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BODYTUNE: Multi Auscultation Device – Personal Health Parameter Monitoring at Home

Abstract: Auscultation methods allow the non-invasive diagnosis of pathological conditions (e.g., of the lung, heart or blood vessels) based on sounds that the body produces (e.g., breathing, heartbeat, swallowing or the blood flow). Through regular homebased examinations and Big Data combined with Machine learning techniques like Deep Learning, these could help detect diseases in an early stage, thus preventing serious health conditions and subsequently ensuring optimal therapy through continuous monitoring. This paper presents BODYTUNE, a novel inexpensive multi-auscultation system that aims at providing a tool for establishing a baseline of audio signal derived classification parameters that could be used for the self-monitoring of personal health for everybody through the analysis of deviations from that baseline. In the future, Big Data analysis could additionally lead to prediction and early detection of disease events.

Keywords: Personal health, home monitoring, Auscultation Cardiovascular, Neurovascular, Respiratory Disorder, Spectral Analysis, Phonoangiography, Continuous wavelet transform (CWT).

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1 Introduction

Auscultation is a diagnostic method that uses sound evaluation to get insights on processes within the body non-invasively. Physicians have used it for decades, listening to, e.g., breathing [1], heartbeats [2] or blood flow [3] using a stethoscope to detect pathological conditions. This procedure is difficult and time-intensive to learn, difficult to describe and teach, and with that, the results are highly dependent on the physician's experience [4]. A lot of health conditions such as atherosclerosis and development of chronic lung disease have a slow progression over time. Also, these diseases don't show any symptom until they reach a level where they show threats to life. In regards to this, the screenings with high-end Ultrasound and Computed Tomography examination usually takes place after pathological symptoms appear. Regular screening and examination could possibly help to detect diseases in an early stage and thus prevent serious health conditions and ensure optimal therapy. However, scans with the above-mentioned technologies at regular intervals are expensive and time consuming. For that a device is needed that is able to quantify and classify the obtained audio data files. For use in homecare the device would need to be cheap and user-friendly consisting of a mobile auscultation device and a smartphone application. This paper gives an overview of the preliminary work involved in designing and evaluation such as system development that we named BODYTUNE, as well as the signal acquisition methodology, signal processing and analysis, and the next steps in development.

2 The BODYTUNE auscultation system

2.1 System overview

Initially, BODYTUNE was built to acquire blood flow sounds at the neck to monitor carotid artery diseases [5].

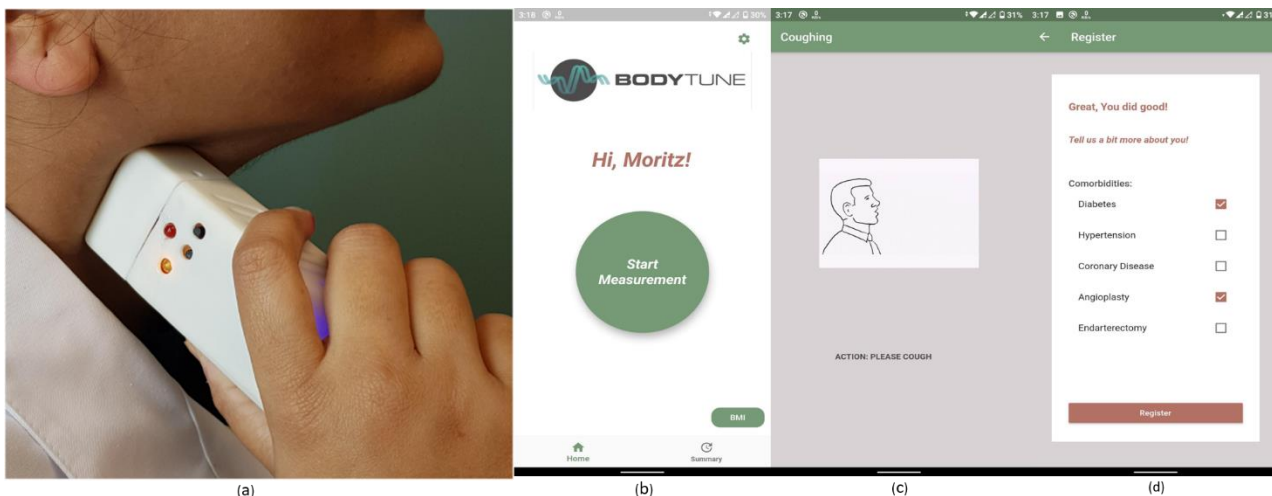


Figure 1: (a) BODYTUNE auscultation device, positioned for measuring; (b)-(d) screenshots of the smartphone application (b) main screen of the app, allows starting measurements; (c) excerpt from the measurement process, shows how the user is asked to cough during the measurement; (d) last page of the registration process, asks for comorbidities that relate to cardiovascular diseases.

