

ECG Analysis System with Event Detection based on Daubechies Wavelets

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Abstract. Over the past ten years, researches of monitoring human health using sensor and wireless network technologies have been evolved rapidly. The wireless monitoring health system that we present can monitor not only biomedical data over a long period of time, but can also reduce resource and cost of medical manpower to a very large extent. Majority of existing devices are only capable of recording ECG of patients that are analyzed later on by cardiologists. The proposed system can continuously monitor the ECG which can be analyzed by the user himself any time. In this paper, we intend to detect and prevent the cardiovascular diseases using a three-lead ECG measurement system. The small ECG signal from the electrodes are amplified, filtered and adjusted for hassle-less detection of peaks and other phenomena. Finally, the data is transferred to a personal computer for detection of various cardiovascular diseases using digital wavelet transform.

Keywords: ECG, Wireless Interface, Syndrome Detection, Daubechies Wavelets, Feature Extraction.

1. Introduction

Cardiovascular Diseases (CVDs) are the number one cause of death globally. An estimated 17.3 million people died from CVDs in 2008, representing 30 percent of all global deaths [11]. CVDs therefore are major threats for human health. Another major issue relating to the CVDs is clinical costs. Majorly all developing countries have a huge gap between people's ability to pay for healthcare and the cost of receiving it. On one hand, early diagnosis and monitoring of cardiovascular disease is particularly important. Thus, providing appropriate method to reduce health care services cost and limitation to patient along with applying most of the requirements is essential. In this work, we propose a portable ECG monitoring system with heart syndrome detection techniques, keeping in mind the cost of an ordinary portable ECG measuring system. Most of the clinically useful information in the ECG is found in the intervals and amplitudes defined by its features (characteristic wave peaks and time durations). In addition to this portable hardware, we have worked on developing a fast and accurate algorithm for automation in ECG feature extraction and syndrome detection. For example, beat detection is necessary to determine the heart rate, and several related arrhythmias such as Tachycardia, Bradycardia and Heart Rate Variation. Further classification of CVDs can be done by extracting various features of ECG. For the same purpose, we have utilized Daubechies Wavelets, primarily because of its similarity to a normal PQRST waveform.

Section II describes the basics of a three-lead ECG system and its advantages. Section III demonstrates the analog circuit, selection of an instrumentation amplifier, band pass filter properties, and removing noise from the signal. DC offset for Analog to Digital conversion and baseline wandering removal technique is also discussed in section III. Transmission of data to a personal computer and extraction of information using wavelets is accounted in section IV. Section V describes the algorithm employed. We conclude the paper in section VI.

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The electrocardiogram (ECG) signal reflects the variation of the cardiac electrical potential over time. The ECG signal is recorded by attaching electrodes on the wrists and legs using the standard *3 lead ECG system*. Our aim was to limit the number of leads present over the body. A 2 lead system was also developed but the electrodes had to be worn on the chest which made the system less handy as the subject had to adjust accordingly. Hence, 3-lead ECG system was chosen.

2.1. Physiology of ECG

In ECG signal each beat is composed of three waves: the P wave, QRS complex and the T wave. The P wave usually has positive polarity and duration of approximately 80ms. The QRS duration varies from 80 to 120ms. Finally, the T wave is usually observed about 300 ms after the QRS complex. However, its exact position depends on the heart rate; appearing closer to the QRS complex at rapid rhythms. The signal-processing algorithms used to study ECG signals utilize its spectral characteristics. A healthy P wave is considered to contribute to the low frequency components ($\approx < 10$ Hz). The QRS complex contributes to the higher frequency components (10–40 Hz) due to its steep slopes.

2.2. Three Lead ECG System

The electrical activity can be represented as a dipole. The placement of the electrodes on the body determines the view of the vector as a function of time. Basic form of the electrode placement is based on Einthoven's triangle. This theoretical triangle is drawn around the heart with each apex of the triangle representing where the fluids around the heart connect electrically with the limbs. Einthoven's law also states that the value of any point of the triangle can be computed as long as values for the other two points are known.

