Early Diagnosis of Heart Defect using Digital Signal Processing

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ABSTRACT
In this paper, we describe a design of a system for preliminary detection of defective hearts is proposed which is based on the phonocardiogram (PCG) signals. The advantage of the proposed system is that a heart defect diagnosis algorithm can be implemented on a smartphone which is a high end embedded system. This device is an advanced phone used as a mode of communication and is available with most humans beings at all times. Such a method can be useful since early detection of heart disease is important because it can ease the treatment and also save people’s lives. The development is proposed to be in the form of an application that by using Digital Signal Processing techniques on the phonocardiogram (PCG) signals can alert the user in case of heart ailment and advise on taking further medical advice or treatment.

Keywords
CHD: Coronary heart disease
CVD: Cardiovascular disease
ECG: Electrocardiogram (also EKG)
EOF: End of file
MI: Myocardial infarction (heart attack)
POC: Point of contact

I. INTRODUCTION
Cardiovascular disease (CVD) or “Heart disease” includes any disorder that affects the heart’s ability to function normally. Cardiovascular disease (CVD) is the single leading cause of death in both developed and developing countries. According to the American Heart Association, in the United States alone 80,000,000 people are estimated to have one or more forms of CVD and nearly 2,400 Americans die of CVD each day. The most deadly CVD is heart attack, which 7,900,000 Americans suffer each year, and 16% of cases (1,200,000) are fatal. Furthermore, some 300,000 Americans a year suffer sudden cardiac death, an event generally defined as death resulting from coronary heart disease (CHD), which usually leads to myocardial infarctions (MIs), popularly known as “Heart Attack”, within an hour of the onset of symptoms. Furthermore, acute heart attacks sometimes leave victims with little-to-no warning signs.

There are various forms of heart disease, for example, arrhythmias, prolapsed mitral valve, coronary artery disease, congenital heart disease, and so on. The most common cause of heart disease is a narrowing of the coronary arteries that supply blood to the heart muscle but some heart diseases are present at birth. In general, heart disease has been investigated by various methods, one of which is the non-invasive method, which has been widely used and recognized as the best method of investigation. Generally, using an electrocardiogram (ECG) signal for heart disease investigation is the most common method recommended as it is a simple and non-invasive diagnostic tool. The signal can be easily obtained by placing the electrodes on the chest wall and limbs and connecting them to an ECG machine.

Besides an ECG signal, a phonocardiogram (PCG) signal is also employed for heart disease diagnosis. In such a case, a PCG signal is the recorded heart sound using a microphone placed on the chest. Both ECG and PCG signals play important roles in heart abnormality detection; however, diagnosis based on ECG signal or PCG signal alone cannot detect all cases of heart symptoms. For example, an ECG signal can reveal various physiological and abnormal behaviours of the
heart. But some symptoms such as heart murmurs often caused by defective heart valves cannot be detected from an ECG signal. However, given the sporadic nature of heart attacks, it is unlikely that the patient will be in a clinical setting at the onset of a heart attack. While Holter-based portable monitoring solutions offer 24 to 48-hour ECG recording, they lack the capability of providing any real-time feedback for the thousands of heart beats they record, which must be tediously analyzed offline. The current project is focused on diagnosing heart defects based on the PCG signals and to evaluate if it can lead to high diagnosis of a heart attack.

With the advent of computers, technology is playing an ever increasing role in society by making jobs easier and faster, providing new medians for communications, and most importantly, increasing quality of life with medical devices. Through the twentieth century, medical devices have helped save lives, there has been an increasing trend to make medical devices smaller and more portable, to allow the patient to use them at all times. Examples of such devices are pacemakers, portable respirators, and automated external defibrillators. More recently, newer, more powerful smartphones, which are becoming increasingly popular, can also serve as platforms for health-related conditions; diabetes patients can keep track of their insulin levels, sleep quality can be monitored, and diet and exercise statistics can be calculated all using smartphones. With a form factor that is designed for portability, powerful computing abilities, and their built-in communication interfaces, smartphones make an ideal platform for portable, real-time assistive medical diagnosis. Processing PCG signals on a smartphone-based platform would unite the portability of Holter monitors and the real-time processing capability of state-of-the-art resting PCG machines to provide an assistive diagnosis for early heart attack warning. Furthermore, smartphones serve as an ideal platform for telemedicine and alert systems and have a portable form factor. To detect heart attacks via PCG processing, a real-time digital signal processing algorithm is proposed and evaluated.

