Lecture #1

Introduction: -

Biological signal analysis1 encompasses several interdisciplinary topics that deal with analyzing signals generated by various physiological processes in the human body. These signals could be electrical, chemical or acoustic in origin and an analysis of these signals are often useful in explaining and/or identifying pathological conditions of the human body. However, these signals in their rawest form do not provide much information and therefore, the motivation behind biological signal analysis is to extract (i.e. to reveal) the relevant information. This analysis has become even more important with modern healthcare striving to provide cost effective point-of-care diagnosis and personalized treatment. Furthermore, fast computing power in recent years has made much of the more complex analysis methodologies possible. The purpose of this chapter is to provide an overview of biological signal origins and describe commonly encountered biological signals.

Before we delve into the analysis of biological signals, it would be useful to understand that they are often represented as discrete in time. For example, Figure 1 shows an example of a sinus rhythm electrocardiogram (ECG), which represents the electrical activity obtained from normal heart. A single measurement of the signal x is a scalar and represents the electrical signals generated by the mechanisms in the heart at a particular instant of time t (denoted with index n) rather than at all points of time.

There are two types of noise inherent in this signal: baseline and powerline interference. Figure 2 shows a cleaned version of Figure 1 obtained through band-pass filtering. This figure also shows a zoomed version of the ECG representing one beat of heart. The sharp peaks in the signal denote the occurrence of what is known as the R wave and the time intervals between consecutive R-R peaks would be useful to measure the heart rate, i.e. the number of times the heart beats in a minute.
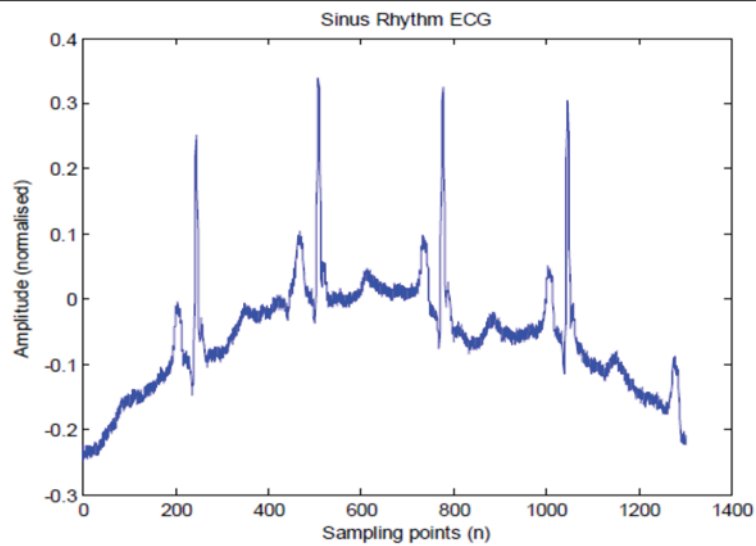
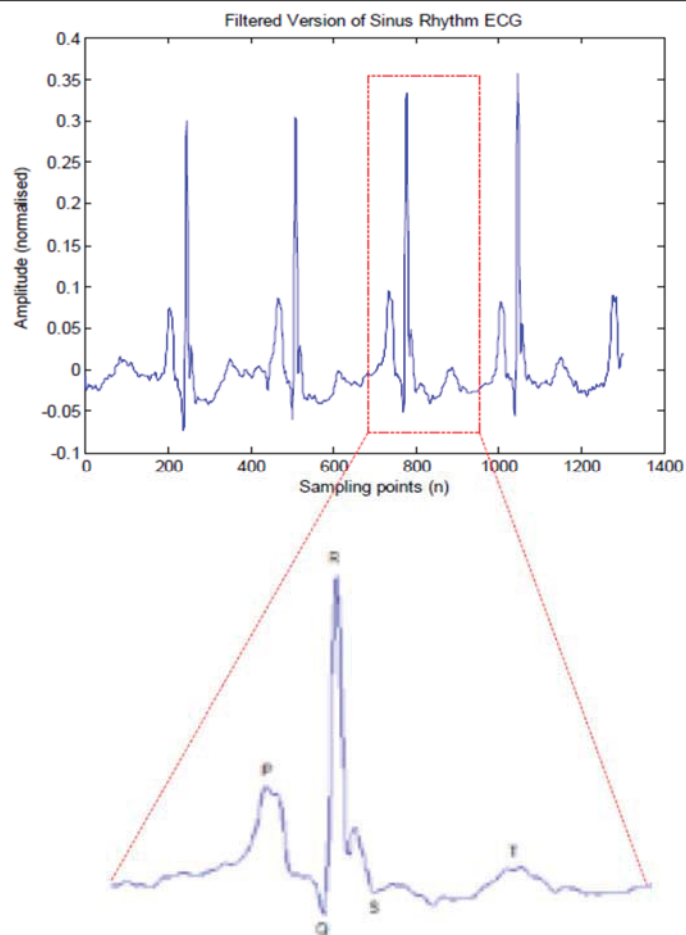**Figure 1:** Normal sinus rhythm ECG. ECG data

Figure 2: Filtered version of sinus rhythm ECG in Figure 1.