- Lead I is the voltage between the (positive) left arm (LA) electrode and right arm (RA) electrode.
- Lead II is the voltage between the (positive) left leg (LL) electrode and the right arm (RA) electrode.
- Lead III is the voltage between the (positive) left leg (LL) electrode and the left arm (LA) electrode.

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3. Circuit Design

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3.1. Amplification

Primarily, the pre-amplifier should feature low noise, high CMRR, and low output impedance. Secondary features such as low power consumption, single supply operation are also important. A single supply, micro-power IA, INA122 was utilized to fulfil these requirements. The minimal CMRR of INA122 is up to 90dB. The gain of INA122 can be set with an external resistor only. An Integrator was designed that formed a negative-feedback loop. The purpose of this circuit is to provide an inverted version of the common-mode interference to the user's right leg, with the intention of cancelling out the interference. Additionally it serves as a virtual ground, for the raw ECG signal.[2]

3.2. Filtering

A band pass filter was implemented by cascading a low pass and a high pass filter. The cutoff of the low pass filter was set to the maximum frequency component of interest, i.e. 150 Hz. The Sallen and Key active filter configuration was preferred to multiple feedback due to its less component count. The Butterworth filter of second order was selected due to its pass-band flatness. A simple RC-high pass filter was implemented with cutoff frequency, 0.5 Hz.

3.3. DC Offset

The ADC peripheral used in this work is unipolar, i.e. it cannot digitize signals below ground level. For this reason, a DC offset circuit was implemented to bring out the voltage in a desired range.

3.4. Baseline Wandering

Due to high sensitivity of the IA used, the output of the amplifier is highly susceptible to any variation in the contact resistance between skin and electrode. This condition results in deviation of DC content of the amplified differential signal and manifests itself as a drift in the baseline of the signal. This phenomenon is often referred to as baseline wander. This problem is overcome by high pass filter, which is often not included initially.[5]



Fig. 1: Analog circuitry output

4. Transmission and Feature Extraction

After successfully extracting the ECG over a DSO, next step was to digitize the signal for transmission using a microcontroller. Atmel's Mega32 was utilized for digitalization and transmission. To make the device cost effective, we switched to Atmega16. It has 8 single-ended 10 bit resolution ADC. However, an additional feature of only storing the ECG reading was also utilized using a microSD card. Here, AtMega16 fails to provide good result against Mega32. Before feeding the signal to ADC, it was passed through a trivial sample and hold circuit, using LF398.

4.1. Transmission

For transmission purpose, first step was to transmit the data using serial communication between the microcontroller and the personal computer. Secondly, we utilized TI's CC2500, RF 2.4 GHz transceiver using the SPI protocol. The motive of using CC2500 was to make the device independent on the availability of Bluetooth connection. Secondly, it is low cost and low power transceiver. The received signal was then plotted on the real time axis using MATLAB.

4.2. Feature Extraction

The ECG feature extraction system provides fundamental features to be used in subsequent automatic analysis. It is therefore important to accurately extract features of prime importance: P-wave, QRS-complex, T-wave, P-Q interval, S-T segment, and Q-T interval.[5] Designing an algorithm for the detection of these features is a difficult problem due to the time varying morphology of the signal subject to physiological conditions, moreover the localization of wave onsets and ends is much more difficult, as the signal amplitude is low at the wave boundaries and the noise level can be higher than the signal itself. Wavelet Transform has been proposed as an alternative way to analyze the non-stationary biomedical signals, which expands the signal onto the basis functions. The wavelet transform acts as a mathematical microscope in which we can observe different parts of the signal by just adjusting the focus.[6]

4.3. Wavelet Transform

Signal transformation aides in converting signal from Time domain to Frequency domain. It is of very important to convert the signal from time domain to frequency domain to get the complete information carried by the signal. There are many different mathematical transformations available for converting time domain signal to frequency domain and vice versa. Typically physiological signals are present in time domain i.e. the signal has a time value and the amplitude value. Frequency value is hidden in these type of signals. When the time domain signal is converted in frequency domain, the hidden frequency values of the signal can be found out. It is important to know the frequency component of a signal to completely analyze

the signal. Hence, mathematical signal transformation plays a crucial role in signal analysis and signal representation that are the key elements in determining the ECG signal and hence important for this project. There are several mathematical transformation tools available, hence choosing the transformation tool that best suits the signal that is under measurement is of high importance.

