

BIOMEDICAL SIGNAL PROCESSING



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PREFACE

The area of biomedical signal analysis has reached to the stage of advanced practical application of signal processing and pattern analysis techniques for efficient and improved invasive diagnosis, on-line monitoring of critically ill patients and rehabilitation and sensory aids for the handicapped.

In fact, Biomedical Signal Processing is a subject for undergraduate and post graduate students in electronics and biomedical engineering to touch the future trends in application of signal processing in biomedical system. This book is primarily intended to serve as a text book in accordance with the syllabus of Biomedical Signal Processing offered by various universities in India as well as abroad.

The whole text has been divided into nine chapters:

Chapter 1: Introduces the basic concept of Biomedical Signals.

Chapter 2: Discuss about ECG, EEG and EMG.

Chapter 3: Discuss about the application of computer in biomedical engineering

Chapter 4: Introduce the different techniques for ECG QRS detection.

Chapter 5: Introduce the ST Segment Analyzer.

Chapter 6: Discuss different algorithms of Data reduction.

Chapter 7: Gives details about EEG.

Chapter 8: Analysis the EEG.

Chapter 9: Discuss different filters, algorithms used for EP estimation.

The authors hope that the book will fulfill the need of interested readers and welcome any suggestions towards the improvement of the book.

— Authors

Dedicated to.....

Our brother

Late Pankaj Kumar

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INTRODUCTION TO BIOMEDICAL SIGNALS

INTRODUCTION

Processing of biomedical signal, until a few years ago, was mainly directed toward filtering for removal of noise and power-line interference; spectral analysis to understand the frequency characteristics of signals; and modeling for feature representation and parameterization. Recent trends have been toward quantitative or objective analysis of physiological systems and phenomena via signal analysis. The field of biomedical signal analysis has advanced to the stage of practical application of signal processing and pattern analysis techniques for efficient and improved invasive diagnosis, on-line monitoring of critically ill patients and rehabilitation and sensory aids for the handicapped. Techniques developed by engineers are gaining wider acceptance by practicing clinicians and the role of engineering in diagnosis and treatment is gaining much-deserved respect.

Any system is made up of several subsystems that carry on many physiological processes. For example, the cardiac system performs the important task of rhythmic pumping of blood throughout the body to facilitate the delivery of nutrients, as well as pumping blood through the pulmonary system for oxidation of blood itself.

Diseases or defects in a biological system cause alterations in its normal physiological processes, leading to pathological processes that affect the performance, health and general wellbeing of the system. If we possess a good understanding of a system of interest, it becomes possible to observe the corresponding signals and assess the state of system.

1.1 BIOMEDICAL SIGNALS

The action potential is the electrical signal that accompanies the mechanical contraction of a single cell when stimulated by an electrical current. It is caused by the flow of sodium (Na^+), potassium (K^+), chloride (Cl^-) and other ions across the cell membrane. The action potential is the basic

component of all biomedical signals. It provides information on the nature of physiological activity at the single-cell level. Various examples of such biomedical signals are as follows:

1. The electroneurogram (ENG) is an electrical signal observed as a stimulus and the associated nerve action potential propagate over the length of a nerve. It may be used to measure the velocity of propagation (or conduction velocity) of a stimulus or action potential in a nerve.
2. The electrocardiogram (ECG) is the electrical manifestation of the contractile activity of the heart and can be recorded fairly easily with the surface electrodes on the limbs or chest. The ECG is perhaps the most commonly known, recognized and used biomedical signal. More important is that the ECG waveshape is altered by cardiovascular diseases and abnormalities such as myocardial ischemia and infarction, ventricular hypertrophy and conduction problems.
3. The electroencephalogram (EEG: popularly known as brain waves) represents the electrical activity of the brain.
4. The phonocardiogram (PCG) is a vibration or sound signal related to the contractile activity of the cardiohemic system (the heart and blood together).
5. The carotid signal (CP) is a pressure signal recorded over the carotid artery as it passes near the surface of the body at the neck. It provides a pulse signal indicating the variations in arterial blood pressure and volume with each heart beat.
6. Pulse waveform is a pressure signal recorded at root of thumb. It also provides the systolic and diastolic behaviour of the heart.

