A Pipeline for Generating Physiological Volumetric ECG Signals

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Introduction

Simulation of electrocardiographic signals from normal and pathophysiological hearts presents a new opportunity to meet a growing demand in research and device development. The demand arises from clinically motivated research and commercial device development to improve detection and localization of, for example, regions of ischemia, abnormal conduction, or arrhythmic substrate. The challenge arises due to limited access, especially to measured intracardiac and torso volume potentials in both humans and animal models. Accurate simulation can fill in these missing gaps, leveraging the measured data that are actually available as well as information from noninvasive imaging techniques to create highly realistic and flexible models.

We have developed a complete pipeline of algorithms and software tools to generate electrocardiographic data in human torso geometries for use in a variety of applications. Our pipeline for cardiac arrhythmia potential simulation (*caps*) makes use of our database of animal experiments [1] by inserting the cardiac geometry and potential data into our human torso geometries [2] and simulating potentials with the Fwd/Inv Toolkit in SCIRun [3]. This modular approach allows for combining data from animal recordings and patient geometries, increasing the amount of data that can be generated.

Using the *caps* pipeline, we combined experimental animal recordings with human geometries to create clinically relevant data in any location of the torso. We created volumetric recording demonstrating arrhythmias in human torsos. These sample data and others generated show that the *caps* can be used to generate realistic torso potential signals, especially those generated by arrhythmias.

Methods

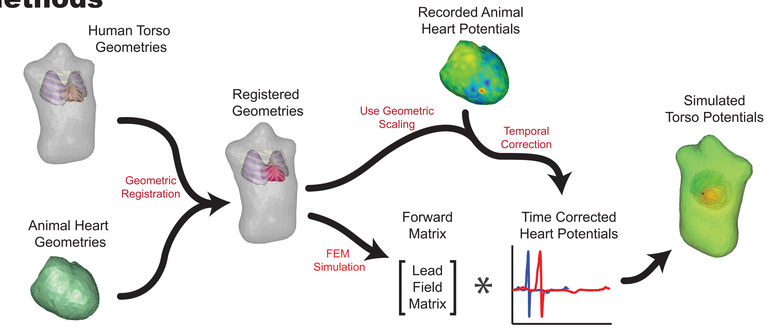

Figure 1. Diagram of the *caps* pipeline for generating volumetric ECGs in human torsos. *caps* combines a database of animal heart data with a database of human torso geometries to generated large amounts of electrograms data in human geometries. The combination involves geometric registration, temporal correction for changes in conduction velocities, and simulation of the forward problem using the Fwd/Inv Toolkit.

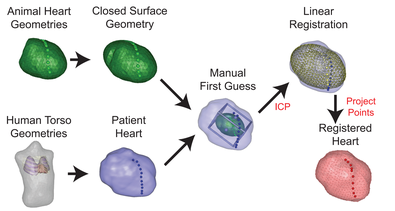

Figure 2. Registration of the experimental heart geometries to the human torso geometries used in the *caps* pipeline. For geometric registration, a modified iterative closest point (ICP) registration with an interactive first guess is used to register the heart geometries, then the electrode locations are projected onto the human hearts.

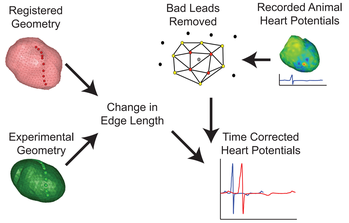

Figure 3. Temporal correction of the time signals used in the *caps* pipeline to mitigate electrical changes due to geometric changes, such as conduction velocity. The temporal correction is based on the change in the edge lengths of the geometry as it is registered to the human torsos. The difference is used to determine the sampling factor for the time signals after bad leads are corrected.

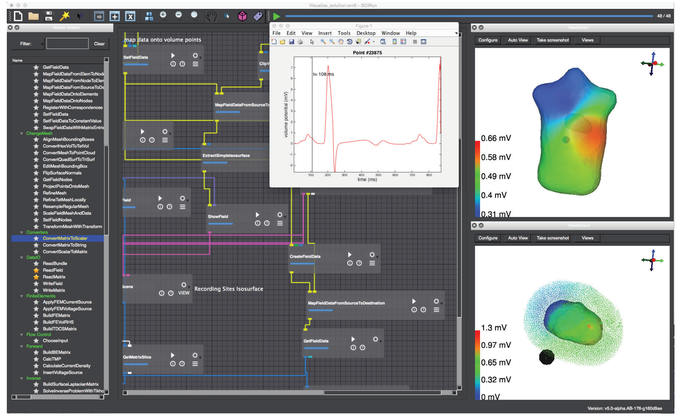

Figure 4. Illustration of the use and output of the *caps* pipeline. The pipeline brings together various data types, software, and algorithms, allowing for many kinds of data to be created. The use of SCIRun and other CIBC software allows various stages of the pipeline to be interactive, as shown here with an interactive simulated probe (far right).

