Extraction of ECG signal with adaptive filter for hearth abnormalities detection

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Abstract. This paper demonstrates an adaptive filter method for extraction of electrocardiogram (ECG) feature in hearth abnormalities detection. In particular, electrocardiogram (ECG) is a recording of the heart's electrical activity by capturing a tracing of cardiac electrical impulse as it moves from the atrium to the ventricles. The applied algorithm is to evaluate and analyze ECG signals for abnormalities detection based on P, Q, R and S peaks. In the first phase, the real-time ECG data is acquired and pre-processed. In the second phase, the procured ECG signal is subjected to feature extraction process. The extracted features detect abnormal peaks present in the waveform. Thus the normal and abnormal ECG signal could be differentiated based on the features extracted.

1. Introduction

Everyone must have known that the heart is the most important organ in the body. Even since the fetus is in the womb, the heartbeat is something eagerly awaited because the heartbeat is a sign of one's life. Therefore, to keep the heart in good health is one of the steps that we should do. But in fact, the variety of physical activity and daily consumption of food and beverages have made us neglect of body health especially heart organ. As a result, most people do not even know if they have a serious illness that can cause complications until the sudden cardiac arrest. Electrocardiogram (ECG) is a graph made by an electrocardiograph, which records the electrical activity of the heart within a certain time [1]. Its name consists of a number of different parts: Electro, as it relates to electronics, cardio, indicates heart, and gram means to write. Analysis of a number of ECG waves and normal vectors of depolarization and repolarization yields important diagnostic information of the heart activity. A typical ECG signal is used to tracks a normal heartbeat (or heart cycle) which consist of P wave, QRS complex and T wave. A small U wave is normally seen at 50-75% in the ECG signal. The baseline voltage of the ECG is known as the isoelectric line. Typically, the isoelectric line is measured as a tracking portion following the T wave and precedes the next P wave.

The distance of hospitals from patients, the limitations of cardiovascular doctors and its equipment, make the number of patients with heart disease especially sudden attacks increased. Since the death rate of patients with heart disease is relatively high, the development and application of the
Telemonitoring of ECG signal are needed [2, 3]. Therefore, an online ECG signal monitoring system for patients with heart disease by identifying the RR signals. With the development of a remote patient monitoring system, it is expected that each patient's condition can be monitored in online and real-time so that the physical condition data and medical history of the patient can be monitored at any time by a team of hospital doctors without regularly visit the hospital. Furthermore, both patients and families can be informed of alarms regarding the patient's condition, especially during an emergency. Several wireless ECG technologies which could significantly improve the mobility and comfort of patients for monitoring and diagnosis has been developed [4–9]. However, some issues related to current wireless ECG technology still need to be improved such as the speed, accuracy, its application, and the best reliability [10]. Heart function can be measured by the wireless ECG system used by the patient wherever located and the recording data is sent to the remote monitoring station. When a patient moves, this communication needs to be maintained with a wireless link and the quality of data with less noise needs to be maintained with powerful software.

Developing wireless ECG technology is required to provide online and real-time remote cardiography. In the conventionally designed wireless applications, it tends only for data transmission processes such that the ECG monitoring applications require only moderate data rate. In this paper, an adaptive wireless technology based on ECG filters to improve data quality, speed data rate, and the best reliability are being developed. The recorded ECG signal (generated by the stimulation of nerve impulses to the heart) from normal heartbeat consists of P waves, QRS complexes, and T waves. The ECG base voltage is known as the isoelectric line measured as part of track following the T wave and predates the next P wave. The purpose of this study was to develop an extraction algorithm that is a distance of the RR between QRS complex using adaptive filter to support the designed wireless ECG system.

2. Methods
To ensure the quality of life and up-to-date information about the physical and physiological health of the users, monitoring and recording of their physiological status are essential [11–13]. Therefore, the ECG technology-based wireless is proposed. The scheme of a wireless ECG technology is given in Figure 1. The developed system consists of electrode sensors (to measure the ECG signal), a wireless ECG recorded module (to preprocessed and transmit the ECG signals via Bluetooth), and an android mobile device. Then, an ECG monitoring algorithm includes the classifier developed in the android mobile device will continuously monitor the subject heart activities. When the abnormal heart rate is detected by a classifier, the classified ECG signals will be sent to the cloud or directly to the physician or family. Based on this mechanism, the cardiac state of the subject can be monitored anywhere in the globe as long as the subject under internet network coverage. The objective of this technology development is to build universal interfaces for medical instrument that are easy to use, cheap, easy to repair, best reliability, and good accuracy.

![Figure 1. The scheme of a wireless ECG technology instrument.](image)

To test the reliability and the quality of the developed system, the data is used from the previous experiment with experiment setup shown in Figure 2 [14-16].
3. Signal Processing

Signal processing concerns the analysis, synthesis, and modification of signals, which are broadly defined as functions conveying information about the behavior of some phenomenon such as ECG signals [17]. In experimental sciences, noise is referred to any random fluctuations of data that hinders perception of the desired signal. The process of elimination or reduction of an undesired signal which considered as noise is needed. An adaptive filter is used reduce noise in the recorded ECG signals while preserving the desired signal characteristics. The adaptive filters described in Figure 3 generally consist of a digital filter to represent the dynamic system and an adaptive algorithm to adjust the coefficient of the dynamic filter. (i.e., the desired signal(k) and the reference signal x(k) are simultaneously applied to the design adaptive filter). Commonly, digital filters use fixed coefficients, but in this design filter, the coefficients are adjusted based on an information from desired, reference, and output signals. The obtained signal d(k) is measured using electrode sensors which consist of both the actuals s(k) and also undesired noise signals n(k) (assumed to be independent). If the contaminated noise signal n(k) is known, the actual signal s(k) is obtained by subtracting noise signal n(k) from contaminated signal d(k). Since the undesired or noise signal is difficult to measure, then the estimated signal is obtained by subtracting the estimated noise signal from the measured signal d(k).

