Vectorcardiogram eLearning Application

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Abstract

In this paper we present educational application illustrating vectorcardiogram and its relation to the heart cycle and recorded ECG signals. In contrast to commonly used visualizations of the ECG signal, 3D animations of vectorcardiogram are not frequently used. The vectorial analysis is important for understanding link between the cardiac abnormalities and the characteristic shapes of the ECG. The vectorcardiogram animation is implemented in Python and based on the publicly available conventional 12 lead ECG signals accompanied with simultaneously measured 3 Frank lead signals. Students can iterate through the signals reviewing temporal change of cardiac vector and ECG vectors of the main limb leads, displaying the QRS, P and T loops per cardiac cycle, and displaying QRS cardiac axes.

Keywords

3D vectorcardiogram • Cardiac cycle • Cardiac axes

1 Introduction

In this paper we present multimedia biomedical educational application illustrating vectorcardiogram and its relations to the heart cycle and the ECG signal. The objective of our research is not to compete with the sophisticated contemporary multimedia and VR applications in medicine, but to describe the solution that can be easily implemented by university students attending biomedical courses and afterwards used as teaching tool both for engineering and medicine students. The vectorial analysis of heart potentials is based on the convention to represent the generated potential of a heart at a particular instant as a summated vector called instantaneous mean vector [1].

The structure of the paper is as follows: the next section provides background information on benefits of eLearning in biomedical education, and of employing multimedia in medicine, including brief overview of highly specialized examples. Section 3 describes the basics of the cardiac cycle, vectorcardiography and the cardiac axes; and discusses the importance in diagnosing heart problems. Last section presents the design and the prototype of the Vectorcardiogram eLearning application and recommendations for the future work.

2 eLearning and Multimedia in Biomedical Education

Understanding the cardiac conduction system, cardiac cycle and principles of measurement and analyses of the ECG is a core competence both for medical and bioengineering professionals. These topics present a good example of the biggest challenge of biomedical engineering (BME) education: the necessity to bring together two demanding fields: biology and engineering and/or math [2].

This is the reason why teaching the BME topics can significantly benefit from using eLearning tools employing multimedia presentation of knowledge units. Visualization and animation of underlying phenomena helps understand spatial and temporal links between anatomic parts, physiological processes and physical quantities.

Unlike general opinion that Virtual Reality (VR) was just recently included in medicine, VR has found its application in medicine much earlier. First, there was Medicine Meets Virtual Reality conference which was held from 1992 [3] until 2016 [4]. In 2018, it grew into Virtual Medicine

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conference [5], broadening the VR application in medicine further. The main reason why is VR so popular now, not just in medicine, but in other fields also, is that now the VR technology has become cheaper and more reliable than before. The most usual application of VR in medicine is in the form of simulations, used for education or as therapy from traumas [6]. Besides surgical simulations, there are many simulations in the field of physiology.

For this paper, VR applications regarding heart are of particular interest. Silva et al. (2018) in their state of the art review [7] give the overview of VR technologies used in cardiovascular medicine. They have concluded that VR is helping with physician's education and performance with better outcomes for the patients. Alongside frameworks and software mentioned in Silva et al. there is also VRLS—VR Learning Studio [8] developed at School of Biomedical Science at the University of Melbourne. Their first project was Virtual Human Heart where an interactive 3D model of the human heart was made in Unity, and the user using the Oculus Rift HMD can hold a beating heart in their hands, disassemble parts, slow down the cycle, can see electrical overlays and physiological readouts. Veliyara (2017) has developed a tool for 3D visualization of cardiac excitation as a part of the educational tool [9].

There are several commercial solutions also like a physiology education system called CyberPhysiology™: SimBioSys™ by Bertas [10]. This system includes realtime simulations, animations, illustrations and quizzes within an interactive environment. For VR representation, the software uses Zspace technology. Another commercial product used for better understanding of the basis for the generation of electrocardiographic waveforms is 3D Heart Instructional Software developed prior for healthcare professionals by ECG-TECH [11]. Apart from educational purposes, there are VR applications in the treatment of patients. Peters et al. (2008) [12] have developed a visualization environment to assist surgeons with therapy delivery inside the beating heart. Gosling et al. (2018) [13] have developed virtual coronary intervention tool that predicts the physiological response to stenting procedure. Gradl et al. (2018) [14] did a user evaluation which visualization of heart activity in VR is the best for the use in virtual environments (VE) for further use in therapy and similar simulations.