Results

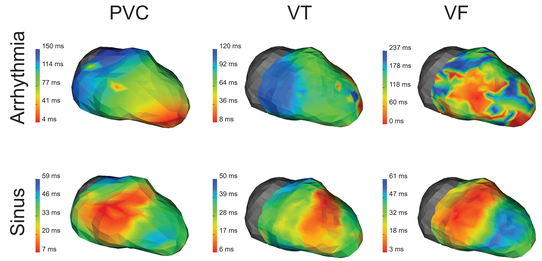

Figure 5. Activation maps from example animal experiments registered to a patient geometry. Top row shows the activation map for an arrhythmia, and the bottom row shows the sinus beat activation profile. The sinus activation is fairly consistent across experiments. Each column is a different arrhythmia. There is a greater difference when comparing to human activation, but the qualitative comparison is still similar [4]. The arrhythmia activation profiles match physiologically expected profiles and are similar to those generated from ECGSim for PVC and VT [5].

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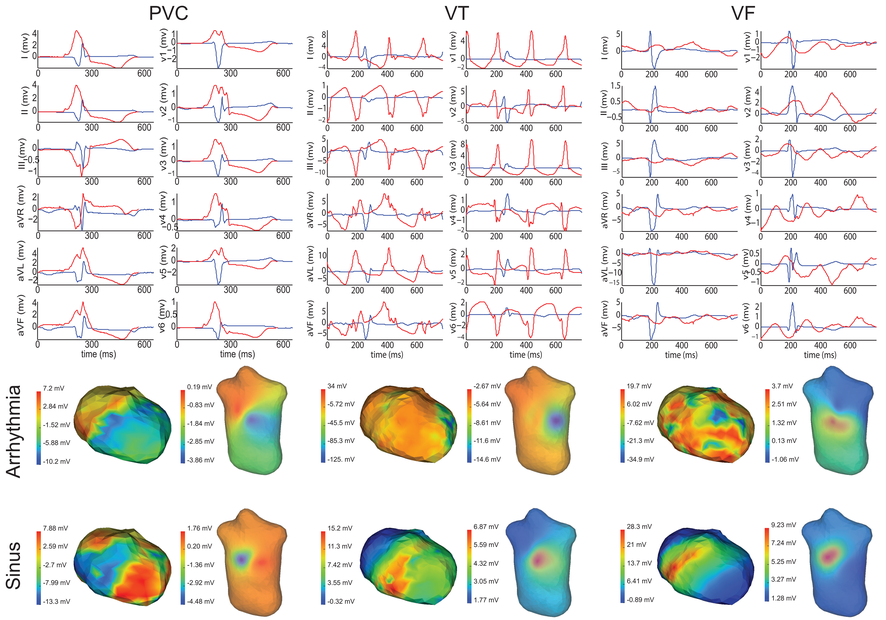

Figure 6. Example ECG recordings and potential maps generated by the *caps* pipeline. Three arrhythmias from three separate animal subjects are shown with their corresponding normal sinus beat data. Time signals are the standard 12 ECG calculated from the collected cardiac data, blue tracings are sinus rhythm, and red tracings are arrhythmia recordings. The potential maps show potential field on the surface of the heart and torso at the peak of the QRS for the normal sinus rhythm and the arrhythmia.

Discussion

The *caps* pipeline can generate much more data by combining animal cardiac recordings with human torso geometry. The results of the pipeline are realistic signals that are comparable to corresponding signals in humans patients.

- In addition to preserving a physiologically consistent conduction velocity, our temporal correction steps help to produce human like timing in the ECG signals.
  - Mean QRS duration of 76 +/- 2 ms for each of the datasets test. The QRS duration recorded from the animal experiments was 43.8 +/- 0.6 ms.
  - Mean QT intervals was 310 +/- 10ms. The QT unterval recorded from the animal experiments was 175 +/- 8 ms.
- Differences in temporal and spatial profiles are likely due to experimental intervention and geometric reconstruction errors.
  - Comparing the morphologies of the sinus rhythm data show similarities to those observed clinically, though there are some noticeable differences, particularly in the limb leads, and some fractionations in some ECG recordings.
  - The potential maps of the sinus rhythm provide suggest that the activation profile is slightly different during the QRS, but also in profiles with each other and compared to human data [4].
- The arrhythmia time signals demonstrate profiles that are qualitatively similar to humans for the provided arrhythmia, as do the potential maps.

Our results show that it is possible to create ECG data that are similar to human arrhythmias from animal cardiac recordings. We showed that PVCs, VT, and VF can be recreated using the *caps* pipeline. We can simulate electrocardiographic fields from ischemia, AV node blocks, and bundle branch block, and other arrhythmias. Using simulated electrocardiographic data, we can generate more volumetric torso recordings than through experimentation alone, including recordings from locations which are otherwise impossible, and can be mapped to differing species with promising results. With the *caps* pipeline, we can provide data needed to improve detection and location, and thus treatment for many cardiac disorders.