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A Comparative Study On Removal Of Noise In ECG Signal Using Different Filters

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Abstract:

The ECG an instrument, which records the electrical activity of heart. Electrical signals from the heart characteristically precede the normal mechanical function and monitoring of these signal has great clinical significance.ECG are used in catherization laboratories, coronary care units and for routine diagnostic applications in cardiology.

Noise is an unwanted problem to achieve spike free ECG signal. To remove this problem we use various filter. In this paper we take an overview of all filters which remove noise from ECG signal .Filter used like FIR, smoothing, Golay , Gaussian etc. in this paper we survey on all type of filter which is used in to achieve noise free signal.

Removing motion artifacts from an electrocardiogram (ECG) is one of the important issues to be considered during real-time heart rate measurements in telemetric health care. However, motion artifacts are part of the transient baseline change caused by the electrode motions that are the results of a subject's movement.

Key words: *Electrocardiogram(ECG), noise, filters.*

1.Introduction

1.1.Artifacts In ECG Signal

The word artifact is similar to artificial in the sense that it is often used to indicate something that is not natural (i.e. man-made). In electrocardiography, an ECG artifact is used to indicate something that is not "heart-made." These include (but are not limited to) electrical interference by outside sources, electrical noise from elsewhere in the body, poor contact, and machine malfunction. Artifacts are extremely common, and knowledge of them is necessary to prevent misinterpretation of a heart's rhythm.

1.1.1.Pacing Spikes

These are seen in someone whose implanted pacemaker is firing. The sharp, thin spike seen in figure1. x-x is an electrical signal produced by an artificial pacemaker. The wide QRS complex that follows it represents the ventricles depolarizing. We say that the "(artificial) pacemaker captures" when it is able to successfully depolarize its intended target. If a pacing spike is not followed by its intended response, we say that it has failed to capture.

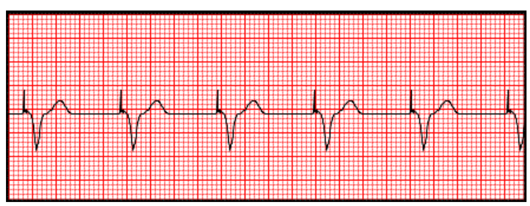


Figure 1: Artificial pacemaker spikes

1.1.2.Reversed Leads / Misplaced Electrodes

Electrode/lead placement is very important. If one were to accidentally confuse the red and white lead cables (i.e. place the white one where the red one should go, vice versa), he might get an ECG that looks like figure 2. In this ECG, we can make out a normal sinus rhythm with all of the waves upside-down. When this happens, you are essentially viewing the rhythm in a completely different lead.

One must also make sure that the lead wires are actually plugged into the machine. If your talkative patient shows a systole, you should suspect this. Many machines are "smart" in that they can sense common errors of this nature, but many such errors aren't always readily apparent.

Figure 2: Reversed leads

1.1.3.AC Interference

Alternating current (AC) describes the type of electricity that we get from the wall. In the United States, the electricity "changes direction" 60 times per second (i.e. 60 hertz). (Many places in Europe use 50 Hz AC electricity.) When an ECG machine is poorly grounded or not equipped to filter out this interference, you can get a thick looking ECG line (as shown in figure 3). If one were to look at this ECG line closely, he would see 60 up-and-down wave pattern in a given second (25 squares).

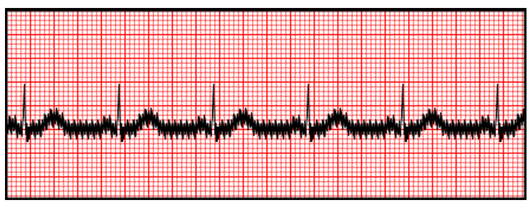


Figure 3 : 60 Hz AC interference

1.1.4.Muscle Tremor / Noise

The heart is not the only thing in the body that produces measurable electricity. When your skeletal muscles undergo tremors, the ECG is bombarded with seemingly random activity. The term noise does not refer to sound but rather to electrical interference. Low amplitude muscle tremor noise can mimic the baseline seen in atrial fibrillation. Muscle tremors are often a lot more subtle than that shown in figure 4.

