Final Report

A Medical Device to Detect Noise Sensitivity in Patients

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Problem

Through her work in acoustic isolation, our sponsor Dr. Bonnie Schnitta has offered services to acoustically treat customers' homes to keep out unwanted sounds. Many of her clients have a condition called Misophonia, better known as selective sound sensitivity syndrome, and have acute sensitivities to certain noises. Triggers can range from mechanical vibrations to sirens, screams, and footfall, and they can cause anxiety, discomfort, and even rage.

In her anecdotal research, Dr. Bonnie noticed that a person exposed to a triggering sound experienced a simultaneous change in vital signs, most notably in heart rate and blood pressure. This research was conducted with an off-the-shelf wristband, so she desired a more robust system to verify her results. A fully-integrated solution would capture changes in vital signs while emitting synchronized audio tones, and because Dr. Bonnie did not know the full range of affected vitals, the system would need to measure as many biosignals as possible. The device would need to be intuitive to a doctor or researcher and comfortable to the patient. Dr. Bonnie would use the system to test a variety of patients with known sound-sensitivity conditions and build a large dataset. Once she gathered enough data, she could implement artificial intelligence (AI) solutions to extract meaningful trends and correlations between audio frequencies and affected vital signs, as well as other known conditions in the patient.

Solution Overview

We created an all-in-one system that measures multiple vital signs synchronized to precise audio tones. The user interacts with the system (shown in Figure 1 below) via an iPad application that connects via Bluetooth Low Energy to a Raspberry Pi 3B+ controller (RPI).

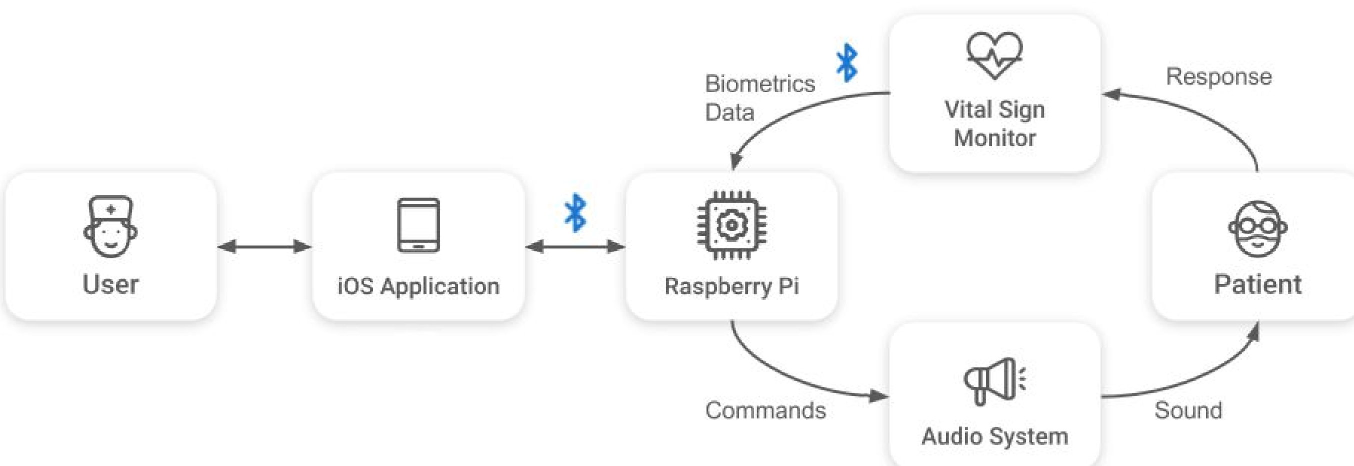

Figure 1: Systems Diagram

The RPI generates audio tones and plays them through headphones while it simultaneously collects biometric data from a BITalino Revolution device over a Bluetooth interface. Doctors and researchers can start and end tests with an iOS device, as well as choose test parameters. The test results are saved to a removable USB drive and will be integrated into the app at a later stage of development.