1.2 COMPUTER AIDED SYSTEMS

Physicians, cardiologists, neuroscientists and health-care technologists are highly trained and skilled practitioners. Why then we want to use computers or electronic instrumentation for the analysis of biomedical signals? The following points provide some arguments in favour of the application of computers to process and analyze biomedical signals:

1. Humans are skilled and fast in the analysis of visual patterns and waveforms, but are slow in arithmetic operations with large numbers. If signals need to be processed to remove noise or extract a parameter, it would not be practical for a person to perform such computation.
2. Humans can be affected by fatigue, boredom and environmental factors and are susceptible to committing errors. *e.g.*, Long-term monitoring of signals by a human observer watching the oscilloscope is neither economical nor feasible.
3. Analysis by humans is usually subjective and qualitative. When a comparative analysis is required between the signal of a subject and another or a standard pattern, a human observer would typically provide a qualitative response.
4. Analysis by humans is subject to inter-observer as well as intra-observer variations (with time). Given the most analyses performed by humans are based upon qualitative judgement, they are liable to vary with time for a given observer, or from one observer to another. Further, it is possible to encode the knowledge (or logic) of many experts

into a single computational procedure and thereby enable a computer with the collective intelligence of several human experts in the area of interest.

5. Real-time analysis is possible as most of the biomedical signals are fairly slow (low-pass) signals.

1.3 DIFFICULTIES IN BIOMEDICAL SIGNAL ANALYSIS

Though the computer-aided systems are very useful for a user, there are many difficulties encountered in acquisition and analysis. Some of them are as listed below:

1. **Accessibility of the variables to measurement**—Most of the systems and organs of interest, such as cardiovascular system and brain, are located well within the body. While the ECG may be recorded using limb electrodes, the signal so acquired is but a projection of the true 3D cardiac electrical vector of the heart onto the axis of the electrodes. Such a signal may be sufficient for rhythm monitoring, but could be inadequate for more specific analysis of the cardiac system.
2. **Variability of the signal source**—The dynamic nature of biological systems causes most signals to exhibit stochastic and nonstationary behaviour. This means that signal statistics such as mean, variance and spectral density change with time. For this reason, signals from a dynamical system should be analysed over extended periods of time including various possible status of the system and the results should be placed in the context of the corresponding status.
3. **Inter-relationships and interactions among physiological systems**—The various systems that compose the human body are inter-related and interact in various ways. Some of the interacting phenomena are compensation, feedback, cause-and-effect, collateral effects, loading and take-over of function of a disabled part by another system or part. Ignoring this inter-relationship could lead to misinterpretation of the signal.
4. Effect of the instrumentation or procedure on the system
5. **Physiological artefacts and interference**—One of the pre-requisites for obtaining a good ECG signal is for the subject to remain relaxed and still with no movements.
6. **Energy limitations**—Most biomedical signals are generated at microvolt or millivolt levels at their sources. Recording such signals requires very sensitive transducers and instrumentation with low noise levels.
7. Patient safety.

BASICS OF ELECTROCARDIOGRAPHY

INTRODUCTION

There are three basic techniques used in clinical electrocardiography. The most familiar is the standard clinical electrocardiogram. This is the test done in a physician's office in which 12 different potential differences called ECG leads are recorded from the body surface of a resting patient. A second approach uses another set of body surface potentials as inputs to a three-dimensional vector model of cardiac excitation. This produces a graphical view of the excitation of the heart called the vectorcardiogram (VCG). Finally, for long-term monitoring in the intensive care unit or on ambulatory patients, one or two ECG leads are monitored or recorded to look for life-threatening disturbances in the rhythm of the heartbeat. This approach is called arrhythmia analysis. Thus, the three basic techniques used in electrocardiography are:

1. Standard clinical ECG (12 leads)
2. VCG (3 orthogonal leads)
3. Monitoring ECG (1 or 2 leads)

Figure 1 shows the basic objective of electrocardiography. By looking at electrical signals recorded only on the body surface, a completely noninvasive procedure, cardiologists attempt to determine the functional state of the heart. Although the ECG is an electrical signal, changes in the mechanical state of the heart lead to changes in how the electrical excitation spreads over the surface of the heart, thereby changing the body surface ECG. The study of cardiology is based on the recording of the ECGs of thousands of patients over many years and observing the relationships between various waveforms in the signal and different abnormalities. Thus clinical electrocardiography is largely empirical, based mostly on experiential knowledge. A cardiologist learns the meanings of the various parts of the ECG signal from experts who have learned from other experts.

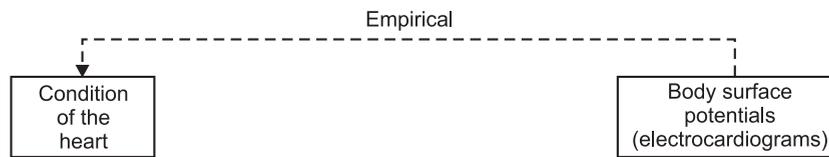


Fig. 1 The object of electrocardiography is to deduce the electrical and mechanical condition of the heart by making noninvasive body surface potential measurements.

2.1 ELECTRODES

As time went on, metallic electrodes were developed to electrically connect to the body. An electrolyte, usually composed of salt solution in a gel, forms the electrical interface between the metal electrode and the skin. In the body, currents are produced by movement of ions whereas in a wire, currents are due to the movement of electrons. Electrode systems do the conversion of ionic currents to electron currents.

