

A VIRTUAL REALITY ELECTROCARDIOGRAPHY TEACHING TOOL

John Ryan

Image Synthesis Group
Computer Science Dept.
Trinity College Dublin
Dublin 2, Ireland
john.t.ryan@cs.tcd.ie

Carol O'Sullivan

Image Synthesis Group
Computer Science Dept.
Trinity College Dublin
Dublin 2, Ireland
osullica@tcd.ie

Christopher Bell

Physiology Dept.
Trinity College Dublin
Dublin 2, Ireland
cbell@tcd.ie

Robert Mooney

Image Synthesis Group
Computer Science Dept.
Trinity College Dublin
Dublin 2, Ireland
rmooney@tcd.ie

ABSTRACT

We present a novel approach to producing a tool for use in the teaching of electrocardiography. A volumetric model is attained by outputting slice information to image files, which are then used to texture polygons in the reconstruction of the volume. A time-stepping algorithm is used to synchronise the playback of the electrical depolarisation and repolarisation cycles of the heart on both the 3D cardiac model and 2D ECG graph. The tool is currently being integrated into undergraduate physiology modules.

Key Words: ECG, Virtual Reality, ECG simulation, cardiac modelling, texture-based volume

Introduction

With the advent of 3D graphics and virtual reality technology, along with a steady increase in capabilities and decrease in cost, realistic models and simulations are becoming commonplace in both the teaching and practice of medicine. Surgical training is an area where VR is very useful. The main principle behind VR training in medicine is that the patient's safety is not jeopardised while the trainee develops the necessary skills to cope with real life procedures as well as real surgery. Kennedy et al. [1] developed a robotic alternative to mechanical stabilisers in coronary artery bypass grafts (CABG's) using graphics and haptics. VR is very useful in teaching anatomy, physiology and pathology because of its multi-dimensional nature giving the student a greater sense of spatial awareness. 3D teaching tools pose some advantages over tools of a 2D nature. Animation, interaction, audio narration and volume representation are obvious advantages over 2D images. Interactivity is a key feature for a VR teaching tool making the student the active participant in the learning process.

In 1902 a Dutch physician and physicist called Willem Einthoven invented the electrocardiograph (ECG). The output of the ECG is a set of two-dimensional waveforms that represent the electrical activity in the heart over time. Each part of the wave shows the different parts of the heart's electrical cycle. Figure 1. shows an ECG that is currently used in our software.

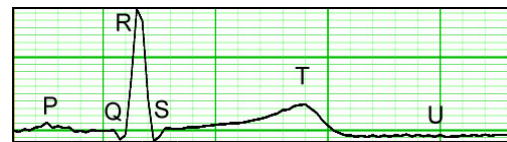


Figure 1. ECG

The above ECG is lead II in a typical 3 lead standard setup. In standard clinical practice there are 12 leads: 3 standard leads, 3 augmented leads and 6 precordial leads. ECG is based on an electrical current travelling from the negative node to the positive node of a bipolar electrode. This causes a positive deflection around the isoelectric line by the lead. The original three-lead bipolar electrode pair setup was first used by the inventor of ECG, Einthoven. It is still referred to as Einthoven's Triangle. Figure 2 demonstrates this.

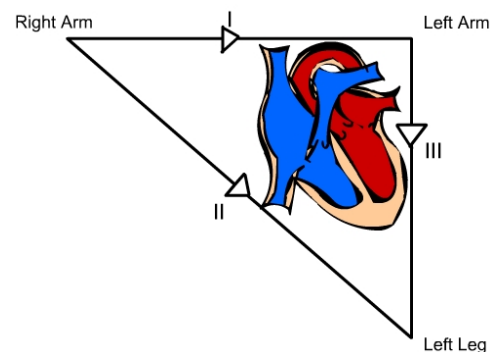


Figure 2. Einthoven's Triangle

There are several research institutes interested in the representation of the heart through virtual reality. Some of these researchers use super-computers for cardiac simulation [2]. CESLab [3] is an ongoing project based on commodity Apple Macintosh computers combining, an interactive user environment with a high level of customisability. The environment allows cells to be configured to exhibit physiological defects such as branch blocks.

The area of automatic ECG interpretation and pattern recognition has been researched since the 1950's [4] and is still in progress. It is a huge area and comprises of two main disciplines. The first area of interest is pattern recognition and parameter measurement and the second is the utilisation of these results to interpret the ECG. Unfortunately, the first task is the most complex with several problematic areas. The most important part of the ECG wave is the ORS complex. The QRS complex is a waveform that correlates to the electrical flow through the bundle branches, from which heart-rate and many other parameters can be measured. Köhler et al [5] reviewed several different QRS detection algorithms and found it difficult to recommend any single one. Some of the best algorithms required significantly more computation time and resources and therefore scored less in these fields. There are many different options including algorithms from fields such as artificial neural networks [6], genetic algorithms [7], wavelet transforms [8] and more recently there have been hybrid algorithms proposed for interpreting ECG data. Tataru and Cinar [9] discuss a method of interpreting ECG data by integrating statistical and artificial intelligence tools. They found that their method reduced the amount of information that practitioners needed to process in time-critical scenarios.