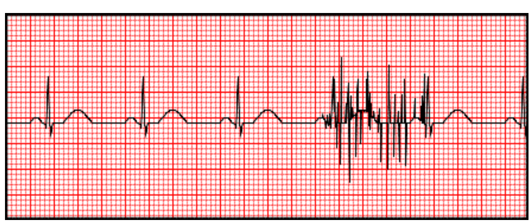


Figure 4 : Muscle tremors

1.1.5.Wandering Baseline

In wandering baseline, the isoelectric line changes position. One possible cause is the cables moving during the reading. Patient movement, dirty lead wires/electrodes, loose electrodes, and a variety of other things can cause this as well.

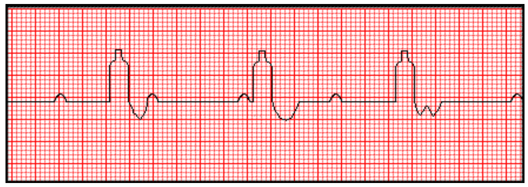


Figure 5: Absolute heart block

1.1.6.Absolute Heart Block

Absolute heart block (or 4th degree heart block) results from over-exposure to imported-liquor advertisements in magazines. QRS complexes are wide and bottle-shaped and show no relationship with the P wave. It occurs very rarely, and even then, only in fictional settings. This should not be confused with the real arrhythmia complete heart block.

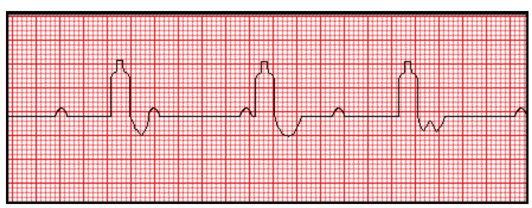


Figure 6: Absolute heart block

2.Physiological Background

2.1.Anatomy Of Heart

The heart is responsible for pumping blood to the organs and cells throughout the body to provide them with the nutrients and oxygen needed for survival. The heart is comprised of four chambers. The upper left and upper right chambers are called atria, while the lower left and lower right chambers are called ventricles. The chambers are separated by a muscle called the septum, and there are multiple valves to connect the various chambers to each other.

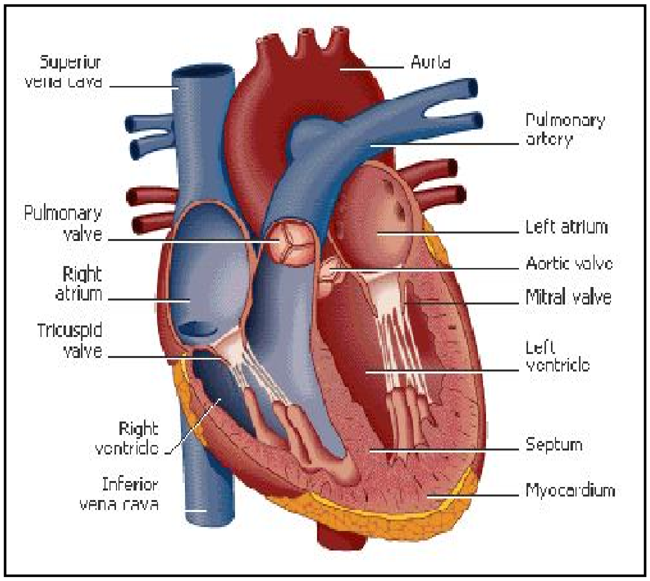


Figure 7: Anatomy of human heart

Oxygen-deficient blood from the right atria flows to the right ventricle through the tricuspid valve and then gets pumped through the pulmonary valve to the lungs in order to gain oxygen. The oxygen-rich blood returns to the heart into the left atrium and gets pumped through the mitral valve to the left ventricle. Finally, the blood flows throughout the rest of the body when the aortic valve opens, and the left ventricle compresses to pump the blood. Blood travels to the organs and cells of the body by means of a network of arteries, arterioles, and capillaries, while the oxygen-deficient blood travels back to the heart through a network of veins and venules. Altogether, the heart and circulatory system of arteries and veins make up the body's cardiovascular system.

