

## Denoising of ECG -- A discrete time approach using DWT.

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### ABSTRACT

This paper is about denoising of ECG signal using DWT transform. In this paper, ECG signals are denoised using DWT transform. ECG signals are taken and noise at different frequencies are generated which are superimposed on this original ECG signal. High frequency noise is of 4000 hertz and power line interference is of 50 hertz. Decomposition of noisy signal is achieved through wavelet packet. Wavelet packets are reconstructed and appropriate wavelet packets are combined to obtain a signal, very similar to original ECG signal. This technique results in the minimization of mean square error in the filtered signals.

**Keywords** - CWT, DENOISING, DFT, DWT, ECG, STFT.

### I. INTRODUCTION

The ECG is the most commonly performed cardiac test. This is because the ECG is a useful screening tool for a variety of cardiac abnormalities; ECG machines are readily available and the test is simple to perform, risk-free and inexpensive. As the heart undergoes depolarization and repolarization, the electrical currents that are generated spread not only within the heart, but also throughout the body. This electrical activity generated by the heart can be measured by an array of electrodes placed on the body surface. The recorded tracing is called an electrocardiogram (ECG, or EKG). From the ECG tracing, the heart rate, heart rhythm and conduction abnormalities can be determined thus helping in diagnosis of any coronary or heart disease.

In first section the human heart is introduced. It explains the valves present which regulate the flow of blood through our heart along with the conduction system of the heart. Furthermore in the second part the electrical activity of the heart is discussed, which results due to the action potentials or rather because of the active sodium-potassium pump (active  $\text{Na}^+$  -  $\text{K}^+$  pump).

Next section discusses the ECG and the noises that can be present in it. ECG is a quasi-periodical, rhythmically repeating signal synchronized by the function of the heart, which acts as a generator of the bioelectrical events. The different waveforms are recorded and standardized in terms of amplitude, time and phase relationship. By looking at a subject's ECG a physician can diagnose the disease of patient. Any sort of noise in an ECG signal results in a deformed ECG, thus making it unsuitable for diagnosis and even resulting in wrong diagnosis.

The signal processing methods are introduced in third section of the paper.

Fourth section discusses with the Problem Considered and the Results obtained. Procedures for

the rectification of the problem to obtain the desired result have also been discussed.

The last section consists of all the conclusions.

### II. HEART

#### 2.1 Heart Anatomy

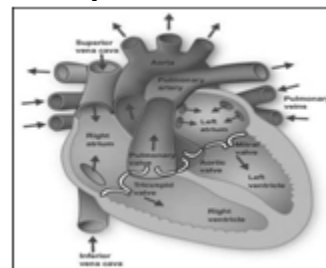


Figure 2.1: Internal Structure of the Heart

The heart weighs between 7 and 15 ounces (200 to 425 grams) and is a little larger than the size of your fist. By the end of a long life, a person's heart may have beat (expanded and contracted) more than 3.5 billion times. In fact, each day, the average heart beats 100,000 times, pumping about 2,000 gallons (7,571 liters) of blood.

Your heart is located between your lungs in the middle of your chest, behind and slightly to the left of your breastbone (sternum). A double-layered membrane called the pericardium surrounds your heart like a sac. The outer layer of the pericardium surrounds the roots of your heart's major blood vessels and is attached by ligaments to your spinal column, diaphragm, and other parts of your body. The inner layer of the pericardium is attached to the heart muscle. A coating of fluid separates the two layers of membrane, letting the heart move as it beats, yet still be attached to your body.

Your heart has 4 chambers. The upper chambers are called the left and right atria, and the lower chambers are called the left and right ventricles. A

wall of muscle called the septum separates the left and right atria and the left and right ventricles.

The left ventricle is the largest and strongest chamber in your heart. The left ventricle's chamber walls are only about a half-inch thick, but they have enough force to push blood through the aortic valve and into your body.

### 2.1.1 Heart Valves

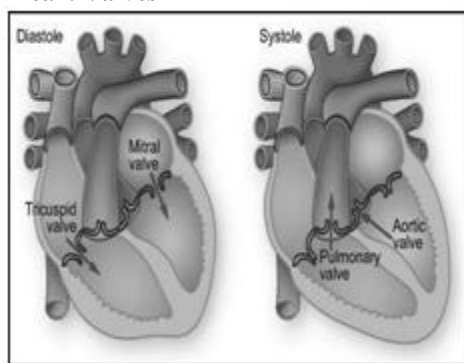


Figure 2.2: Heart Valves

Four valves regulate blood flow through your heart:

1. The tricuspid valve regulates blood flow between the right atrium and right ventricle.
2. The pulmonary valve controls blood flow from the right ventricle into the pulmonary arteries, which carry blood to your lungs to pick up oxygen.
3. The mitral valve lets oxygen-rich blood from your lungs pass from the left atrium into the left ventricle.
4. The aortic valve opens the way for oxygen-rich blood to pass from the left ventricle into the aorta, your body's largest artery, where it is delivered to the rest of the body.

