iCare: An Intelligent System for Remote Cardiac Monitoring in Smart Healthcare

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***Abstract*—Heart disease poses a great threat to the health of an individual and even leads to sudden cardiac death, and hence a ubiquitous and portable tool for early detection and warning is of significant value. Benefiting from the speedy advance of sensor technology, artificial intelligence, and internet of things, we have developed an intelligent system that can remotely collect heart sounds, process the signals, and predict common cardiac diseases with the trained machine learning model. In this study, we detail our designed smart stethoscope and show the system architecture and its components. Besides, initial results demonstrate its power.**

***Keywords*—cardiac health, heart sound, telemedicine**

I. Introduction

Statistical data indicate that cardiovascular diseases have become the number one killer of mankind and tend to happen in young groups [1]. Even worse, at the grassroots level, it is quite difficult to detect with traditional electrocardiographs many cardiovascular diseases, especially the structural heart diseases (e.g., congenital heart disease and acquired valvular heart disease). These diseases are often identified with a two-step method. A well-trained professional doctor first analyzes the signals of a stethoscope. If abnormal sounds are detected, further screening and examination equipment such as cardiac color Doppler ultrasound is used for final diagnosis. Although effective, such a method has limitations in practical use. First, the used medical devices are expensive and affordable by a general hospital, so it is inconvenient to be accessed by those living in remote areas and fails to provide ubiquitous services, where remote health monitoring can provide an economic and timely assistant. Second, under the situation of COVID-19 pandemic, medical staffs are required to wear the protective equipment in providing services to patients, which increases, to a certain extent, the risk of infection [2]. Accordingly, how to accurately, effectively, and safely monitor the health status of quarantined individuals suffering from the respiratory and cardiovascular diseases remains meaningful in balancing the supply-demand relationships of medical resources. Besides, it is an extremely urgent task to develop an intelligent device that can provide telemedicine to help people in areas with poor medical resources and to avoid the disease infection caused by the hospital infection and crowd gathering [3].

To detect heart diseases, researchers have explored various methods that can be categorized into biochemical experiment and signal analysis. The former usually detects heart diseases by conducting gene-based tests or analyzing blood constituent changes [4]. Such methods rely on lab experiments and cost much. Signal analysis method aims to utilize physiological signals such as electrocardiogram (ECG), electromyogram (EMG), electroencephalogram (EEG), and heart sound [5], among which, heart sound is one of the most important physiology signals and it provides a convenient and economic means of capturing and understanding the status of heart and cardiovascular system. Compared with ECG, EEG, and EMG, the use of heart sound has the advantage of better portability, low cost, and high acceptance. Besides, it requires only one-lead signal and has better sensitivity to some heart diseases.

In this study, we develop an intelligent system, called iCare, for remote cardiac monitoring, where we design a smart hardware to collect the heart sound of users and design signal processing algorithms and machine learning models to predict the heart status of an individual and to return the outcome to a professional doctor.

II. Cardiac Monitoring System

We in this section present the architecture of the proposed health monitoring system and illustrate its components. Figure 1 shows the architecture that typically has four layers of an artificial internet of things (AIOT) application: *sensing layer*, *network layer*, *middleware layer*, and *application layer* from bottom to up.

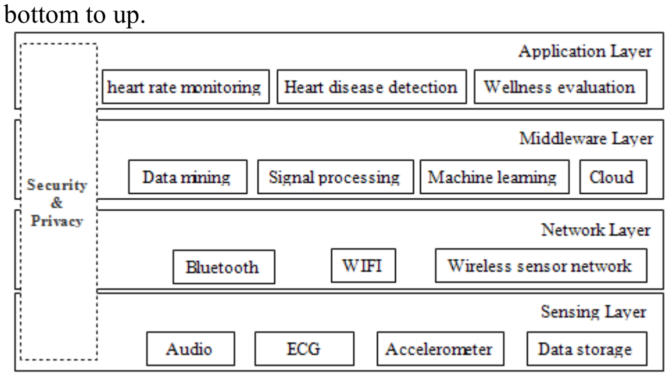

Figure 1. The architecture of the health monitoring system

1) Sensing Layer

From the view of information flow, the role of sensing layer is to integrate a collection of different types of sensors to build a sensing network for collecting, recording, storing, and pre-processing data related to a subject and the surroundings. In our system, we develop a stethoscope by embedding Bluetooth and audio chips in a printed circuit board and encapsulating the board in a compact metal housing, as shown in Figure 2. Particularly, the stethoscope uses high-sensitivity sensing units that have a sampling rate of 44100 Hz and we use it to collect heart sounds when we keep it close to the skin of specified

