Cook Engineering Design Center

Proposal

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ENGS 89: Engineering Design Methodology and Project Initiation

Low-Cost Boothless Audiometry

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Project Team 12

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Executive Summary

Problem Introduction and Context

360 million people worldwide experience mild to moderate levels of hearing loss, a majority of which come from developing countries with poor access to appropriate hearing diagnostics tools and services.[1] Boothless audiometry has served as a solution to this problem in recent years. In particular, the Wireless Automated Hearing Test System (WAHTS) was developed by Creare LLC as a boothless audiometry system (see Appendix A). It consists of three main components: the innovative low-cost high-quality noise-attenuating ear cups, the mobile open-source Android-based platform TabSINT that performs the automated audiometry and produces the audiogram of the hearing test results, and the Svantek 104A (SV104A) dosimeter to measure the ambient noise during hearing tests.

The WAHTS provides a low-supervision platform that requires only limited training before use, making it more accessible to those in low-income countries, but the results can be easily invalidated due to transient noise spikes. Although the SV104A measures ambient noise, it only reports the mean noise level over the test. The mean noise level does not accurately depict transient noise spikes, which can invalidate test results. In addition, it costs $2,568. It is unrealistic that such an expensive piece of equipment be a permanent solution to boothless audiometry, given it is meant to expand access to communities without much medical infrastructure.Therefore, there is a need for the technology to be cheaper, more informative, reliable, and easy-to-use to aid audiologists in making more accurate and informed hearing loss diagnoses.

Objectives and Impact

In order to address this problem, our engineering team aims to replace the SV104A with a cheaper alternative, the Tympan, which costs $299. This will require (1) validating the Tympan as a reliable and accurate sound level meter based on international standards, (2) connecting the Tympan with the testing software, TabSINT, over Bluetooth so that the system is fully integrated, and (3) altering the TabSINT user interface so that ambient noise data can be included in the testing procedure. These three tasks serve as our main objectives for the project, which we will work towards together with the help of our sponsors and advisers. Doctors at DHMC have provided us with information from the user standpoint and engineers at Creare LLC have been helpful as we tackle technical challenges. In general, all input from our stakeholders has informed the way we approached the problem and, therefore, the solution, and we will continue to communicate with them as we iterate through the system design. Once implemented, the new system can be used around the world to diagnose hearing loss in children, preventing further developmental delays and poor educational outcomes.

Problem Definition and Value

The majority of people with hearing problems (around 360 million people worldwide) come from developing countries with poor access to appropriate hearing diagnostics tools and services.[1] One of the most common birth defects is hearing loss, and children born in low or middle-income countries are almost twice as likely to have hearing issues compared to infants born in wealthy states (6 cases/1000 children versus 2–4 cases/1000 children).[2]

Currently, the immediate solution to the problem of early-stage hearing diagnostics in low-income countries is regular screening in local schools and children's organizations. However, conducting hearing tests in low-resource conditions can be challenging due to the scarcity of audiologists to conduct the hearing tests. There are also fewer audiometric booths in which hearing tests may be conducted, thus tests have to be conducted in the open where ambient noise may invalidate results.

A mobile-based, high-accuracy, "boothless" automated audiometry test system, called the Wireless Automated Hearing Test System, provides a low-supervision platform that requires only limited training before use. A research team of experienced hearing professionals from DHMC led by Dr. Saunders and Dr. Buckey organized hearing screening of elementary and middle school-aged children in rural Nicaragua and Tanzania using the WAHTS.

While WAHTS provides a solution for the scarcity of trained hearing professionals, the issue of background noise while conducting hearing tests in developing countries remains. Audiometry tests require the patient to respond to the lowest signal levels (lowest volume) for 8 frequencies (octave bands) usually from 250 Hz to 8000 Hz at different intensities (in dB), detecting them at least 50% of the time.[3] It is crucial for the accuracy of the hearing test to have admissible levels of ambient noise (the background noise in the test room) so that the patient would not confuse the test signal with the ambient noise. According to the American National Standards Institute (ANSI), the maximum permissible ambient noise levels (MPANLs) should not exceed the thresholds specified in Appendix B1.

As part of the Capstone Project, our team will focus on improving the quality of the manual and automated pure-tone audiometry tests, following the Hughson-Westlake protocol (see Appendix C1). Currently, state-of-the-art solutions employ sound-level meters to measure the mean ambient noise level during the testing procedures. Sound-level meters consist of a microphone, a preamplifier, signal processing, and a display. These devices are used for monitoring the background noise levels in the test room environment and documenting ambient noise information for the duration of the audiometry test.[4] The sound levels are usually measured in dB, calculated using the root mean squared (RMS) of the measured sound pressure and averaged over a stated period of time. Sound level measurements are A-weighted to best represent the sound impact on the human ear.[5] The output of the sound level meter measurement is the dBA (A-weighted dB measurements) value averaged over a certain interval of time.

As shown through this introduction, boothless audiometry is a technology that promises to increase access to hearing examinations in low-income regions. **However, there is a need for the technology to be more informative, reliable, and easy-to-use to aid audiologists in making more accurate and informed hearing loss diagnoses.** Thus, our engineering team aims to enhance the quality of current hearing testing and lead to better medical outcomes by providing more informative ambient noise measurements and updating the TabSINT software interface to allow for a better user experience for patients and hearing professionals.

Technical Plan

Objectives

As stated in the Problem Definition and Value section, there is a need for boothless audiometric tests to be more reliable, informative, and easy-to-use. For our project, we shall build upon the WAHTS. Having consulted with partners at Creare, as well as our clients and stakeholders, we have established three major objectives for our project, each of which shall be further expounded upon:

1. To test the Tympan and validate it can function as an appropriate sound level meter.
2. To integrate the Tympan into the already existing WAHTS.
3. To design a UI in the TabSINT software which displays all the data requested by our clients.

For the WAHTS to meet the various standards set forth by ANSI concerning boothless audiometry, sufficient noise attenuation is required by the headset (the WAHTS makes use of Amplivox Audiocups as the noise-attenuating headset). Noise attenuation data for the Amplivox Audiocups is provided in Appendix B2. The WAHTS also makes use of a dosimeter, the SV104A, to monitor the ambient noise during hearing tests. Priced at $2,568, it is quite expensive, and thus we intend to replace it with the much cheaper Tympan (priced at $299). Before making the switch, we must first confirm that the Tympan functions as an appropriate class 2 sound level meter. The authoritative source on class 2 sound level meters is the International Electrotechnical Commission (IEC). The organization has released the IEC 61672, a three-part document which details the performance characteristics a device must have in order to be classified as a class 2 sound level meter, as well as the testing procedures that need to be conducted to verify the specifications.[6] After consulting the document, as well as our partners at Creare, we have determined that the following are the specifications to focus on when validating the tympan:

1. **Measurement Tolerance/ Acceptance Limits:** This refers to the precision of sound level measurements made by the sound level meter at various frequencies. The IEC has defined ranges of tolerance for various frequencies. (See Appendix D)
2. **Frequency Range:** This refers to the sensitivity of the sound level meter's microphone to sounds at different frequencies. According to the IEC, the microphone must be uniformly sensitive to at least the frequencies in the range of 31.5Hz to 8kHz.
3. **Level Linearity:** The measured sound level on microphone should be a linear function of sound pressure on microphone. The IEC allows for a deviation of ±0.5 dB in the expected output.
4. **Self-Generated Noise:** This refers to the contribution of internal electrical components to the sound level measured by the sound level meter. The IEC states that this value has to be measured and recorded.

5. **Acoustic Overload Indication:** This refers to the highest level of sound the meter can measure, within the specified distortion limit. The IEC states that this value has to be measured and recorded (we decided to aim for 100 dB to ensure we can accurately detect transient noise spikes of that caliber).

Once we have confirmed that the Tympan functions as desired (i.e. that it is able to function as a valid sound level meter and produce accurate ambient sound level measurements in dB over the 250Hz-8,000Hz range), the next objective is to integrate it into the WAHTS in replacement of the SV104A. This integration must be independent of Wi-Fi or other internet-dependent connections, as we intend for our modified WAHTS to be used in remote regions which may not have internet access.

The UI design is the third major objective in our project, and it is where we believe we shall have the most creative input. Our team shall create the UI within the TabSINT. From our conversations with our clients, we have determined that in addition to the audiogram data (i.e. data on the lowest sounds heard for tones played at various frequencies in the testing range specified above), the software should also display ambient noise level data from the Tympan. This ambient level noise data may be displayed along with some sort of indication of whether it invalidates a test. This indication will be determined based on the MPANL in dB SPL (Sound Pressure Level) for ears covered with the WAHTS headset, as per the ANSI S3.1-R2008 standard (see Appendix B1). To evaluate the efficacy of the UI, we shall check how our application handles user input, and whether the visual elements (and in particular the kinds of data we display) are displayed correctly. Our modified WAHTS, executed appropriately, would serve as a potential solution to the problems outlined in the problem statement.

The framing of our objectives is such that they need to be tackled in the sequence identified above in order for our system to function successfully. Therefore, our milestones for the project may be formulated from the main objectives outlined above:

1. Obtain all the components of our modified WAHTS (i.e. the Amplivox Audiocups headset, the Tympan device to serve as the sound level meter, and a tablet to run the TabSINT software and do UI design iterations)
2. Gather as much testing information as possible on the functioning of the Tympan device as a sound level meter (i.e. obtaining its frequency response, measuring self-noise, and comparing them to industry standards. This also involves testing the characteristics of the in-built microphone such as its volume sensitivity and measurement accuracy, and then comparing with other microphones to determine if a replacement is warranted.)
3. Integrate the Tympan into the WAHTS by connecting it to the TabSINT software platform using Bluetooth.
4. Develop a UI that works effectively and displays all the data that needs to be displayed
5. Test our system in the field by conducting hearing assessments on people with suspected hearing impairments.
6. (Time-dependent) Explore the automation of WAHTS to minimize the amount of oversight required of an audiologist.

Evidence for the success of our project will include a report detailing the Tympan's performance across various metrics outlined above and further down in this report. We also hope to present a working prototype of our system to our partners and have them conduct audiometric tests using our system. Video evidence of the system's use in the field shall be presented to the review board, along with an in-person demonstration. Iterative prototypes of the UI shall be shared with our adviser, Nikki Stevens, for the purposes of modification and improvement, as well as accountability. Already, our tackling of the first two milestones is underway. We have obtained all components of the WAHTS and the Tympan. We also have a substantial amount of data on the Tympan's performance from our partners at Creare, as well as a representative from the Tympan vendor, and our own validation tests. By the end of ENGS 89, we hope to compile all of our relevant findings on the Tympan in a coherent format that aids us in making a decision on whether or not to include it in our modified WAHTS. The various sound level meter specifications we have deemed important are outlined in Appendix E and are compiled from the appropriate datasheets.

Innovation

In order to address the issues identified in our problem statement, the team shall be making various modifications to Creare's WAHTS system as our solution. As mentioned in the Objectives section, one of the main aspects of our team's solution is the validation of the Tympan Rev E device as a class 2 sound level meter and its integration into the existing WAHTS system. In order to gauge the utility of our solution and the edge it provides, it is important to consider the tools which have been previously used. The SV104A, a Class 2 sound level meter and a dosimeter, is one of the main components of Creare's original WAHTS. Although it has impressive specifications, our sponsors stopped using SV104A due to its price. It is unrealistic that such an expensive piece of equipment be a permanent solution to boothless audiometry, given it is meant to expand access to communities without much medical infrastructure. Due to its significantly lower price, the use of the Tympan Rev E, should it be shown to function as a valid class 2 sound level meter, would be particularly advantageous over the use of the SV104A in the WAHTS.

After the DHMC team decided to stop using SV104A, they began using an Android App called decibelX, which uses the built-in Android microphone and displays the current sound level, the mean sound level, and the max sound level in dB. Although the app delivers the necessary information, it requires a strong wifi connection, which is often not feasible in the field where tests are being conducted. This is another area where the Tympan would offer a significant advantage over an existing solution. This is because the device conducts data transmission over Bluetooth, which is not a network-dependent protocol. It is also fitted with a microSD card slot for audio recording and data logging, and can thus store data without having to upload to a cloud. With the potential benefits of switching to the Tympan in mind, it is worthwhile to examine the structure of the Tympan, and the contributions made thus far by Creare towards its development. The Tympan has two Knowles MEMS microphones built into the device, as well as a jack for an external microphone. Additionally, it contains a Teensy 4.1 Processor, and is Bluetooth-enabled. Creare initially developed the device as an open-source hearing aid development platform in response to a funding opportunity by the National Institute on Deafness and Other

Communication Disorders (NIDCD). The NIDCD sought to "support the development of hardware and software tools that could be readily reconfigured by the research community to enable new basic psychophysical research studies, encourage studies with novel acoustic processing algorithms, and facilitate the translation of the results of these studies into applications for hearing aids, cochlear implants, and consumer electronics devices." While the intended purpose for the Tympan during its design was to lower barriers for hardware and software development of hearing aids, cochlear implants, and consumer devices, our team has recognized that the device could be co-opted for use in boothless audiometry. Creare has generated multiple versions of the Tympan, with each new model improving upon the previous one. There exists documentation about testing procedures and testing results for previous models, and this data serves as a useful reference and guide as we work with the latest model (the Tympan Rev E).

Documentation about the Tympan Rev E is scarce, and this is one of the areas where our team is making a contribution and building upon prior work. As noted in the objectives section, there are a set of specifications which the Tympan must have in order to be classified as a class 2 sound level meter. These specifications are highly dependent on the microphone which the sound level meter uses. Our testing process thus involves gauging whether the Tympan meets the various requirements for the class 2 sound level meter with its onboard microphone, and then comparing that performance with the tympan's performance when connected to an external microphone (the micW i436 has been recommended by our Creare partners as a valid external microphone to consider).

Another benefit which our solution affords over preexisting ones is that our modified WAHTS solution will provide audiologists with more comprehensive data about ambient noise in an easily interpretable format. We plan to follow the international standards to determine the threshold for permissible ambient noise, since the system will be used most often outside of the United States. In particular, we will follow the ISO 8253 standard for Audiometric test results from 2010. Based on this standard, the maximum permissible ambient noise levels when using over-the-ear headphones, such as the WAHTS headset, are shown in the report. Permissible ambient noise is dependent on frequency, seeing that sounds with different frequencies have different chances of permeating sound-proof headphones. Therefore, we will include frequency in our ambient noise calculations and what we report on TabSINT. We will also factor in the attenuation of the WAHTS headset to determine the best threshold. The amount of attenuation at relevant frequencies of the WAHTS headset is included in this report. These results were found to be in accordance with ANSI Specifications and have been confirmed by the Occupational Safety and Health Administration (OSHA).