### 2.2 Conduction System

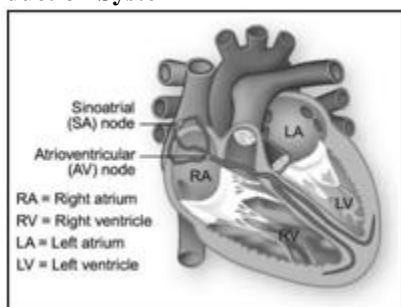


Figure 2.3: Four Chamber Structure of the Heart

Electrical impulses from your heart muscle (the myocardium) cause your heart to beat (contract). This electrical signal begins in the sinoatrial (SA) node, located at the top of the right atrium. The SA node is sometimes called the heart's "natural pacemaker." When an electrical impulse is released from this natural pacemaker, it causes the atria to contract. The

signal then passes through the atrioventricular (AV) node. The AV node checks the signal and sends it through the muscle fibers of the ventricles, causing them to contract.

The SA node sends electrical impulses at a certain rate, but your heart rate may still change depending on physical demands, stress, or hormonal factors.

### 2.2.1 Rhythm of the Heart

The word "rhythm" is used to refer to the part of the heart which is controlling the activation sequence. The normal heart rhythm, with electrical activation beginning in the SA node, is called "sinus rhythm". Electrical activation of heart can sometimes begin in places other than SA node also.

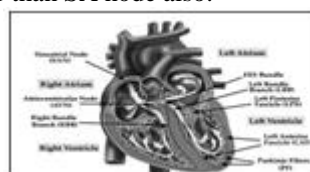


Figure 2.4: Cardiac Conduction System

The electrical activity of the heart is integral to the operation of several types of medical instruments, including the electrocardiograph, the pacemaker, and the defibrillator. A very small electrical disturbance can cause this vital organ to cease pumping blood necessary to sustain life. The heart consists of two major smooth muscles the atrium, and the ventricle which form the syncytium, or fusion of cells, that conducts depolarization from one cell to the next. Because of the ionic leakage in the smooth muscle membrane the tissue of the heart depolarizes spontaneously from its resting state and effectively oscillates, or beats. The sinoatrial (SA) node beats at a rate of from 70 to 80 beats per minute (bpm) at rest. The atrioventricular (AV) node beats at 40 to 60 bpm and the bundle branch oscillate at 15 to 40 bpm.

The SA node, normally determines the heart rate, since it beats at the fastest rate and causes stimulation of the other tissues before it reaches its self-pacing threshold. Thus, the SA node can be considered the heart's pacemaker.

The depolarization of the SA node spreads throughout the atrium and reaches the AV node about 40ms. Because of the low conduction velocity of the AV node tissue, it requires about 110ms for the depolarization to reach the bundle branches called the Purkinje system. The ventricles then contract, the right ventricle then forcing blood into the lungs, the left ventricle pushing blood into the aorta and subsequently through the circulation system. The contraction period of the heart is called systole.

The action potentials in the ventricle hold for 200 - 250ms. This relatively long time allows the ventricular contraction to empty blood into the

arteries. The heart then re-polarizes during the rest period, called diastole, then the cycle repeats.

### 2.3 Biopotentials in the Heart

The contraction of any muscle is associated with electrical changes called "depolarization", and these changes can be detected by electrodes attached to the surface of the body. Since all muscular contraction will be detected, the electrical changes associated with contraction will be detected, the electrical changes associated with contraction of the heart muscle will only be clear if the patient is fully relaxed and no skeletal muscles are contracting.

Although the heart has four chambers, from the electrical point of view it can be thought as having only two, because two atria contract together and then the two ventricles contract together.

The electrical discharge for each cardiac cycle normally starts in a special area of the right atrium called the "sinoatrial (SA) node". Depolarization then spreads through the atrial muscle fibers. There is a delay while the depolarization spreads through another special area of atrium, the "atrioventricular (AV) node". Thereafter, the electrical discharge travels very rapidly, down specialized conducting tissue: first a single pathway, the "bundle of His", which then divides in the septum between the ventricles into right and left bundle branches. The left bundle branch itself divides into two. Within the mass of ventricular muscle, conduction spreads somewhat more slowly, through specialized tissue called "purkinje fibers".

#### 2.3.1 Sources of Bioelectric Potentials

In carrying out their various functions, certain systems of body generate their own monitoring signals, which convey useful information about the functions they represent. These signals are the bioelectric potentials associated with nerve conduction, brain activity, heartbeats, muscle activity, and so on. BIOELECTRIC

POTENTIALS are actually ionic voltage produced as a result of the electrochemical activity of certain special types of cells. Through the use of transducers capable of converting ionic potentials into electrical voltages, these natural monitoring signals can be measured and results displayed in a meaningful way to aid the physician in his diagnosis and treatment of various diseases.