2.2 .Electrocardiogram

The electrical activity of the heart is represented by the ECG signal. The ECG scan is essentially a periodic waveform. One cycle of the blood transfer process from heart to the arteries is represented by the one period of the ECG waveform. This part of the waveform is generated by an electrical impulse originated at sino-atrial node in the right atrium of the heart. The impulses causes contraction of the atria which forces the blood in each atrium to squeeze into its corresponding ventricle. The resulting signal is called the P wave. The atrioventricular node delays the excitation impulse until the blood transfers from atria to the ventricles is completed, Resulting in PR interval of the ECG waveform. The excitation impulse then causes contraction of the ventricles which squeezes blood into the arteries. This generates the QRS part of the ECG waveform. During this phase the atria are relaxed and filled with blood. The T wave of the waveform represents the relaxation of ventricles. The complete process is repeated periodically, generating the ECG trace.

Each portion of the ECG waveform carries various type of informations for the physician analyzing a patient's heart condition. For example amplitude and timing of the P and QRS portions indicate the condition of cardiac muscle mass. Loss of amplitude indicates muscle damage, whereas increased amplitudes indicates abnormal heart rates. Too long a delay in the atrioventricular node is indicated by very long PR interval. Likewise, blockage of some or all of contraction muscles is reflected by intermittent synchronization between P and QRS waves. Most of these abnormalities can be treated with various drugs and the effectiveness of the drugs can be monitored by observing the ECG waveforms taken after the drug treatment.

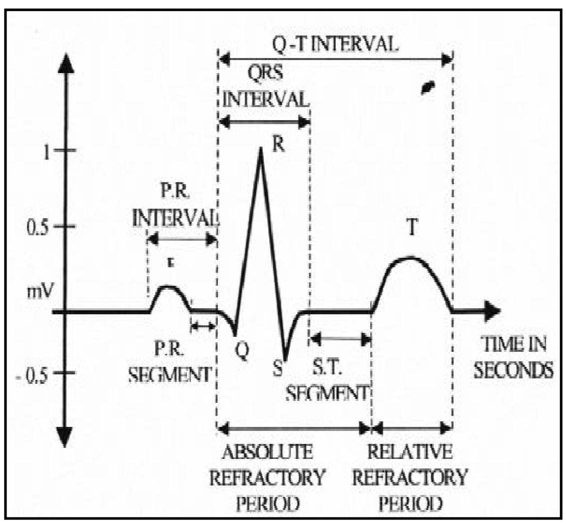


Figure 8: Typical ECG waveform

2.3.Cardiovascular Diseases

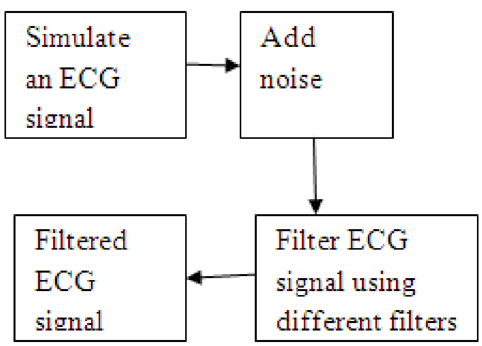
According to the World Health Organization (WHO), cardiovascular diseases are among the top three leading causes of death worldwide regardless of country income levels. 1 in 2005, 17 million people died from cardiovascular diseases globally and the World Health Organization expects this number to reach 20 million by 2015.

Performing the ECG analysis is one of the easiest ways to help detect heart anomalies and treat them early, before the onset of more serious heart issues. ECG technology is one of the most non invasive tests to record the electrical activity of the heart.

Over the past two decades various types of ECG analysis algorithms are developed and improved. Various mathematical tools are available for performing complex and tedious calculations like MATLAB.

Some types of cardiovascular disease include coronary heart disease-disease of the blood vessels supplying the heart muscle, Cerebrovascular disease- disease of the blood vessels supplying the brain, Peripheral heart disease- disease of blood vessels supplying the arms and legs, Congenital heart disease- malformations of heart structure existing at birth.