One other edge our solution has over the preexisting WAHTS system is that the test protocol and ambient noise data will all occur within the same interface. Not being able to monitor ambient noise levels on the testing tablet while conducting an audiometric test was a problem that our stakeholders voiced multiple times. For this reason, we believe it is necessary to deliver a fully integrated system. This is particularly important since the long-term goal for boothless audiometry is to have minimally trained community health workers (CHWs) conducting the tests. Using CHWs addresses the lack of audiologists, and an integrated system would reduce the number of misdiagnoses made by CHWs.

In our solution, we will have Tympan integrated into TabSINT, meaning that Tympan can be detected and added as the noise dosimeter of TabSINT in the "Dosimeter" block of the "Setup" page (see Appendix F2). In addition, the Tympan can automatically start or stop recording ambient noise according to the signals from TabSINT and the data from Tympan can be stored properly in the local database. To build the connection between Tympan and TabSINT, we will explore two existing options, TabSINT's connection with dosimeters and Tympan's connection with the TympanRemote App.

In regards to TabSINT's connection with dosimeters, SV104A has been integrated into TabSINT for recording background noise during TabSINT exams through Bluetooth.[7] We are studying the source code of how TabSINT connects with SV104A, including the Bluetooth version and TabSINT's backend support on SV104A, which can be found in TabSINT's GitLab.[8] According to the documentation of TabSINT, TabSINT can measure, display, and record background noise data during an exam using a SV104A.[9] When used with SV104A, TabSINT starts recording when an exam begins and stops recording when it is finished. The mean levels of each frequency (in dB SPL) over the test duration can only be viewed by switching over to a new page after finishing the exam. Since the data is an average over the test duration, noise spikes that interfere with the test are not represented. Moreover, in both manual and automated audiometry (see Appendix C), the exam procedure does not consider ambient noise spikes above the MPANLs. In addition, the TabSINT documentation mentions how TabSINT integrates with the Sensimetric sound level meter, a software plugin to measure sound pressure level and spectra from the Nexus 7 tablet.[10] Through our conversation with a software engineer from Creare, we learned that the Sensimetric sound level meter is not fully supported on TabSINT at this stage, and the information available is very limited. Therefore, in our project, we will explore the files related to the Sensitmetric sound level meter, but only consider SV104A as the currently supported solution.

TympanRemote is the mobile app for controlling Tympan. Built with an Ionic framework, the interface of TympanRemote has two tabs: settings and full logs (See Appendix G).[11] By compiling the SoundLevelMeter example from Tympan library and connecting with the app, we were able to display the noise measurement data on the full logs tab.[12] We will learn about the connection by going into the source code on Tympan's repository.[13] To fully understand the source code, we will have to research Node.js and Android SDK.

According to our conversations with stakeholders, our goals of software development on TabSINT are to display the noise measurement data to CHWs effectively during manual audiometry, to improve the logic of the hearing tests with noise measurement data in both manual and automated audiometry, and to incorporate the data into the results.

After meeting with a DHMC research assistant, Torri Lee, we determined that we should provide context with the reported ambient noise, rather than only offering raw data. This decision was made because the planned users of the system are minimally trained CHWs who may not have the experience to accurately interpret how the raw ambient noise would impact the audiometry test. Therefore, the final software product will include several additions to the current TabSINT platform. First, we will add a data block on each exam page that reports the mean, max, and current sound levels from the Tympan. Second, the final product will have pop-ups and automate testing procedures when the ambient noise gets too high. Third, the final product will properly store the noise data from Tympan in the database. Lastly, the final product will have additional features that our stakeholders proposed, which are listed in the user backlog (see Appendix J1). Our user backlog discusses the priority and specific tasks related to these objectives, and that will be shown in the next section. A user interface sketch is attached in Appendix P.

TabSINT follows a standard client-server architecture. Clients include tablets that administer hearing-related exams and standard administrator computers that allow administrators to upload protocols, and download results (see Appendix H1). Due to limited access to the Internet in developing countries, our project will focus on operating tablet clients in an offline environment. In the later stages of our project, we will also work on storing noise measurement data in the remote server and displaying the data on computer clients (see Appendix H1).

The tablet client is implemented using standard web technologies: HTML5, CSS, and JavaScript. The responsibilities of each programming language are shown in Appendix H2. The hearing-related exams in TabSINT are presented as a series of exam pages defined by protocols. See Appendix H3 for an example page and more information about exam pages.

To improve the logic of the hearing tests with noise measurement data in our solution, we will add features that pause the exam and notify users when a noise spike that exceeds MPANLs appears. Interfered data will be deleted and users can automatically go back to the beginning of the current exam by clicking the “Restart” button on the notification window. This feature can be applied to both manual and automated audiometry.

In regards to data collection, TabSINT supports storing noise measurement data from SV104A in JSON format. Data from the Tympan, however, will need more result fields than those for SV104A due to the transmission of real-time data. Fortunately, the result fields of the Sensimetric sound level meter are similar to those for Tympan.[14] We will study the corresponding JSON files in order to modify the database and store Tympan data.

Approach and Methodology

We have conducted several preliminary tests to validate the Tympan thus far. In particular, we have tested the self-noise, accuracy, and frequency response of the Tympan’s on-board microphones. Detailed information about the instruments used is included in the Facilities and Equipment section of the report. The signal to noise ratio that we measured matches the specified value from the microphone’s datasheet, 70 dB. This means that the noise generated by the microphone’s electronics is 70 dB less than the noise being measured, and therefore will not interfere with our measurements. We calculated this by positioning the Tympan next to a validated class 1 sound level meter (Brüel and Kjaer 2250) and recording in a soundproof booth. Therefore, the class 1 SLM could measure the noise generated by the Tympan’s microphones which were recording silence.

Next, we tested the accuracy and frequency response of the onboard microphones. To conduct these tests, we placed the class 1 SLM next to the Tympan in a soundproof booth and played tones at specified frequencies (125 Hz - 8000 Hz) and volumes (30-50 dB) through speakers. We plotted the measured values for both the class 1 SLM and the Tympan to see the difference between the two as well as each device’s response pattern. The graphs are shown below in figures 1-4.

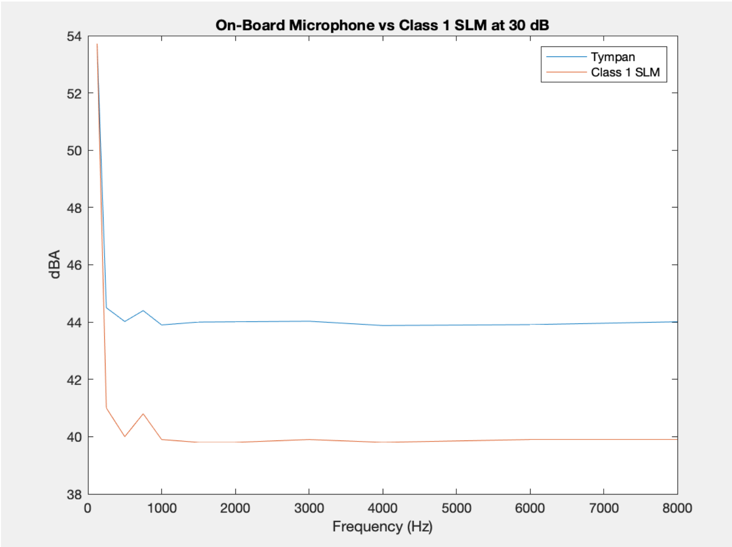

Figure 1: Frequency Response at 30 dB

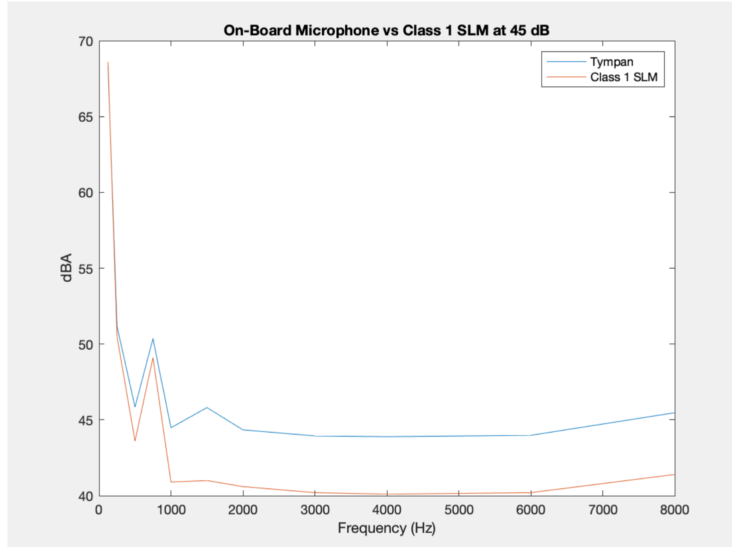

Figure 2: Frequency Response at 45 dB

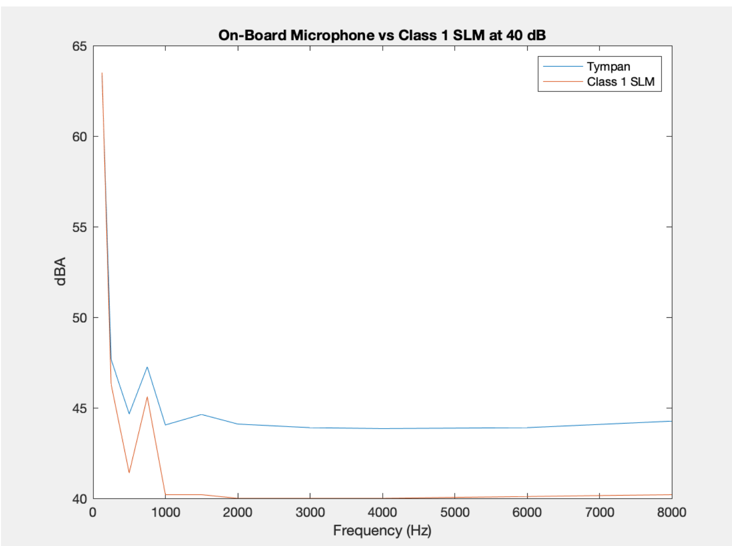

Figure 3: Frequency Response at 40 dB

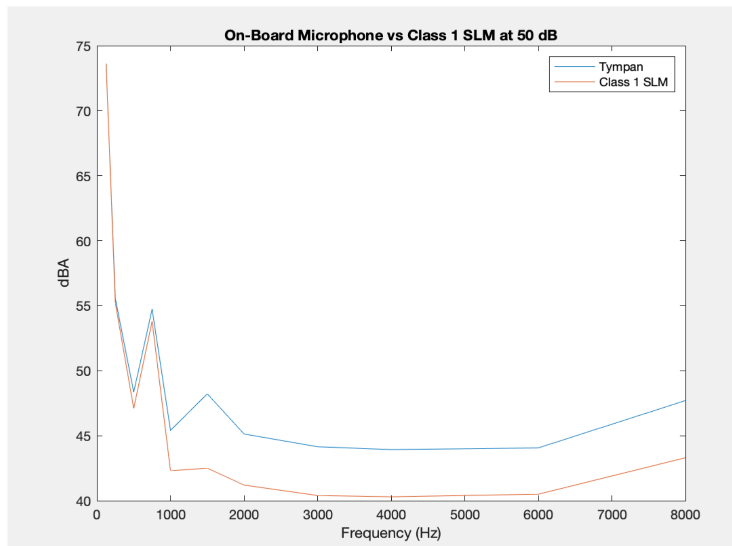

Figure 4: Frequency Response at 50 dB

The results show that the Tympan's on board microphones had very similar behavior to the class 1 sound level meter and the response was never more than 4 dB off from the other measurements. Therefore, our next round of testing will include calibrating the Tympan in a different way (namely altering the gain) to see if we can make the difference smaller. For the frequency response, we wanted to see a relatively flat response across the whole spectrum. This meant that we didn't want more than 2 dB difference from one tone to the next. This was achieved for around 1000 Hz - 8000 Hz for 30 dB and 40 dB, but there was more fluctuation in the 45 dB and 50 dB tests. Even in the less consistent trials, the response was flat from approximately 2000 Hz to 6000 Hz. In all cases, the Tympan's response mimicked the class 1 SLM response, meaning that the volatile sections at the extreme ends of the spectrum may be permissible. We will talk with our sponsors at Creare about the results and see what their thoughts are.

We had intended to conduct the same tests using the external micW i436 microphone, however when we began testing it became clear that the Tympan was not handling the microphone's input correctly. We tried to alter the calibration, gain, and connection to the external microphone in the Tympan's code base, but it was never able to give accurate results. When connected to the Android tablet, however, the external microphone gave precise and timely results. Therefore, we believe there is a disconnect with how the microphone's data is being passed to the analog to digital converter within the Tympan's program and will explore that before conducting further tests. We will also reach out to the Creare engineers, Eric Yuan and Chip Audette in particular, to see if they have run into similar issues in the past. Based on the preliminary results, however, we are confident that the Tympan can serve as a class 2 sound level meter, especially once it is calibrated and compatible with the external microphone.

To simplify the workflow, the integration of Tympan and TabSINT is combined with the software development of TabSINT as the next task to be completed. To set up the development environment on our personal laptops, we followed the developer guide in TabSINT's GitLab repository. We forked (made a copy of) the original repository and downloaded necessary technologies like Node.js. TabSINT can be run on both a browser and a tablet. Currently, we can run TabSINT on the browser (see Appendix F). However, because TabSINT is running on a browser, it has less functionalities than when running on a tablet, such as Bluetooth and Wifi. Therefore, our next step in building the development environment is to buy an Android tablet to run TabSINT on, which will be done by the end of the first week of ENGS 90.

To complete the integration, we will first explore TabSINT's connection with dosimeters and Tympan's connection with the TympanRemote App. As for TabSINT's connection with dosimeters, we have identified the related files that we need to investigate through our conversation with Creare's software engineer, including Svantek.js, config.html, Svantek-admin.js, and Slm.js. In addition, we have noticed that Creare engineers are currently modifying related files to add support for another Svantek dosimeter SV973, from which we could learn about how to add the support for a new dosimeter in TabSINT.

In regards to Tympan's connection with the TympanRemote App, we have compiled the SoundLevelMeter example from the Tympan library, connected Tympan with the app, and displayed the noise measurement data on the app (see Appendix G). We will learn about the connection by going into the source code on Tympan's repository and studying the information shown on the app.[13] During winter break and the first week of ENGS 90, we will study the materials mentioned in the two paragraphs above to be prepared for the software implementation starting in the second week of ENGS 90.