The idea of electricity being generated in the body goes back as far as 1786, when an Italian anatomy professor, Luigi Galvani, claimed to have found electricity in the muscle of a frog, s leg. In the century that followed several other scientists discovered electrical activity in various animals and in man. But it was not until 1903, when the Dutch physician Willem Einthoven introduced the string galvanometer that any practical application could be

made of these potentials. The advent of the vacuum tube and amplification and, more recently, of solid-state technology has made possible better representation of the bioelectric potentials. These developments, combined with a large amount of physiological research activity, have opened many new avenues of knowledge in the application and interpretation of these important signals.

#### 2.3.2 Resting and Action Potentials

Certain types of cells within the body, such as nerve and muscle cell, are encased in a semi permeable membrane that permits some substances to pass through the membrane while others are kept out. Neither the exact structure of the membrane nor the mechanism by which its permeability is controlled is known, but the substances involved have been identified by experimentation.

Surrounding the cells of the body are the body fluids. These fluids are conductive solutions containing charged atoms known as ions. The principal ions are sodium (Na<sup>+</sup>), potassium (K<sup>+</sup>), and chloride (Cl<sup>-</sup>). The membrane of excitable cells readily permits entry of potassium and chloride ions effectively blocks the entry of sodium ions. Since the various ions seek a balance between the inside of the cells and the outside, both according to concentration and electric charge, the inability of the sodium to penetrate the membrane results in two conditions. First, the intercellular fluid outside. Since the sodium ions are positive, this would tend to make the outside of the cell becomes much lower than in intercellular fluid outside of the cell more positive than the inside. Second, in an attempt to balance the electric charge, additional potassium ions, which are also positive, enter the cell, causing a higher concentration of the potassium on the inside than on the outside. This charge balance cannot be achieved, however, because of the concentration imbalance of potassium ions. Equilibrium is reached with a potential difference across the membrane, negative on the inside and positive on the outside.

This membrane potential is called the resting potential of the cell and is maintained until some kind of disturbance upsets the equilibrium. Since measurement of the membrane potential is generally made from inside the cell with respect to the body fluids, the resting potential of a cell is given as negative.

Research investigators have reported measuring membrane potentials in various cells ranging from -60 to -100 mV. Figure 2.5 illustrates in simplified from the cross section of a cell with its resting potential. A cell in resting state is said to be polarized.

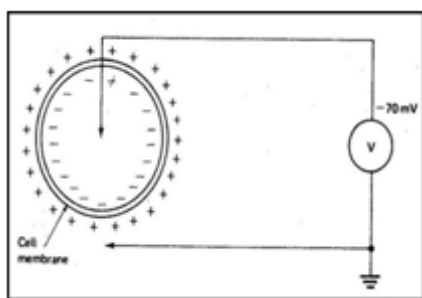


Figure 2.5: Polarized cell with its Resting Potential

When a section of the cell membrane is excited by the flow of ionic current or by some form of externally applied energy, the membrane changes its characteristics and begins to allow some of the sodium ions to enter. This movement of sodium ions into cell constitutes an ionic current flow that further reduces the barrier of the membrane to sodium ions. The net result is an avalanche effect in which sodium ions literally rush into the cell to try to reach a balance with the ions outside. At the same time potassium ions, which were in higher concentration inside the cell during the resting state, try to leave the cell has a slightly positive potential on the inside due to the imbalance of potassium ions.

This potential is known as the action potential and is approximately +20 mV. A cell that has been excited and that displays an action potential is said to be depolarized; the process of changing from the resting state to the action potential is called depolarized. Figure 2.6 shows the ionic movements associated with depolarization, and Figure 2.7 illustrates the cross section of depolarized cell.

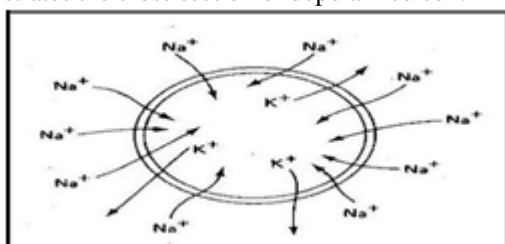


Figure 2.6: Depolarization of a cell Na<sup>+</sup> ions rush into the cell while K<sup>+</sup> ions attempt to leave

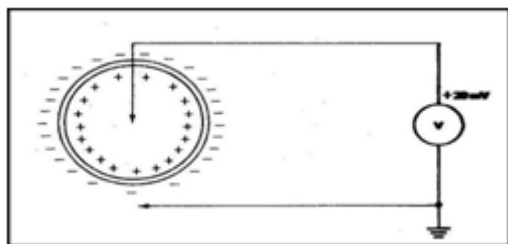


Figure 2.7: Depolarized cell during an Action Potential

Once the rush of sodium ions through the cell membrane has stopped (a new state of equilibrium is

reached), the ionic currents that lowered the barrier to sodium ions are no longer present and the membrane reverts back to its original, selectively permeable condition, wherein the passage of sodium ions from the outside to the inside of the cell is again blocked. Were this the only effect, however, it would take a long time for a resting potential to develop again. But such is not the case. By an active process, called a sodium pump, the sodium ions are quickly transported to the outside of the cell, and the cell again becomes polarized and assumes its resting potential. This process is called re depolarization. Although little is known of the exact chemical steps involved in the sodium pump, it is quite generally believed that sodium by some form of high-energy phosphate compound. The rate of pumping is directly proportional to the sodium concentration in the cell. It is also believed that the operation of this pump is linked with the influx of potassium existed.