Nevertheless, preliminary experimental results indicated that it also allows the recording of other significant body sounds at the neck such as breathing, coughing, and swallowing, which could further enable long-term monitoring and early-stage assessment of cardiovascular, neurovascular, and respiratory disorders.

The BODYTUNE system consists of two main components: A custom-built auscultation device and a mobile application (app) that guides through measurements. The auscultation device consists of a digital microphone fabricated in a micro-electro-mechanical-system packaged together with a host device powered by a Lithium-Polymer battery. The microphone and the host device are enclosed in a 3D printed (FormLabs Form 2 3D printer) mechanical case with the battery. Figure 1(a) shows a user holding the BODYTUNE auscultation device at the neck. When the device is booted, it connects to the app via Bluetooth. Within the app, the user can start a measurement (see Figure 1(b)). The app guides through the complete acquisition process, starting from indicating the user to locate the correct position until it reaches the desired signal quality. Further, the app also guides the user through the measurement protocol (see Figure 1(c)). After measurements, the app asks for inputs such as daily activity level, and medication intake, if any. Finally, it provides a summary of the measurement and stores the annotated file on the smartphone. Additionally, the app allows the user to input supplemental information such as comorbidities (see Figure 1(d)), and to manage their data. In addition to the mobile app, there is also a desktop version available. For a more detailed description of the auscultation device and the desktop

application, refer to Sühn et al. [6]. At the moment, recorded signals are stored on the smartphone and are manually extracted to perform signal processing and analysis. In the future, signal processing and Machine learning algorithms for automatic detection of medical abnormalities will be integrated into the app, making it a Software as a Service (SaaS) based application. In prior research [6], the stability and repeatability of this system; was tested in experiments on several individuals. The signals recorded by the auscultation system were stable and repeatable. For further improvement, we now designed a focused measurement protocol considering acquisition of different body sounds at the neck. The aim is to analyze what information could be drawn from these signals. The following section briefly describes the measurement protocol and data acquisition.

2.2 Data Acquisition

Beside recording the blood flow sound, the new idea is to record different sounds such as normal breathing, controlled breathing, swallowing, and coughing in one audio file. To facilitate the segmentation of these different events for further processing, we defined a protocol of 60 seconds length that each measurement follows. It starts with 12 seconds of normal breathing followed by 12 seconds of apnea and 12 seconds of controlled breathing. After that, two swallowing events within the next 12 seconds and two coughing events within the last 12 seconds follow. The next step was to find out if the different events are distinguishable from each other, what information they possess, and what parameters can support in identification and classification of these sounds. For this, a signal processing

method named continuous wavelet transform (CWT) was used. The following section gives information on this method, and the results obtained after applying this methodology.

2.3 Signal processing and qualitative analysis

The acquired signals are processed and analyzed using CWT, which provides spectral information of the acquired audio signals. We assume that the body sounds involve complex dynamics involving oscillatory and transient behavior. Considering both types of dynamics, CWT is more appropriate for the analysis than other techniques such as Fourier transform [5]. Figure 1(a) shows an example of a 60-second recording acquired according to the protocol described in the previous section. The red benchmarks represent the beginning and end of swallowing and coughing events, which were manually set for the proposed analysis. The CWT spectral information of this signal is presented in Figure 2(b). In general, we can observe that the studied episodes present spectral dynamics that differ from one type of episode to another. Although in the frequency band from approximately 4 to 47 Hz, the spectral dynamics are relatively stable throughout the recording, during controlled respiration, there are relevant variations in both the lower and higher frequency dynamics. This phenomenon can also be appreciated during

swallowing and coughing events but involving a different behavior. These preliminary observations indicate that the acquired signals of the BODYTUNE device not only contain relevant carotid sound signals but also can characterize other physiological phenomena such as respiration, swallowing, and coughing.

3 Potential Applications

We hypothesize that with a sufficient amount of data and trained algorithms, we will be able to identify these physiological phenomena and classify them as diseased and healthy. This can lead to several applications that we describe in this section.

The BODYTUNE system was originally designed for the detection and monitoring of carotid stenosis only. As skilled physicians can use a stethoscope to detect a stenosis, the BODYTUNE system could automatically distinguish between the blood flow sounds of healthy arteries and those that are narrowed. As a cheap and user-friendly system that runs on any smartphone, the system could be used as a tool for continuous monitoring of the carotid arteries at home by everybody. It could allow early detection of stenosis' begin, e.g., for persons at risk like diabetics or smokers, even before any notable symptoms occur. In addition, it could allow