In software development, the software development life cycle (SDLC) has seven stages: initial requirements gathering, requirements analysis and planning, design architecture, development, testing, deployment, and maintenance. In our project, we will contribute to the TabSINT platform which has a developed architecture and is mainly administered by software engineers from Creare, so we will not go further into the design architecture, deployment, and maintenance stages. To select the most suitable SDLC model, we list the characteristics of our project:

- Fixed time (end of ENGS 90)

- Adding features to existing software instead of starting from the bottom
- Dynamic scope (additional features might be implemented if time permitted)
- Low burden in deployment or maintenance
- Low documentation (only need documentation for newly implemented features).

Through the analysis of project characteristics, we decided to use the Agile model with Scrum framework and Kanban methodology. The Agile model emphasizes breaking tasks into smaller iterations. The number of iterations, the duration, and the scope of each iteration are defined in advance and can be adjusted flexibly.[15] Details about Scrum and Kanban are in Appendix I.

The first step in the Scrum framework is to create a product backlog that stores user stories (See Appendix I). We built our product backlog according to the content of our meetings with stakeholders. It is structured with a user story and the corresponding development tasks:

1. **Integrate Tympan into TabSINT**: As a doctor, I want to have Tympan incorporated into the system, so that I don't have to deal with two pieces of software.
    - 1.1. **Learn Tympan-TympanRemote**: Study the connection between the Tympan and TympanRemote.
    - 1.2. **Learn Svantek-TabSINT**: Study the connection between SV104A and TabSINT.
    - 1.3. **Modify TabSINT files to support Tympan**: Modify the configuration of the "Setup" tab so that the "dosimeter" dropdown menu supports Tympan. Ensure that Tympan and TabSINT are connected through Bluetooth.
    - 1.4. **Testing**: Test adding Tympan as the dosimeter and running through the protocol.
2. **Display noise level data in exam page**: As a research assistant, I want to see noise measurement data on the screen while conducting manual audiometry, so that I can monitor the noise level and rerun the exam when there is a transient noise spike.
    - 2.1. **Determine type of data**: Decide which data should be displayed that can help health workers in the best way. Temporary options are mean value in the period, max value in the period, and live value.
    - 2.2. **Design the interface**: Determine the interface of the block that displays the data.
    - 2.3. **implement the interface:** Implement the module according to the decisions made above.
    - 2.4. **Testing**: Integrate into current system and test.
3. **Store Tympan results**: As a doctor, I want to store max levels of noise or averages across the test period, when spikes occurred, and how large the spikes were, so that I can examine the data after the audiometry.
    - 3.1. **Learn about database**: Learn about the database that stores the data. Especially how the data is added and how it should be deleted. Ask Creare about "Sensimetric Sound Level Meter" mentioned in "Result Analysis" of TabSINT documentation.
    - 3.2. **Check the capability of tablet storage**: Check the size of result files. Check if the tablet has enough storage for test results.
    - 3.3. **Modify the database (optional)**: If the attributes needed to store were different from those that SV104A or "Sensimetric Sound Level Meter" stores, modify the

database and related functionalities such as the compatibility with the cloud server.

3.4. **Testing**: Integrate into the system and test.

4. **Automate Tympan's start/end recording**: As a research assistant, I want to automate Tympan's start and end recording so that the Tympan starts recording after pressing "Go" and stops recording when the test ends.

   4.1. **Study the remote control over Tympan**: Study how TympanRemote turns on/off Tympan remotely.

   4.2. **Implement remote control over Tympan**: Add a testing button to the exam page that does the same as the button in TympanRemote.

   4.3. **Design Tympan workflow in the protocol**: Determine when Tympan should be turned on/off in the protocol. Decide if Tympan is only turned on /off once (at the beginning/end of the protocol) or once for each exam page (stop and restart when going to the next page).

   4.4. **Implementation**: Implement the on/off functionality.

   4.5. **Testing**: Integrate into the current system and test

5. **Automatically pause after noise spike**: As research assistants and doctors, we want to pause the exam automatically when a transient noise spike is detected, so that in manual audiometry we don't need to pay too much attention to noise level and in automated audiometry the participant doesn't need any extra action when there is a noise spike.

   5.1. **Determine noise level threshold**: Decide the minimum noise level that triggers the pause.

   5.2. **Pop-up message**: Learn about how to add a notification in the protocol.

   5.3. **Design message**: Design the content and the interface message displayed when noise spike is detected.

   5.4. **Implement pop-up**: Implement the notification workflow.

   5.5. **Freeze the test during notification**: Ensure that the test is suspended when the noise spike notification is displayed.

   5.6. **Testing**: Integrate into current system and test

6. **Restart the current test after pause**: As research assistants and doctors, we want to redo the current test after the pause caused by the noise spike, so that we don't need to manually select the test that runs next.

   6.1. **Add "Restart" button to the noise spike notification**: Add a "Restart" button to the pause notification that pops up after a noise spike. While the noise level is still higher than the threshold, the button is disabled. When the noise level returns to acceptable value, the button can be pressed.

   6.2. **Learn about database**: Learn about the database that stores the data before implementation. Especially how the data is added and how it should be deleted.

   6.3. **Implement restart functionalities**: After the "Restart" button is pressed, abort the data recorded for the current test and return the beginning of the test. Ensure the Tympan recordings are also deleted and Tympan restarts to measure noise level.

   6.4. **Testing**: Integrate into the current system and test.

7. **Plot ambient sound level in exam pages**: As a research assistant, I want to have a plot of ambient sound level during manual audiometry, so that health workers can see the noise levels intuitively and act accordingly to the noise level.
    7.1. **Add "Display plot" option to protocol**: On the first page of the protocol, the health worker can choose whether to display the ambient sound level plot or not with a button.
    7.2. **Determine the location of plot**: Determine on which part of the exam page the plot is displayed. Temporary options are: in the "Show debug info" dropdown list, right below the response area of exam pages, etc.
    7.3. **Interface of the plot**: Determine what data to be displayed on the plot. Design the appearance of the plot such as the axis names, plot type (line? bar?), etc.
    7.4. **Refreshing the plot**: Implement the refreshing of the plot after each specified time period (e.g. 1 second).
    7.5. **Testing**: Integrate the plot into the current system and test.
8. **Add option to abort invalid results**: As a doctor, I want to give technicians the option to abort an automated test if the child was too interested in the button or there are transient noise spikes, so that invalid results are not stored.
    8.1. **Learn about the database**: Learn about the database that stores the data. Especially how the data is added and how it should be deleted.
    8.2. **Determine what to delete**: Decide if the system should enable the health worker to delete all the data, or to select tests and to delete only the selected ones' results.
    8.3. **Add "Delete result" option to the last page**: On the last page of the automated audiometry, ask the participant to return the tablet to the health worker. Add the "Delete" button(s) and notification on that page. The notification asks if the health worker wants to delete the results. If so, the health worker can press the button(s) to delete.
9. **Pre-test on noise level**: As a doctor, I want to run a pre-test at the beginning of the audiometry to see ambient noise, so that the audiometry only continues when the noise level is acceptable.
    9.1. **Determine the workflow**: Determine if the pre-test is mandatory or optional. If mandatory, an exam page or a notification can be added at the beginning of the protocol. If optional, a button can be added to the first exam page.
    9.2. **Implementation**: Implement the functionalities needed according to the decision. Tympan results are NOT recorded in the pre-test.
    9.3. **Testing**: Integrate into current system and test.
10. **Stop measuring when participant talks**: As a research assistant, I want to include a button that could be pressed to ignore following ambient noise when doing the tests that require the participant to repeat the sentence they heard back to them, so that the voice of the participants doesn't influence the test.
    10.1. **Learn testing procedure**: Go through the protocol and check when the participants are asked to talk.
    10.2. **Design button interface**: Determine the position and the appearance of the button in the exam page.

10.3. **Implementation**: Implement the functionality.
10.4. **Testing**: Integrate into current system and test.

The user stories are listed from high priority to low, in which 1-4 (required for minimum viable product) must be completed before the others, 5-7 should be completed before the end of ENGS 90, and 8-10 are optional. In addition, we had our first Scrum meeting where the Scrum master went through each task in the product backlog, asked for each teammate's estimation on the number of hours needed for the task, and recorded the average in the backlog (see Appendix J1). We also calculated the total amount of time we have in ENGS 90 for software development. By assuming that each person works 7 hours per week, each sprint lasts 2 weeks, and we need 4 hours per sprint for planning, retrospective, and check-ins, we found that we have 50 work hours of work for each sprint, and 150 work hours for ENGS 90. The total estimated time that we need to complete all the tasks is 144 hours (see Appendix J1). So we are confident with finishing our project in time.

Before the start of the first sprint (second week of ENGS 90), we will study the programming languages and technologies that each feature requires. We will need JavaScript for the integration of Tympan and TabSINT and JSON for protocol and database development, and potentially HTML and CSS for UI design.

We will also use Unified Modeling Language (UML) to visualize the software system that we will implement to help us and the stakeholders understand the different stages of the project better. We will create Use Case Diagrams (see Appendix K1) to capture system specifications and visualize user needs. We will make Sequence Diagrams (see Appendix K2) to analyze the workflow of each feature that we are going to implement. In addition, because the JSON format consists of objects, we will also create Class Diagrams (see Appendix K3) and Object Diagrams (see Appendix K4) that visualize the interconnection between classes and objects. All the diagrams will be completed according to our product backlog by the end of the first week of ENGS 90. The diagrams will be shown and interpreted in our meetings with stakeholders.

During the development, we will use Git and GitLab for version control. We will create branches for each of the features we are going to implement. Each of the branches won't be merged into the main branch until it has been fully tested. For instance, to test the line chart on the exam page, we will compare it with the data on the TympanRemote app. To test the automated pausing functionality, we will artificially create noise spikes with proper volume to see if the system reacts accordingly.

After each Scrum sprint, we will have a retrospective meeting with stakeholders to collect their feedback on the implemented feature and address issues in the next sprint. As we implement all the intended features and conduct unit tests on each of them, we will conduct an integration test on the compatibility of new features with the current version of TabSINT.

We conducted risk analysis on the software development of TabSINT and created a risk severity matrix, in which risks are put into blocks according to their likelihood of occurrence and harm severity (Appendix Q). For over-budget, we don't have any expenditure for software development. For integration failure, two existing implementations, TabSINT's connection with dosimeters and Tympan's connection with the TympanRemote App, proves the feasibility of integration so that integration failure is unlikely to happen. The risks of overtime and change in software requirements are well controlled by our management plan.

Key Personnel

MacKenzie and Daniel are studying electrical engineering with a focus on signal processing, Di and Azariah are studying computer engineering, and Zhanel is a biomedical engineer with a minor in computer science. Therefore, every member of the team has a computer science background. Given the three aspects of our solution, MacKenzie and Daniel will focus on the signal processing and validation of the hardware, and Di, Azariah, and Zhanel will focus on the Bluetooth integration and software development for the TabSINT during ENGS 89. Software development will be the main task during ENGS 90, so all five members of the team will participate in each scrum. The resumes of all five group members can be found in Appendix L, in which there is detailed information about our most relevant experience.

In order to fill any knowledge gaps, we plan to make use of our consultants and supporting staff, who will be introduced in the next section. In addition, our sponsors at DHMC, Dr. Buckey, Dr. Saunders, Dr. Niemczak, and Torri Lee, have helped determine the problems with the current system, as well as the societal impacts of the research. We will continue to use them to fill our knowledge gaps regarding audiometry, the testing procedures, and how we can make this product most helpful for the users. Lastly, our technical partners at Creare, Odile Clavier, Eric Yuan, Blaine Ayotte, Chip Audette, and Joel Murphy, have provided previous documentation on the Tympan and will be helpful resources as we continue our technical work with the Tympan and TabSINT.

Consultants and Supporting Staff

Our two professor advisers, Professor Chin and Nikki Stevens, will help fill our knowledge gaps in signal processing and UI design. In particular, we will need guidance on how to evaluate our UI design and what aspects make for the best possible display. Nikki Stevens has extensive knowledge on the societal impacts of technology as well as technical skills regarding front-end, back-end, and open-source programming. Their experience with open-source communities will also be helpful as we learn how to navigate the Tympan and TabSINT repositories. Professor Chin will help us analyze our tests of the Tympan and potentially alter any sampling algorithms, using his extensive knowledge of signal processing.

Management Plan

The lengthy, technical, and demanding nature of our project requires that we have a management plan and a shared governance within our team. Whether we are meeting with the engineers at Creare, the doctors at DHMC, our advising professors, or our group members, the project manager ensures that we are following this basic outline:

1. Socially checking in with each other
2. Reorienting to remind each other where we are within the project and what the current goals are
3. Setting an outline or direction for the meeting

4. Facilitating what was agreed upon in the outline
5. Discussing results and noting possible risks and conflicts
6. Planning for the next meeting

We recognize that engineers, doctors, professors, and our team of students are extremely busy, so by following this outline we hope to be efficient with time and maximize productivity. In addition to the project manager, we also have the roles of the liaison, the scrum master, and the treasurer. The liaison interacts with all interested parties to simplify the conservation threads and condense the material. MacKenzie has been the liaison for our first term and has gracefully managed our long list of sponsors, doctors, researchers, professors, and technical partners. Di is taking the initiative as becoming the first Scrum master and ensuring the backlog is finalized and the first sprint will be executable in the Winter. Lastly, Daniel has been the treasurer for the past term where he has been ordering hardware for our team and contacting companies for quotes. Each member will continue with their duties into the Winter break until we have a discussion about rotating roles.

The team also utilizes Smartsheet to break large tasks into smaller subtasks that can be assigned to group members. For example, we broke the Tympan validation tests down into 3 subgroups: test of self-noise, test of frequency response, and the test of accuracy. Each subtask is assigned to a different team member to assume responsibility and initiate the process. The team member taking responsibility for that task determines the start date, end date, and approximately how long in hours it would take to complete the subtask. We refer to Smartsheet to have an up-to-date reference of what the current task is and who is taking the lead. More details about project management with Smartsheet can be found in Appendix J.

Facilities and Equipment

All tests will be conducted in Dr. Buckey's audiometry booth within the Space Medicine Innovation Laboratory of DHMC. The sound proof booth, located in 700C of the Williamson Translational Research Building, is normally utilized to conduct hearing tests on participants of their study and validate sound levels of their fMRI audio system. The audiometry booth comes equipped with a built-in 1996 Grason-Stadler audiometer that can produce sounds ranging from -10 to 115 dbHL and 125Hz to 1000Hz to a range of different devices. The transducers that have proven to be useful in our tests are the booth's built-in speakers to create a sound field and insert wires to send pure tones directly into our microphones. The insert wires are calibrated, however the speakers within the room are not. When conducting tests with the speakers we need to ensure that there is a class 1 sound level meter close to the Typman's running microphone to acquire the true sound pressure level that the Tympan would be reading. We made sure to do this when conducting the tests described earlier in the report.

