MACHINE LEARNING ENABLED WEARABLE STETHOSCOPE

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Introduction

Objective

Millions of people in the United States suffer from chronic conditions related to the lungs and heart. Many more are in professions or positions which place them at risk of sudden afflictions of these two organs. In these cases, the time of response and diagnosis is crucial to the survivability of the individual.

We propose a wearable device, which constantly monitors the heart and lungs much like a doctor would with a stethoscope. Databases of lung and heart sounds used to train machine learning models like [1], [2] would allow this device to recognize conditions and communicate to the appropriate parties immediately.

Background

There are many conditions which can be diagnosed from listening to the sound produced by the organs, a practice called auscultation. In our proposal we are focusing on the conditions afflicting the heart and lungs, mainly: chronic obstructive pulmonary disease (COPD), pertussis, pneumonia, heart murmurs and irregular heart beats (a longer list of conditions that can be diagnosed through auscultation can be found in Appendix A).

In the United States, there are 40 million people living with some chronic respiratory disease. There are also 735,000 Americans which have heart attacks, with 610,000 Americans a year dying from a heart condition [12]. When it comes to either heart or lung conditions, the quality of life and survivability can be improved by constant monitoring, and early detection (and communication) of emergency events.

In the current market, heart rate monitors are available commercially. The most extensively used product requires the user to put a band around the chest and wear a watch that displays the heart rate the band is picking up. The band uses electrocardiography to pick up heart electrical activity and requires moisture, whether you put water on the band or your sweat gets on the band, in order to pick up the electrical signal. The band contains a microprocessor that analyzes the electrical signals given off by the heartbeat and transmits the data to the watch via Bluetooth [13]. In the more recent years, the data has been able to transmit to mobile apps as well. Our product deviates from this heart rate monitor in the fact that it also measures lung sounds. Instead of using electrocardiography, our wearable stethoscope uses multiple microphones to pick up sound, therefore not requiring the band to be damp and uncomfortable. Our proposed project also doesn't just listen to sounds, it'll detect any abnormalities within the heart and lungs.

High-Level Requirements

The system must be able to

- Use its microphones to capture the heart and lung sounds and filter out the ambient noise
- Take the captured audio input and determine if it corresponds to an illness with an accuracy of ~90%
- Communicate to user's doctor in the event of a detected emergency in a power efficient manner (power efficiency to be determined)

