

DESIGN OF LAB EXPERIMENTS ON SIGNAL PROCESSING APPLIED TO SOLVING BIOMEDICAL PROBLEMS

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Abstract--Several challenges are faced by the educators to train engineers for the next decade due to fast pace of advancement in technology. One of the challenges is to introduce interesting multi-disciplinary applications of engineering concepts and tools, especially at the junior level. Signal processing is an essential course in most engineering programs. Introducing to students a biomedical problem and applying relevant signal processing techniques to solve such a problem can be an effective pedagogical approach. The objective of the present work is to apply simple signal processing techniques to solve the biomedical problems of detecting selected arrhythmia conditions from a patient's electrocardiograph (ECG) signals.

Cardiovascular disease is considered as the number one killer in United States and early detection of cardiac arrhythmia is critical for effective care of patients. Finding arrhythmia characteristics corresponding to Atrial Fibrillation (AF), heart rate variability (HRV), etc., from ECG recording have received considerable attention in recent years.

Several advanced signal processing techniques have been applied for cardiac arrhythmia detection using Fourier Transforms, Wavelets, Artificial Neural Networks, Independent Component Analyses, etc. However, those techniques typically involve higher than undergraduate level of expertise in mathematics and statistics. Introducing a simple algorithm for arrhythmia detection can be very useful for better conceptual understanding of signal processing for the junior level undergraduate students. The main goal of the present work is to develop a simple method to extract required parameters detect arrhythmia condition AF using the morphological characteristics of ECG waveforms and applying basic signal processing techniques.

In this project, ECG waveforms are analyzed based on morphological differences between AF waveforms and normal waveforms. A simple algorithm for determining R peaks, R-R intervals, QRS amplitudes and base-line drifts has been developed and tested on five sets of normal and abnormal ECG signals. The results appear to be reasonable. The detection of AF is quite challenging and the work on a suitable algorithm to take into account different morphological characteristics is in process.

Students correlate the linkage between the theoretical aspects of signal processing taught in class with an application to solve a real-life practical problem in the laboratory. This proposed lab assignment also leads to open-ended problems and thus will triggers improved creative problem-solving capabilities of the students.

In conclusion, a set of laboratory experiments is designed involving signal processing techniques applied to solve multi-disciplinary biomedical problems. Approaches on such practical multi-disciplinary applications will tend to facilitate creating interests in students and enhance their learning, which will be a key to training engineers of the future.

1. Introduction

Several difficulties are faced by the educators to train the engineers in courses and in providing a meaningful exposure to relevant multidisciplinary emerging and contemporary areas. One of the challenges is to introduce interesting practical applications of engineering concepts and tools at the undergraduate junior level¹. Biology is becoming a required course in many undergraduate engineering programs. Students may find biomedical problems interesting since they can possibly relate to them easier than to those in defense, space or petrochemical fields. Introducing to students a biomedical problem and applying relevant signal processing technique to solve such a problem can be an effective pedagogical approach.

The objective of the present work is to apply simple signal processing techniques to solve the biomedical problems of detecting selected arrhythmia conditions from a patient's ECG signals.

2. Background

Signal processing refers to an area of electrical engineering and applied mathematics that deals with operations on or analysis of signals, in either discrete or continuous time, to extract useful information from those signals. Operations of signal processing may include filtering, smoothing, digitization, feature extraction, modulation, prediction and a variety of other operations. Application of signal processing can be carried out for systems such as biomedical systems, bioinformatics systems, audio, video communications, sonar, radar systems, electronic and environmental systems. There is great interest in biomedical systems since faculty and students are concerned about health care, clinical diagnosis and treatment.

Signal processing introduces mathematical operations which can be abstract for student to understand. They may not be very interesting to some students. Applications especially to real-life problems such as biomedicine or defense may facilitate understanding and enhance the interest of the students. In this paper, signal processing applied to biomedical signals is discussed. The physiological system considered is cardiovascular system and the signal considered is electrocardiogram (ECG).