Additionally, Dr. Buckey and his team have provided us with a Brüel and Kjaer 2250 (B&K 2250) class 1 sound level meter, different microphones for the B&K 2250, a Samsung Tablet, WAHTS headset, and a calibrator tool. The two microphones that we are using to conduct tests are either calibrated for a sound field or for a direct input. The first microphone is used when playing sounds through the speakers and the latter is used when playing tones through the wire inserts. The lab is generally available for our use from 8:00PM to 5:00PM Monday through Friday with the exception of days that audiometric tests are being conducted or when the booth will be in use by the doctors or researchers (email correspondence shown in Appendix M). Given that DHMC is within a close proximity to Dartmouth College, we plan to conduct testing often and be flexible with our schedule since the threshold to start on any given day only depends on how available the team is and whether or not the laboratory is conducting their occasional hearing tests.

Other than the facilities and equipment at DHMC, we have requested storage space on campus for our equipment and computational equipment such as monitors and/or access to a computer lab for the user interface development that will begin with our first sprint in January 2023 or the second week of ENGS 90.

Budget

Within the $1,500 budget limit of this project, we are planning to use an upper limit of $620. We have purchased a $299 Tympan device and a $219 external microphone, and we will be purchasing a Samsung Galaxy Tablet that costs $170 and an SD card that costs less than $10. We have been borrowing a Samsung Galaxy Tablet from Torri Lee but recognize that when we start to implement the user interface, we will need to test the implementations on a tablet that will not interfere with the testing that Torri uses it for.

Timeline

Figure 5 below shows our timeline for completing the project in ENGS 89 and 90.

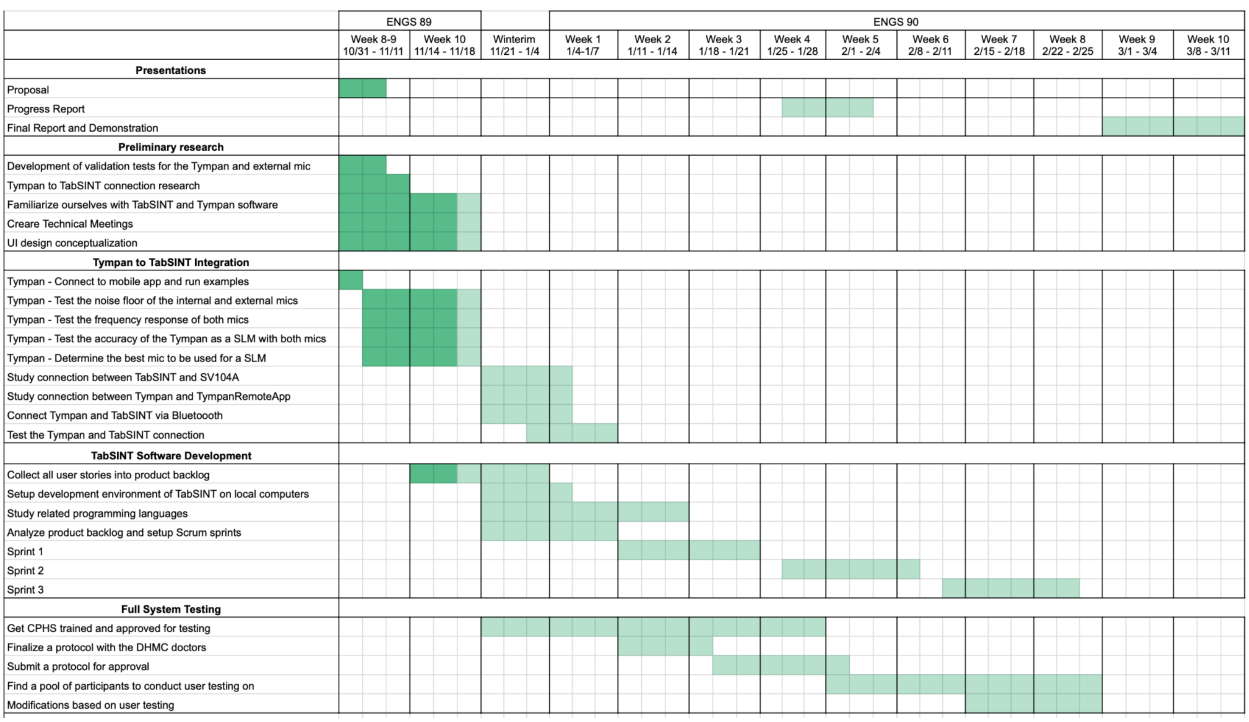

Figure 5: ENGS 89-90 Timeline

By the end of Fall term, we plan to complete the hardware validation tests. We are giving this task the highest priority because it requires us to conduct in-person testing at the Space Medicine Innovation Laboratory within DHMC. The validation tests include the quantification of the noise floor, studying the frequency response, and ensuring the accuracy of the Tympan as a sound level meter matches that of a class 2 sound level meter. When our team disperses for the Winter holiday break, we plan to continue doing work that can be achieved remotely. Therefore, during this time we plan to ensure everyone has their local coding environments set up in order to study and familiarize ourselves with the connection code between the SV104A and the Tympan and the connection code between the TympanRemoteApp and the Tympan. These steps will be completed early within our Winter break to achieve our goal of creating a reliable connection between the Tympan and TabSINT via Bluetooth. During this time, we will also finalize our descriptive backlog with estimated times to organize sprints that will start during the second week of Winter term. From now until we reach our second sprint, we will have been working towards getting CPHS trained to eventually be approved to conduct testing on a pool of participants by the middle of Winter term. We expect that feedback from user testing will lead us to modify our user interface. Therefore, we allocate adequate space in our timeline to address any concerns that may arise after testing. In the unlikely and risky event that our sprints do not go as planned, we have decided to make the first sprint the minimum for our project to be considered a success. Due to any reasons that prevent us from starting the latter sprints, our first sprint will create a user interface that is operational and meets the minimum requirements of our project specifications.

Desirability Plan

Stakeholder Engagement

The main stakeholders that we have engaged with so far are doctors at Dartmouth Hitchcock Medical Center (DHMC) and engineers at Creare. The DHMC doctors we have been communicating with are Dr. Buckey, Dr. Saunders, and Dr. Niemczak. They have provided us with information from the standpoint of users, as they have used the current WAHTS for research in Nicaragua.[1] Based on this, we have mainly engaged them through interviews to identify their initial thoughts on the problem and potential solutions as well as ongoing interviews to build up our backlog. In addition to understanding their experiences with the system, we have been able to take a partial hearing test to better understand the system from the patient's perspective, borrow an Android tablet and headset from the lab for development, and conduct tests in the lab's soundproof booth with their validated sound level meter and tone generator.

The Creare engineers we have been working with are Dr. Odile Clavier, a principal engineer working on technology to lower the cost of healthcare, Eric Yuan, a research engineer who has worked with the Tympan, Blaine Ayotte, a software engineer who has worked with TabSINT, and Chip Audette, an engineer who focuses on hearing systems and signal processing. Odile also introduced us to Joel Murphy, who runs Tympan.org and is very knowledgeable about the device. Chip, Joel, and Eric have been helpful in providing previous validation procedures and results for the Tympan as we were planning our own validation processes. Blaine has provided technical advice and expertise as we set up the TabSINT for development in our local environments. Lastly, Odile has been helpful in providing guidance on the general structure of our project and ensuring that we are on the right track for all technical aspects.

In general, all input from our stakeholders has informed the way we approached the problem and, therefore, the solution. The engineers at Creare have given us extensive background information on the Tympan so that we may verify it can work as part of our final system. The doctors at DHMC have given us a first-hand account of the human aspects of the problem, and the ways that we can make the system work for all of its users. In particular, we will continue to communicate with them as we iterate through the user interface design.

Societal Context

As was mentioned in the problem background section, hearing loss is the most common birth defect that can be treated if proper diagnostics and early-stage treatment would be readily available in low- and middle-income countries. However, due to a lack of resources in those regions, early-stage hearing defects in children are constantly overlooked, leading to developmental delays and poor educational outcomes. These disabilities economically disadvantage people and perpetuate cycles of poverty in developing countries. Introducing a more cost-efficient, user-friendly hearing test system with automated ambient noise monitoring would allow for rapid and more accurate low-cost audiometry in low-income countries. By catching hearing defects early on in primary- and middle-school children, community health workers (CHWs) and other hearing professionals could receive more accurate results from hearing tests updated with our solution. Thus, they would be able to make more educated clinical decisions and assign more effective hearing treatment. As a result, this would allow children with hearing defects to partially or fully restore their hearing abilities and, thus, better perform in class and break the cycles of employment market disadvantage and poverty.

Design for Inclusion

The WAHTS is intended to increase access to audiometry across the world. Therefore, it is an inherently inclusive device. With that being said, we want to guarantee that we are not excluding anyone from using our final system. In particular, we will design the user interface, keeping all disabilities in mind. These include color blindness, which we will consider as we decide our color scheme for the app, visual impairment, which will be important to consider with the font size, and others. We will also try to account for as many disabilities as possible when selecting the participant pool for user testing. This way, we can iterate on the design in the most inclusive and efficient way. The Tympan has already been designed to be inclusive, seeing that it is manufactured with materials to keep the price below $300 and has indicators for how to use the device on its encasing. Photos of the device are included in Appendix N.

Financial Viability

Sponsoring Company

Our project is sponsored by Creare, an engineering research and development company. They are located in Hanover, NH and work on projects in a wide range of industries, including medical, aerospace, energy, and manufacturing. Currently, they employ over 65 engineers and over 40 supporting technical staff members.[16] Since they were founded in 1961, Creare has been dedicated to creating innovative technology and product development, especially through the commercialization of their Small Business Innovation Research (SBIR) projects.[17] Technology created by Creare has been licensed to other firms, branched into spin-off organizations, and sold as specialized products. Through these avenues, Creare has made $700 million in revenue since it was founded.[17]

The Tympan and the WHATS products, which we are working with for our project, now fall under spin-off organizations, Tympan and Edare respectively. The TabSINT was also developed by Creare and has become its own product. All three products were developed for the medical industry, but can be helpful across several other fields. For example, the WAHTS has been used for research purposes on active military personnel.[18] Our project will make the current system accessible for low-income settings and improve the reliability of hearing tests conducted in the field. In doing so, we will be contributing to Creare's overall mission to solve critical engineering problems for their clients.

Market Context

Our solution aims to impact the healthcare market primarily. This is because it will be used in communities that lack audiometric healthcare and will help diagnose children with hearing loss. Therefore, the customer will be healthcare professionals and organizations that are either conducting research in this field or wish to perform boothless audiometry. Another user is the people who will be taking the hearing tests, primarily children in school. This group is the one which may pose the largest barrier to entry for our system. The barrier is no greater than what already exists for boothless audiometry, however, and can be remedied with education and by keeping the cost low so that individual families won't have to pay for the tests.

Currently, the WAHTS is only approved for research use. Once it is approved for commercial use by the FDA, it can be sold. By this point, we hope that our additions will be thoroughly integrated into the system and will only help the marketability, given the reduced price. Given that the system may only be used for research in the foreseeable future, our key partnerships will be with the Space Medicine Innovation Lab at DHMC, whose members have conducted research with the WAHTS in recent years. In addition, partnerships with Creare, Tympan.org, micW, and Edare will be important as they are the suppliers for all of the WAHTS components and have engineers who can improve upon the technology as needed.

The current competitive landscape was explained thoroughly in the Innovation section of the report. Briefly, our main competitors are Svantek and decibelX, two alternative sound level meters that have previously been used in boothless audiometry. They likely will continue to develop new products and improve upon existing ones, so it will be important to monitor their devices and ensure that our system can offer better results.

Intellectual Property Plan

Our project is not IP assigned, meaning that our solution will not fall under Creare's intellectual property (IP). We must also take the open-source nature of our project into account when discussing how we can protect the IP of our solution. Since we don't want to prevent future users from accessing our system, we may not want to patent our solution. However, we could file for different types of IP protection, such as copyright or copyleft. In this way, we would want to potentially file to protect our system, seeing as the Tympan has never been fully integrated into the hearing test system before. In addition, our extension of the TabSINT user interface to include ambient noise data could be protected. We will build in time to further explore these options during ENGS 90. In particular, we will research whether our system would qualify for copyright protection, the details of what copyleft entails and whether our system qualifies, review the IP policies of the college, and meet with Dartmouth's resources regarding the feasibility and eligibility of protecting our IP.

Implementation Plan

Our proposed system will be implemented in the same way that the current WAHTS is implemented. The WAHTS is intended for research purposes only at this point. This is because it has not yet been approved by the FDA as a device that can be used for the public. Because of this, the current WAHTS users will likely be the ones to implement our changes. In order to do so, they would buy several Tympan devices from Tympan.org, which is based in Lebanon, NH, and several external microphones from micW. Once they have these products, they can integrate them with their existing devices (the headset and tablet) and begin testing.

In the past, testing has occurred in Nicaragua with the help of three selected volunteers to serve as the community healthcare workers. Testing with our revised system would follow the same structure. The headset, tablet, Tympan, and external microphone would be taken to a low-income country to be distributed to several (usually three) volunteers. The volunteers would take the testing equipment with them to several schools to test the hearing of thousands of children over the course of several months. The results of these tests would be used to diagnose hearing loss for those who haven't been tested previously, but also would be used for research purposes. These circumstances may change once the WAHTS is approved for public use by the FDA, but by that point our solution should be integrated into the system thoroughly.

We have thought about these circumstances when thinking about our solution. In particular, we understand that the people administering the tests may not be medically trained, so we need to be cognisant of how we present ambient noise information.Our additions to the system also must be robust and relatively inexpensive. This is so that the solution is still accessible for low-income communities and can be easily transported between schools by the community healthcare workers.

Pro Forma Financials

Our pro forma financials plan is shown in the table below. It consists of a series of investments, which include the cost of the Tympan and the external microphone. I assumed that the Tympan will maintain its cost of $299 over the next ten years. I also assumed that the users (likely hospitals and community health workers) would purchase three Tympans at a time so that there can be three hearing tests happening simultaneously. Lastly, I assumed that the system would need to be replaced no more than every 5 years. This assumption was made because the Teensy 4.1 (the microprocessor in the Tympan) is on par with other microprocessors in that it should be able to be used for 10-20 years before wearing down, especially since we would not be completing particularly CPU intensive tasks with it.[21] The same could be said for the external microphone which we will be using, however I wanted to include the possibility that a new revision is released and the users would want to upgrade. Therefore, it is conservative to say the sound level meter would need to be replaced every 5 years. The other aspects of the system (Amplivox Attenuating headset and Android tablet) are not included in this analysis since our solution would be able to interface with those components which are already in use. Therefore, there is no need to purchase them again when implementing our changes.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Total
Investments	1341	0	0	0	897	0	0	0	0	897	3135
Recurring Costs	0	0	0	0	0	0	0	0	0	0	0
Revenue	0	0	0	0	0	0	0	0	0	0	0

Table 1: Pro-Forma Financial Plan

The plan also includes recurring costs and revenue. The system would incur no revenue, seeing as it is meant to increase healthcare access in low-income countries and should not charge the patients for using it. This would deter families from letting their children be tested and would not accomplish the project's overall goal. There are also no recurring costs since the system would not require maintenance on its components. Lastly, the community healthcare workers who would be administering the tests are volunteers, meaning that there is no need to account for their pay. Following this logic, our system would cost $3135 over the course of ten years of use.