Figure 2.8 shows a typical action-potentials waveforms, beginning at the resting potential after repolarization. The time scale for the action potentials depends on the type of cell producing the potential. In nerve and muscle, on the other hand, repolarizes much more slowly, with the action potential for heart muscle usually lasting from 150 to 300 msec.

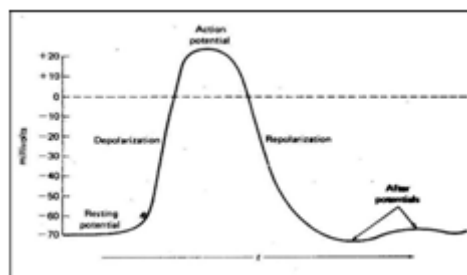


Figure 2.8: Waveform of the Action Potential

Regardless of the method by which a cell is excited or the intensity of the stimulus (provided it is sufficient to activate the cell), the action potential is always the same for any given cell. This is known as the all-or-nothing law. The net height of the action potential of the depolarized membrane at the peak of the action potential and the resting potential.

### 2.3.3 Cardiac Action Potentials

The cardiac action potential differs from the neuronal action potential by having an extended plateau, in which the membrane is held at a high voltage for a few hundred milliseconds prior to being repolarized by the potassium current as usual. This plateau is due to the action of slower calcium channels opening and holding the membrane voltage near their equilibrium potential even after the sodium channels have inactivated.

The cardiac action potential plays an important role in coordinating the contraction of the heart. The cardiac cells of the sinoatrial node provide the pacemaker potential that synchronizes the heart. The action potentials of those cells propagate to and through the atrioventricular node (AV node), which is normally the only conduction pathway between the atria and the ventricles. Action potentials from the AV node travel through the bundle of His and thence to the Purkinje fibers. Conversely, anomalies in the cardiac action potential-whether due to a congenital mutation or injury-can lead to human pathologies, especially arrhythmias. Several anti-arrhythmia drugs act on the cardiac action potential, such as quinidine, lidocaine, beta blockers, and verapamil.

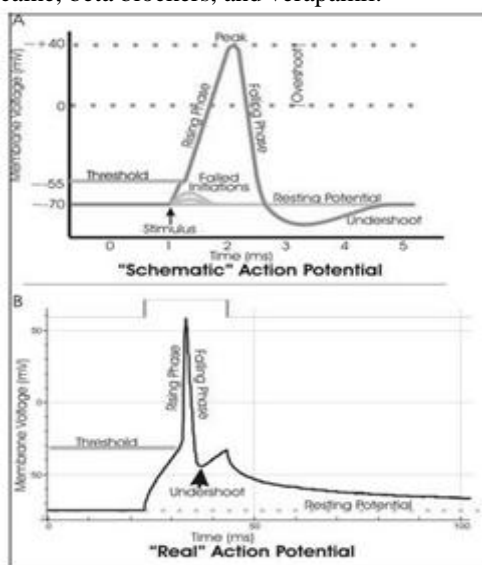


Figure 2.9: Action Potential

### III. ELECTROCARDIOGRAM

#### 3.1 .Electrocardiogram

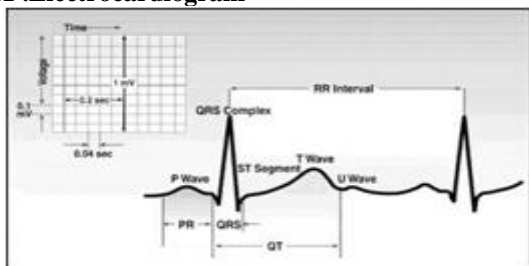


Figure 3.1: Electrocardiogram

During diastole, while the heart is at rest, all of the cells are polarized so that the potential inside each cell is negative with respect to the outside. Normally, depolarization occurs first at the SA node, making the outside of the tissue negative with respect to the inside of the cells and making it negative with respect to the tissues not yet depolarized. This imbalance results in an ionic current,  $I$ , causing the left arm to measure positive with respect to the right arm. The resulting voltage is called the P wave.

After about 90 ms, the atrium is completely depolarized, and the ionic current measured by lead I reduces to zero. The depolarization then passes through the AV node causing a delay of 110ms. The depolarization then passes to the right ventricular muscle depolarizing it and making it negative relative to the still polarized left ventricular muscle. Again the direction of  $I$  causes a + to - voltage from LA to RA called the R-wave.