5. Description of Algorithm applied

The algorithm is developed for Myocardial ischemia and subclasses of arrhythmia whose characteristic conditions were collected. Algorithm presented can also be applied directly at one run over the whole digitized ECG signal. MIT-BIH database was utilized to cross check the correctness of the algorithm.[9][10]

5.1. Coefficients of WT and Savitzky-Golay filtering

MATLAB emerges as the biggest tool for designing practical algorithms to detect various syndromes. The input signal has large amount of noise present. Savitzky-Golay filter, along with the Daubechies wavelet transform, serves as a smoothing filter, which removes unwanted signal to a considerable extent. Savitzky-Golay filters perform much better than standard averaging FIR filters, which tend to filter out a significant portion of the signal's high frequency content along with the noise. Since we are reconstructing the signal using wavelets, the order of selection of coefficients is of prime importance. The basic idea is to transform the signal first and then reconstruct it using the appropriate coefficient according to the requirement. Finally the output is seen as a 'filtered' outcome.

5.2. Denoising Using Wavelets

Firstly, selecting a wavelet function which closely matches the signal to be processed is of utmost importance in wavelet applications. Due to its symmetry with a QRS complex as well as concentration of the energy spectrum at lower frequencies, Daubechies wavelets are utilized. Number of constant terms for Daubechies wavelets was decided between 4 or 6. After many trials, Db4 was chosen over Db6 as it provided excellent results. However, it is merely a selection which is based on the algorithm and this does not imply that Db4 is superior to Db6 for feature extraction. It is to be noted that Db6 is closer to the QRS complex in similarity when compared to Db4.

Then, Wavelet decomposition of the ECG samples is performed upto three levels which results in the samples at much lower frequency than the original signal. Thus, QRS complex is preserved. Further, extracting and then plotting the coefficients at each level results in the plot of cleaner signal. Figure 2 shows the plot of coefficients of the decomposed data of a Myocardial Ischemia diseased person. It is clear from the figure that 2nd level decomposed data is noise free. Therefore, we consider this signal as ideal ECG signal from which all the peaks are detected.

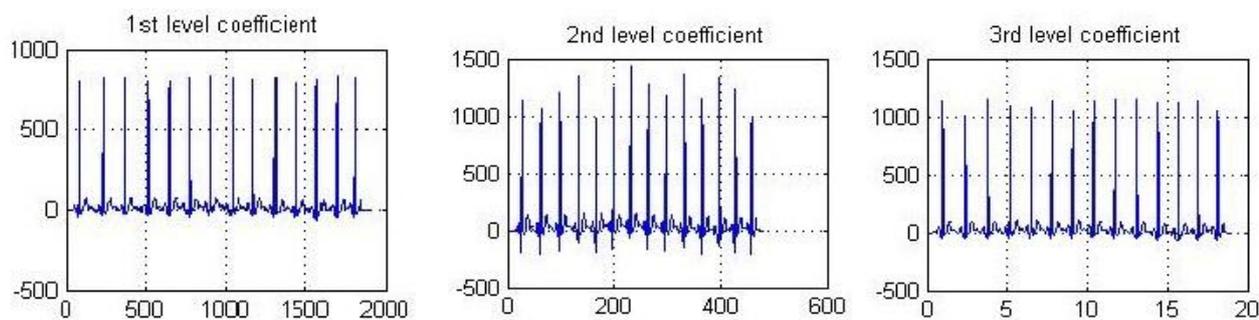


Fig. 2: Plot of the Coefficients upto 3 levels

5.3. R-R Interval Detection

R-R interval detection is one of the major features of interest because they define the cardiac beats and the exactness of all forthcoming detections is dependent on this. R is the tallest peak, with the highest amplitude and is detected by finding the maximum value of voltage in particular range of time.