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(25) Silver, Natalie. “How to Read Your Audiogram.” *Healthline*, Healthline Media, 26 July 2022, https://www.healthline.com/health/audiogram.

(26) Franks, John. “Modified Hughson-Westlake Flow Chart. .” *ResearchGate*, https://www.researchgate.net/figure/Modified-Hughson-Westlake-flow-chart-Adapted-from-Martin-1983_fig2_266580646.

(27) Meinke, Deanna K, et al. “Going Wireless and Booth-Less for Hearing Testing in Industry.” *International Journal of Audiology*, U.S. National Library of Medicine, 2017, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5581305/.

(28) “Architecture · Background · TABSINT.” *TabSINT*, 2022, https://tabsint.org/docs/user-guide/background.html#architecture.

(29) “Technologies · Background · TABSINT.” *TabSINT*, 2022, https://tabsint.org/docs/user-guide/background.html#technologies.

(30) “Exam Pages · Background · TABSINT.” *TabSINT*, 2022, https://tabsint.org/docs/user-guide/background.html#exam-pages

(31) International Electrotechnical Commission. *Electroacoustics - Sound level meters - Part 1: Specifications.* IEC 6172-1:2013.

(32) *Wireless Automated Hearing Test System TN-1096 - TABSINT*. (n.d.). Retrieved October 25, 2022, from https://tabsint.org/references/TN-1096.pdf

Supplementary Materials

Appendix A
WAHTS

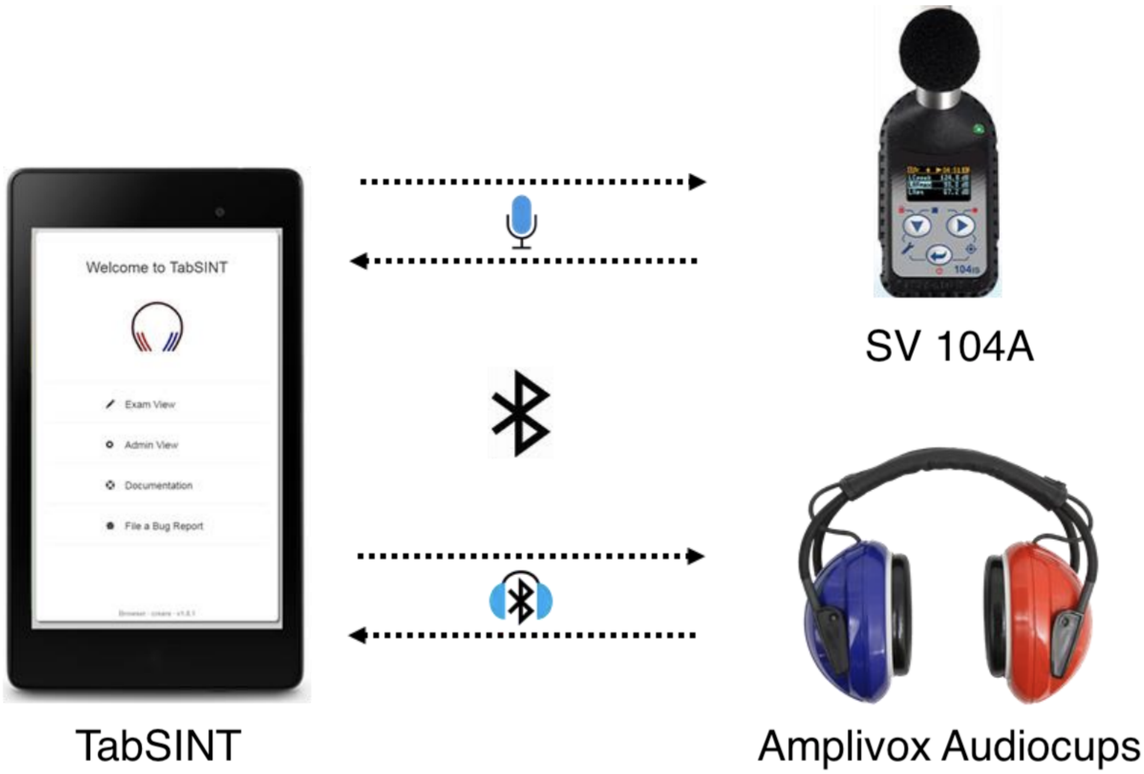

Figure A1: Diagrammatic Representation of the current WAHTS[32]

Appendix B
Relevant Tables and Graphs

I. ISO and ANSI Standards for Maximum Ambient Noise Levels

	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
ISO 8253	47 dB	33 dB	18 dB	20 dB	27 dB	34 dB	33 dB
ANSI S3.1-1999	49 dB	35 dB	21 dB	26 dB	34 dB	37 dB	37 dB

Table B1: Maximum Permissible Ambient Noise by Frequency[27]

II. MPANLs for the WAHTS headset (Amplivox Audiocups)

Frequency (Hz)	Ears uncovered† (dB SPL)	WAHTS attenuation (dB)	**WAHTS MPANLs (dB SPL)**
125	29	30.6	**59.6**
250	21	31.6	**52.6**
500	16	37.5	**53.5**
1000	13	39.5	**52.5**
2000	14	34.5	**48.5**
4000	11	36.0	**47.0**
8000	14	36.9	**50.9**

Table B2: MPANLs for the WAHTS headset[14]

Appendix C
Audiometric Tests

Test names:

I. Manual Pure-Tone Audiometry (following hughson westlake protocol)

This is the main hearing test used to establish the hearing thresholds of a person (and thus the degree of hearing loss). In Manual Pure-Tone audiometry, an audiologist uses an audiometry software on a tablet to play pure tones at various frequencies (i.e. 500 Hz, 1000Hz, 2000 Hz, 4000 Hz, 8000 Hz), with the tone at each frequency being played at various volumes (in dB). The goal is to identify the lowest volume a participant in the test can hear for various tone frequencies. For each tone, the sound is played at 40 dB, and then at decrements of 10 dB until the sound can no longer be heard. The protocol, known as the hughson westlake protocol, is outlined in figure 2 below. From that value, the sound is played at increments of 5dB until the sound can once again be heard by the participant. The sound value at which this occurs is plotted for the various frequencies tested on a graph known as an audiogram (See figure C1).[25] The participant indicates that they hear the tone by raising their hand, and a health worker determines when the tone is played.

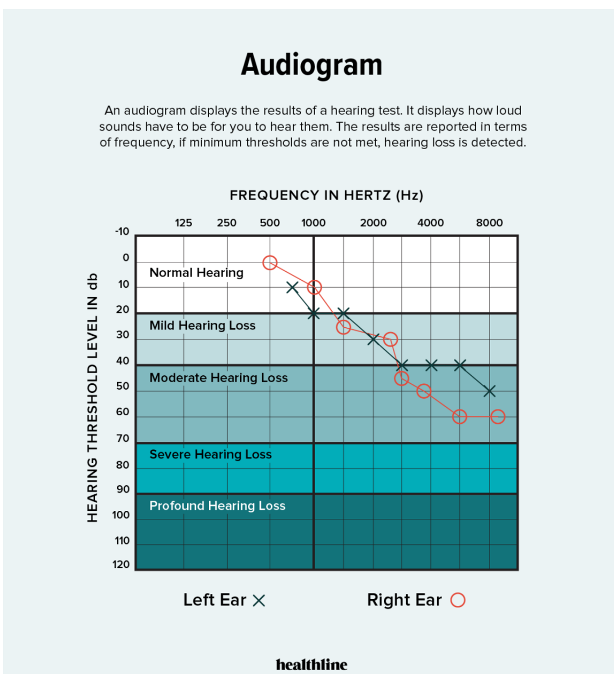

Figure C1: Example Result from Pure-tone test

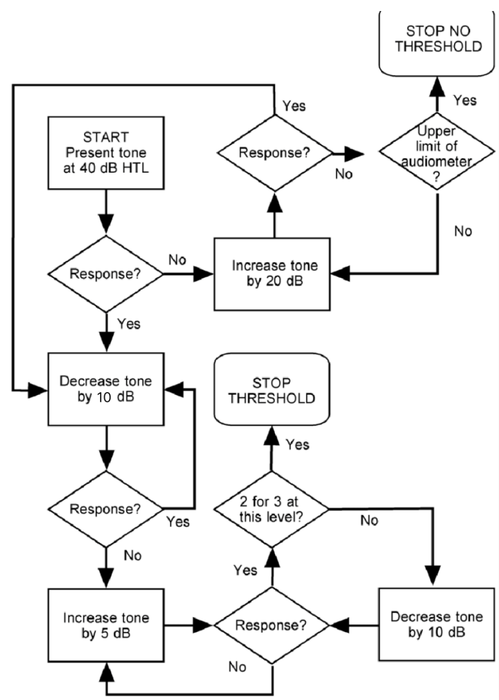

Figure C2: Hughson-Westlake protocol[26]

II. Automated Pure-Tone Audiometry (following hughson westlake protocol)

This test follows the same procedure as outlined in manual audiometry (see figure C2). The only difference is that the participant is given the tablet and a video explaining how to take the test. As the test begins, the tablet determines which frequencies and volumes to play and when they are played. To indicate that the participant heard the tone, they press a button.

Appendix D
IEC 6167 Specifications

I. Measurement Tolerance

Refers to the precision of sound level measurements made by the sound level meter at various frequencies.[31]

Table 3 – Frequency weightings and acceptance limits

Nominal frequency Hz	Frequency weightings dB			Acceptance limits, dB Performance class	
	A	C	Z	1	2
10	-70,4	-14,3	0,0	+3,0; -∞	+5,0; -∞
12,5	-63,4	-11,2	0,0	+2,5; -∞	+5,0; -∞
16	-56,7	-8,5	0,0	+2,0; -4,0	+5,0; -∞
20	-50,5	-6,2	0,0	±2,0	±3,0
25	-44,7	-4,4	0,0	+2,0; -1,5	±3,0
31,5	-39,4	-3,0	0,0	±1,5	±3,0
40	-34,6	-2,0	0,0	±1,0	±2,0
50	-30,2	-1,3	0,0	±1,0	±2,0
63	-26,2	-0,8	0,0	±1,0	±2,0
80	-22,5	-0,5	0,0	±1,0	±2,0
100	-19,1	-0,3	0,0	±1,0	±1,5
125	-16,1	-0,2	0,0	±1,0	±1,5
160	-13,4	-0,1	0,0	±1,0	±1,5
200	-10,9	0,0	0,0	±1,0	±1,5
250	-8,6	0,0	0,0	±1,0	±1,5
315	-6,6	0,0	0,0	±1,0	±1,5
400	-4,8	0,0	0,0	±1,0	±1,5
500	-3,2	0,0	0,0	±1,0	±1,5
630	-1,9	0,0	0,0	±1,0	±1,5
800	-0,8	0,0	0,0	±1,0	±1,5
1 000	0	0	0	±0,7	±1,0
1 250	+0,6	0,0	0,0	±1,0	±1,5
1 600	+1,0	-0,1	0,0	±1,0	±2,0
2 000	+1,2	-0,2	0,0	±1,0	±2,0
2 500	+1,3	-0,3	0,0	±1,0	±2,5
3 150	+1,2	-0,5	0,0	±1,0	±2,5
4 000	+1,0	-0,8	0,0	±1,0	±3,0
5 000	+0,5	-1,3	0,0	±1,5	±3,5
6 300	-0,1	-2,0	0,0	+1,5; -2.0	±4,5
8 000	-1,1	-3,0	0,0	+1,5; -2,5	±5,0
10 000	-2,5	-4,4	0,0	+2,0; -3,0	+5,0; -∞
12 500	-4,3	-6,2	0,0	+2,0; -5,0	+5,0; -∞
16 000	-6,6	-8,5	0,0	+2,5; -16,0	+5,0; -∞
20 000	-9,3	-11,2	0,0	+3,0; -∞	+5,0; -∞

NOTE Frequency weightings were calculated by use of the analytical expressions in Annex E with frequency f computed from $f = f_r\,[10^{0,1(n-30)}]$ with f_r = 1 000 Hz and n an integer between 10 and 43. The weightings were rounded to a tenth of a decibel.

Appendix E
Sound Level Meter and Microphone Specifications

In this section of the appendix, we have compiled specifications from the respective datasheets, which are included on the reference page.