3 Heart Axis and Vectorcardiogram

Electrical impulses originate in specialized excitatory and conductive muscle fibers causing depolarization of atrial and ventricular muscle followed by muscle contraction, as a source of power for moving blood through the circulatory system. Opposite to depolarization is the cardiac muscle fibers repolarization, causing muscle relaxation and filling of atria or ventricles with blood. The concept of cardiac vectors and vectorial analysis is important in understanding how cardiac abnormalities affect the characteristic shapes of the ECG chart. The vectorial analysis of heart potentials is based on the convention to represent the generated potential of a heart at a particular instant as a summated vector called instantaneous mean vector [1]. A vector is pointing in the direction of the electrical potential generated by the cardiac current flow, by convention it is in the positive direction. The magnitude of the vector is proportional to the voltage. Vectorcardiography (VCG) is a method of recording the electrical forces that are generated by the heart by means of a continuous series of mean vectors.

Maximum difference of potential is manifested during the depolarization of ventricles and repolarization of atria. The concept of the electric axis of the heart denotes the average direction of the electric activity throughout ventricular activation. The term mean vector is frequently used instead of "electric axis." The direction of the electric axis also denote the instantaneous direction of the cardiac electric vector [15]. Electrical exes can be constructed based on the limb or unipolar augmented ECG leads. The most common approach is to use lead pairs: I and II, or I and aVF.

The orthogonal 3-lead VCG signals records the cardiac electrical activity along axes of the co-ordinate system defined by three orthogonal planes of the body: frontal, transverse, and sagittal. The VCG signals are accordingly projected onto different planes or visualized in a 3D space. A heart cycle is represented by three loops corresponding to P, QRS, and T wave activities [16].

The ability to transform from 12-lead ECG to orthogonal 3-lead VCG and vice versa enables the use of different ECG and VCG recordings for computer visualization and vector analysis. The orthogonal Frank XYZ leads are recognized as best suited for 3-D visualization and computer vector analysis. Early lead transformation studies [17] have shown that it is possible to derive the 12-lead ECG from the Frank XYZ leads. In [18] authors present a statistical approach to transform 3-lead Frank VCG to 12-lead ECG signals and vice versa, and in addition that the transform coefficients can serve as discriminating features for classification/discrimination between healthy and myocardial infarction subjects.

4 Vectorcardiogram Application

Vectorcardiogram application consists of two parts: multimedia animation of cardiac cycle and vectorcardiogram and ECG simultaneous visualization. VR animation of cardiac cycle is accompanied with display of relevant physiological signals: ECG waveforms, continuous blood pressure and blood volume. The application is developed in Python.

We have used the ECG data from the PhysioNet [19] databases: PTB database [20] for 3D visualization and MIMIC II Waveform database [21] for physiological signals.

The PTB Diagnostic ECG Database was provided by the National Metrology Institute of Germany, as a compilation of digitized ECG recordings to be used for research, algorithmic benchmarking and teaching. The database contains 549 records from 290 subjects, each record including 15 simultaneously measured signals: the conventional 12 ECG leads and the 3 Frank lead ECGs (Vx, Vy, Vz). Each signal is digitized with 1000 Hz sampling rate and with 16 bit resolution. Results of the initial analysis of signals performed using MATLAB is presented in Fig. 1. The MATLAB environment enable students of electrical engineering to explore easily features of the signals and select relevant parts of the signal to be animated.