Cardiovascular disease is considered as the number one killer in United States. While there are several types of diseases within the cardiovascular system, abnormal electrical activities referred to arrhythmia play a significant part. These arrhythmia can be detected by extracting information from ECG after appropriate signal processing. Early detection of cardiac arrhythmia is critical for effective care of patients. ECG is a remarkable diagnostic tool which represents heart's electrical activity measured from the electrodes placed on the body surface. A single normal cardiac cycle consists of three sub-waves referred to as P wave, QRS complex wave, and T wave. P wave is caused by atrial depolarization and the sequential activation of the right and left atria. QRS complex is due to right and left ventricular depolarization, and T wave represents ventricular repolarization².

A sample normal ECG for a lead II configuration for one cardiac cycle is shown in Figure 1. An ECG tracing for about four seconds is presented in Figure 2.

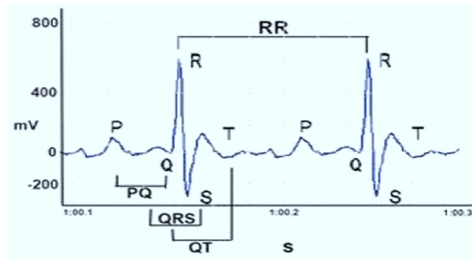


Figure 1: Lead II ECG record of normal sinus rhythm in one cardiac cycle.

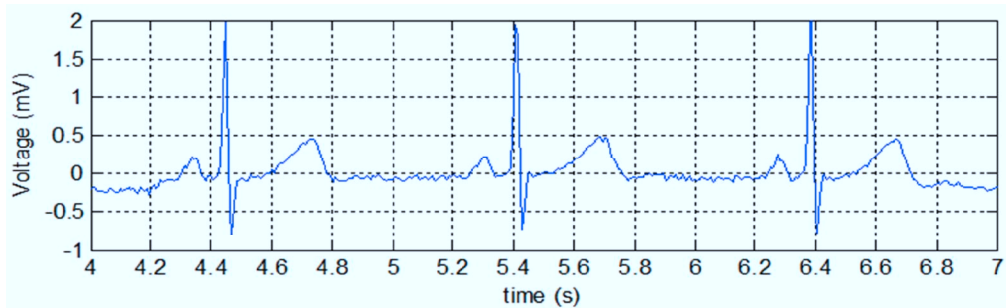


Figure 2: Normal sinus rhythm in lead II of average adult [MIT-BIH NSRBD/16272]

In normal sinus rhythm of average healthy adult, the three sub-waves appear in regular manner throughout every heartbeat. However, heartbeat rhythm can vary significantly under different disease conditions. It is to be noted that there are several cardiac arrhythmic conditions and great difficulties may be experienced to discriminate and identify the arrhythmia using simple set of rules. The amplitude, duration and morphological characteristics of the P wave, QRS complex and T wave vary significantly even for healthy adults. A set of values for these parameters are given in Table 1³.

Table 1: Lead II ECG characteristics of average healthy adult

	Duration (ms)	Amplitude (mV)	Morphology
P wave	80-100	0.2 – 0.3	Smooth curve
PR interval	120-200	0	Straight line along base
QRS complex	60-100	1.3 – 1.5	Sharp zigzag turns
ST interval	80-120	0	Straight line along base
T wave	40-80	> P wave	Smooth curve

One set of cardiac arrhythmia of interest includes atrial malfunction conditions comprising atrial tachycardia (ATach), atrial flutter (AFlut) and atrial fibrillation (AF). In AF episode, atria fail to beat in a normal fashion; instead, they quiver rapidly multiple times in a cardiac cycle, leading to inefficient pumping of blood and ultimately leading to a high possibility of blood clots and strokes. The morbidity and mortality among patients with AF is rather high. AF is characterized by uncoordinated atrial activation with consequent deterioration of atrial mechanical function. AF is described by the replacement of consistent P waves by rapid oscillations or fibrillation waves that varies in size, shape and timing, resulting in an irregular, frequently rapid ventricular response⁴. A sample of abnormal ECG waveform with AF episodes is given in Figure 3.

