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A novel heart-mobile interface for detection and classification of heart sounds

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ABSTRACT

Diagnosis of heart disease requires that a medical practitioner investigate heart auscultations for irregular sounds, followed by echocardiography and electrocardiography tests. These expensive tests also require specialized technicians to operate. We present a low-cost, patient-centered device for the initial screening of the heart sounds that can be potentially used by the users on themselves. They can later share these readings with their healthcare providers. We have created an innovative mobile-health service platform for analyzing and classifying heart sounds.

The presented system enables remote patient-monitoring by integrating advanced wireless communications with a customized low-cost stethoscope. This system also permits remote management of a patient's cardiac status while maximizing patient mobility. The smartphone application facilitates recording, processing, visualizing, listening to, and classification of heart sounds. We build our classification model using the Mel-Frequency Cepstral Coefficient and Hidden Markov Model. This application is tested in a hospital environment to collect live recordings from patients with positive results. The smartphone application correctly detected 92.68% of abnormal heart conditions in clinical trials at UT Southwestern Hospital.

1. Introduction

The latest generation of smartphones has become an essential commodity due to its variety of sensors, powerful computing capability, high memory capacity, and open source operating systems that encourage application development. Apart from communication, smartphones also provide services and applications such as daily planners, cameras, web surfing, navigation, health applications, etc. Being palm-sized, they allow for easy mobility and portability. Hence, the mobile health (mHealth) sector is very interested in mobile applications that provide remote-monitoring health care services. mHealth is also used for illness surveillance, patient tracking, and collecting health information.

1.1. Motivation

Interpretation of heart sounds is subjective and requires a medical expert to identify sound abnormalities. Currently, patients with abnormal cardiac sounds must visit a health professional to get diagnosed. The medical practitioner uses a stethoscope to do an initial screening that entails listening for irregular sounds from the patient's chest. Next, the practitioner employs echocardiography and electrocardiography tests for further diagnosis.

In this process, the practitioner evaluates properties of heart sounds to identify irregularities, such as the number of heart beats and gallops, intensity, frequency, and duration. Because heart sounds are generated in low frequencies, human ears tend to miss certain sounds as the high frequency sounds may mask the lower ones. To improve evaluations, traditional stethoscopes were innovated into digital stethoscopes which incorporate a small microprocessor. This microprocessor attenuates high frequency

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signals and amplifies heart sounds, enabling physicians to hear clean cardiac sounds. In addition, with digital stethoscopes, computer applications have become available to assist physicians in visualizing and identifying types of heart sounds. However, the cost of this diagnostic tool is high, so patients still need to visit a hospital or clinic to get diagnosed. Five major products are currently available in the market: CardioSleeve [1], SensiCardiac [2], Eko Core [3], HeartBuds [4], and Thinklabs [5]. At this time, only Eko Core and Thinklabs are customized electronic stethoscopes that also work with a smartphone application and desktop application software. However, the software only records, displays, and shares heart sounds. Their computer and smartphone software also does not provide analytics for or determine the type of heart sound. A physician is required to evaluate and identify the sounds. HeartBuds, a similar device, is a custom-made acoustic amplifier. CardioSleeve, a 3-lead electrocardiogram (ECG) combined with a digital stethoscope, has a smartphone application to visualize ECG and heart sounds via Bluetooth. The software calculates the systolic performance index as an indication of ejection fraction to assess heart failure and displays the value of isovolumic contraction, isovolumic relaxation, RR interval, PT interval, and QRS interval obtained from the ECG leads. SensiCardiac, a cloud-based software, analyzes heart sounds recorded from an electronic stethoscope. A user records heart sounds and sends them to the cloud to interpret if the heart sound is normal, a class I murmur, or a class III murmur. A class I murmur can be any systolic or diastolic murmur, while a class III is a flow murmur.

Apart from these products, Dr. Raj Shekhar of Children's National Health System [6], in a major research project, is building a smartphone application called StethAid that allows pediatricians to discriminate Still's murmurs from pathological murmurs in children. This allows a physician to establish a child's murmur as benign, thus eliminating the need for a cardiac referral. The application will work in conjunction with a digital stethoscope.

1.2. Objective

This paper focuses on developing an innovative mHealth service platform for analyzing and classifying heart sounds. This service enables remote patient-monitoring using advanced wireless communications by integrating a customized low-cost stethoscope with a smartphone application. It also permits remote management of patients' cardiac status while maximizing patient mobility.