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Similarly, the segment from the Q wave to the S wave (more commonly known as QRS segment), is useful in indicating certain pathological variations in the heart's electrical system. For example, Figure 3 shows an ECG waveform from a subject with an ectopic beat of Premature Ventricular Contraction (PVC) type. Ectopic beats are premature beats with a complex waveform that can occur occasionally in most people. However, the presence of frequent ectopic beats (more than six per minute) could indicate a serious fatal problem if left uncorrected. While it is visually obvious that the QRS segment for the PVC beat is different from Figure 1, it is impractical to sit and manually detect the occurrences from an ECG chart (or onscreen monitor) of a patient over many hours/days. Rather, a computer that is trained to automatically analyze and detect the occurrence of such beats using signal processing algorithms is employed. This is a typical biological signal analysis application.
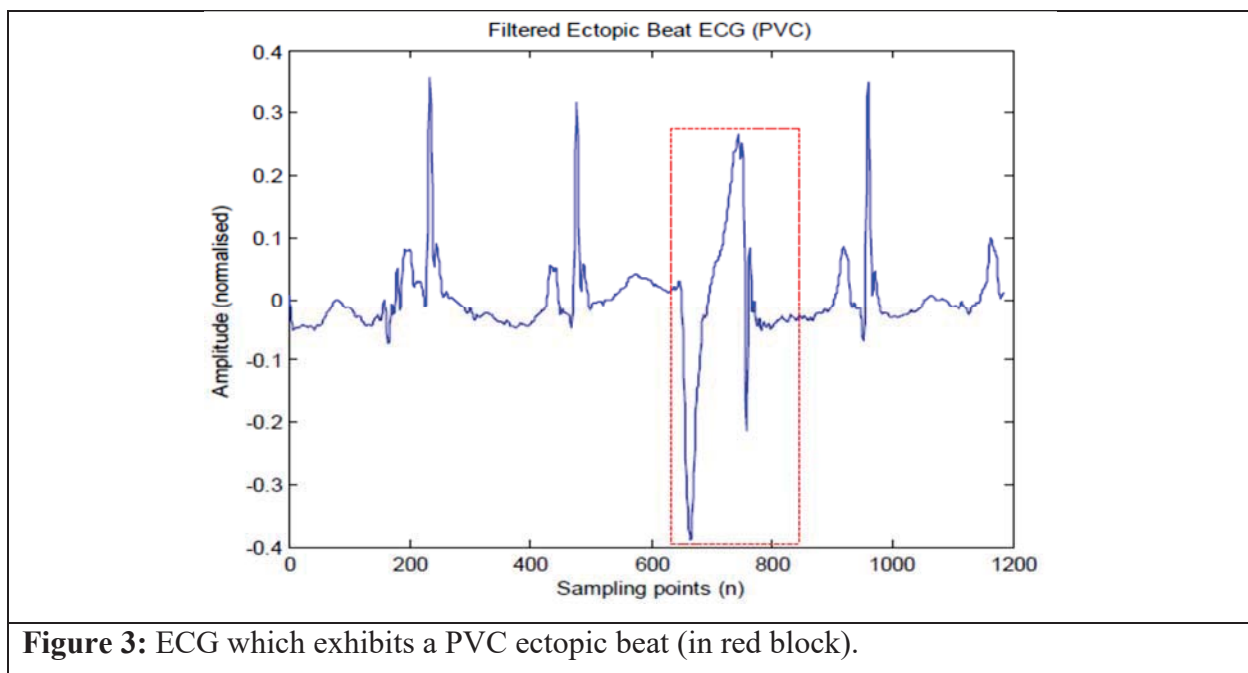

Figure 3: ECG which exhibits a PVC ectopic beat (in red block).

Examples of Common Biological Signals: -

Commonly encountered biological signals that describe the electrical activity of the brain, heart, muscles etc will be introduced in this section. Some of these signals like ECG and electroencephalogram (EEG) are spontaneous activity of the human body while others such as evoked potentials are signals in response to external stimulus, for example the presentation of

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visual stimuli which results in visual evoked potential (VEP) signals. While some analysis procedures are common (like using filters to extract components in specific frequency range), the different properties of these biological signals do call for the application of widely varying analysis procedures. Hence, it is useful to know the fundamental details of how these signals are generated before studying analysis procedures for extraction of the required information.

