm is used to reconstruct the piecewise constant conductivity using the assumption that the conductivity does not vary from a constant by a large amount. The file that uses this algorithm is fTodler_act5.mat and has multiple dependent files found in the folder Todler_Human_ACT5. There are currently two methods of using the conductivity returned by the ToDLeR algorithm, one is to use the best fit constant conductivity fitted to the EIT data and the other is to use the variable conductivity projected from the Joshua Tree mesh to the FEM mesh used in the simulations. The first option, the constant conductivity that changes over time, is currently much faster than the variable conductivity. For the set of EIT voltages over the set of L electrodes, $\{\vec{V}^{(k)}_{EIT}\}_{k=1}^{L-1}$, this conductivity is found using:

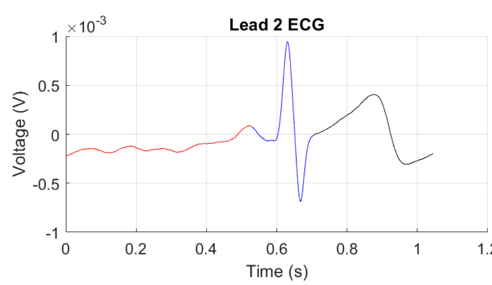
$$\sigma_0 = \frac{\sum_{k=1}^{L-1}\sum_{l=1}^{L}[U_l^k(1)]^2}{\sum_{k=1}^{L-1}\sum_{l=1}^{L}[V_l^k(\sigma)U_l^k(1)]} \tag{3.1}$$

where $\{\vec{U}^k(\sigma_0)\}_{k=1}^{L-1}$ is the set of predicted voltages from the set of applied current patterns on a tank of homogenous conductivity, σ_0. It is easily shown that for

4 Sample Output

Below is the results from a healthy adult male. The plot on the left shows the path of the Total Cardiac Vector pointing outward from the dipole source with the axes aligning with this point as the origin. The plot on the right shows the approximated lead 2 Electrocardiogram.





5 Credits

The ACT 5 system was produced by Ahmed Abdelwahab, Omid Rajabi Shishvan, and Gary Saulnier at the State University of New York at Albany. The human subject data was taken by Nilton Barbosa da Rosa Jr. and Jennifer Mueller in association with Colorado State University. This project is a result of my PhD thesis "Linearized Conductivity Reconstructions and ECG Imaging" under the supervision of Dr. David Isaacson at Rensselaer Polytechnic Institute.