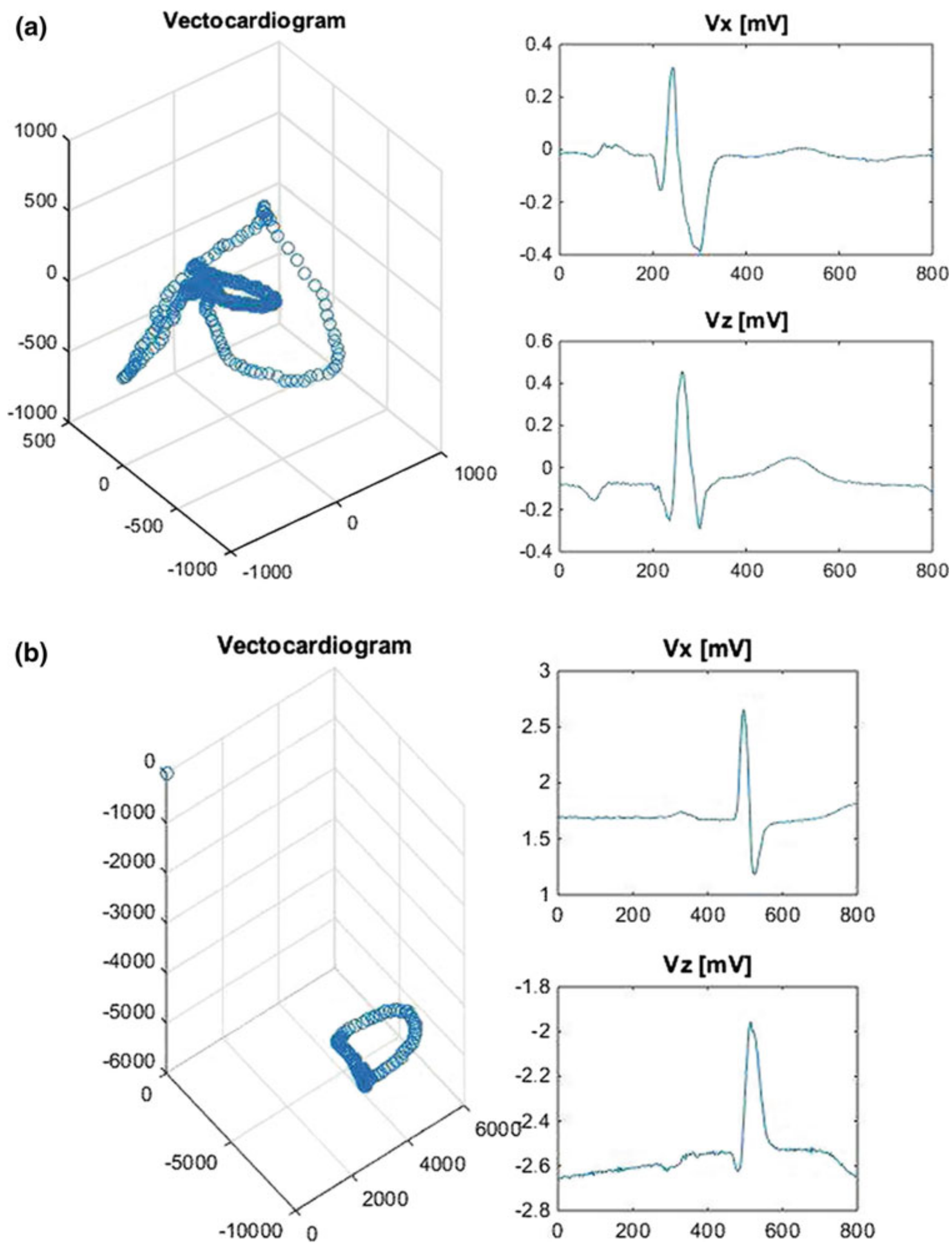

Fig. 1 Vectorcardiogram and Frank leads Vx and Vz visualization in MATLAB: **a** healthy subject signal s00 10re, **b** myocardial infarction patient signal s00431re