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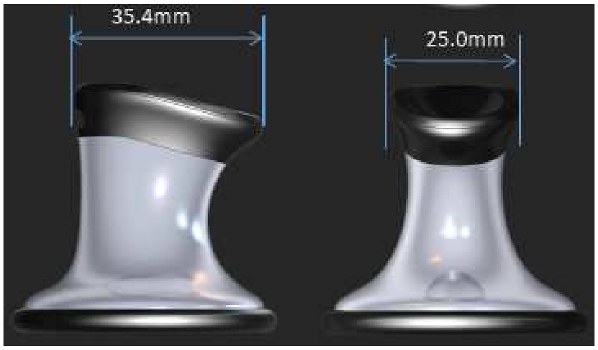

Figure 2. The designed smart stethoscope

area. Amplifiers and filters are integrated to improve the signal quality. Obviously, this device enables us to monitor cardiac signals remotely even under the risk of COVID-19 or other infection diseases.

2) Network Layer

The core function of network layer is to make connections between sensing layer and its upper layer and to transmit data. Currently, the designed device supports Bluetooth and WiFi to send the collected data to our cloud end or to our application installed on a smartphone for further processing and analysis.

3) Middleware Layer

We develop the middleware to hide the complex underlying details and to support the application layer. In this layer, we integrate data preprocessing algorithms and machine learning models. For example, signal processing algorithms, including fast Fourier transform, wavelet analysis, and variational mode decomposition are integrated. To extract discriminant features, feature extraction and selection methods are integrated. In addition, we maintain a collection of machine learning models that can be further optimized in new applications.

4) Application Layer

This layer provides the users application services such as health status evaluation and behavior analysis. Currently, our system can be used to detect cardiac diseases with heart sound data, where the classifier is trained with collected heart sounds. Our system also supports longitudinal health evaluation and provides both Android app-based and web-based services to satisfy different needs. Figure 3 presents the initial results in distinguishing between a normal subject and a patient with aortic stenosis. The X-axis of Figure 3 (a) and (b) denotes the indices of samples and Y-axis is the sensor readings. We can observe that they have clearly different sound pattens.

Besides, security and privacy are important topics closely related to the four layers, and we consider different levels of security and privacy protection methods.

III. Conclusion

With the aim to provide remote monitoring services for heart health, we develop a stethoscope-based intelligent system. The designed device has better portability and can be used by users pervasively. Second, it adopts the idea of AIOT and the detection accuracy could be enhanced with the increase of data. For further study, we plan to incorporate with hospitals to collect more data for incrementally updating the predictor.

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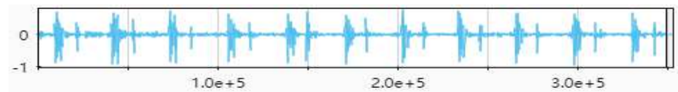
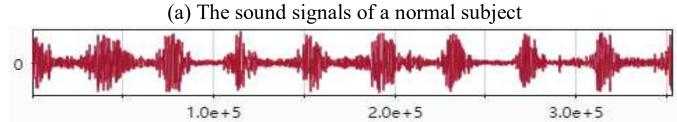
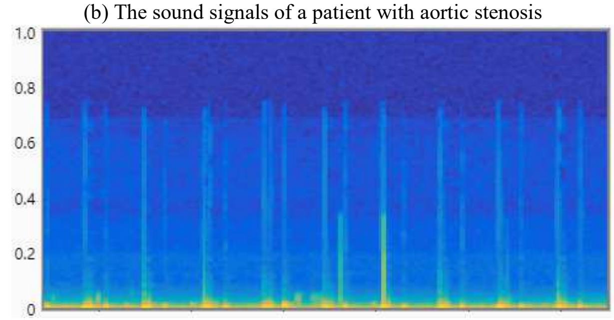


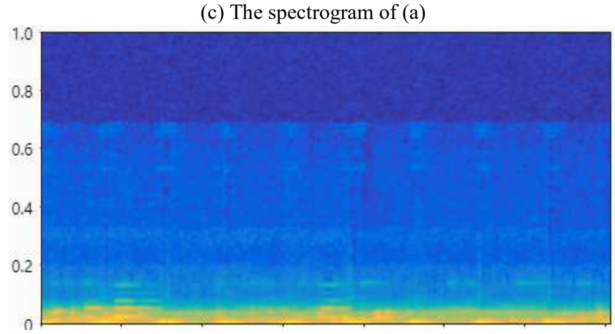
(a) The sound signals of a normal subject



(b) The sound signals of a patient with aortic stenosis



(c) The spectrogram of (a)



(d) The spectrogram of (b)

Figure 3. Signals of a normal subject and a patient with heart disease

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