The iOS app acts as the intermediary between the user and the integrated system. It provides customization of test parameters such as frequency, duration, and amplitude of tones, and it allows the user to view system status and test results. The user can stop a test if the patient expresses discomfort. COVID-19 required descoping of the app but it is still robust and elegant.

The whole team spent time reviewing, designing, and scrutinizing our general user flow, and the app continued to get cleaner and more robust even though we were unable to complete as many rounds of user testing as desired. The app shows pertinent system status such as battery levels, connection status, data collection statutes, and feedback when data has been transferred to a USB drive for analysis. The next steps section details the intended improvements for our app, whose proposed design is shown in Figure 2.

The Raspberry Pi acts as the central controller and facilitates execution of the test. It uses python multiprocessing libraries to control various subprocesses at once, as shown in Figure 3. The RPI communicates with the iOS device over Bluetooth Low Energy (BLE) to know when to initialize, start, and stop the test, and it controls the audio system and receives data from the vital sign monitor. It formats the results so that the vitals data are time-synchronized with the corresponding audio tones.

We designed the RPI software to require zero user interaction aside from pressing a sleep/wake button and plugging and unplugging a USB drive. These actions have corresponding feedback LEDs, as shown in Figure 6.

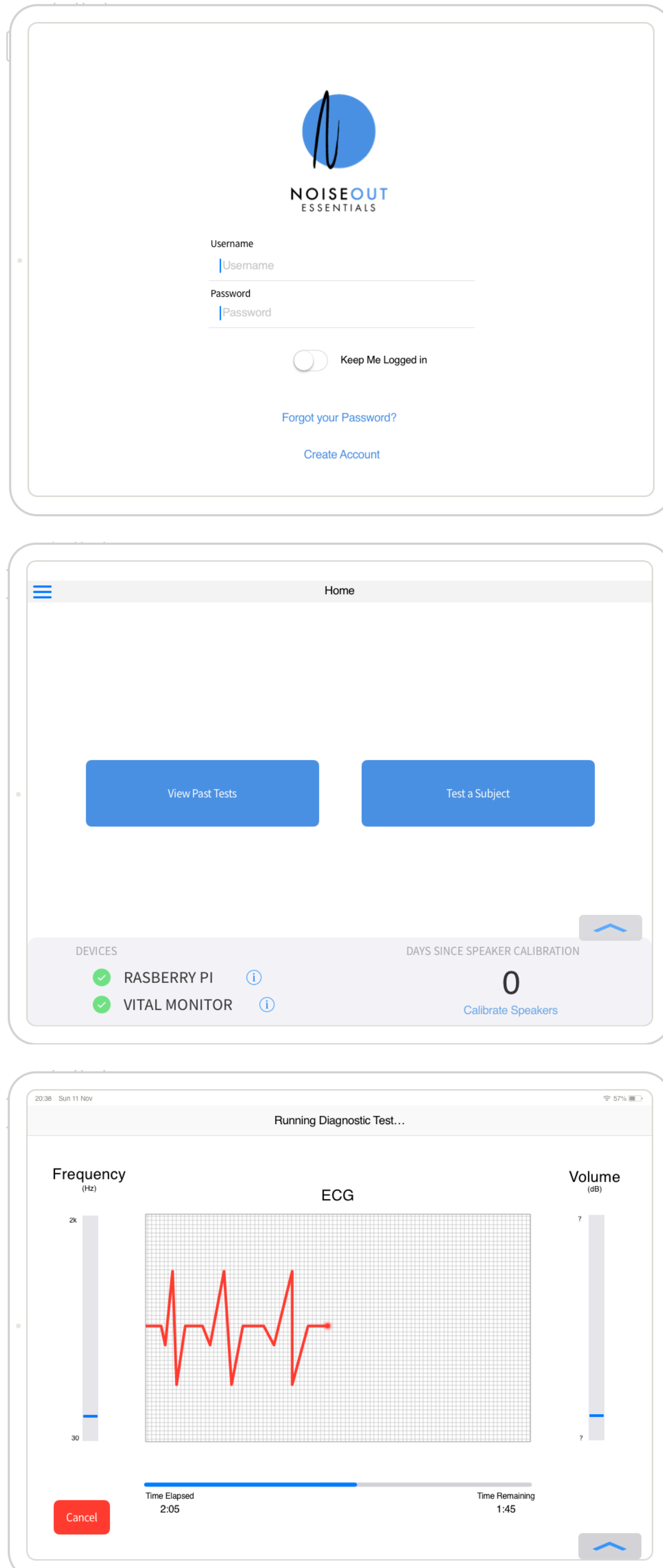

Figure 2: Proposed App Screens

As of May 4, 2020, our system synchronously emits precise tones while collecting biometric data, and it saves the formatted data to a comma-separated value (CSV) file on RPI and a portable thumb drive. We will soon document, package, and ship our system to Dr. Bonnie to support her research.

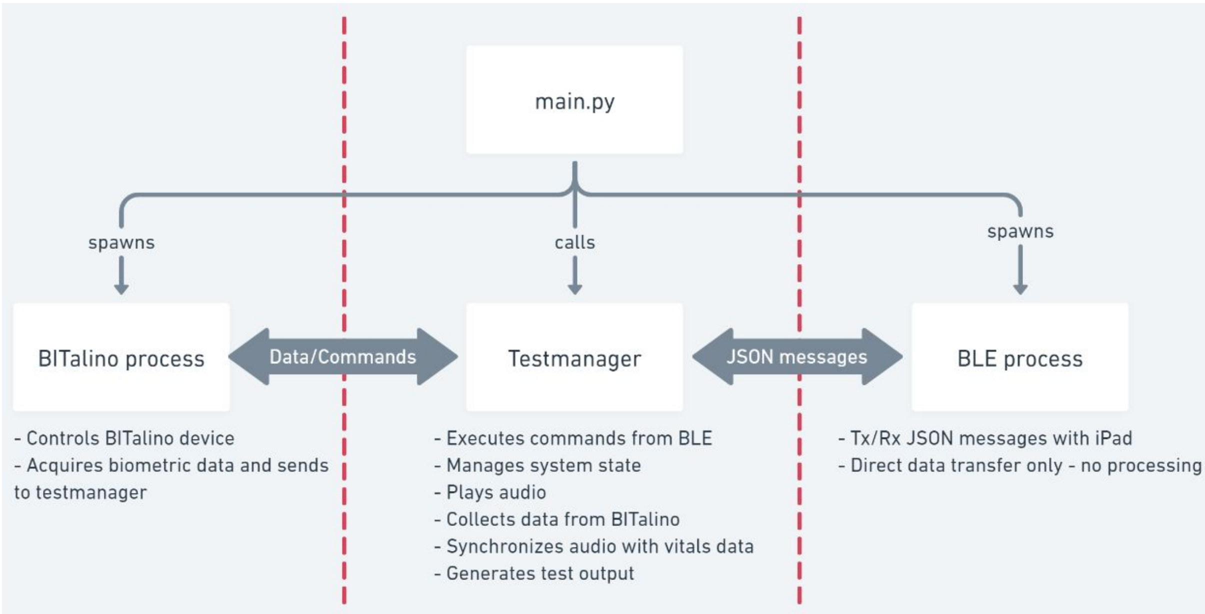

Figure 3: Raspberry Pi Subprocesses

Results

On March 2, we tested our system on a sound-sensitive subject in Dr. Bonnie's personal network. Our proof-of-concept played audio through headphones while collecting electrocardiograph (ECG) and electrodermal activity (EDA) data. In MATLAB, we used the Pan-Tompkins algorithm to extract heart rate from the ECG data, as shown in Figure 4. EDA is visualized in Figure 5.

