Real-time T-Wave Residuum

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Abstract

The recent recognition of prolonged corrected QT electrocardiographic intervals (QTc intervals) in astronauts returning from long-duration space flight as well as premature ventricular contractions (PVCs) while in flight has stimulated NASA to develop software for real-time analysis of the ECGs of astronauts as they prepare for and participate in highly stressful activities.

The T-wave Residuum (TWR) is a new form of T-wave morphology analysis and is one of several techniques proposed for real-time ECG analysis. It examines the repolarization heterogeneity of the individual dipoles in the heart muscles relative to each other. TWR has been cited clinically for its sensitivity and specificity in detecting conditions such as cardiomyopathy and for predicting mortality after myocardial infarction.

A real-time TWR calculates the beat-by-beat T-wave residuum of an ECG and is designed to integrate into the software package, CardioSoft®, used by NASA. CardioSoft® provides the computer interface for a high frequency ECG recorder, as well as ECG record notation, storage, organization, and replay. The T-wave obtained from the 8 channel recordings (I, II, CR1-6) is sampled at 1 KHz and the DC offsets are removed. Singular value decomposition (SVD) is then performed on the array and the TWR calculated from the eigenvalues returned by SVD:

$$TWR = \sum_{i=4}^{8} \rho_i^2 / \sum_{i=1}^{8} \rho_i^2$$

The program plots one user specified channel of data, the current and previous T-wave in the user specified channel, and finally the TWR parameter.

The TWR calculation program will be used to process a variety of clinical patient records to verify its practical relevance.

Introduction

It is well established that the electrocardiogram (ECG) contains much more information about cardiovascular health than traditional electrocardiographic analysis typically recognizes. The ECG has been used for over 100 years, but with the advent of computer technology, many new methods for ECG analysis have been proposed. Because of the recent recognition of prolonged corrected QT electrocardiographic intervals (QTc intervals) in astronauts returning from long-duration space flight[1], NASA is particularly interested in the development of software for real-time analysis of the ECGs of astronauts as they prepare for and participate in highly stressful activities.

Several T-wave analysis methods have been proposed and show much promise for cardiovascular disease risk stratification[2]. The T-wave represents the electrical repolarization of the ventricles.. The process of examining the heterogeneity of ventricular repolarization, known as T-wave morphology analysis, promises to yield much clinically relevant information[3]. The T-wave Residuum (TWR) is a new form of T-wave morphology analysis, and examines the repolarization heterogeneity of the individual dipoles in the heart muscles relative to each other[4].

This project implemented a computerized, real-time, beat-by-beat TWR calculator.

Methods

The TWR program designed in this project was coupled to a commercially available software package called CardioSoft®. CardioSoft® provides the computer interface for a high frequency ECG recorder, as well as ECG record notation, storage, organization, and replay. CardioSoft® sends the original 1000 Hz sampled data from leads I, II and the six CR leads through a named pipe server in 200 ms packets. CR lead voltages are the potentials between the standard precordial electrodes referenced to the right arm electrode instead of the Wilson central terminal.

The TWR program as implemented reads the data from the named pipe server in real time. The data come across as a single dimensional array with 8 interleaved channels. The array is decomposed into a 2D array with 8 channels of 200 ms each. Channel Two data, which represents lead II and typically an upright QRS signal, is then processed through a QRS peak detection algorithm developed by Hamilton et al.[5,6]. This algorithm was developed for 200 Hz data, but is easily modified for 1000 Hz data. The QRS detection algorithm returns the delay in data points of the last QRS peak. Since this is often contained in a previous data array, the two previous arrays are saved. Measuring from the current index backward by the delay time and then forward by a user-specified amount (default 50 ms) gives the approximate beginning of the T-wave. This can be adjusted in real-time. The T-wave from each channel is then copied into another 2D array of 8 channels of 450 ms each. The DC offset of the T-wave is then eliminated by fitting a line 100 ms long to the T-wave starting 250 ms into the T-wave. The line is advanced by 10 ms and refit to the line until the slope of the line is with in $0 \pm .05$. When the slope fits this condition, the y-intercept of the fit line is subtracted from each data point. This process is repeated for each channel to set the baseline of the T-wave approximately on the 0 origin.