Conductive metals such as nickel-plated brass are used as ECG electrodes but they have a problem. The two electrodes necessary to acquire an ECG together with the electrolyte and the salt-filled torso act like a battery. A dc offset potential occurs across the electrodes that may be as large or larger than the peak ECG signal. A charge double layer (positive and negative ions separated by a distance) occurs in the electrolyte. Movement of the electrode such as that caused by motion of the patient disturbs this double layer and changes the dc offset. Since this offset potential is amplified about 1,000 times along with the ECG, small changes give rise to large baseline shifts in the output signal. An electrode that behaves in this way is called a polarizable electrode and is only useful for resting patients.

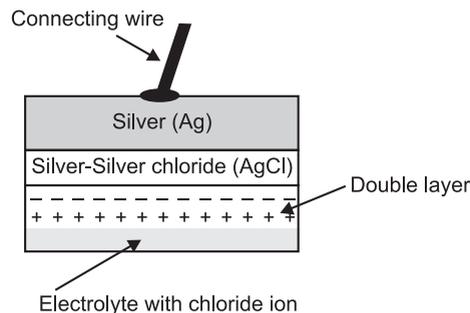


Fig. 2 A silver-silver chloride ECG electrode. Many modern electrodes have electrolyte layers that are made of a firm gel which has adhesive properties. The firm gel minimizes the disturbance of the charge double layer.

The most-used material for electrodes these days is silver-silver chloride (AgAgCl) since it approximates a nonpolarizable electrode. Figure 2 shows such an electrode. This type of electrode has a very small offset potential. It has an AgCl layer deposited on an Ag plate. The chloride ions move in the body, in the electrolyte and in the AgCl layer, where they get converted to electron flow in the Ag plate and in the connecting wire. This approach reduces the dc offset potential to a very small value compared to the peak ECG signal. Thus, movement of the electrode causes a much smaller baseline shift in the amplified ECG than that of a polarizable electrode.

2.2 THE CARDIAC EQUIVALENT GENERATOR

Figure 3 shows how a physical model called a cardiac equivalent generator can be used to represent the cardiac electrical activity. The most popular physical model is a dipole current source that is represented mathematically as a time-varying vector which gives rise to the clinical vectorcardiogram (VCG). Einthoven postulated that the cardiac excitation could be modeled as a vector. He also realized that the limbs are like direct connections to points on the torso since the current fluxes set up inside the body by the dipole source flow primarily inside the thorax and do not flow significantly into the limbs. Thus he visualized a situation where electrodes could just as well have been connected to each of the shoulders and to a point near the navel had he not been restricted to using vats of saline.

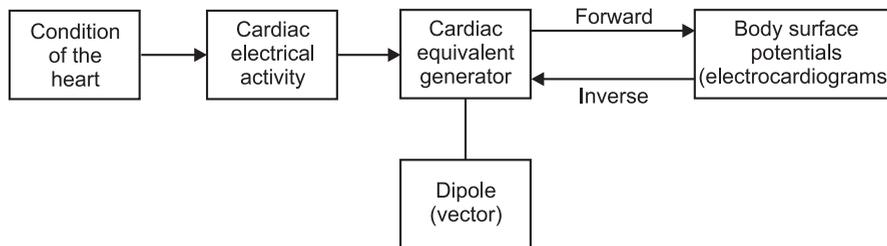


Fig. 3 Both the electrical and mechanical conditions of the heart are involved in determining the characteristics of the spread of electrical activity over the surface of the heart. A model of this activity is called a cardiac equivalent generator.

Einthoven drew a triangle using as vertices the two shoulders and the navel and observed that the sides of the triangle were about the same length. This triangle, shown in Fig. 4, has become known as the Einthoven equilateral triangle. If the vector representing the spread of cardiac excitation is known, then the potential difference measured between two limbs (*i.e.*, two vertices of the triangle) is proportional simply to the projection of the vector on the side of the triangle which connects the limbs. The figure shows the relationship between the Einthoven vector and each of the three frontal limb leads (leads I, II, and III). The positive signs show which connection goes to the positive input of the instrumentation amplifier for each lead.

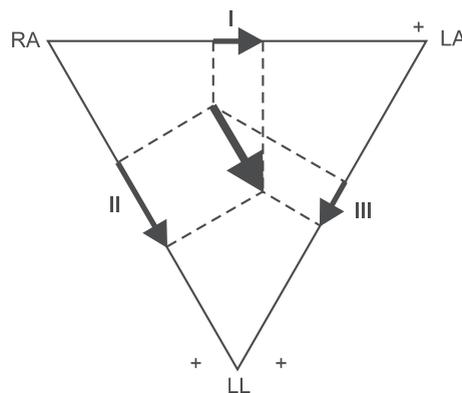


Fig. 4 Einthoven equilateral triangle. RA and LA are the right and left arms and LL is the left leg.