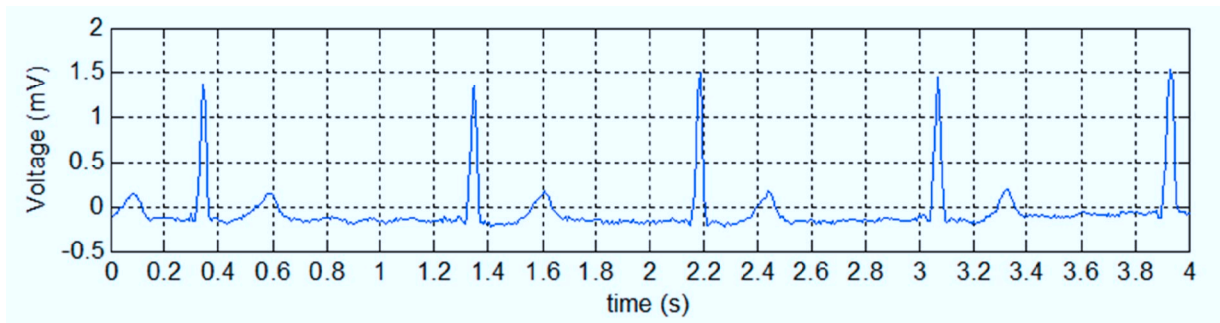


Figure 3: Abnormal ECG signal with AF episodes [AFTDB/learning-set/n01]

Detecting AF from ECG recording has received considerable attention in recent years. Several advanced methods have been applied for cardiac arrhythmia detection. Key characteristics for AF identification are irregular rhythm, no identifiable P waves and rapid atrial activity. A summary of atrial arrhythmia characteristics is displayed in Figure 4⁵.