When the T-wave is properly captured and the DC offset eliminated, singular value decomposition (SVD) is performed on the array of 8 channels of 450 ms. The TWR is then calculated from the eigenvalues, ρ_i , returned by SVD:

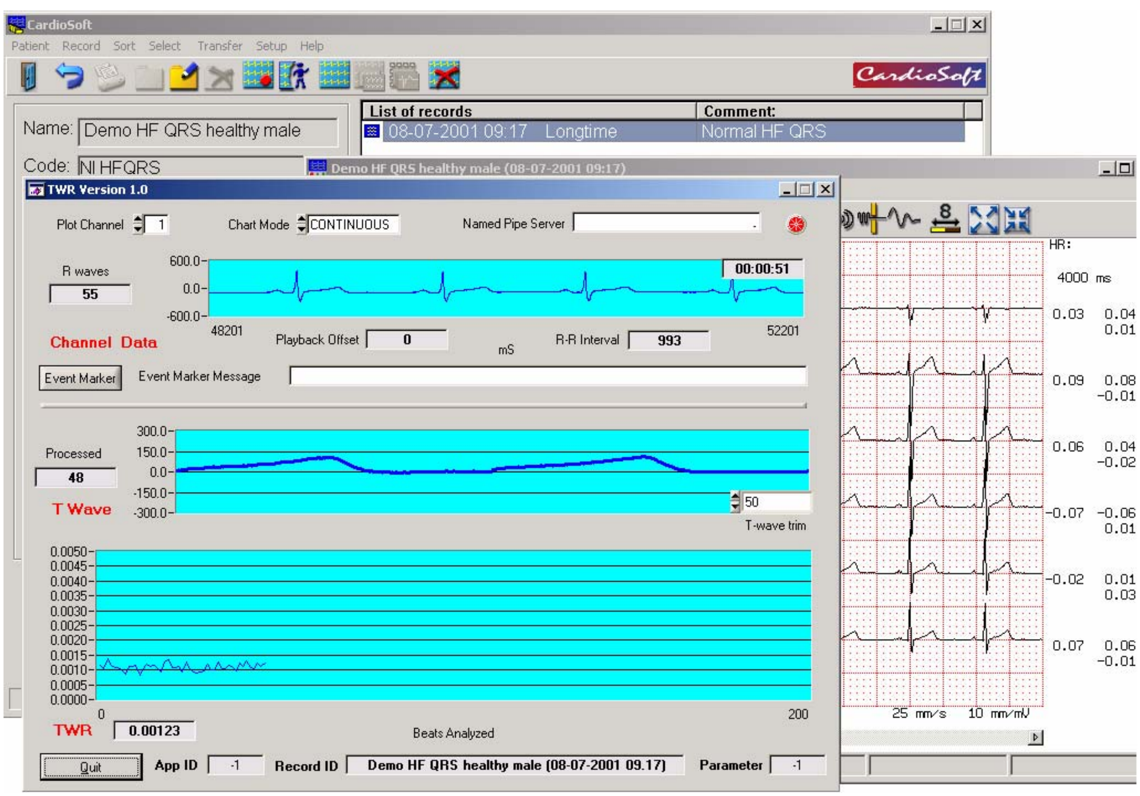
$$TWR = \sum_{i=4}^{8} \rho_i^2 / \sum_{i=1}^{8} \rho_i^2 \qquad \text{where } \rho_1 \geq \rho_2 \geq \cdots \geq \rho_8$$

The first three eigenvectors contain the maximum energy of the dipole, as represented by the magnitude of their respective eigenvalues, and the last 5 eigenvectors represent the non-dipolar components. The TWR parameter is a ratio of the energy contained in the non-dipolar components to the energy in all 8 eigenvectors and represents the localized heterogeneities of the heart[7].