I. Svantek 104A

The Svantek 104A is a sound level meter and a dosimeter. A dosimeter is a device that is meant to measure the direct noise exposure for one person. This is far more exact and intricate than what our system would need from the sound level meter, and likely contributes to the elevated cost. More specifications that speak to the technical capabilities of the Svantek are shown in the table below.[22]

Weighting Filters	A, C, and Z
Microphone	ST 104A MEMS Microphone
Linear Operating Range	53 dBA - 141 dBA
Dynamic Range	98 dB
Frequency Range	20 Hz - 20 kHz
Memory	8 GB
Communication Interfaces	USB 2.0, Bluetooth 4.0, Electrical Contacts
Operating Temperature	-10 ºC - 50 ºC
Dimensions	88 x 49.5 x 19.2 mm
Weight	121 grams

II. MicW i436 External Microphone[23]

Frequency Response	20 Hz - 20 kHz
S/N Ratio	More than 62 dB
Operating Temperature	-20 ºC - 50 ºC
Length	50 mm
Weight	8 grams

III. Tympan

The below specifications are for the on-board microphone of the Tympan, as well as the dimensions of the device itself.[24]

Weighting Filters	A, C, and Z
S/N Ratio	70 dB
Dimensions of microphone	4.72 mm x 3.76 mm x 1.25 mm
Frequency Range	10 Hz to 10 kHz
Acoustic Overload Value (Max. Volume)	130 dBA
Operating Temperature	-30 ºC - 100 ºC
Dimensions of Tympan	74mm x 38mm x 33mm
Communication Interfaces	Bluetooth 4.0
Memory	microSD slot for up to 64 GB

Appendix F
TabSINT running on browser

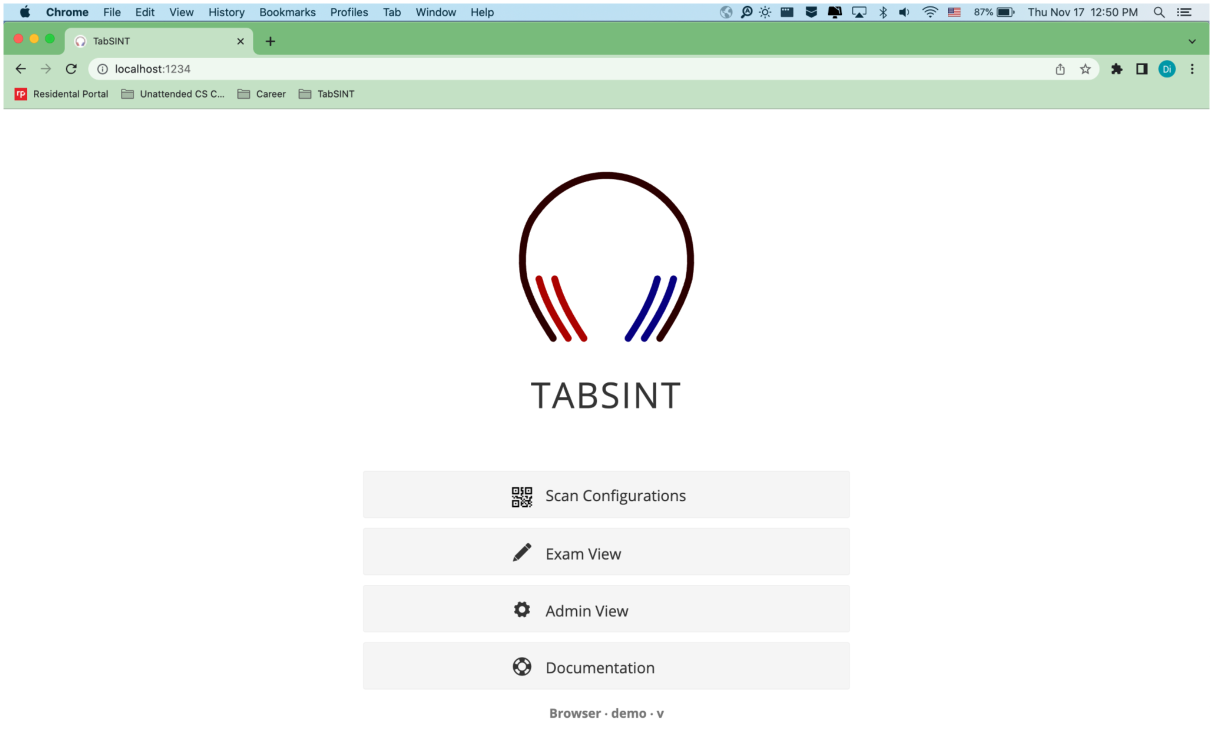

Figure F1: TabSINT front page on Chrome

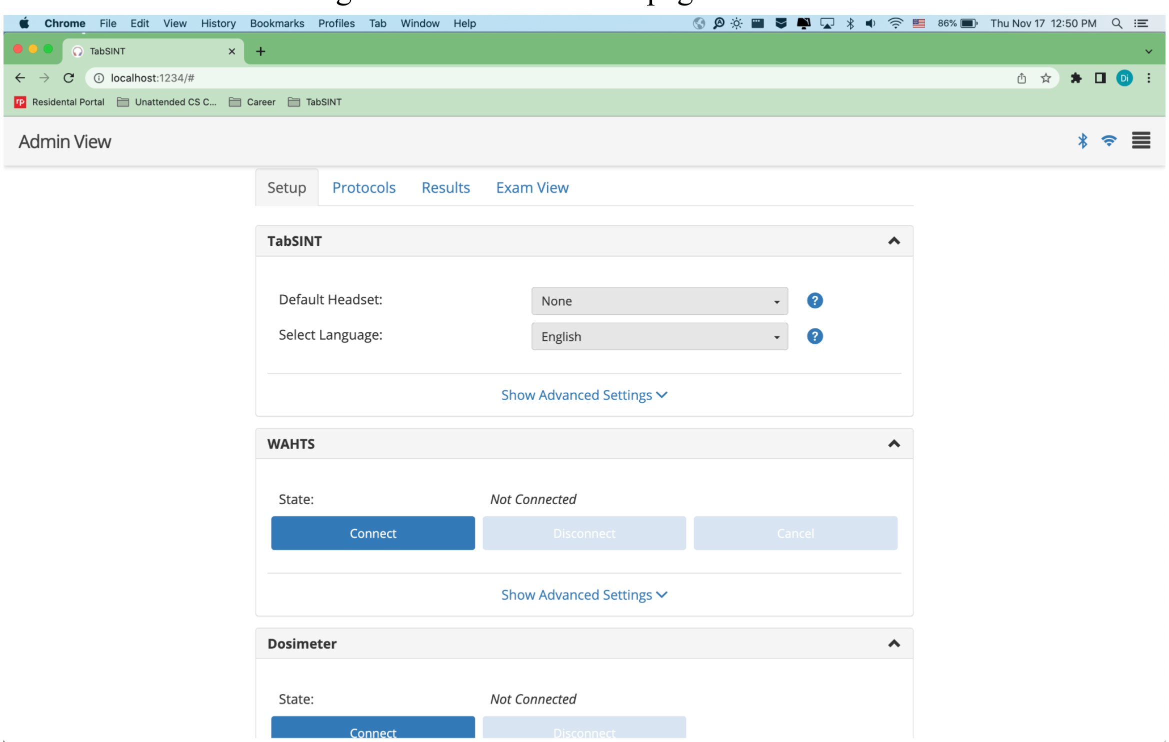

Figure F2: TabSINT “Setup” page on Chrome

Appendix G
TympanRemote App

TympanRemote is the mobile app for controlling Tympan. Source code is stored in Tympan's GitHub repository.[13] We will not go deep into the app design but focus on the connection and data transmission between Tympan and TympanRemote.

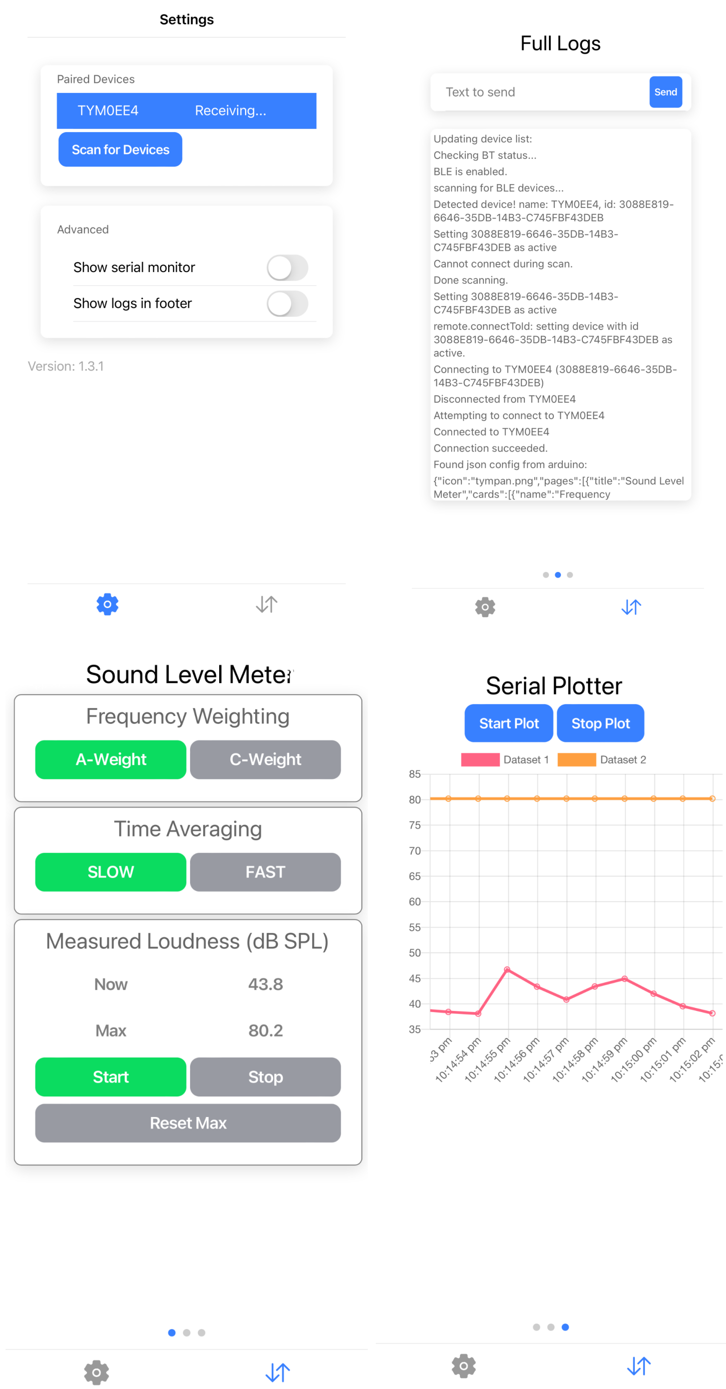

Figure G1: TympanRemote app user interface

Appendix H
TabSINT Information

I. Architecture[28]

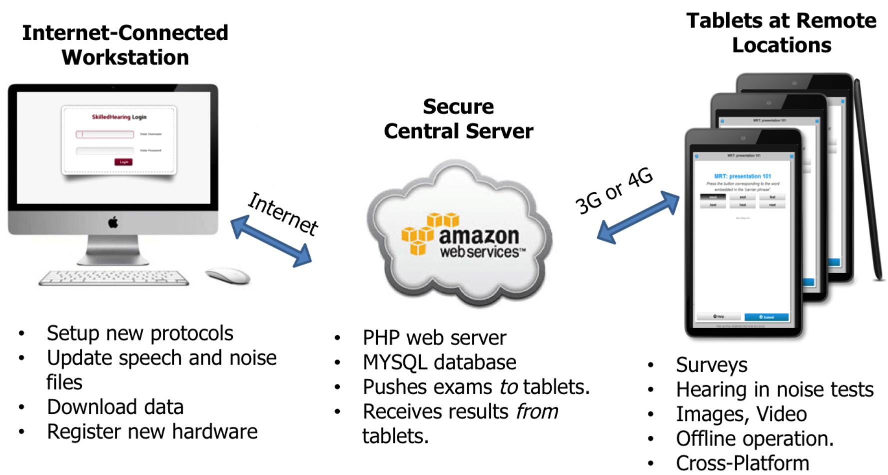

Figure H1: Client-server architecture of TabSINT

If there is time, we will expand our work scope to work on uploading data to the central server, which requires knowledge of PHP web server and MySQL database. In addition, we can present the noise measurement data on computers to improve doctors' experience when examining results.

II. Technologies[29]

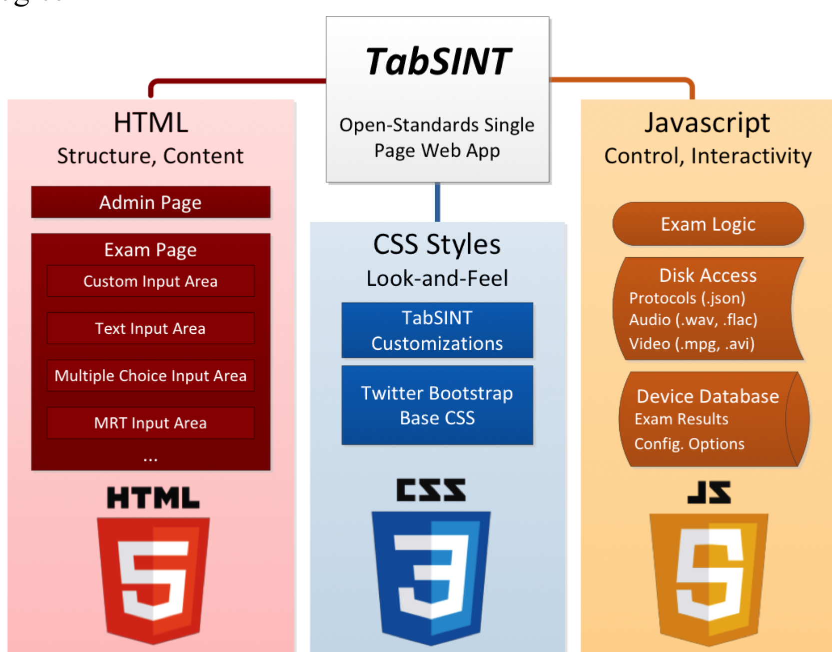

Figure H2: Standard web technologies in TabSINT

In addition, the Cordova (aka PhoneGap) toolchain packaged the tablet client as a hybrid mobile app (an app that is written with web technologies, but which functions as and appears as a native app) and the Google-backed AngularJS platform improves the interactivity of the software and allows for extensive automated testing to help detect bugs.

III. TabSINT Exam Pages[30]

The bulk of a protocol is a series of Exam pages. As the exam progresses, TabSINT progresses from one exam page to another. Protocols are written in text-based JavaScript Object Notation (JSON) format and define the content and logic of a set of interactive pages.

Each page is composed of UI components, which are arranged in the same order on every page. An exam page might include all, some, or (in the case of an empty page), none of these components. Taken together, these highly configurable components can create a very diverse range of exam pages.

The following figure shows several of the basic components, all of which can be configured in the protocol file.

The most diverse and important component is the input response area. Each page can contain only a single input response. Each response area is specialized for a particular type of question. For example:

- a text box
- a multiple choice question
- a modified rhyme test (MRT)

and many others.

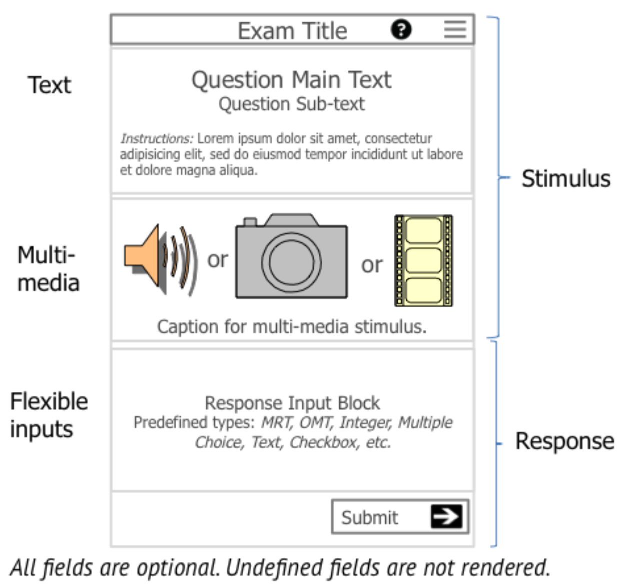

Figure H3: TabSINT exam page template

Appendix I
Scrum Framework & Kanban Methodology

The Scrum framework (see Figure I1), in specific, divides the team into product owner, scrum master, and development team with respective responsibilities (see Figure I2).