A new direction for smartphone assistive diagnosis is monitoring the body’s internal signals for changes in a user’s health that are life-threatening. The goal of this research is to provide portable, real-time heart attack detection via smartphone and digital signal processing. For users, such a device would serve as an additional layer of heart attack detection, aside from the conventional warning signs, such as chest pain. By continuously monitoring the heart, heart attacks that could be previously undetectable by users may be able to be detected before damage occurs.

II. Background:

Before discussing a heart attack detection algorithm, it is first necessary to introduce the proper biomedical background to understand heart attacks. Therefore, this chapter provides a brief introduction to the clinical aspects of cardiology.

Officially known as myocardial infarctions (MIs), heart attacks are the most deadly CVD in which the patient may succumb to sudden cardiac death, an event generally defined as death resulting from coronary heart disease (CHD), which usually leads to heart attack, within an hour of the onset of symptoms. Heart attacks occur when the supply of blood to the heart is interrupted, commonly due to the blockage of a coronary artery, which causes heart cells to die. When left untreated, the blockage of blood supply (ischemia) results in the infarction of heart muscle tissue (myocardium). Classic heart attack warning signs include chest/shoulder pain, shortness of breath, nausea, vomiting, and sweating. However, heart attacks frequently occur without any warning signs; these heart attacks are referred to as silent.
III. Heart detection and diagnosis based on ECG and EPCG relationships:

An article in the Dove Press Journal: Medical Devices: Evidence and Research 25th August 2011 by W Phanphaisarn, A Roeksabutr, P Wardkein, J Koseeyaporn, PP Yupapin, “Heart detection and diagnosis based on ECG and EPCG relationships”, wherein a new design of a system for preliminary detection of defective hearts is proposed which is composed of two subsystems, in which one is based on the relationship between the electrocardiogram (ECG) and phonocardiogram (PCG) signals. The relationship between both signals is determined as an impulse response (h(n)) of a system, where the decision is made based on the linear predictive coding coefficients of a heart’s impulse response. The other subsystem uses a phase space approach, in which the mean squared error between the distance vectors of the phase space of the normal heart and abnormal heart is judged by the likelihood ratio test (Λ) value, on which the decision is made. The advantage of the proposed system is that a heart’s diagnosis system based on the ECG and EPCG signals can lead to high performance heart diagnostics.

A. Theoretical background:

An electrocardiogram (ECG) signal for heart disease investigation is a simple and non-invasive diagnostic tool. The signal can be easily obtained by placing the electrodes on the chest wall and limbs and hooking them to an ECG machine. Besides an ECG signal, a phonocardiogram (PCG) signal is also employed for heart disease diagnosis. In such a case, a PCG signal is the recorded heart sound using a microphone placed on the chest. Both ECG and PCG signals play important roles in heart abnormality detection; however, diagnosis based on ECG signal or PCG signal alone cannot detect all cases of heart symptoms. For example, an ECG signal can reveal various physiological and abnormal behaviours of the heart. But some symptoms such as heart murmurs often caused by defective heart valves cannot be detected from an ECG signal. Hence, some research has focused on diagnosing heart defects based on the relationship between ECG and PCG signals which can lead to high performance heart diagnostics.