5.4. QRS Complex Detection

A QRS complex corresponds to the depolarization of right and left ventricles and usually lasts for 0.6 to 1.0 sec. Q is the local minima before the above calculated R-peak while S complex is the local minima after one R-peak. Hence, the reconstructed wave was used and Q & S points are observed. Another method is to differentiate the signal subsequently until a largest and smallest slope appears one after another. But the wavelet based method, as discussed before provides the best results.

5.5. P and T Waves Detection

These waves are more noticeable when the resolution of coefficients is higher. Hence, we find the local maxima point prior to Q-point to find P. Similarly, we find local minima after S-point to find T. Roughly, local maxima and minima points are determined by zero crossing of the signal, which was fixed in the analog circuitry part(refer section 3.4)

Based on the knowledge and information acquired after event detection, symptoms of major CVDs can be detected using subsequent algorithms. For example, for myocardial ischemia, T wave is generally inverted, i.e. below the zero crossing line. Similarly characteristic conditions of major arrhythmias were collected [8]. Sinus Bradycardia & tachycardia, asystole, Bigeminy, trigeminy(PVC), R-on-T phenomenon, ventricular tachycardia and myocardial ischemia are covered in this work. Results are comparable to the results shown on the MIT-BIH database.[9]

6. Conclusion

By using the wavelet transform, we are able to detect various features from a ECG signal. Since it was difficult to avail subjects with positive arrhythmia, the algorithm was tested on the already available database. The algorithm created in MATLAB was successful in extracting all the events of ECG signal. The QRS complex was detected and was used to identify ST segment and thus ST elevation was calculated. We also succeeded in eliminating noises and baseline drifts that could degrade the accuracy of algorithm. Use of wavelet transform speeds the signal processing of ECG which gives us faster response. In a view to solve the problems related to the patients regularly using ECG design, this work proposes a better method to detect symptoms of some major arrhythmias. The parallel working of hardware as well as software provides a user friendly platform. The portable design works up-to our expectations during the tests.

7. References

- [1] Yi-Li Tseng, Hung-Wei Chiu, Tsung-Hsien Lin and Fu-Shan Jaw, Miniature modules for multi-lead ECG recordings *Biomedical Engineering: Applications, Basis and Communications*, Vol. 20, No. 4 (2008) 219–222
- [2] Webster JG, *Medical Instrumentation, Application and Design*, John Wiley and Sons, New York, pp. 241–245, 1998
- [3] Ms. Kanwade A. B. , Prof. Dr. Patil S. P., Prof. Dr. Bormane D.S., Wireless ECG Monitoring System.
- [4] Northrop, Robert B. *Analysis and Application of Analog Electronic Circuits to Biomedical Instrumentation*, ch-6,7,8
- [5] Rangayyan M, Rangaraj, *Biomedical signal analysis: a case-study approach*, John Wiley and Sons, 2008, pg 14-28
- [6] D C Reddy, *Biomedical Signal Processing: Principles and Techniques*, Tata McGraw Hill, 2005 pg 295-299
- [7] Frazier: An Introduction to Wavelets through Linear Algebra, Springer-Verlag, NY, 1999. Pg 240-255
- [8] Robert J. Huzar, *Basic Dysrhythmias, Interpretation and Management* (C.V. Mosby Co., 1988).
- [9] Goldberg AL, Amaral LAN, Glass L, Hausdorff JM, Ivanov PCh, Mark RG, Mietus JE, Moody GB, Peng C-K, Stanley HE. PhysioBank, PhysioToolkit and PhysioNet: Components of a New Research Resource for Complex Physiological Signals. *Circulation* 101(23):e215-e220[Circulation Electronics Pages; <http://circ.ahajournals.org/cgi/content/full/101/23/e215>]; 2000(June 13).
- [10] Sivanarayana N. and D.C. Reddy, *Biorthogonal wavelet transforms for ECG parameters estimation*, *Med. Eng. Phys.*,-1999;21(110):167-174
- [11] World Health Organization Media Centre: <http://www.who.int/mediacentre/factsheets/fs317/en/index.html>