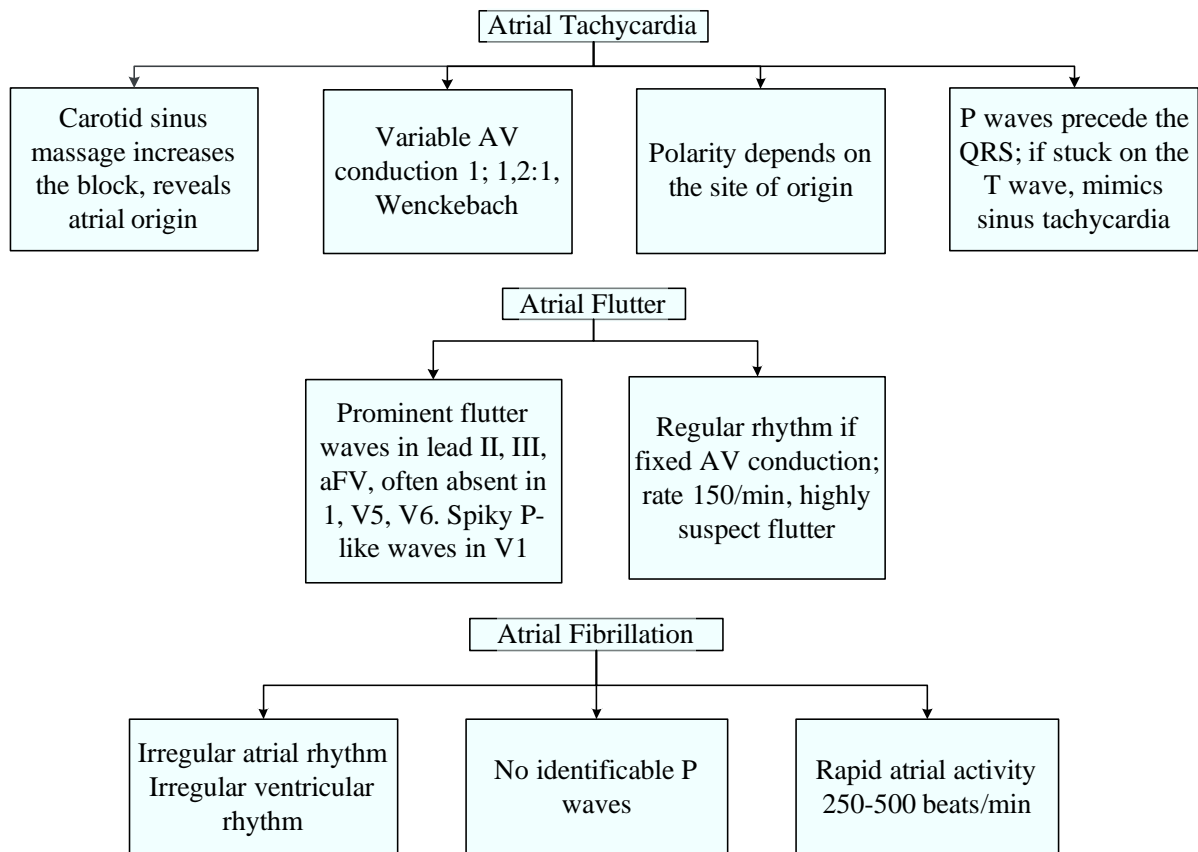


Figure 4: Atrial Tachycardia, Atrial Flutter and Fibrillation Characteristics

During the past years, dynamics of atrial activity of AF have been object of intense research for the detection and prediction of AF. To extract atrial activity, some approaches are based on Independent component analysis⁶, Blind Source Separation (BSS)⁷, Energy Ratio Measure⁸.

Irregular atrial and ventricular rhythm, another AF main characteristic is also exploited using statistical methods⁹, wavelet transform¹⁰, Poincare Plot¹¹, independent component analysis⁶ have been used. However, those techniques typically involve graduate level of expertise in mathematics and statistics. At the junior level of engineering and some engineering technology programs, it will not be possible to introduce advanced signal processing techniques. A simple cardiac signal processing and automatic diagnosis system is developed to demonstrate the power and the usefulness of applying signal processing techniques to solve relatively complex biological system problems.

Introducing a simple algorithm for arrhythmia detection can be very useful for better conceptual understanding of signal processing for the junior level undergraduate students. The main goal of the present work is to develop a method to compute RR intervals, and to detect AF using the morphological characteristics of ECG waveforms and applying basic signal processing techniques.

3. Method

In this project, ECG waveforms are analyzed based on morphological differences between AF waveforms and normal waveforms. Practically, ECG signal does not come automatically in high-resolution. There can be numerous artifacts such as electromyography (EMG) noise from the electrical activity in body muscles, electromagnetic interferences (EMI) from power lines and other devices, movement artifacts, etc. Applying signal processing filters to extract the weak ECG components contaminated with noise and permit the measurement of essential features in the ECG is necessary¹². Bandpass filtering is often used as a preliminary process to extract information with cutoff frequencies 0.5 to 150 Hz. Additional digital filters, often band stop filters and Butterworth low pass filters are also needed on top of band pass filter to further trim down interference¹³. Analog and digital filtering can be employed for performing required filtering operations. The resulting ECG cardiac signal is now ready for further analysis. Processes taken for ECG denoising and AF detection are summarized in Figure 5.

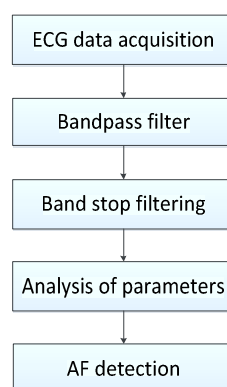


Figure 5: Schematic Diagram of the algorithm

The scope of this project is to facilitate interest of students in signal processing by using biomedical applications. Hence, individual steps can form interesting learning modules. The next

task is to develop a simple algorithm for determining R peaks, R-R intervals, QRS amplitudes and base-line drifts.

In a given ECG waveform, number of data points surrounding the baseline level is rather large. Thus, relative frequency of amplitude of ECG signal data is tabulated, in which the most frequently occurred amplitude range typically contains the baseline of the signal. A point is considered at maximum peak if its first derivative is equal to zero and its second derivative is negative. From the processed waveform data, local maxima corresponding to sequential R wave peaks are determined based on the proposed peak detection algorithm. In normal ECG waveforms, R peaks carry the highest amplitudes, and then followed by T peaks and P peaks respectively. Therefore, by suppressing QRS complexes to the baseline, the resulted waveform has local maxims corresponding to T peaks and subsequently P peaks. At current state, AF episodes are defined as periods in which P waves are undetectable or occur multiple times within a cardiac cycle. If AF is present, the number of P waves detected is greater than normally corresponding R peaks.

For experimental purposes, previously acquired ECG data sets can be used. One source of data is ECG waveform is MIT-BIH database. A simple data acquisition method is developed using waveform generator with simulation for normal and several different arrhythmic conditions.

4. Results

The proposed method was implemented in a MATLAB program to test on MIT-BIH LTDB/14046. R peaks, T peaks and P peaks were located in most normal sinus rhythm episodes. Figure 6 illustrates ECG waveform in four seconds with detected R peaks, T peaks and P peaks.