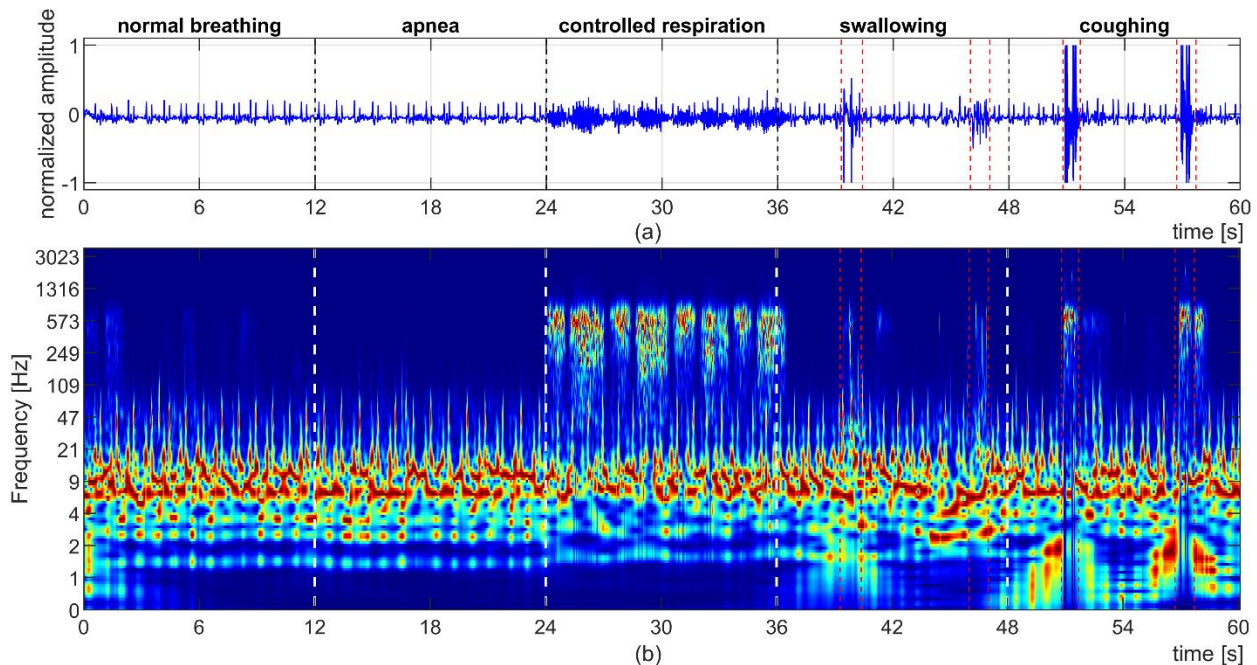


Figure 2. (a) Example of a carotid sound recording acquired according to the protocol described in section 2.2, (b) Continuous Wavelet Transform based Spectrum computed from (a).

monitoring of the progression of known stenosis or evaluation of the effects of medical treatment. This is not limited to carotid stenosis; it could also be applied to other arteries of the body like e.g., femoral artery. Since the positioning of the sensor also allows the acquisition of clearly distinguishable swallowing and coughing sounds, it can also be used to detect and monitor diseases that influence those body sounds. Based on the swallowing sounds, the system could be used on, e.g., difficulties in swallowing (dysphagia). Using the sounds of coughing, the system could be used on, e.g., the chronic obstructive pulmonary disease (COPD), a chronic progressive disease of the lung, or the coronavirus SARS-CoV-2. Apart from the detection of specific diseases, regular measuring of blood flow sounds, potentially in combination with other body sounds and/or additional information like physical activity or stress level, would allow creating a user-specific audio profile (baseline). This can allow the detection of unspecific changes from that baseline that might lead to a disease onset, making it a helpful tool for everybody. While this paper focuses on possible applications for home monitoring, it should be stated that the BODYTUNE device could also be used in other scenarios in the healthcare sector, e.g., to support caregivers or clinicians. Applications outside of the healthcare sector are thinkable as well, e.g., for biometric purposes.

However, we still need to take a long way to reach the final goal i.e., to progress on receiving maximum clinical data points required for each application we discuss above and then testing them with the custom designed algorithms to detect and classify different diseases.

4 Next Steps

This section describes the next steps in terms of technology development, improvement in app development, and usability studies for users in all age groups. Clinical data would need to be acquired to cement our hypothesis further. However, the analysis of the signals using CWT indicates the presence of relevant features. The next step would be to extract these features and classify the events using Machine Learning. The trained algorithm would then be integrated into a smartphone application that could give potential users feedback on their health condition. Additionally, usability studies need to be conducted following the app integration.

5 Conclusion

BODYTUNE is an inexpensive tool that has the potential to enable people to monitor their health remotely at home, even by non-professional users. At the moment, the device is capable of recording stable and repeatable signals. Additionally, the preliminary observations show significant features that differ from event to event. Extraction of these features from the clinical data will provide further insights and open perspective for applying machine learning approaches to further enable automated detection and classification of diseases based on the features. This way, long term and regular monitoring at home will detect any shifts or changes from the baseline and diagnose diseases in very early stages, which would eventually avoid medical emergencies.

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