Challenges

As with any project, especially those completed in Spring 2020, we faced a series of obstacles on our road to completion. We initially encountered a sequence of miscommunications with our sponsor related to system requirements. The design review board in February helped us realize the importance of defining a minimum product, so we created a requirements document and reviewed it with our sponsor. We had fewer communication hiccups from this point forward.

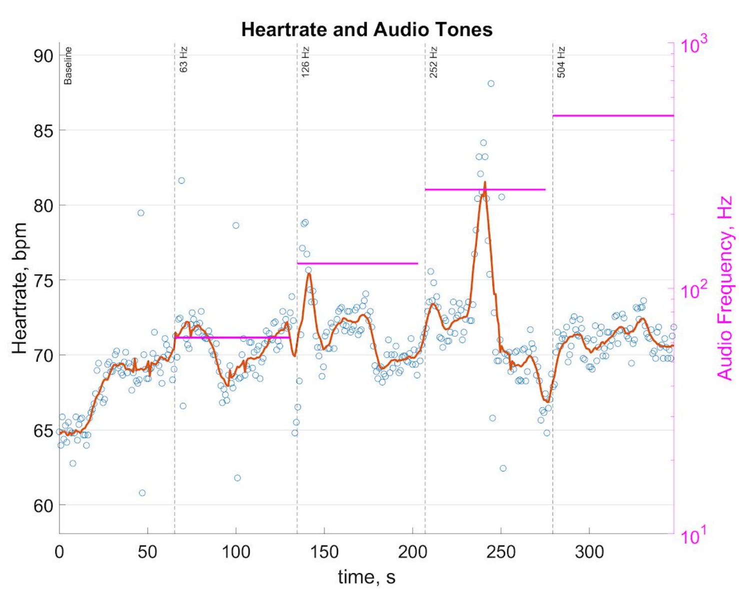

Figure 4: Heart rate versus audio frequency

We struggled to source system components throughout the project. We went through several iterations of components of our system, including the vital sign monitor and audio interface. As we expanded our project to collect more vital signs, we required additional sensors as well as a more modular version of the BITalino. Our integrated solution involved many different devices, and a large portion of our project consisted of handshaking the various components and developing a communication protocol between the iPad and the RPI controller. We also spent many engineering hours making the RPI controller run “headless,” so the user would have zero interaction with the device aside from a sleep/wake button and plugging/unplugging a USB drive.

Lastly, just like the rest of our classmates, COVID-19 introduced a whole slew of new challenges. We were forced to remove our hardware from Halligan Hall and transition to a remote workflow involving Zoom calls and SSH port forwarding from our home networks. After a big push to make the necessary adjustments and renew our commitment to the project, we delivered our device to our sponsor only slightly descoped.