Model and ECG Data Acquisition

The initial polygonal cardiac model used in the system was created in New York University's School of Medicine. The model was designed through collaboration between consultant cardiologists and graphical designers for the specific purposes of interactive learning and VR teaching aids. However, in its initial state it was unsuitable for use within our system since it lacked many of the important features in the heart's electrical network i.e. SA node, AV node, left and right bundle branches. The SA node and AV node were added to the polygonal model using a commercial editor and were each represented by a single spherical primitive. Surface representations for the bundle branches and Purkinje network were also added at this stage. However, the creation of a necessarily dense Purkinje network proved too cumbersome. Furthermore, volumization of such a fine-featured network is not possible on anything other than high-resolution volume lattices. Therefore, the

bundle branches and purkinje system were later replaced by translating texture maps into 3D.

The ECG data used in this teaching tool was attained by monitoring one of the staff members in the department. This ECG was free from any pathologies and was obtained using the standard 12 lead configuration.

Textured Slice Model Volumization

A pilot version of this project used actual points/cubes to represent each voxel within the volume [10]. This, however, was too processor-intensive, so a simpler volume representation needed to be developed. Instead of having a volume made up of voxels representing groups of cells, 100 textured quads made up of 256 x 256 images are used. In order to attain the image information for each textured quad, a short viewing field was used along with an orthographic projection of the model and this image information was outputted to an image file. Most of the colour information was extracted leaving two possible colours (blank cells and myocardial cells). The non-myocardial pixels have a zero alpha value. Figures 3, 4 and 5 show this process.

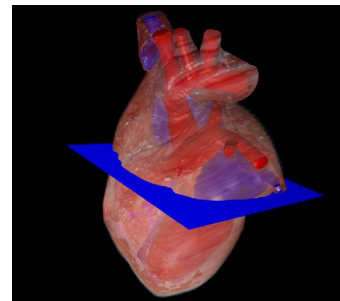


Figure 3. Location of viewing plane.

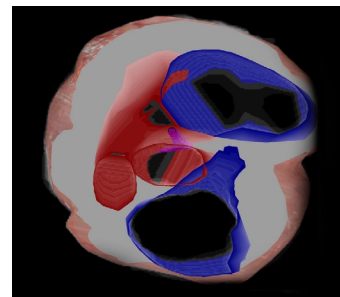


Figure 4 Slice as viewed in opengl window.

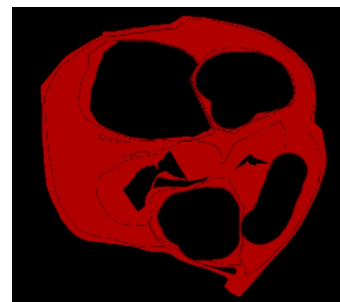


Figure 5. Typical slice with dual colour representation.

The model's volume information is then reconstructed by displaying each slice in the same orientation as the original image along the bounding box axis. There are several advantages with using the technique. Firstly, the main advantage is speed. Because there are no precomputations the program loads instantly, and also leaves extra scope for the processing of ECG data. There is also a graphical advantage. The volume looks more uniform and less "blocky". Another advantage is that by using this kind of volume representation, graphics hardware may be exploited to take some of the processing workload. At the moment, the area of graphics hardware seems to be developing quickly. After approximately 20 minutes of precomputations the earlier model displayed at a frame rate as slow as 2 fps (frames per second). However, our new application runs with real-time computations at approximately 12 fps. Figures 6 and 7 show the graphical difference between the earlier volumetric technique and our new technique.