Many developing and under-developed regions lack access to medical facilities with echocardiograms and specialized doctors such as cardiologists, but these regions do have access to mobile platforms such as smartphones. So, the presented mechanism of diagnosing heart sounds provides immense value to such populations [76]. The smartphone application provides capabilities such as recording, processing, visualizing, listening to, and identifying cardiac sounds. The recorded sounds are identified as abnormal rhythms such as split sounds, aortic stenosis, pulmonary stenosis, atrial septal defect, ventricular septal defect, mitral valve prolapse, mitral regurgitation, tricuspid regurgitation, aortic regurgitation, pulmonary regurgitation, tricuspid stenosis, mitral stenosis, flow murmur, and patent ductus arteriosus.

This work focuses on mobility and remote monitoring, and centers on the patient or user. This work's significance lies in presenting a convenient, independent, and portable device that aid physicians to monitor a patient's heart while the patient is remote. Since this work is deployed on a smartphone, it makes a novel contribution to mHealth, mobile, and pervasive computing domain specifically in the following methods:

1) We use discrete wavelet transform (DWT) and continuous wavelet transform (CWT) to process heart sounds. DWT helps to down-sample data and to remove redundant information. CWT helps to identify valve movement in the heart sound by calculating the energy level in the signal.
2) We can filter and amplify signals without using a digital stethoscope by using a modified traditional-stethoscope to collect heart sounds. This low-cost device is easily available in any pharmacy. We study time and frequency resolution of all murmurs using fast Fourier transform and short-time Fourier transform. Using these digital processing techniques, we have calculated a cutoff range to filter the signal, which we then normalize.
3) We design a classification model using Mel-Frequency Cepstral Coefficient (MFCC) and Hidden Markov Model (HMM) to detect normal heart sound and 13 types of heart murmurs. The model also works with split detection technique to determine the split intervals. Our classification model is built based on frequency features extracted using MFCC. The model has 4 systolic HMMs and 4 diastolic HMMs. We also use the auscultation area to identify certain murmurs.
4) We have designed a heart-sound application using a smartphone, and here we show our software and the graphical user interface's overall architecture. This software records and analyzes cardiac sounds and generates graphs, audio, and electronic medical records. As this application generates electronic medical records, we use an elliptic-curve integrated scheme to secure data while sharing information with a physician. The details of the mechanism for securing the data has been presented in a different paper [78].

The rest of this paper is organized as follows. We provide a brief description of the heart and its sounds in Section II, explaining the origin of normal and abnormal heart sounds with the heart valve's movement. The pattern of each murmur and its corresponding auscultation are also discussed here. We focus on preprocessing the recorded heart sounds in Section III for accurate split calculation and classification in later sections. In Section IV, we provide our methodology of identifying and measuring split intervals in the heart sounds. In Section V, we present the classification model used to determine split intervals and to detect normal heart sound and 13 types of heart murmurs. We outline the software design of the heart sound application using a smartphone in Section VI. Finally, Section VII concludes the paper.

2. The heart

2.1. Heart sounds and murmurs

Heart valves' movements create audible sounds, usually described as "lub-dub." The "lub" sound, also known as the first heart sound (S1), is heard when the mitral (M1) and tricuspid (T1) valves close. The M1 closure precedes T1 closure by 20–30 ms. As the left ventricle contracts first, the M1 component occurs earlier than the T1 component. An S1 split (the delay between M1 and T1) has a typical duration of 100–200 ms [9]. Its frequency components lie in the range of 40–200 Hz [9,10]. An S1 split is considered pathological if the delay time is above 30 ms [7–9].

"Dub", the second heart sound (S2), occurs when the aortic (A2) and pulmonary (P2) valves shut. S2 has a shorter duration and higher frequency (range of 50–250 Hz) than S1 [7,10]. Aortic pressure is superior to pulmonary pressure causing the A2 component to appear before P2. Analysis of the split and the relative intensities of A2 and P2 can identify the presence of cardiac abnormalities such as pulmonary stenosis and atrial septal defect. During deep inspiration, the interval between A2 and P2 prolongs, resulting in wide splitting. On expiration, the delay is less than 30 ms [7–9].