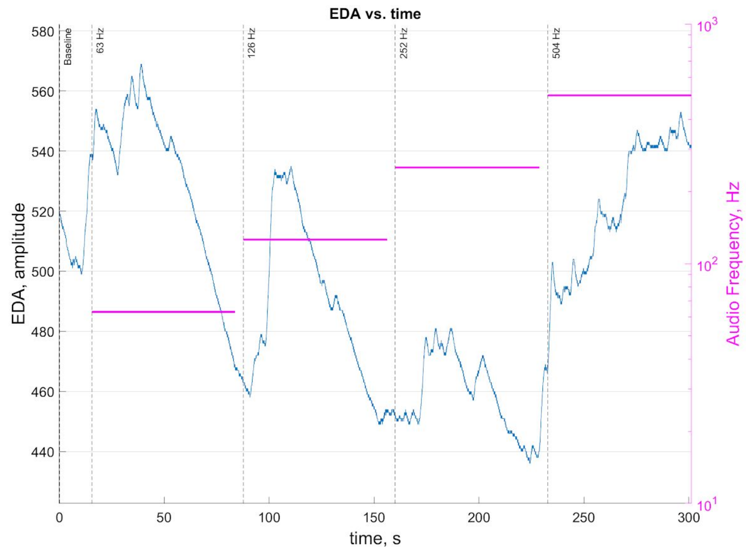

Figure 5: EDA versus audio frequency

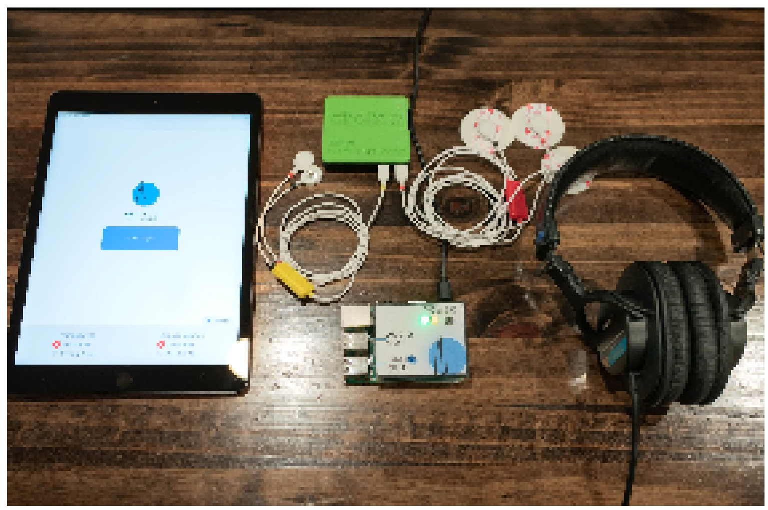

Figure 6: Final Prototype Assembly

Next Steps

Our capstone course took place within unprecedented times which affected our project scope. While we did meet our minimum viability requirements, we have some ideas in mind to take our product from a prototype to a micro-manufacturable piece of diagnostic equipment.

We plan on collaborating further with our sponsor to develop our functionalities and create a polished prototype that can be replicated. Our sponsor plans on using our system to conduct exploratory studies along with other possibilities. We will discuss her possible next steps as well.

Prepare for prototype handoff

In the next few weeks, we will deliver our prototype to Dr. Bonnie for testing. This will include the Raspberry Pi with installed firmware, the BITalino device with appropriate sensors, and a pair of headphones. The iPad application will be uploaded to an accessible host, and we will include a detailed manual that defines all parts and functionalities of our system. Usability-focused instructions will be included with diagrams and step-by-step guides to set up the system and administer tests.

Package All Components in a Durable, Portable Case.

Before shipping the system to our sponsor, we want it to be durable and visually appealing. We have already created a labeled shield for the Raspberry Pi, and we purchased a 3D-printed cover for the Bitalino. We currently plan to fit all components in a custom pelican case with latches and mounts for each component of the device. If we add loudspeakers (see next section), they will add another 15 LBS of weight and a great deal of space for safe storage. A speaker system will be larger and less user-friendly than a headphone-only system.

Play Audio through Calibrated Loudspeakers

The original scope of this project included the calibration of loudspeakers to an acoustically-treated test environment. Work-from-home constraints forced us to descope this functionality, but it is still part of the original project description and could be useful to detect body responses to low-frequency tones.

Connect the System to IBM Watson through a Database

We have begun to interface with IBM-affiliated consultants that are introducing us to IBM's supercomputer, Watson. We plan on finding the proper methods to pass over to our sponsor and potentially begin training Watson to analyze our biometric data and find correlations. We will also set up a database to feed Watson new test results and allow for cross-referencing as a population of test results is established. To keep patient data safe, we will ensure data is encrypted. Once a user base is established, each user/organization will have separate accounts so results can be partitioned.

Enable Real-Time Display and Analysis of Data

We hope to enable the live display and analysis of data. Part of this will be user-facing, where we display ECG and other data in real-time in our application. We will need to move our analysis from the current MATLAB solution to something contained in our app and real-time. This will then allow us to provide live data to Watson for analysis.