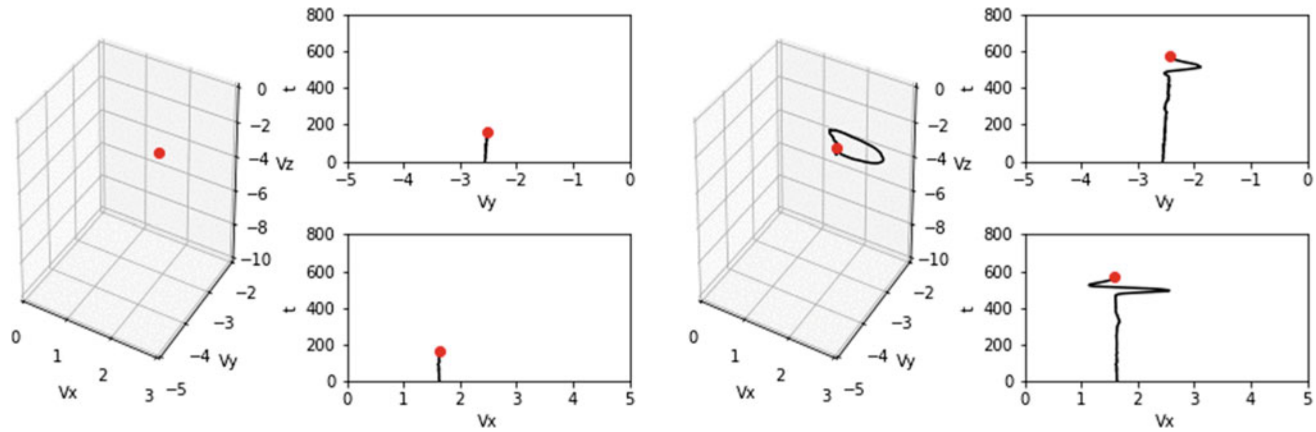

Fig. 2 3D animation screens

The MIMIC II Waveform database signals are digitized with 125 Hz sampling frequency and contains the following signals: ECG waveforms including limb leads and two precordial leads, continuous blood pressure waveforms including invasive arterial blood pressure, left and right atrial pressure, and uncalibrated raw output of fingertip plethysmograph.

Animation of 3D vectorcardiogram is developed in Python 3.7. For simultaneous presentation of the vectorcardiogram 3D loop and 2D animation of the ECG signal plots we based our solution on matplotlib.pyplot and matplotlib. animation.ArtistAnimation [22].

The combined 3D/2D animation can be saved as MP4 video file and GIF animation, and used afterwards as multimedia Learning Object. The illustrative screens of the animation are presented in Fig. 2.

The developed application could be used by electrical engineering and medicine students. While 3D animation of vectorcardiogram is useful demonstration tool for both groups, students of electrical engineering can work on further development and improvements of the application.

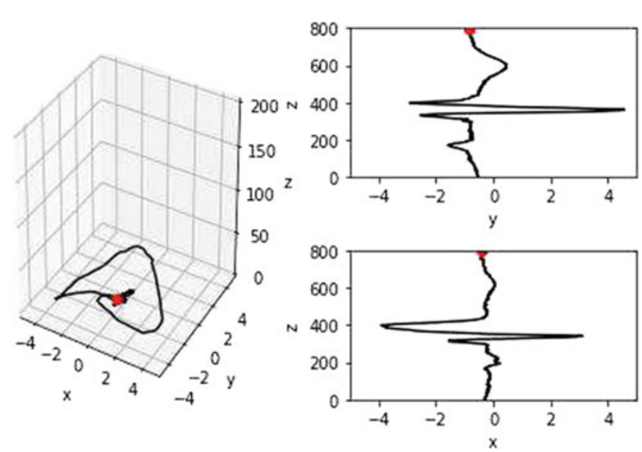

Fig. 3 Vectorcardiogram and Frank leads Vy and Vx animation: healthy subject signal "s00 10re"

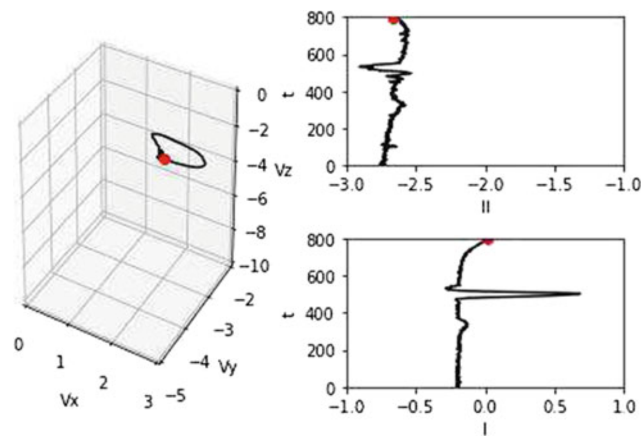

Fig. 4 Vectorcardiogram and limb leads I and II animation: myocardial infarction patient signal "s00431re"

The application is using real clinical measurements and user can select different signals for viewing animations. This can be helpful in linking different ECG waveforms to specific issues in the heart conduction system and different health conditions. This is illustrated by animations of a healthy subject in Fig. 3 (signal "s00 10re") and Myocardial Infarction patient in Fig. 4 (signal "s00431re"). Presented examples are based on signals for the PTB Diagnostic ECG Database [20] from Physionet platform.

5 Conclusion

The proposed Vectorcardiogram application exploit real physiological signals data, while providing fully functional and low cost eLearning tool.

The solution is suitable for illustrating basic principles of cardiac conductivity and cardiac cycle, understanding of the

ECG signal and its relation to cardiac cycle. The application also demonstrates possibility to employ vector analysis in discriminating between healthy subjects and subjects with heart problems.

The future work will enable comparison of transformations between lead systems and include more interactive parts introducing knowledge assessment.

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