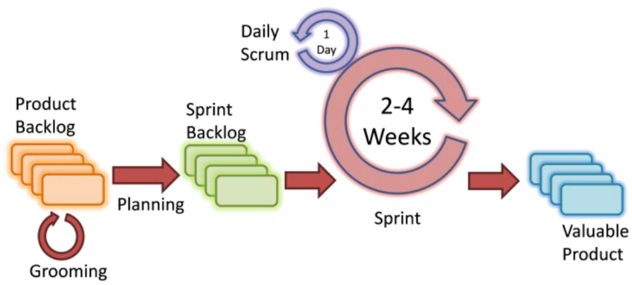

Figure I1: General Scrum Flow

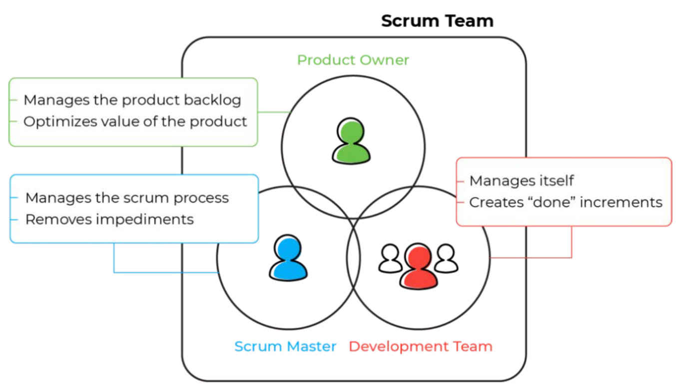

Figure I2: Breakdown of Scrum Team

Lengthy documentation is avoided by focusing on specific features written from the perspective of a user on user story cards (see Figure I3).

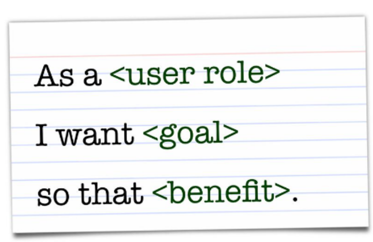

Figure I3: User Story Template

User stories are collected into the product backlog and are analyzed to clarify the priority and the estimated time of each user story (see Figure I4).

Figure I4: Product Backlog with Priorities and Estimated Time

Then user stories are separated into sprints, short duration milestones that allow the team to implement a feature or a few features that can be tested (see Figure I5).

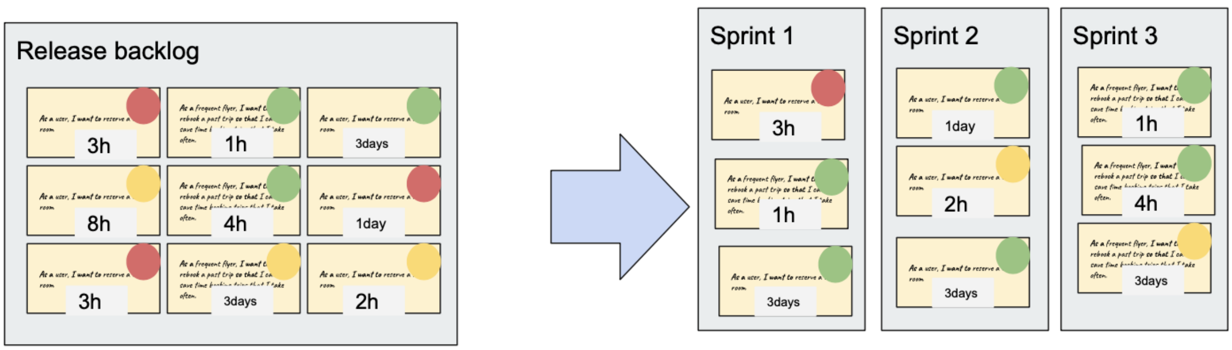

Figure I5: Making Sprints from Product Backlog

Daily scrum meetings enable the team to keep track of the progress and to dynamically adjust speed according to the progress. With the Scrum framework, we can have a clear understanding of the timeline and adjust our plan accordingly if we need to add features.

Kanban (see Figure I6) visualizes the workflow to help the team understand the current state. Fortunately, Smartsheet, the planning platform we were suggested to use, supports both Scrum and Kanban.

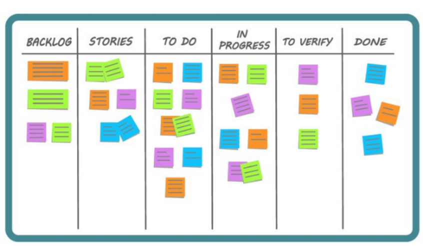

Figure I6: Kanban

Appendix J
Product Backlog and Smartsheet

Sheet - Backlog & Sprint Planner

smartsheet

	Sprint	Story or Task	Epic	Type	Description	Stage	Status	Story Points	Points Capacity	Points Available
1		Release 1 (R1)						0	150	150
2	Sprint 1 (R1)	Sprint 1 (R1)						0	50	50
3	Sprint 2 (R1)	Sprint 2 (R1)						0	50	50
4	Sprint 3 (R1)	Sprint 3 (R1)						0	50	50
5										
6		Product Backlog								
7	Backlog	Backlog						144		
8	Backlog	Integrate Tympan into TabSINT		Story	As a doctor, I want to have Tympan incorporated into the system, so that I don't have to deal with two pieces of software.			17		
9	Backlog	Learn Tympan-TympanRemote		Task	Study the connection between Tympan and TympanRemote.			4		
10	Backlog	Learn Svantek-TabSINT		Task	Study the connection between SV104A and TabSINT.			5		
11	Backlog	Modify TabSINT files to support Tympan		Task	Modify the configuration of "Setup" tab so that the "dosimeter" dropdown menu supports Tympan. Ensure that Tympan and TabSINT are connected through Bluetooth.			6		
12	Backlog	Testing		Task	Test adding Tympan as the dosimeter and running through the protocol.			2		
13	Backlog	Display noise level data in exam page		Story	As a research assistant, I want to see noise measurement data on the screen while conducting manual audiometry, so that I can monitor the noise level and rerun the exam when there is a transient noise spike.			13		
14	Backlog	Determine type of data		Task	Decide which data should be displayed that can help health workers in the best way. Temporary options are mean value in the period, max value in the period, and live value.			1		
15	Backlog	Design interface		Task	Determine the interface of the block that displays the data.			4		
16	Backlog	Implement interface		Task	Implement the module according to the decisions made above.			4		
17	Backlog	Testing		Task	integrate into current system and test			4		
18	Backlog	Automatically pause after noise spike		Story	As research assistants and doctors, we want to pause the exam automatically when a transient noise spike is detected, so that in manual audiometry we don't need to pay too much attention to noise level and in automated audiometry the participant doesn't need any extra action when there is a noise spike.			17		
19	Backlog	Determine noise level threshold		Task	Decide the minimum noise level that triggers the pause.			1		
20	Backlog	Pop-up message		Task	Learn about how to add notification in the protocol and design the content and the interface message displayed when noise spike is detected.			5		
21	Backlog	Implement notification feature		Task	Implement the notification workflow.			5		
22	Backlog	Freeze the test during notification		Task	Ensure that the test is suspended when the noise spike notification is displayed.			4		
23	Backlog	Testing		Task	Integrate into current system and test			2		

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	Sprint	Story or Task	Epic	Type	Description	Stage	Status	Story Points
24	Backlog	Restart the current test after pause		Story	As research assistants and doctors, we want to redo the current test after the pause, so that we don't need to manually select the test that runs next.			17
25	Backlog	Add "Restart" button to the pause notification		Task	Add "Restart" button to the pause notification that pops up after noise spike. When the noise level is still higher than the threshold, the button is disabled. When the noise level returns to acceptable value, the button can be pressed.			5
26	Backlog	Learn about database		Task	Learn about the database that stores the data before implementation. Especially how the data is added and how it should be deleted.			4
27	Backlog	Implement restart functionalities		Task	After "Restart" button is pressed, abort the data recorded for the current test and return the beginning of the test. Ensure the Tympan recordings are also deleted and Tympan restarts to measure noise level.			6
28	Backlog	Testing		Task	Integrate into current system and test			2
29	Backlog	Option to abort interfered results		Story	As a doctor, I want to give technicians the option to abort an automated test if the child was too interested in the button or there are transient noise spikes, so that invalid results are not stored.			12
30	Backlog	Learn about database		Task	Learn about the database that stores the data. Especially how the data is added and how it should be deleted.			4
31	Backlog	Determine what to delete		Task	Decide if the system should enable the health worker to delete all the data, or to select tests and to delete only the selected ones' results.			2
32	Backlog	Add "Delete result" option to last page		Task	On the last page of the automated audiometry, ask participant to return the tablet to the health worker. Add "Delete" button(s) and notification on that page. The notification asks if the health worker wants to delete the results. If so, the health worker can press the button(s) to delete.			6
33	Backlog	Pre-test on noise level		Story	As a doctor, I want to run a pre-test at the beginning of the audiometry to see ambient noise, so that the audiometry only continues when the noise level is acceptable.			7
34	Backlog	Determine the workflow		Task	Determine if the pre-test is mandatory or optional. If mandatory, an exam page or a notification can be added at the beginning of the protocol. If optional, a button can be added to the first exam page.			1
35	Backlog	Implementation		Task	Implement the functionalities needed according to the decision. Tympan results are NOT recorded in the pre-test.			4
36	Backlog	Testing		Task	Integrate into current system and test			2
37	Backlog	Store Tympan results		Story	As a doctor, I want to store max levels of noise or averages across the test period, when the spikes occurred, and how large the spikes were, so that I can examine the data after the audiometry.			18
38	Backlog	Learn about database		Task	Learn about the database that stores the data. Especially how the data is added and how it should be deleted. Ask Creare about "Sensimetric Sound Level Meter" mentioned in "Result Analysis" of TabSINT documentation.			6
39	Backlog	Check the capability of tablet storage		Task	Check the size of result files. Check if the tablet has enough storage for test results.			2
40	Backlog	Optional: Modify the database		Task	If the attributes needed to store are different from those that SV104A or "Sensimetric Sound Level Meter" stores, modify the database and related functionalities such as the compatibility with the cloud server.			8
41	Backlog	Testing		Task	Integrate into the system and test			2

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	Sprint	Story or Task	Epic	Type	Description	Stage	Status	Story Points
42	Backlog	Plot ambient sound level in exam pages		Story	As a research assistant, I want to have a plot of ambient sound level during manual audiometry, so that health workers can see the noise levels intuitively and act accordingly to the noise level.			13
43	Backlog	Add "Display plot" option to protocol		Task	On the first page of the protocol, the health worker can choose whether to display the ambient sound level plot or not with a option button.			2
44	Backlog	Determine the location of plot		Task	Determine on which part of the exam page the plot is displayed. Temporary options are: in the "Show debug info" dropdown list, right below the response area of exam pages, etc.			1
45	Backlog	Interface of the plot		Task	Determine what data to be displayed on the plot. Design the appearance of the plot such as the axis names, plot type (line? bar?), etc.			2
46	Backlog	Refreshing the plot		Task	Implement the refreshing of the plot after each specified time period (e.g. 1 second).			6
47	Backlog	Testing		Task	Integrate the plot into current system and test			2
48	Backlog	Automate Tympan's start/end recording		Story	As a research assistant, I want to automate Tympan's start and end recoding so that Tympan starts recording after pressing "Go" and stops recoding when the test ends.			17
49	Backlog	Implement remote control over Tympan		Task	Study how TympanRemote turns on/off Tympan remotely. Add a testing button to the exam page that does the same as the button in TympanRemote.			6
50	Backlog	Design Tympan workflow in the protocol		Task	Determine when Tympan should be turned on/off in the protocol. Decide if Tympan is only turned on /off once (at the beginning/end of the protocol) or once for each exam page (stop and restart when going to next page).			3
51	Backlog	Implementation		Task	Implement the functionality			6
52	Backlog	Testing		Task	Integrate into the current system and test			2
53	Backlog	Stop measuring when participant talks		Story	As a research assistant, I want to include a button that could be pressed to ignore following ambient noise when doing the tests that require the participant to repeat the sentence they heard back to them, so that the voice of the participants doesn't influence the test.			13
54	Backlog	Learn testing procedure		Task	Go through the protocol and check when the participants are asked to talk.			2
55	Backlog	Design button interface		Task	Determine the position and the appearance of the button in the exam page.			2
56	Backlog	Implementation		Task	Implement the functionality			7
57	Backlog	Testing		Task	Integrate into current system and test			2

Figure J1: Product backlog for software development of TabSINT

Figure J2: Smartsheet in Card View, displaying different stages (Kanban)