The complete wave form is called an electrocardiogram with labels P, Q, R, S, and T indicating its distinctive features. The P wave arises from the depolarization of the atrium. The QRS complex arises from depolarization of the ventricles. The magnitude of the R-wave within this complex is approximately 1mV. The T wave arises from repolarization of the ventricle muscle. The U wave that sometimes follows the T-wave is second order effect of uncertain origin and is of little diagnostic significance.

#### 3.1.1 ECG Waves and Intervals

1. P wave: the sequential activation (depolarization) of the right and left atria
2. QRS complex: right and left ventricular depolarization (normally the ventricles are activated simultaneously)
3. ST-T wave: ventricular repolarization
4. U wave: origin for this wave is not clear-but probably represents "after depolarizations" in the ventricles
5. PR interval: time interval from onset of atria depolarization (P wave) to onset of ventricular depolarization (QRS complex)
6. QRS duration: duration of ventricular muscle depolarization
7. QT interval: duration of ventricular depolarization and repolarization
8. RR interval: duration of ventricular cardiac cycle (an indicator of ventricular rate)
9. PP interval: duration of atrial cycle (an indicator of atrial rate)

#### 3.2 Generation of ECG Signal

The heart is innervated by the autonomic nervous system, which increases or decreases heart rate; it does not initiate contraction. The heart can go on beating without any direct stimulus from the nervous system. This is possible because the heart has an intrinsic regulating system called the conduction system. The conduction system is composed of specialized muscle tissue that generates and distributes the action potentials that stimulate the cardiac muscle fibers to contract.

These tissues are found in the

1. Sinoatrial (SA) node,
2. Atrioventricular (AV) node,

3. Atrioventricular (AV)
4. Bundle (bundle of His),
5. Bundle branches, and
6. Conduction myofibres (Purkinje fibers).

All cardiac muscle is capable of self-excitation; that is, it spontaneously and rhythmically generates action potentials that result in contraction of the muscle.

The normal resting rate of self-excitation of the sinoatrial node is about 75 times per minute in adults.

Since this rate occurs faster than that of other cardiac muscle fibres, the SA node is called the "pacemaker". The onset of depolarisation in the heart begins within a focus of pacemaker cells found at the upper right border of the heart, just below the opening to the superior vena cava. These cells which give the initial activation are collectively known as the sinoatrial node

Since the SA node spontaneously generates action potentials faster than other components of the conduction system, nerve impulses from the SA node spread to the other areas and stimulate them so frequently they are not able to generate action potentials at their own inherent rates.

Thus the faster SA node sets the rhythm for the rest of the heart. The rate set by the SA node may be altered by nerve impulses from the autonomic nervous system or by chemicals such as thyroid hormones and epinephrine.

The conduction continues to travel in a wave downwards, leftwards and posteriorly, through both atria, depolarising each cell in turn. It is this propagation of charge that can be seen as the P wave on the electrocardiograph

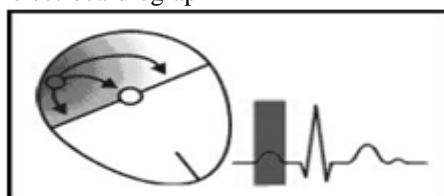


Figure 3.2: Atrial Depolarization

Eventually this conduction of depolarisation meets the atrioventricular node near the centre of the heart at the top of the interventricular septum. It is the atrioventricular node that is the main cause of delay in conducting the impulse from the atria to the ventricles. Since the atrioventricular node is small no depolarisation voltage is recorded and an isoelectric PR segment is seen on the electrocardiograph

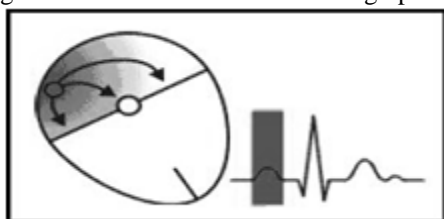


Figure 3.3: Atrioventricular Nodal

Depolarization and Activation of Bundle of His  
 The depolarization continues down the septum, along the bundle of His, before splitting to follow the left and right bundle branches and onwards to the conduction myofibres (Purkinje fibres) which distribute the action potential and thus depolarize the myocardial cells of the ventricles. Since the left bundle branch is activated first, the septal depolarisation proceeds from left to right and gives rise to a small negative deflection within the electrocardiograph - the Q wave.

As the impulse travels down the septum the atria and sinoatrial node start to polarize. The wave of depolarisation continues down the septum and into the ventricular free wall. Since the left ventricular wall mass is significantly greater than the right, the mean vector of depolarisation of the ventricular free wall is to the left. The depolarisation takes place from the endocardium to the epicardium and is seen as the R wave.

Atrial, atrioventricular nodal and bundle of His polarization continue but are obscured by the higher the rim of the ventricular muscle below the atrioventricular groove is the last to be depolarized. The direction of depolarisation leads to the S wave.