The user interface for the TWR program plots one user specified channel of data, the current and previous T-wave in the user specified channel, and finally the TWR parameter.

Results

The user interface for the TWR Version 1.0 program is shown along with the CardioSoft® mother program below.



TWR Version 1.0 calculates the beat-by-beat T-wave residuum of an ECG in real time. The program requires 8-10 beats to initialize and begin calculation.

Improvements

TWR Version 1.0 was developed primarily using one record: Demo HF QRS Healthy Male. It does not always produce reasonable or useful results on other records. Much improvement is needed to create a robust and adaptable TWR calculator. Suggested improvements fall into two categories: Direct Program Improvement, and Methodology Improvement.

Direct Program Improvement

One of the most obvious improvements to the program would be an autoscale feature for the stripcharts. Particularly in the TWR plot, many records have TWRs higher than the scale can plot.

The CardioSoft® mother program has its own QRS detector. It appears that the location of the R-peaks may be identified and available through the named pipe server. This possibility should be further explored, and may provide a more robust, accurate, and more efficient peak detection than the Hamilton code. Conversion of the CR precordial lead data to V precordial lead data prior to SVD might also significantly enhance the comparability of our real-time results with the offline results of others.

The T-wave is located by a combination of arbitrary numbers and user-input trim. An actual T-wave detector may improve the accuracy, particularly in abnormal records.

In some records the baseline detector as implemented doesn't accurately detect the DC offset. In the current version, if the slope of the baseline never falls to $0 \pm .05$ then the offset will not be corrected for at all. Also, if the peak occurs very much earlier than 250 ms into the wave, the peak may be identified as the zero-slope point. An improved baseline detector would first identify the peak, and then locate the base of the T-wave. This point would be considered the baseline.

Methodology Improvement

Spline "filtering" is an improved baseline removal procedure, eliminating both DC offset and very low frequency AC components of the original signal, and has been used in previous research. The CardioSoft® mother program also implements a type of spline "filter", but the raw data sent to the named pipe server is not filtered. Implementation of a spline "filter" would involve a piece-wise polynomial fit to the baseline at selected points.

Previous T-wave analysis research utilized several different procedures from the approach taken in the present project. Most of these previous analytical procedures were a result of the limitations of the instrumentation used to acquire the ECG. While these methods are not necessarily inferior to the present methods, they do potentially yield different results. In order to compare our results with previous reported research, the current program should contain a parallel implementation of some of the previous methods. For example, previous ECG data were sampled at 250 Hz, and the TWR was performed on a median beat[2,3,4,7]. A useful addition to the program would be a parallel analysis that down samples the data to 250 Hz, and creates a median beat. The TWR could then be calculated on this median beat and then compared to the 1000 Hz beat-by-beat calculation. Another improvement that might reduce the effects of noise on TWR calculations and thus enhance reproducibility would be to perform the SVD analysis on signal-averaged data rather than on single beats or on short-duration median beats.

Conclusions

This work was accomplished as part of a project in biomedical signal processing class. It has been demonstrated that a real-time cardiac repolarization analysis can be accomplished with the addition of an application program coupled via a named pipe client with an existing cardiac data acquisition system. Once the real-time TWR calculation program has been enhanced, clinical studies will begin to evaluate the practical relevance of the real-time TWR parameter.

Reference

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Biographical Information

Nathaniel Scott is a junior at Arkansas Tech majoring in electrical engineering.

Carl Greco is an associate professor of electrical engineering at Arkansas Tech. He received a BSEE in 1967 from Louisiana Tech and MS and Ph.D. in 1974 and 1976 respectively from Rice. His research interests are in the area of biomedical signal processing.

Todd T. Schlegel is a senior scientist in the neuro-autonomic laboratory and managing physician at the human test facility NASA – JSC. He received a BS in 1985 and the M.D. in 1989 from University of Minnesota and completed a residency in internal medicine in 1992 at the Mayo Graduate School of Medicine.