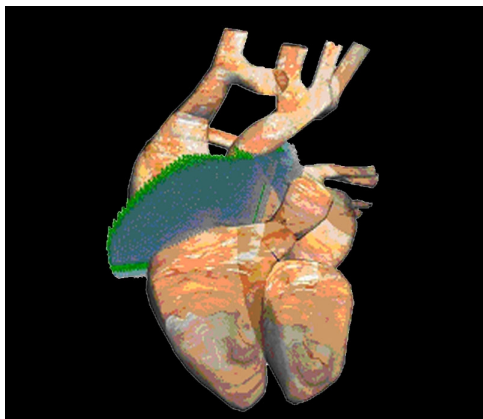


Figure 6. *Voxel per group of cells*

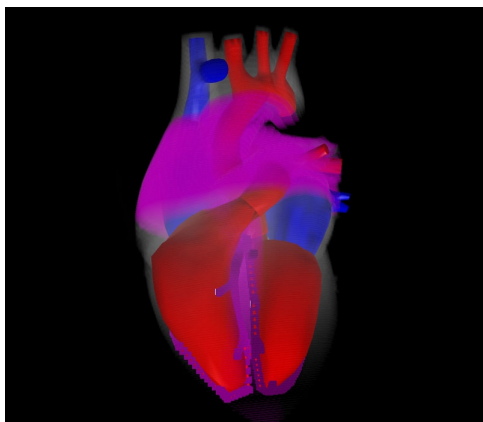


Figure 7. *Textured slices*

The first heart model generally had a nearest-neighbour isotropic spread algorithm for displaying the depolarisation and repolarisation phases. However, this method required a lot of pre-computation, which was not ideal for the system's usability. We found that, by representing the same isotropic spread with a database of differently positioned and sized circles, a similar if not better visual result was achieved, while saving valuable time and resources. This does not take fibre orientations and ventricular anisotropy into account, but does achieve a simple and effective way of representing the cardiac electrical cycle. With standard commodity PC's in mind, compromises on detail need to be made and so far this seems to be the best method.

OpenGL is a library of functions that enables stable cross-platform 3D rendering and is used as the primary display system for this project. Along with the normal volumetric activation within the ventricles it was decided to make use of the bundle branch meshes in the demonstration of ventricular depolarisation. OpenGL points were added to each vertex of each triangle. However, there were several obstacles in getting a smooth progression. Firstly, the mesh was not listed from the top to the outer edges, which meant that a reorganisation of the mesh was necessary. In order to reorganise these meshes, two algorithms were tried. The first algorithm went through every triangle within the mesh and inputted it into the new mesh if it had a shared vertex with any of the already present triangles. This algorithm proved useless when it was discovered that the mesh had certain flaws and holes. The second algorithm, which is currently in use, traversed through the original mesh and found the nearest neighbouring triangles by averaging each triangle and inputting them into the new mesh array according to their proximity to the last entered triangle. Figure 8 shows a zoomed view of the bundle branches in action.

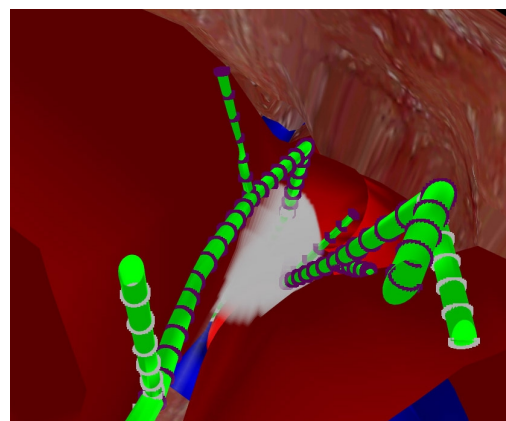


Figure 8. *Bundle Branches looking superiorly from the septal region of the ventricles.*

The synchronisation of the model's animation to the progressing ECG window was another task. This was achieved by time-stepping with the aim of abolishing the need for any hardcoding, therefore enabling the software to read in any ECG file. Figure 9 shows the ECG window with timeline identification markers. Basically, the model's animation speed is determined by the amount of steps from marker to marker. For example, from the R wave marker to the S wave marker the bundle branches and ventricle cells would go from semi depolarised to fully depolarised (with the bundle branches leading) and the atrial cells would be repolarising in the same time.

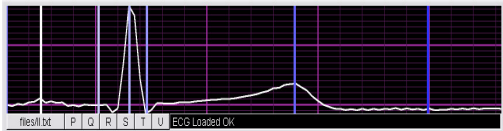


Figure 9. ECG window with markers

There were several additions to the software to prepare for future aims. One of these was the implementation of a full-screen mode from the original GUI (Graphical User Interface) based FLTK (library) mode. This will make the implementation of a stereoscopic viewing mode relatively trouble-free.

In the current system there are preset ECG waveforms with predefined wave markers. Although, more recently these wave definitions or landmarks are becoming automated. The wave markers allow the system to configure the amount of frames necessary to get from landmark to landmark, thus synchronising the VR model with the progressing ECG window.

Conclusions & Future Work

A very useful tool has been developed to aid the teaching of electrocardiography. The 3D volumetric model gives the user a greater sense of spatial awareness along with a real-time synchronised animation of the progressing ECG. This system will act as a foundation for the next stage of the project. This next diagnostic phase will involve the implementation of automatic ECG recognition and detection algorithms in the aim of automatic representation of myocardial infarctions. At the moment the current application is being beta tested by incorporating it as part of the physiology course for medical and paramedical students in the University of Dublin.

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