FIR filter is one of the digital filters that commonly used in an adaptive system. The coefficient of the dynamic filter at time k is arranged by vector w(k) with length of K. A filter with K tap can be considered by K sample of reference input x(k) at time k as a vector as follows [11][18].

\[
W(k) = [w_0(k), w_1(k), ..., w_{M-1}(k)]^T
\]

\[
x(k) = [x(k), x(k-1), ..., x(k-M+1)]
\]

\[
y(k) = \sum_{i=0}^{M-1} w_i(k)x(k-i) = w^T(k)x(k)
\]

The Least Mean Square (LMS) is an approximation of the gradient vector with instantaneous value. The error signal e(k) is minimized in the mean-square sense to change the weighting filter. The conventional LMS algorithm can simply replace the cost function [19].

\[
\xi(k) = E[e^2(k)]
\]

The error estimation

\[
e(k) = d(k) - y(k) = d(k) - w(k)x(k)
\]

with the coefficient updating equation is

\[
w(k+1) = w(k) + \mu e(k)x(k)
\]

where w(k) and w(k+1) represent the weight and the next weight vectors, respectively, x(k) and e(k) are the input and error signals and \( \mu \) is an appropriate step size of the convergence factor to be chosen.

**Figure 2.** Experiment setup and ECG recorded signals with relaxing and typing conditions.
to determine the filter speed [19-21]. The larger of the step sizes could make the coefficients of the filter become wildly fluctuate and eventually become unstable.

![Diagram of filter design for ECG signal]

**Figure 3.** An adaptive filter design for the ECG signal.

To avoid the gradient noise amplification condition especially when $\mu$ is large, then the Normalized Least Mean Square (NLMS) algorithm is applied. The convergence factor of the NLMS algorithm in the time-varying form is calculated as

$$\mu(k) = \frac{\alpha}{c + \|x(k)\|^2}$$  \hspace{1cm} (7)

where $\alpha$ is the adaptation value ($0 < \alpha < 2$) used to improve the convergence rate of the developed algorithm and $c$ is a constant which usually less than 1. Then, the weights vector of the design filter will be updated in the form of

$$w(k + 1) = w(k) + \frac{\alpha}{c + \|x(k)\|^2} e(k)\mu(k)$$  \hspace{1cm} (8)

When $x(k)$ is large, the noise amplification problem is diminished by normalization of the term $\|x(k)\|^2$.

**4. Results and Discussions**

The results of data processing on advanced ECG recording allows doctors and users to easily understand and observe the performance and condition of the heart as well as to make a real-time diagnosis. For the purpose, the signal disturbance in the form of power lines, muscle artifacts, electrode motion artifacts, etc. Should be eliminated as good as possible. The noise signal is mainly due to patient breathing, movement, poor electrode conditions and improper location electrode preparation. All these disturbances will mask the original signal and tend to be smaller amplitude. If this problem can not be solved properly, then it can result in a false diagnosis. In this paper, adaptive filters are implemented.

The algorithm is evaluated on the recorded data from ten healthy volunteers subject aged around 25 ± 3 years old and it functions normally. Figure 4 and 5 show the recorded using developed system (top) and filtered signals using the adaptive filter with the normalized mean square algorithm (bottom). In normal ECG, the time interval between R-R is 0.6-1s, in case of the fast heartbeat the time interval is less 0.6s which is known as sinus tachycardia; in case of a slow heartbeat, the time interval is more than 1 sec that is known as sinus bradycardia. By referring Figure 4 and 5 we can say that the R-R interval for normal case is between 0.6-1s. All signals from all subject and different distance of wireless ECG recording signals are in the standard form of ECG signals. Compared with the data measured by medical instruments in nursing centers and hospitals, our physiological status monitoring system has reached the application level. By improving the signal processing ability for filtering, the quality of filtered signal from a farther distance.
Initial stage on detecting subject's heart condition is developing an algorithm that can be used to detect the QRS position as in Figure 6. The QRS positioning information on each recording signal will make it easier for doctors or family to know their heart conditions. To enhance the accuracy of peak detection related to the QRS position, the signal is preprocessed using an adaptive filter. The R and S points including RR interval were well detected as shown in Figure 7. The obtained results clearly different from the recorded data of relax than typing subjects. If in the previous results with a general filter algorithm the difference is highly significant but with the adaptive filter, the peak detection accuracy is only slightly different. Then the proposed filter is sufficiently able to overcome the dynamic interference on the signal recording. That difference can be seen in Figure 8 and 9.

Figure 4. Filtered ECG signals from relaxing subject.

Figure 5. Filtered ECG signals from typing subject.

Figure 6. The standard form of ECG Signals [12].
Figure 7. Detected R & S point and RR Interval.

Figure 8. Detected QRS for relax condition.

Figure 9. Detected QRS for typing condition.
5. Conclusions
In this paper, the developed (i.e., wireless ECG system that consists of mobile physiological examination device and wireless base station) and its application in the experiment is evaluated. One of the crucial steps in the ECG analysis is to accurately detect the different forms of P, Q, R and S which represent the entire heart cycle. An application of the adaptive filter with the developed system, the higher quality of the ECG signals is achieved. An improvement of QRS peak detection accuracy supported by adaptive filter about 86% is achieved.

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