Create & Launch a Full-Scope Application

The app's scope was cut back significantly as it directly links to system functionality. Instead of creating a full test administration **and** analysis application, we were only able to create a robust test administration app. Our full-scoped app would include live displays of data, a login portal for access to a database, a database/report viewing UI, and more features that we may implement such as speaker calibration and system setup. In full function, our app will eliminate some clunky elements of our current user interaction. The analysis will all happen in the background, less interaction will have to happen between the user and the chipsets, and more processes will be automated. Below are sample screens that would have shown up in a full-scoped app.

The Device's Future

All good things will come to an end, and once we say goodbye to our hard work, it may live on for a long time with Dr. Bonnie, with great potential. The device could end up serving its purpose and allowing Dr. Bonnie to back up her misophonia hypotheses. If Dr. Bonnie's hypotheses prove to be true, she may experience commercial success and bring new innovation to the medical field. In a less fruitful case, our device may see usage in studying sleep, emotion, and how people react to sound in non-medical ways. This could have applications in psychology research, public policy, product development, and more.

Takeaways

A note from each teammate:

Danielle
One big takeaway, engineering is hard. Senior Design transitions us from students to engineers, and this project offers a peek into life after school. This project was my introduction to working collaboratively, although I was lucky enough to work with great engineers and even better friends. It was my introduction to designing a solution to a problem instead of completing a task. It was my introduction to working on a product intended for the world outside of Tufts. Following this project from start to finish over the course of a year emphasized several concepts and conclusions. Come out of meetings with clear action items. If I feel lost, ask for clarification. If I still feel lost, ask for an explanation. If I still feel lost, maybe try google and come back with more questions. Plan and do at the same time. Take notes. Schedule more time than I think I'll need, and then add a little more time. Although this process has seared many lessons into my brain, by far my most valuable take away has been to care about what you do. If you're going to work hard, you might as well be interested. Solving wicked problems is impossible by definition, but engineers continue to try.

George
I was lucky to be looped in with 3 friends and incredibly talented engineers. Through a great deal of mental energy and a whole year of work, we have ended our semester standing with a great sense of accomplishment and a promising future developing and exiting from this opportunity. I learned more about what my role may be in the world through this experience and some practices to bring through my life. I learned to let people's abilities shine through. This was career advice I got from Bonnie a few years ago when she told me that success is found by allowing people to do what they excel at. I want to be the engineer, the project manager, the human factors guy, and run the company all at once, but that is not reality; I'm an engineering psychologist and with a logical business mind. My value lies in my logic, my background in usability and cognitive science, my ability to know the right thing or person to utilize, and my entrepreneurial spirit. I have and will continue to be the person to vouch for our users, and will ensure that our team is getting a good deal out of any future work, working towards a successful exit from our venture.

Chris
I am incredibly proud of the work this team has put in over the last 9 months to bring this project to fruition. It has taken countless late nights of hard work and lots and lots of careful planning and focused execution to bring the project to where it is today but I wouldn't have it any other way. I have learned far too many lessons from this project to sum them all up in a single paragraph but one stands out above the rest. This project has been a fantastic learning experience in project scope management. It was a challenge to continually redefine the project scope in light of new constraints on time or materials, particularly in light of the Covid-19 pandemic. However, I think we did a good job of managing our project scope and delivering a prototype that will provide real utility to our sponsor!

Benny
I really enjoyed working on this project. Whether we were spending late nights writing a project plan, debugging software over Zoom, or trying to figure out sponsor requirements, I enjoyed pretty much every second of it.

This is due in no small part to my amazing teammates, who helped to maintain a positive, light-hearted, yet diligent atmosphere no matter what curveballs the project and world threw at us this semester. I'm proud to have worked with such dedicated engineers and great friends, and I'm excited to see where this project takes us in the future. Gushiness aside, I definitely learned a ton about engineering this year. I learned to be comfortable with large problems and unknowns, and to treat them as opportunities for personal growth. I learned of the delicate balance between planning and doing, and how one often affects the other. Most of all, I learned that large projects *never* go as planned, and that communication is key to maintaining realistic expectations. I look forward to calling upon this very practical experience to my post-grad career, and I hope I will not forget the engineering and life lessons this project taught me!