Design

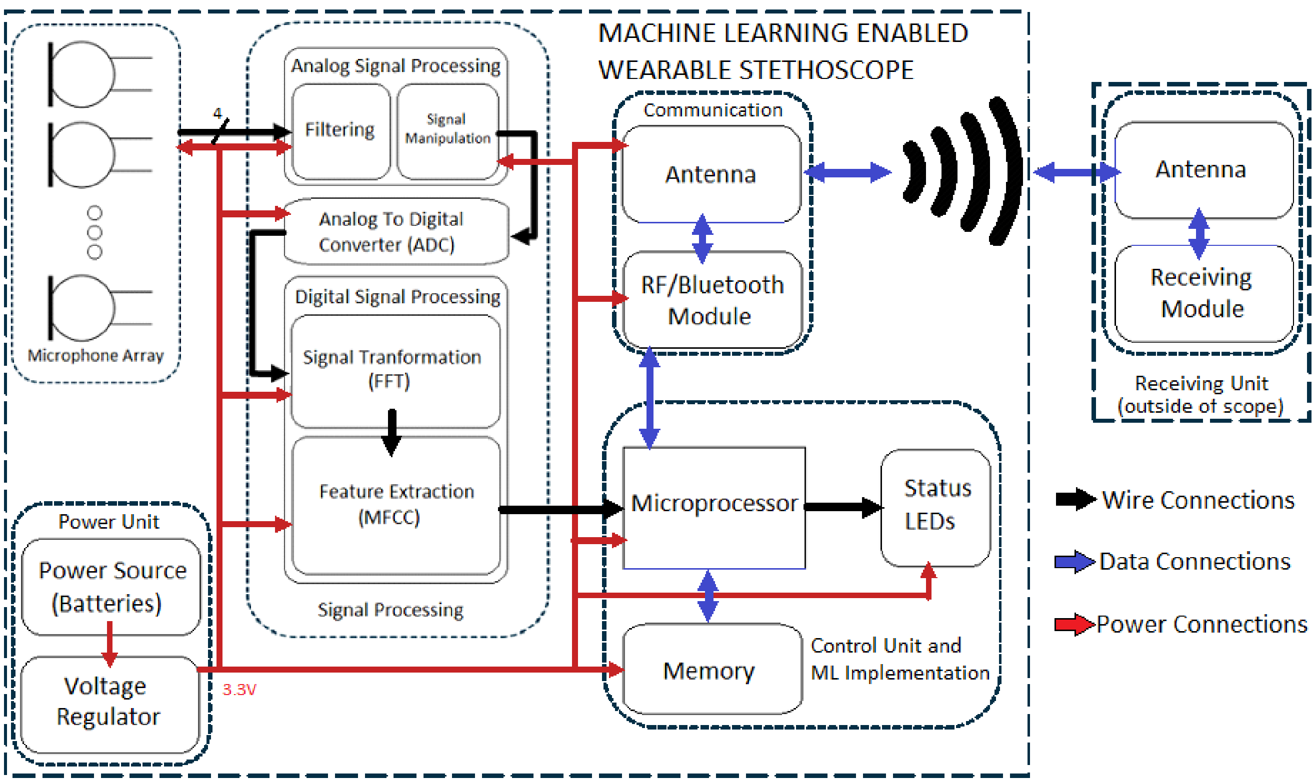

Figure 1: Block diagram design of system

Block Diagram

The block diagram design described in Figure 1 (above) fulfills the high-level requirements described. First, the microphone array and associated analog and digital signal processing fulfills the system's ability to sense the sounds produced by the heart and lungs. Second, the microprocessor and memory (parts of the control unit) will allow the implementation of the machine learning algorithms required to detect conditions of the organs. Finally, the wireless capability will enable the system to warn the user (or doctor) of any detected issues.

Physical Design

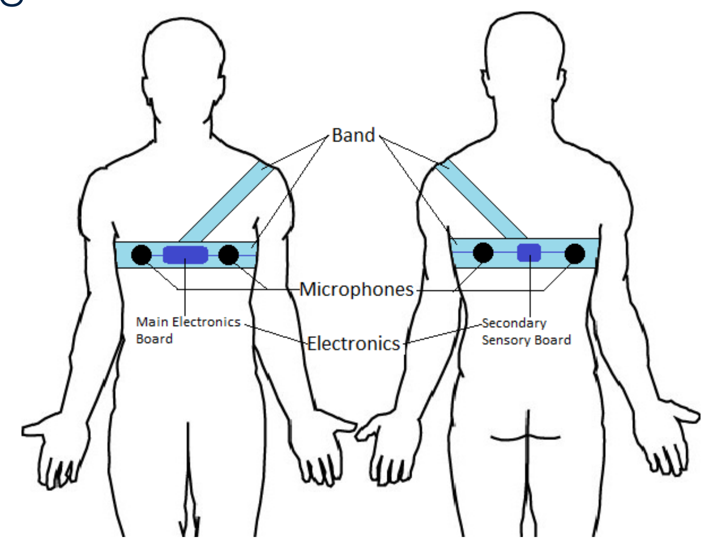

Figure 2: Physics design of system

The physical design of the system will comprise of a band to be worn around the chest with an appendage to help with comfort and placement – shown in Figure 2. The main band is placed around the circumference of the chest and there will be four microphone sensors. These are placed strategically to record sounds from the heart and both lungs, as well as to analyze different sensor outputs for filtering out noise. The electronics will be embedded in the band and the electronics boards will perform all the necessary signal processing and computation to fulfill the high-level requirements. The material of the band is discussed in the Safety and Ethics portion due to the wide range of materials that are plausible and the concerns it raises. We propose the band to be similar to a gauze bandage that is 100% cotton.

Functional Overview

Microphone Array

The microphone array acts as the system's sensors. The sensors are the interface between the organs we are monitoring and the system we are designing. For the microphone array to function as required, it must be able to detect sounds and vibrations in the range corresponding to the conditions we are trying to detect. Heart sounds occur in the range between 20 and 150 Hz and lung sounds between 50 and 2500 Hz [6]. Therefore, our microphones would have to detect sounds in the range between 20 Hz and 2500 Hz to fulfill the high-level requirement. The output from these microphones is directly connected to the signal processing unit.