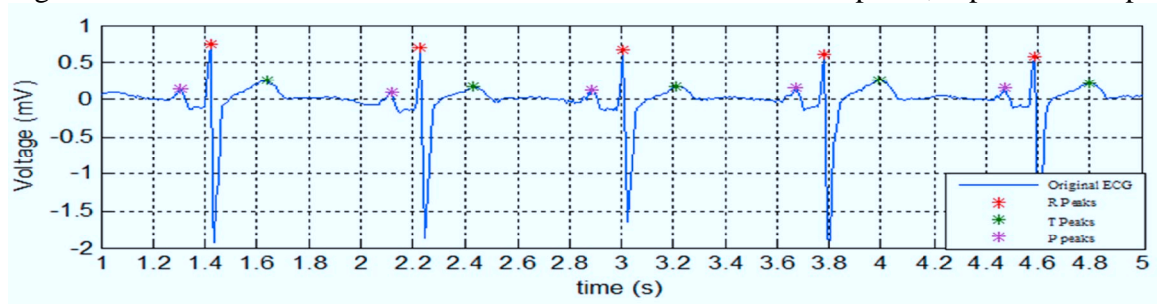


Figure 6: A Sample ECG waveform with detected R peaks, T peaks and P peaks

RR intervals were calculated and HRV was computed based on standard deviation of RR intervals. A graphical presentation of resulted RR interval is given in Figure 7.

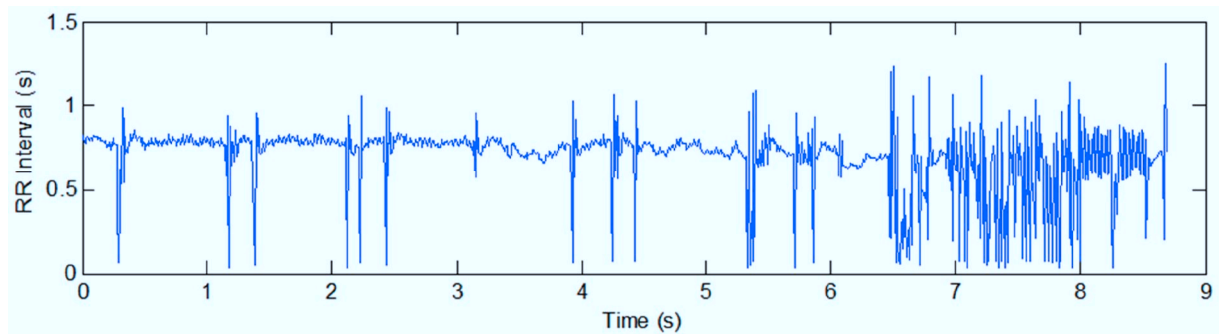


Figure 7: RR interval of an abnormal ECG tracing in about ten seconds.

In few cases, T peaks and P peaks were mislocated or detected multiple times. However, once AF is present, the number of P peak occurrence well exceeded the number of falsely detected P peaks. When the program ran on different sets of data, thresholds of R peaks, T peaks and P peaks needed to be tuned due to variations in ECG from patient to patient.

There are several steps in the detection of HRV. The algorithm for HRV detection is in the process of refinement.

5. Discussion

The variations in the characteristic parameter in ECG waveform are rather large. Thus, applying signal processing techniques yields reasonably encouraging results. However, they also emphasize the need for comprehensive feature extraction techniques and advanced signal processing.

It is to be noted that other arrhythmic conditions such as Tachycardia, Bradycardia are easily detected with acceptable results. However, discriminating Atrial Tachycardia, Atrial Flutter and Atrial Fibrillation and HRV pose difficulties with simple approaches. Developing suitable methods and obtaining appropriate data sets for laboratory experiments may be applicable at the senior undergraduate level.

Students correlate the linkage between the theoretical aspects of signal processing taught in class with an application to solve a real-life practical problem in the laboratory environment. The proposed laboratory assignment also leads to open-ended problems and thus triggers improving the creative problem-solving capabilities of the students.

6. Conclusion

In conclusion, a set of laboratory experiments is designed involving signal processing techniques applied to solve multi-disciplinary biomedical problems. Approaches on such practical multi-disciplinary applications will tend to facilitate creating interests in students and enhance their learning, which will be a key to training engineers of the future.

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