3.Block Diagram



3.1.Simulation Of ECG Signal

The aim of the ECG simulator is to produce the typical ECG waveforms of different leads and as many arrhythmias as possible. The ECG simulator is a matlab based simulator and is able to produce normal lead II ECG waveform.

The use of a simulator has many advantages in the simulation of ECG waveforms. First one is saving of time and another one is removing the difficulties of taking real ECG signals with invasive and noninvasive methods. The ECG simulator enables us to analyze and study normal and abnormal ECG waveforms without actually using the ECG machine. One can simulate any given ECG waveform using the ECG simulator.

3.2.Add Noise To The ECG Signal

To add noise to the ECG signal, the following is to be known,

- the simulated signal
- the time step of the data, i.e. what is the elapsed time between the first data and second data
- the length of your ECG signal, i.e. how many total time does your ECG signal last.

Then to generate the noise signal, use the same time step and generate the signal with the same length and simply add them together.

3.3.Removal Of Noise Using Filters

3.3.1.Savitzky-Golay Filter

The Savitzky–Golay smoothing filter is a filter that essentially performs a local polynomial regression (of degree k) on a series of values (of at least k+1 points which are treated as being equally spaced in the series) to determine the smoothed value for each point. The main advantage of this approach is that it tends to preserve features of the distribution such as relative maxima, minima and width, which are usually 'flattened' by other adjacent averaging techniques.

3.3.2.Smoothing Filters

To smooth a data set is to create an approximating function that attempts to capture important patterns in the data, while leaving out noise or other fine-scale structures/rapid phenomena. In smoothing, the data points of a signal are modified so individual points (presumably because of noise) are reduced, and points that are lower than the adjacent points are increased leading to a smoother signal.

Smoothing may be used in two important ways that can aid in data analysis,

- by being able to extract more information from the data as long as the assumption of smoothing is reasonable, and
- by being able to provide analyses that are both flexible and robust.

3.3.3.Moving Average Filter

A moving average, also called rolling average, rolling mean or running average, is a type of finite impulse response filter used to analyze a set of data points by creating a series of averages of different subsets of the full data set.

Given a series of numbers and a fixed subset size, the first element of the moving average is obtained by taking the average of the initial fixed subset of the number series. Then the subset is modified by "shifting forward", that is excluding the first number of the series and including the next number following the original subset in the series. This creates a new subset of numbers, which is averaged. This process is repeated over the entire data series. The plot line connecting all the (fixed) averages is the moving average. A moving average is a set of numbers, each of which is the average of the corresponding subset of a larger set of datum points. A moving average may also use unequal weights for each datum value in the subset to emphasize particular values in the subset.

3.3.4 Gaussian Filter

In electronics and signal processing, a Gaussian filter is a filter whose impulse response is a Gaussian function. Gaussian filters are designed to give no overshoot to a step function input while minimizing the rise and fall time. This behavior is closely connected to the fact that the Gaussian filter has the minimum possible group delay. Mathematically, a Gaussian filter modifies the input signal by convolution with a Gaussian function; this transformation is also known as the Weierstrass transform.

3.3.5.Median Filter

The median filter is a nonlinear digital filtering technique, often used to remove noise. Such noise reduction is a typical pre-processing step to improve the results of later processing (for example, edge detection on an image).

The main idea of the median filter is to run through the signal entry by entry, replacing each entry with the median of neighboring entries. The pattern of neighbors is called the "window", which slides, entry by entry, over the entire signal. For 1D signals, the most obvious window is just the first few preceding and following entries, whereas for 2D (or higher-dimensional) signals such as images, more complex window patterns are possible (such as "box" or "cross" patterns). Note that if the window has an odd number of entries, then the median is simple to define: it is just the middle value after all the entries in the window are sorted numerically.\

3.3.6.FIR Filter

A finite impulse response (FIR) filter is a filter whose impulse response (or response to any finite length input) is of finite duration, because it settles to zero in finite time. This is in contrast to infinite impulse response (IIR) filters, which may have internal feedback and may continue to respond indefinitely (usually decaying).