Electrocardiogram

The ECG is a representation of the electrical activity of the heart and the cardiac rhythm is controlled by the pacemaker cells known as sinoatrial (SA) node. The PQRST waveform (as shown in Figure 4) represents one complete ECG cycle: P wave occurs when SA node fires and the impulse spreads across atria and triggers atrial contraction; PQ interval (isometric segment) is the propagation delay when the impulse travels from atria to ventricles (allowing blood flow to complete in similar direction); QRS complex occurs when the impulse spreads to ventricles and triggers ventricular contraction; ST segment is the period when the ventricles are depolarized and ventricular repolarization (relaxation) begins and T wave represents the return to resting state by the ventricles.
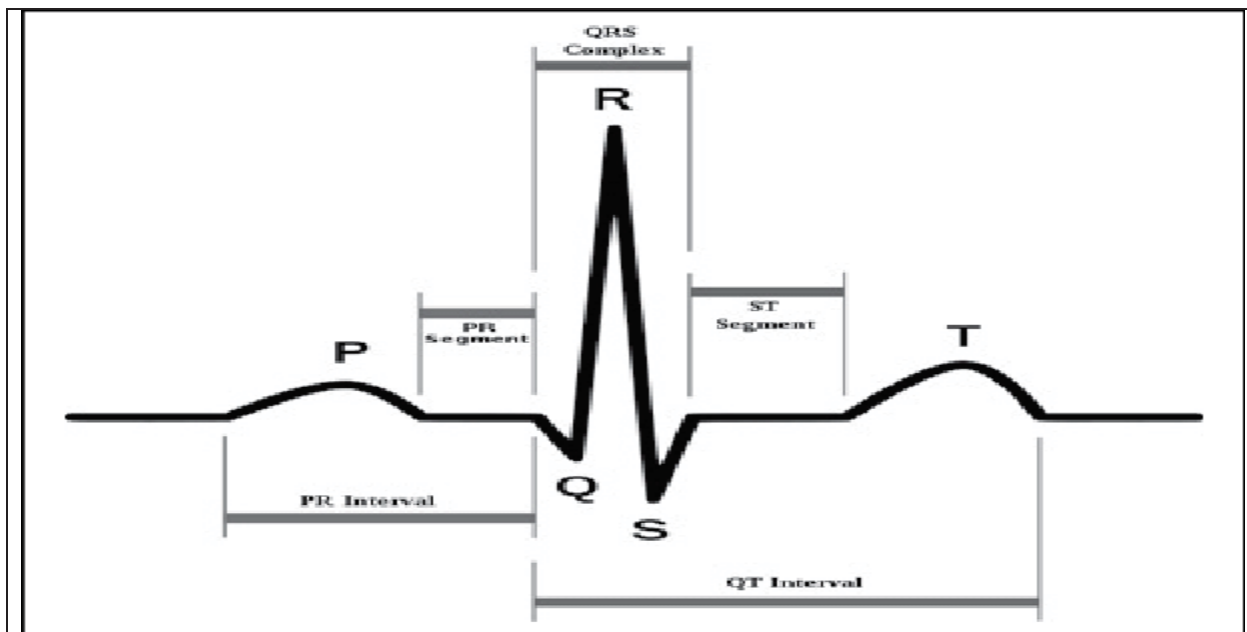

Figure 4: ECG waveform

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These electrical impulses are normally recorded through electrodes placed on particular areas of the body either using 12-channel ECG in a hospital or 3-channel ECG in the field. Figure 5 shows the hypothetical Einthoven's triangle that is commonly used for the electrode setup. The setup requires four limb electrodes placed on the right and left arms and legs; the fourth limb electrode that is not shown in the diagram is placed on the right leg and serves as reference channel. The top of the Einthoven's triangle forms Lead I, while the left forms Lead II and right forms Lead III. Each lead represents a different aspect of the heart's electrical system. The voltage differences between the limb electrodes: left arm (LA), right arm (RA), and left leg (LL) are used to obtain Leads I, II and III:

$$I = V_{LA} - V_{RA}, \qquad (1.1)$$

$$II = V_{LL} - V_{RA}, \qquad (1.2)$$
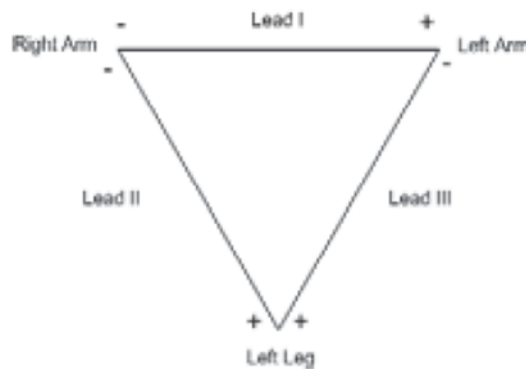
$$III = V_{LL} - V_{LA}. \qquad (1.3)$$

Figure 5: Einthoven's triangle.

Electroencephalogram: -

EEG which represents the electrical activity of the brain has become very useful in the clinical diagnosis and electrophysiological analysis related to functions of the brain. The basic functional unit in the brain is the neuron, which is found in the cerebral cortex. Four different areas of the cortex (frontal, parietal, temporal and occipital) are responsible for varying functions, for example