A current dipole is a current source and a current sink separated by a distance. Since such a dipole has magnitude and direction which change throughout a heartbeat as the cells in the heart depolarize, this leads to the vector representation

$$\mathbf{p}(t) = p_x(t)\mathbf{x} + p_y(t)\mathbf{y} + p_z(t)\mathbf{z} \quad \dots(1)$$

where $\mathbf{p}(t)$ is the time-varying cardiac vector, $p_i(t)$ are the orthogonal components of the vector also called scalar leads and x, y, z are unit vectors in the x, y, z directions. A predominant VCG researcher in the 1950s named Frank shaped a plaster cast of a subject's body like the one shown in Fig. 5, waterproofed it, and lined it with salt water. He placed a dipole source composed of a set of two electrodes on a stick in the torso model at the location of the heart. A current source supplied current to the electrodes which then produced current fluxes in the volume conductor. From electrodes embedded in the plaster, Frank measured the body surface potential distribution at many thoracic points resulting from the current source. From the measurements in such a study, he found the geometrical transfer coefficients that relate the dipole source to each of the body surface potentials.

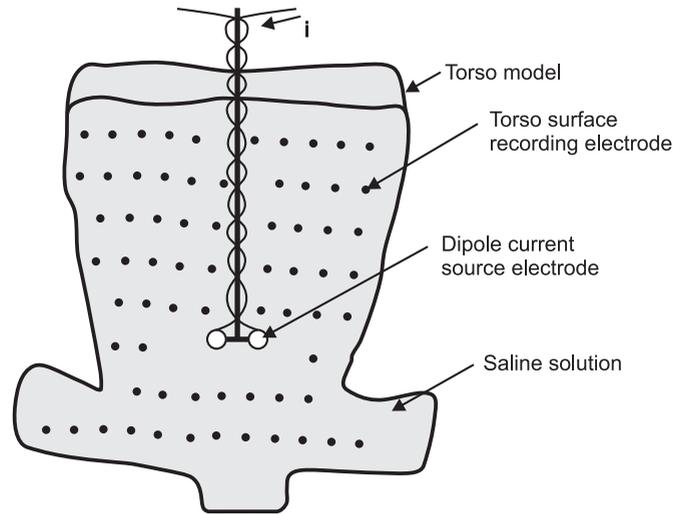


Fig. 5 Torso model used to develop the Frank lead system for vectorcardiography.

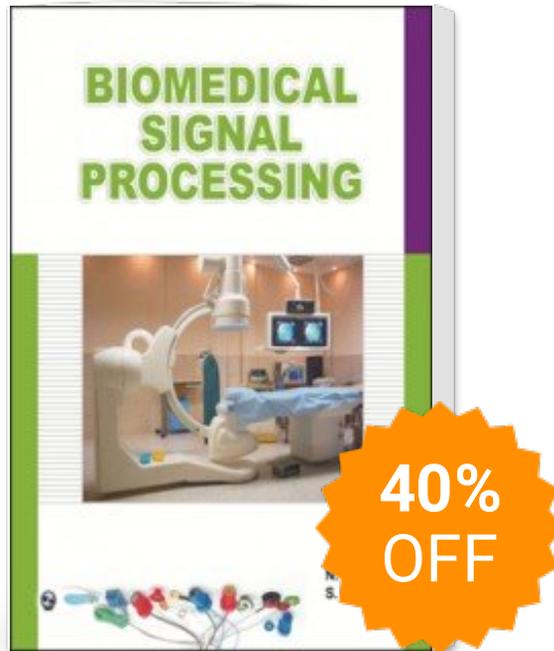
Once the transfer coefficients are known, the forward problem of electrocardiography can be solved for any dipole source. The forward solution provides the potential at any arbitrary point on the body surface for a given cardiac-dipole. Expressed mathematically,

$$v_n(t) = t_{nx} p_x(t) + t_{ny} p_y(t) + t_{nz} p_z(t) \quad \dots(2)$$

This forward solution shows that the potential $v_n(t)$ (*i.e.*, the ECG) at any point n on the body surface is given by the linear sum of the products of a set of transfer coefficients $[t_{ne}]$ unique to that point and the corresponding orthogonal dipole vector components $[p_i(t)]$. The ECGs are time varying as are the dipole components, while the transfer coefficients are only dependent on the thoracic geometry and inhomogeneities. Thus for a set of k body surface potentials (*i.e.*, leads), there is a set of k equations that can be expressed in matrix form

$$\mathbf{V} = \mathbf{T} \times \mathbf{P} \quad \dots(3)$$

Biomedical Signal Processing



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