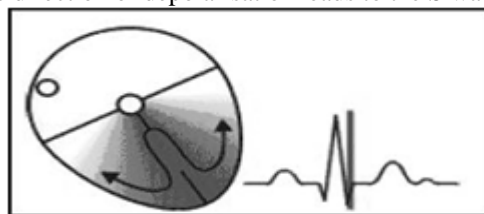


Figure 3.4: Ventricular Systole

Polarization is the return of the membrane potential to the baseline. This gives a deflection in the same direction as depolarisation because both polarity and direction are negated - the T wave.

Because the bundle of His has the greatest capacitance within the conduction cycle, it is the final part of the heart to polarize. The positive deflection caused by this is so small that it is often unclear. When detected it is referred to as the U wave.

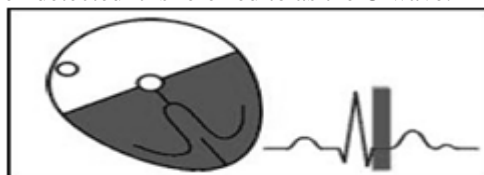


Figure 3.5: Ventricular

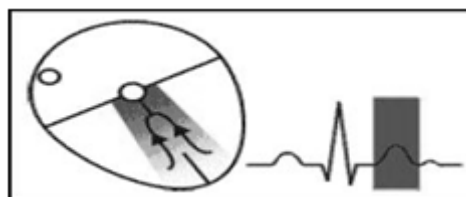


Figure 3.6: Bundle of His

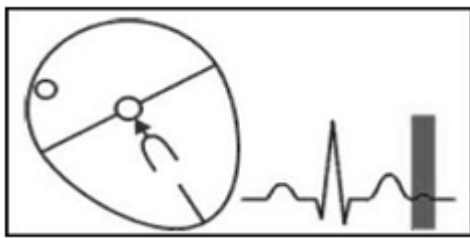


Figure: 3.7 Explanations of the ECG Waves

### 3.4 Noises in ECG Signal

Electrocardiographic signals (ECG) may be corrupted by various kinds of noise. Typical examples are:

1. Power Line Interference
2. Electrode Contact Noise.
3. Motion Artifacts.
4. Muscle Contraction.
5. Base Line Drift.
6. Instrumentation Noise generated by Electronic Devices.
7. Electrosurgical Noise.

#### 3.4.1 Power Line Interference

It consists of 50-60Hz pickup and harmonics, which can be modeled as sinusoids.

Characteristics, which might need to be varied in a model of power line noise, of 60Hz component (as most of the signals of study were digitized in USA) include the amplitude and frequency content of the signal. The amplitude varies up to 50 percent of the peak to peak ECG amplitude. It is shown in Figure 3.13 where power signal is affecting the signal between 1000 to 3000 units of time.

#### 3.4.2 Electrode Contact Noise

It is a transient interference caused by loss of contact between the electrode and the skin that effectively disconnects the measurement system from the subject. The loss of contact can be permanent, or can be intermittent as would be the case when a loose electrode is brought in and out of contact with the skin as a result of movements and vibration. This switching action at the measurement system input can result in large artifacts since the ECG signal is usually capacitively coupled to the system.

It can be modeled as randomly occurring rapid base line transition, which decays exponentially to the base line value and has a superimposed 60 Hz component. Typically the values of amplitude may vary to the maximum recorder output.

## IV. SIGNAL PROCESSING

A general transform equation can be written as:-

$$X(a, b) = \int_{-\infty}^{\infty} x(t) \Psi_{a, b}(t) dt \quad (4.1)$$

The signal to be processed is given as  $x(t)$ . Depending on the function  $\Psi_{a, b}(t)$  chosen, one gets different transforms. In order to evaluate the integral, certain conditions have to be imposed on this function. In this paper, we shall consider only three such transforms and these are the Fourier Transform, Short-Time Fourier Transform and the Wavelet Transform.

One of the major Signal Processing tools is the Fourier Analysis, which has different forms like Fourier Series, Fourier Transform, Discrete Fourier Transform, and so on. Fourier analysis methods use orthogonal sets of functions in order to expand a given periodic function into an infinite series.

### 4.2 Fourier Transform

Fourier analysis is extremely useful for data analysis, as it breaks down a signal into constituent sinusoids of different frequencies. For sampled vector data, Fourier analysis is performed using the Discrete Fourier transform (DFT).

The Fourier transform, in essence, decomposes or separates a waveform or function into sinusoids of different frequency which sum to the original waveform. It identifies or distinguishes the different frequency sinusoids and their respective amplitudes.

The Fourier Transform of  $f(x)$  is defined as:

$$F(s) = \int_{-\infty}^{\infty} f(x) e^{-j2\pi xs} dx \quad (4.2)$$

#### 4.2.2 Drawbacks of Fourier Transform

1. One of the shortcomings of the Fourier Transform is that it does not give any information on the time at which a frequency component occurs.
2. This is not a problem for "stationary" signals but does leave room for improvement when "non-stationary" signals are involved. (A stationary signal is one in which frequency content remains unchanged in time while in a non-stationary signal frequency changes with time).
3. The biggest problem is that frequency components in a signal cannot be localized in time.
4. FT is a "global" analysis. A small perturbation of the function at any one point on the time-axis influences all points on the frequency-axis and vice versa.
5. It can only be computed for one frequency at a time.
6. It cannot be computed in real-time.
7. Time-domain information is difficult to be interpreted from the spectrum.