Generally, the ECG and PCG signals are concurrent phenomena, in which the former is the electrical signal while the latter is the mechanical signal. However, the phenomenon of ECG and PCG signals is related, because the PCG signal is obtained by the mechanical heart operation, which relies on the electrical heart operation. In order to activate the mechanical heart operation that generates the PCG signal, the ECG and PCG correlated signals are used. Based on the previous concept, the ECG and EPCG impulse response signals have shown a linear relationship and time-invariance. Thus, the human heart will be considered as a linear system in order to find the heart impulse response. The concept of the automated preliminary heart defects detection system can be illustrated as a block diagram (see Figure 1). There are two subsystems, the impulse response and the phase space subsystems. The details of each subsystem will be described later in this paper. However, it is worth noting that the ECG and EPCG signals employed in this research are normalized to be the signals at a standard heart rate, which for an adult whose heart is healthy (normal) in relaxing state is around 80 beats per minute. This pre-processing is needed because the recorded ECG/PCG signals of each person are derived from different heart rates. Even the signals recorded from the same person but at different times can be derived from different heart rates. Therefore, one period of different signals may have different numbers of signal samples. Thus, the signals processed in this work are pre-processed by frequency normalization. With this pre-processing, the signals will be the same during each period of data collection. Then the details of the impulse response and phase space subsystems are discussed.
Before the results are demonstrated, it should be noted that for the impulse response-based algorithm, it is important that the ECG signal and the PCG signal employed to determine the impulse response $h(n)$ of a heart system must be recorded or measured at the same time. This restriction results in limited numbers of signal samples in the experiment. In this research, 80 sets of ECG signals and PCG signals measured at the same time from the voluntary patients are employed. Among these sets of signals, 40 sets were measured in normal cases and 40 sets in abnormal cases. First, all signals (ECG and PCG signals) employed in this research are normalized to 80 beats per minute heart rate. In addition, the magnitude of these signals is normalized so that it is confined in the range $-1$ and $1$. An example of the normalized ECG signal and the normalized PCG signal is demonstrated in Figure 2.

Examples of the envelope of the normalized PCG signals for normal cases and abnormal cases are illustrated in Figures 4 and 5, respectively. As can be seen, the first and second sounds clearly appeared in the normal cardiac sound (Figure 4, upper). But for abnormal mitral valve regurgitation case (Figure 5, upper), these sounds cannot be distinguished from each other. Once the ECG and PCG signals are normalized and the EPCG signals are obtained, the impulse response of a heart system is then determined.

For PCG signals, the envelope of the signals is employed for the decision-making procedure. Examples of the impulse response of a normal heart system and of an abnormal heart system are illustrated in Figures 6 and 7, respectively. From 80 sets of ECG signals and PCG signals, 80 impulse response signals are
obtained; 40 signals are of normal cases and 40 signals are of abnormal cases.

Figure 5 The impulse response of a normal heart system.

Figure 6 Impulse response of an abnormal heart system

The results for PPV and NPV are approximately 85% and 90%, respectively. These numbers could be improved if the collected data samples are large. Because volunteer numbers were limited and because of the restriction that an ECG signal and a PCG signal must be measured at the same time and from the same person, the number of data samples used in this technique is not as high as desired.

IV. Conclusion

In this paper, a non-invasive system for detecting heart malfunction is presented. The proposed system consists of two subsystems. One is based on the impulse response of a heart system derived from the relationship between an ECG signal and the envelope of a PCG signal (EPCG). The percentage accuracy obtained was 90% and 85% for NPVs and PPVs, respectively. Increasing the size of the collected data samples can improve the accuracy. Because the restriction that there must be an ECG signal and a PCG signal measured at the same time and from the same person limited the number of volunteers, number of data samples used in this technique was not as high as desired. The other subsystem is based on phase space of the signal (ECG or EPCG). The MSE value obtained by comparing the distance vector of the testing signal with the reference distance vector is judged by the likelihood ratio test result. This technique provides 100% accuracy for decision making. The results from both techniques show that the impulse response-based method can be used primarily to detect a heart abnormality, whereas the phase space-based approach can be used to indicate whether the heart defect is caused from the abnormal ECG signal and/or abnormal PCG signal.

This proposed preliminary automated heart defect detection technique can provide the opportunity to help patients but the drawback of requirement and cost of instrument to measure ECG & PCG makes the concept difficult to be made available.

References


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