The impulse response of an Nth-order discrete-time FIR filter lasts for N + 1 samples, and then settles to zero.

FIR filters can be discrete-time or continuous-time, and digital or analog.

3.3.7.Butterworth Filter

The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the passband. It is also referred to as a maximally flat magnitude filter.

4.Algorithm

Algorithm for the removal of noise in ECG signal is as follows,

- Step 1: Simulate an ECG signal.
- Step 2: Add noise to the ECG signal.
- Step 3: Plot the noisy ECG signal.
- Step 4: Perform filtering using SGolay filter.
- Step 5: Perform filtering using smoothing function.
- Step6: Perform filtering using moving average filter.
- Step 7: Perform filtering using weighted window filter.
- Step 8: Perform filtering using Gaussian filter.
- Step 9: Perform filtering using median filter.
- Step10: Perform filtering using FIR filter.
- Step 11: Perform filtering using Butterworth filter.

5. Results

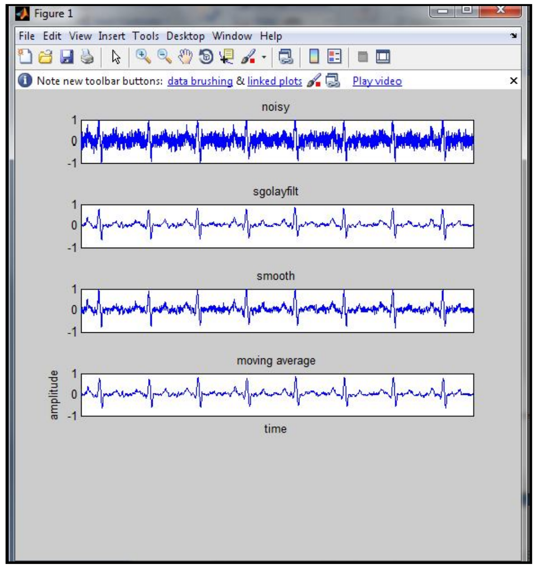


Figure 9: Results of golay, smoothing and average filters

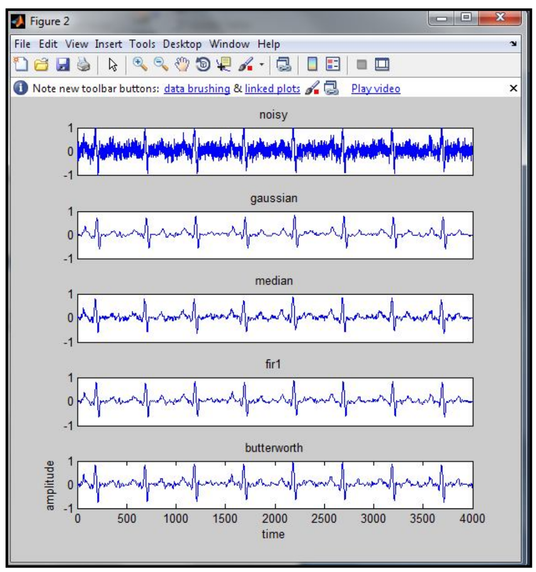


Figure 10:Results of gaussian, median, FIR and butterworth filters

5.1.A Comparative Study

The aim of the work is to develop a novel algorithm for spike free ECG for successful diagnosis Of heart related problems. Here, a noisy ECG is simulated in matlab and noise is filtered using different filters like Gaussian, median, weighted window, FIR, butterworth, smoothing. A comparative study is done based on the modifications happened after filtering using different filters. The modifications are on the P wave, QRS complex, T waves.

6.Conclusion

This work throws light on the basics of electrocardiogram, artifacts corrupting the ECG signal and ECG enhancement using different algorithms. The work begins with the review of some popular work in the field of ECG signal processing. The physiology of heart, heart beat generation, morphology of electrocardiogram are elaborately discussed. Different types of noises that affect the ECG and their origins are also described.

The noise in the ECG signal is filtered using different filters. The results show that golay filter can be effectively used to remove noise in the ECG signal. The different noise levels can be removed using savitzky-golay filter.

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