8. It cannot display time-frequency information effectively.
9. FT Only Gives what Frequency Components Exist in the Signal.
10. The Time and Frequency Information can not be Seen at the Same Time.

#### 4.2 Wavelet Transforms

The basic idea which lies behind wavelets is the representation of an arbitrary function as a combination of simpler functions, generated as scaled and dilated versions of a particular oscillatory mother function.

This mother wavelet is used to generate a set of daughter functions through the operations of scaling and dilation applied to the mother wavelet. This set forms an orthogonal basis that allows, using inner products, to decompose any given signal much like in the case of Fourier analysis. Wavelets, however, are superior to Fourier analysis for time information is not lost when moving to the frequency domain. This property makes them suitable for applications from diverse fields where the frequency content of a signal as well as the energy's temporal location is valuable.

The wavelets application of interest for this work is their use for data analysis, especially for signals denoising. Denoising stands for the process of removing noise, i.e. unwanted information, present in an unknown signal.

The term wavelet is mostly used for denoting a particular wave whose energy is concentrated in a specific temporal location. A wavelet is therefore a known signal with some peculiar characteristics that allow it to be employed for studying the properties of other signals simultaneously in the frequency and time domains.

## V. RESULTS

Problem considered 1:

Muscle contractions cause artifactual milli-volt level potentials to be generated. The base line electromyogram is usually in the micro-volt range and therefore is usually insignificant. It is simulated by adding random noise to the ECG signal. The maximum noise level is formed by adding random single precision numbers of  $\pm 50\%$  of the ECG maximum amplitude to the uncorrupted ECG.

We have a high frequency noise which is superimposed on ECG signal each which is to be denoised using wavelet transform.

Frequency of noise: 4000 Hz

Number of Samples in single ECG signal: 4096

Result:

We generated a high frequency cosine signal and superimposed it on a pure ECG signal and hence

generated a noisy ECG signal as illustrated in the Figure 5.1.

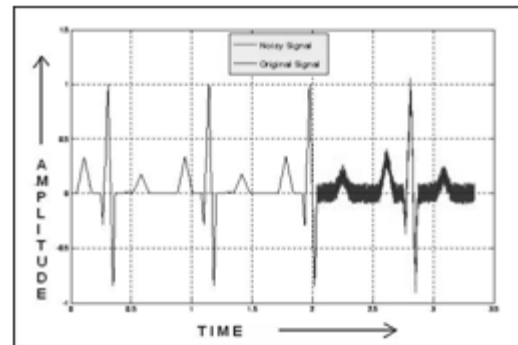


Figure 5.1: Noisy Signal for High Frequency Noise of Frequency 4000 Hz

#### Course of Denoising:

Wavelet used: - Daubechies wavelet (db7) up to level 12

In discrete wavelet transform the signal is analyzed at different frequency bands with different resolution by decomposing the signal into a coarse approximation and detail information. The coarse approximation is then further decomposed using the same wavelet decomposition step. This is achieved by successive high pass and low pass filtering of the time domain signal.

Approximations ( $A_i$ ) signify low frequency components and details ( $D_i$ ) signify high frequency components of the signal.

Signal 'S' is decomposed into high frequency component (detail  $D_1$ ) and low frequency component (approximation  $A_1$ ). Now approximation 'A1' is further decomposed into high frequency component (detail  $D_2$ ) and low frequency component (approximation  $A_2$ ). Similarly the decomposition of approximations is continued up to 12th level.

Using Matlab, when we program to decompose the noisy signal we obtain co-efficients of the approximations and details. These are reconstructed to obtain approximation and detail information.

To remove the high frequency noise we need to remove the detail components from the signal as they are high frequency component of the signal.

After removing high frequency detail components from the signal or equivalently adding all the low frequency approximation and detail components we obtain the filtered signal which is similar to the original ECG signal.



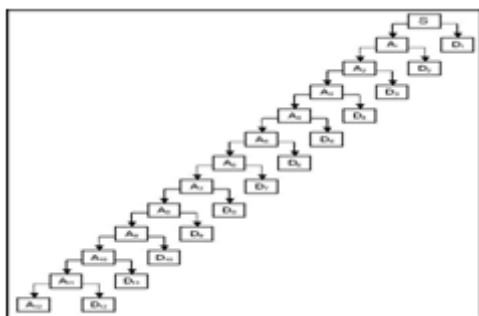


Figure 5.2: Signal Processing using Wavelets

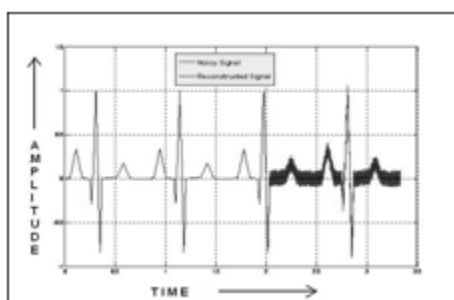


Figure 5.3: Filtered Signal in comparison to High Frequency Noisy Signal

In the figure red colour represents noisy signal and the blue colour represents the reconstructed signal.