Requirements:

- Our frequency range needs to be in the desired area so that we can detect both heart and long sounds accurately.
- The microphones need to be able to detect a minimum decibel range of 3 db.
- They need to operate between 3 and 5 volts so we can use the same power supply.

Power Unit

The power unit provides the power required to operate all the other components in the system. The system is comprised of components which operate at 3-5V. As such, it should be possible to use a single power line to power all the components of the system.

Batteries

The batteries need to be small and safe since this is a wearable device. They also need to have a high-power density to improve user interface. We plan on using lithium-based coin batteries. They provide the right power range (200mAh each) and maintain a small profile. This choice of battery would match well with the intended low power design of the system.

Requirements:

- Be chemically stable under duress
- Each battery unit should last for a minimum of 24 hours.

Voltage Regulator

The voltage regulator would simply make sure that the voltage supplied by the batteries is in the right range for the rest of the system. The voltage regulator would step down the voltage to 3.3V and add safety features for power spikes (Zener diode and fuse combo to cover voltage and current spikes).

Requirements:

- Output 3.3 V +- 0.1
- Should protect the circuit from power spikes
- Thermally stable

Signal Processing

The signal processing unit is responsible for taking the sensory information from the microphone array, filter away the noise, and extract features that'll be used to detect issues in the heart or lungs. This subsystem is comprised of an analog signal processing unit, a digital-to-analog converter, and finally a digital processing unit. This unit interfaces the raw audio input with the microprocessor.

Analog Signal Processing

The analog signal processing takes care of filtering out noise coming from outside the frequency range for which we are interested in. It also amplifies the signal strength for the region. This sub-unit takes its input from the microphones and manipulates the signals before sending them to the Analog-To-Digital Converter (ADC). The analog filter would remove noise below 20Hz and above 2500Hz. It would also amplify signal strength in the frequency ranges that correspond to the symptoms of heart/lung diseases [6].

Requirements:

- Be able to filter out signals outside of the required range 25hz to 25khz [6]
- Amplify the signal within the range

Digital Signal Processing

The digital signal processing unit handles the processing of the converted and filtered signals into meaningful data to be used by the control unit (microcontroller) to detect and diagnose abnormalities. This unit will have to do this quickly and reliably. It will either be done through special circuitry or through a dedicated microprocessor that will handle the computations. Its output is the input for the control unit.

Requirements:

- Performs required transformations in .5 seconds

Analog to Digital Converter

The ADC will then take the output from the analog signal processing unit and convert it into digital readings. These will allow for the processing required that cannot be done through analog signals alone. The conversion to digital enables the transformations for features to be generated (MFCC). The analog to digital converter will have to be quick and have a large enough accuracy to prevent bias. It will also require a good bit-width so as not to quantize the readings too much.

Requirements:

- Only use up to 25 microwatts [3]
- Allow for 10 bit resolution [3]

Control Unit

The control unit handles the decision-making in this system. It takes in the filtered and modified measurements and uses it to detect and diagnose. Once a decision is made on the status of the measurements, the microcontroller decides whether or not it needs to send a signal to the doctor. If it decides to send a signal, it'll send the instructions and data to the communication unit.

Microprocessor

The microprocessor will be the unit which does all the computations necessary for the machine learning algorithms to do the diagnosing. It will also handle the preparation of the data for sending through the communication unit and will choose the data to be stored in the memory.

Requirements:

- Computes output for machine learning algorithms
- Needs to communicate with memory and communication module

Memory

The memory will be both embedded and external. Due to the sensitivity of the type of data, medical data, it is crucial to store the history of the patient. Therefore, there needs to be a means of permanently storing the patient history gathered by the device. The memory unit will have to be able to handle several hundred instances worth of data, which includes the timestamp and the audio file. This means it requires several megabytes of data capacity.

Requirements:

- Several MBytes of memory to store data

Communication

The communication unit interfaces our device to the outside world, where actionable information can reach the right people and lives can potentially be saved. The communication unit will need to consume little power and ideally it would be powered on only when a message needs to be sent. The technologies that fulfills this criteria include RF and Bluetooth Low Energy technologies. Whichever specific technology is used will need to interface with the devices currently in use by doctors and other emergency personnel (this includes pagers and cellphones – hence the RF and Bluetooth Low Energy to interface with the two existing widely used technologies). The technology used will depend on bandwidth and power usage [4].

Requirements:

- Be able to communicate through UART protocol [5]
- Use at most 25 mW [4]

Receiving Unit

The receiving unit will comprise of a pager or a cellphone. This side of the implementation is outside of the scope by design – the device should interface with existing infrastructure in the medical field.

Risk Analysis

We believe the biggest risk in the project is within the analog signal processing block. Our concern is with filtering the external noise from the heartbeats and lung sounds we are trying to measure. While there are small things that can be done to improve accuracy, such as using training data sets to define the norm, putting the microphones as close to the heart and lungs as possible, padding the side of the microphones that aren't pressed up against the body, etc., it'll still be difficult to differentiate between sounds that other organs in the body could making at the same time. We believe that because stethoscopes are capable of picking up heartbeat sounds when placed on the chest and picking up lung sounds when placed on the back, we will be able to recreate the same effect in the digital world. Our plan is to mock the mechanical effect of stethoscopes in aid of the microphones if the microphones alone cannot pick up the noise we need.

Ethics and Safety

There are a few safety hazards to highlight with our proposed project. Starting from the simplest, there is a chance that the battery in the band can overheat, resulting in user discomfort or worse, an exploding battery. In order to avoid this, we are taking extra precaution in testing our circuitry in the safety lab and making sure the battery does not overcharge. Another circuit-related hazard in our project is potential water damage to the device. Getting water onto the band can result in shorting the circuits, ultimately hurting the user as well. Our product is not yet intended to protect against water, so here it is incredibly crucial that the user is aware of the product's flaws, which correlates with IEEE Code of Ethics #3 [7].

The material of the band is another important concern to the individual using the wearable stethoscope. Certain materials have the ability to induce an allergic reaction or create an uncomfortable rash on the individual where the band is placed. To avoid any kind of reaction, we plan on coating the device with a gauze bandage. Gauze bandages are prevalent in the medical world and are used specifically to protect the body. In order to decrease the chances of getting textile contact dermatitis from the gauze bandage, we are using a gauze bandage that is 100% cotton and dye-free [8].

The last safety concern we want to highlight is that our device will not be 100% effective. With our goal of 90% efficiency, there is a 10% chance that the device fails to detect a lung or heart problem for a user that may be completely dependent on the device. The initiative we are taking with this safety hazard is ensuring that, again, we follow the IEEE Code of Ethics #3 and to be transparent about the product's success rates as well as the potential flaws mentioned above [7].

Some studies [9], [10] show that heart rates are directly related to racial or gender differences. Although this is just a theory, we want to enforce equality and not segregate heartbeats or lung sounds into different groups, essentially following IEEE

Code of Ethics #8 [7]. We know that machine learning training sets can create bias towards groups. So in order to prevent discrimination, we will continuously audit our algorithm and create a standard that works best for our device.

Because our medical device requires human participants, it's necessary that we go through the Institutional Review Board (IRB). It's particularly important because we need to access heartbeat and lung sound data from public records. Although there is an exception for using public data if the subjects cannot be identified [11], in order to both connect the public data to any kind of related heart or lung illness and to continuously get new data over time, we indeed need to identify the subjects. We do, however, qualify for the expedited process because our research is neither invasive and it only requires digital voice recordings [11].

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Appendix A

Irregular rhythm, heart murmurs, signs of congestive heart failure, fluid in the lungs, valve leakage, aortic stenosis, pneumonia, atelectasis, pulmonary fibrosis, acute bronchitis, bronchiectasis, interstitial lung disease or post thoracotomy or metastasis ablation, hypersensitivity pneumonitis, alveolitis, asthma attacks, though it can also be a symptom of lung cancer, congestive heart failure, and certain types of heart diseases, Caused by narrowing of airways, such as in asthma, chronic obstructive pulmonary disease, foreign body. epiglottitis, foreign body, laryngeal oedema, crouppertussis (whooping cough) pneumonia, pulmonar edema, tuberculosis, bronchitis, inflammation of lung linings, lung tumors, pneumomediastinum, pneumopericardium

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