Mean Square Error of 16384 samples with respect to the original signal is 0.3524 Frequency Response of Reconstructed approximation and detail vectors for High Frequency Noise

Problem considered 2:

The drift of the base line with respiration can be represented by a sinusoidal component at the frequency of respiration added to the ECG signal. The amplitude and the frequency of the sinusoidal component should be variables. Extraneous low frequency components can severely influence the visual interpretation of an ECG as well as the results obtained from computer based ECG analysis. Removal of base line wander is therefore required in the analysis of the ECG signals to minimize the changes in beat morphology with no physiological counterpart. Respiration and electrode impedance changes due to perspiration are important sources of base line wander in most types of ECG recordings. The frequency content of the base line wander is usually in a range well below 0.5Hz. The variations could be reproduced by amplitude modulation of the ECG by the sinusoidal component added to the base line. Reduction of ECG baseline wandering is very important for the measurement of the S-T segment with high accuracy, which is used for diagnosing ischemia, myocardial infarction and indicating the imbalance of myocardial oxygen supply.

We have a low frequency noise which is superimposed on ECG signal which is to be denoised using wavelet transform.

Frequency of noise: 0.4 Hz

Number of Samples in single ECG signal: 4096

Result:

We generated a low frequency cosine signal and superimposed it on a pure ECG signal and hence generated a noisy ECG signal as illustrated in the Figure 5.5.

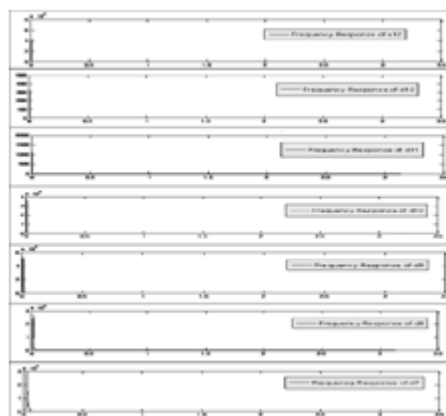


Figure 5.4: Noisy Signal for Baseline Wandering Noise of Frequency 0.4 Hz

Course of Denoising:

Wavelet used: - Daubechies wavelet (db7) up to level 12

Referring to the explanation of discrete wavelet transform in the previous problem

To remove the low frequency noise we need to remove the approximation components from the signal as they are low frequency component of the signal.

After removing low frequency approximation components from the signal or equivalently adding all the high frequency detail components we obtain the filtered signal which is similar to the original ECG signal.

The filtered signal is as in the Figure-5.6 along with the noisy signal.

Problem considered 3:

Power Line Interference consists of 50-60Hz pickup and harmonics, which can be modeled as sinusoids. Characteristics, which might need to be varied in a model of power line noise, of 60Hz component (as most of the signals of study were digitized in USA), include the amplitude and frequency content of the signal. The amplitude varies up to 50 percent of the peak to peak ECG amplitude where power signal is affecting the signal between 1000 to 3000 units of time.

We have a high frequency noise which is superimposed on ECG signal which is to be denoised using wavelet transform.

Frequency of noise: 50 Hz

Number of Samples in single ECG signal: 4096

Result:

We generated a high frequency sinusoidal signal and superimposed it on a pure ECG signal and hence generated a noisy ECG signal as illustrated in the Figure-5.8.

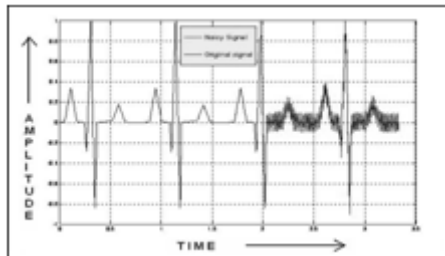


Figure 5.8: Noisy Signal for Power Line Interference of Frequency 50 Hz

Course of Denoising:

Wavelet used: - Daubechies wavelet (db22) up to level 12

Referring to the explanation of discrete wavelet transform in the first problem

To remove the high frequency noise we need to remove the detail components from the signal as they are high frequency component of the signal.

After removing high frequency detail components from the signal or equivalently adding all the low frequency approximation and detail components we obtain the filtered signal which is similar to the original ECG signal.

## VI. CONCLUSION

We have taken three ECG signals, which are superimposed by three different noises, viz., baseline wander, power line interference and muscle contraction, thereby obtaining noisy ECG signals.

Then we have decomposed them using wavelet decomposition.

The signals are reconstructed by adding 'selected' appropriate approximation and detail information.

Finally comparing the reconstructed ECG signals with the original ECG signal, error is obtained, which is very low, as specified in the results in the above section.

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