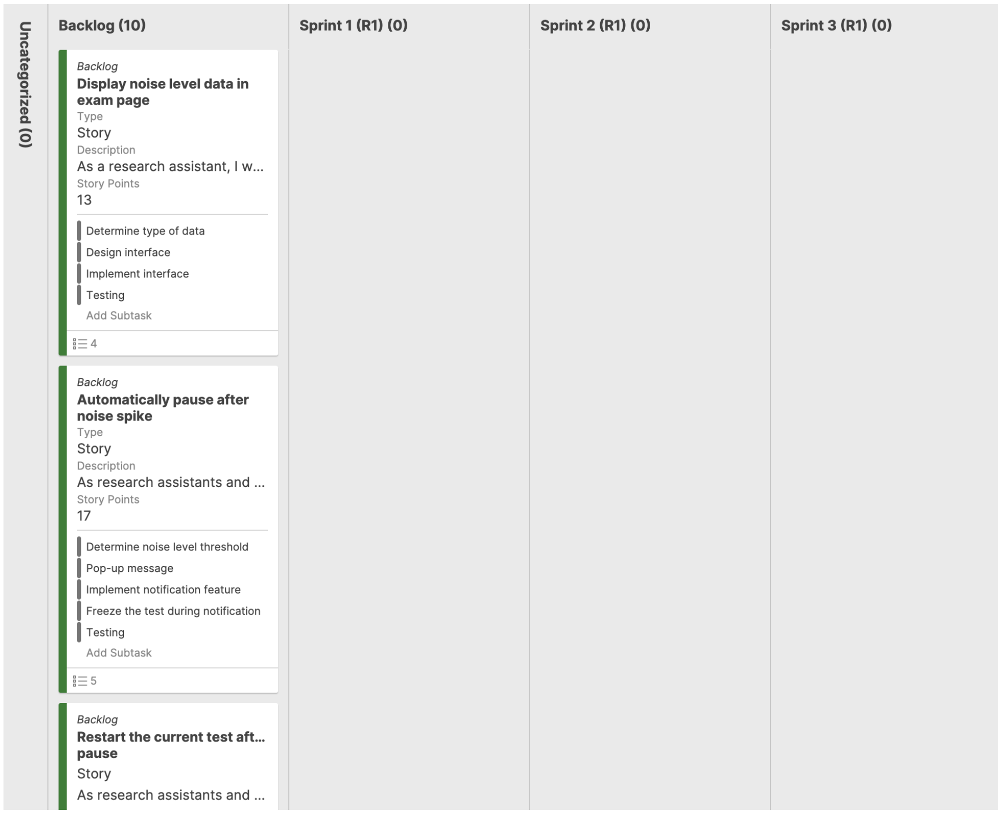

Figure J3: Smartsheet in Card View, displaying different sprints

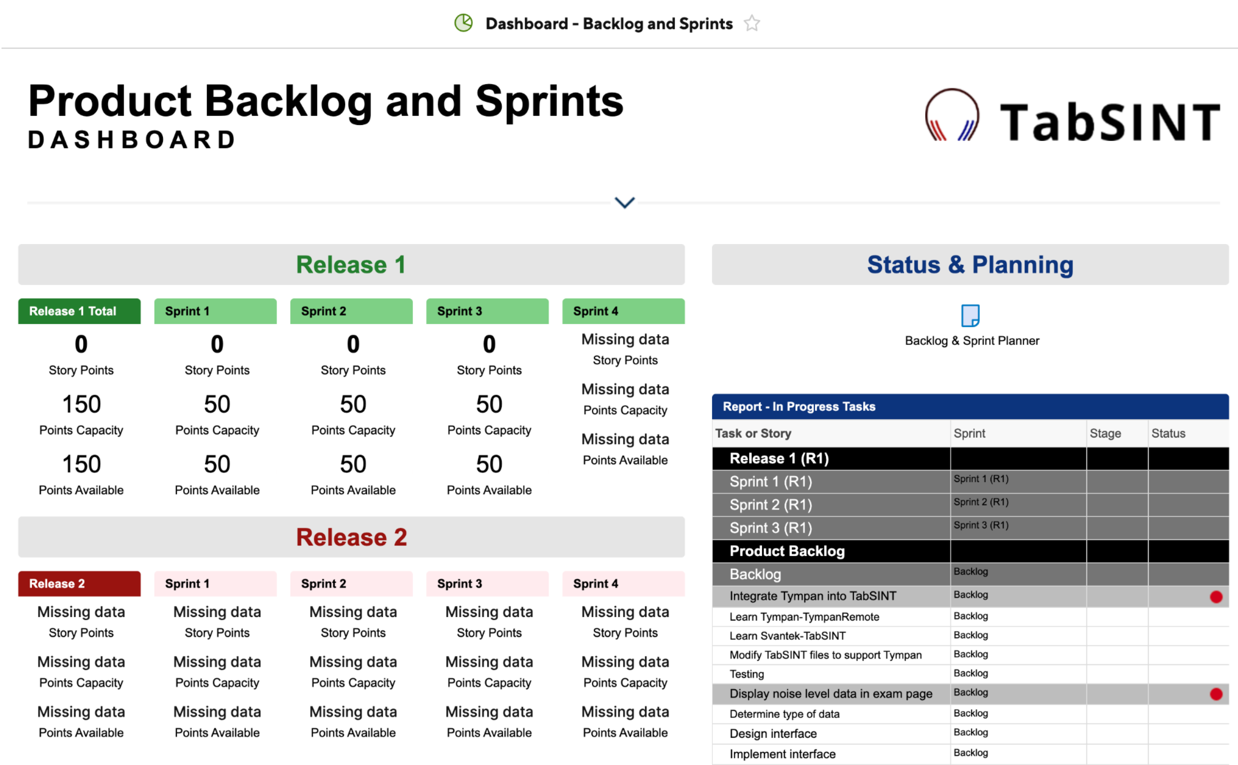

Figure J4: Dashboard for software development of TabSINT

Appendix K
Unified Modeling Language

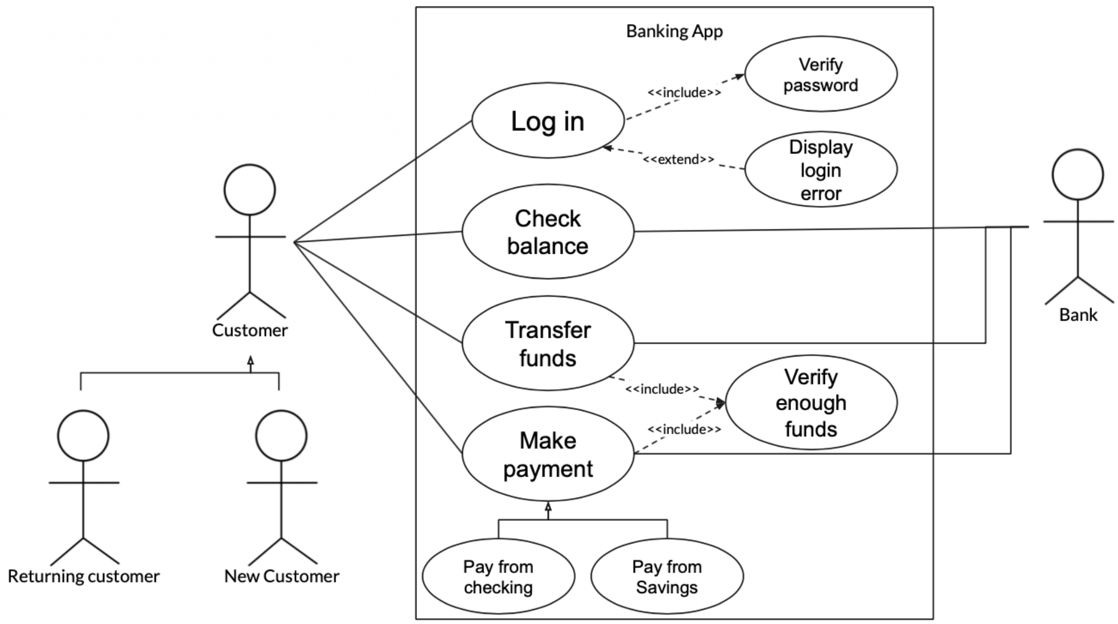

Figure K1: Use Case Diagram Example

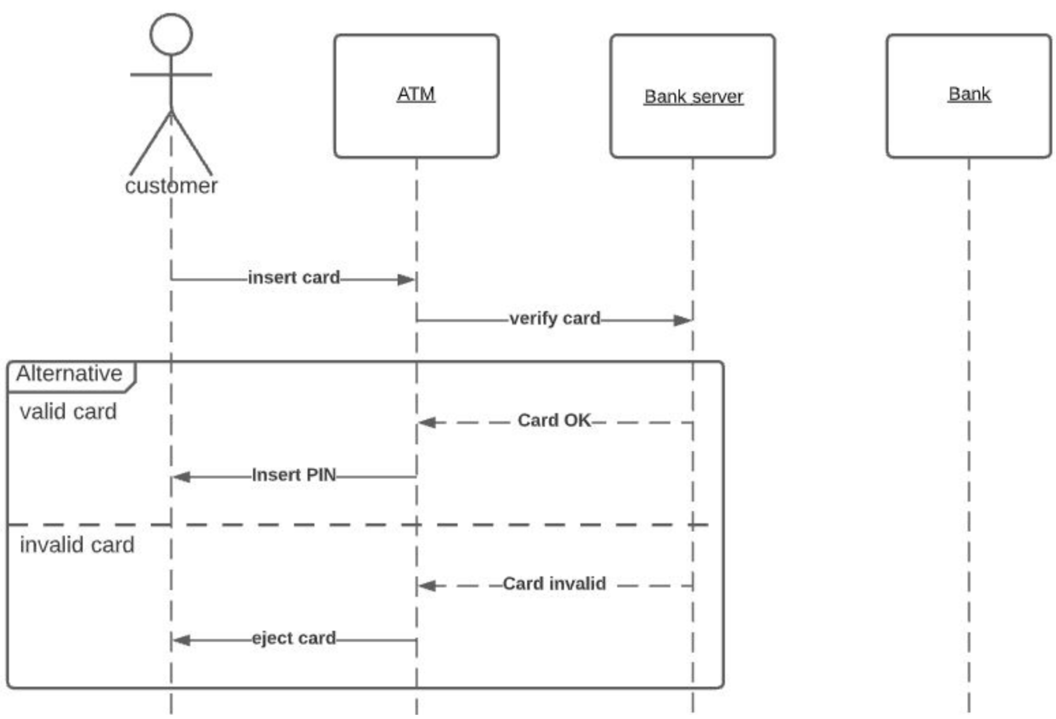

Figure K2: Sequence Diagram Example

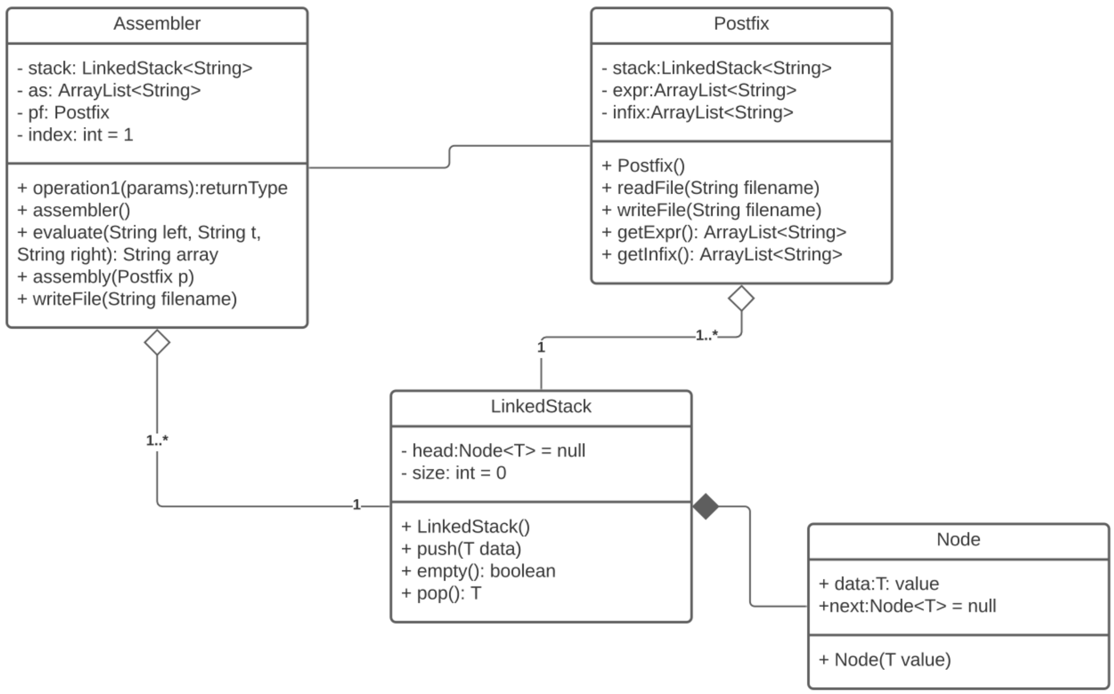

Figure K3: Class Diagram Example

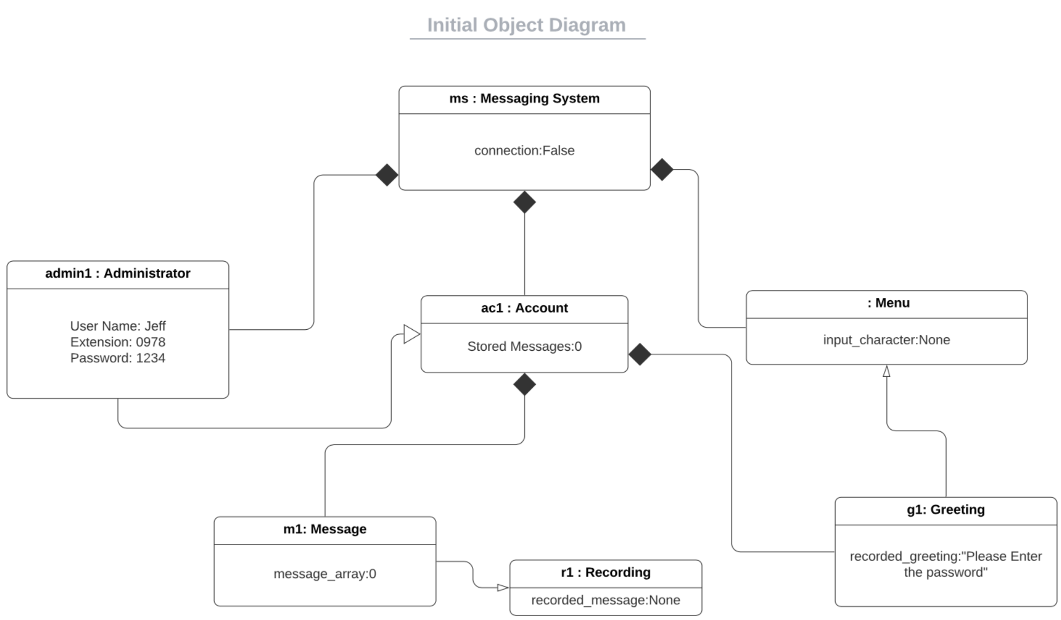

Figure K4: Object Diagram Example

Appendix L
Team members' Resumes

AZARIAH JAVILLONAR

Kamuela, HI · (808) 937-0099 · azariahjavillonar01@gmail.com · linkedin.com/in/azjavillonar

EDUCATION

Dartmouth College, Hanover, NH **June 2023**
Bachelor of Arts, Major in Engineering Sciences Modified with Computer Science

- Relevant Coursework: Operating Systems, Computer Architecture, Control Theory, Scientific Computing, Systems, Object-Oriented Programming, Embedded Systems, Distributed Systems and Fields, Software Design and Implementation, Engineering Design Methodology (*Fall '22), Electronics: Linear and Digital Circuits (*Winter '23), Microprocessors in Engineered Systems (*Winter '23), Digital Electronics (*Spring '23), Computer Networks (*Fall '23)
- Awards & Recognitions: Dartmouth Native and Indigenous community's Emerging Leader Award, Native American Program's Exceptional Community Member Award, Academic Honors Citation in Scientific Computing

Kamehameha Schools at Kapālama, Honolulu, HI **May 2019**

- Activities: Math Team President (ranked 12th nationally), Dormitory Residential Advisory Council, Varsity Sailing, Canoe Paddling
- Graduated with an academic honors diploma

WORK EXPERIENCE

FUJIFILM Dimatix, Lebanon, NH **June 2022-September 2022**
Systems Engineer Intern

- Initiated SolidWorks drawings of the in-house built low-pressure press that is now used to virtually interact and improve on the design.
- Developed programs to efficiently clean epoxy vessels via a furnace bake-out cycle. Corrected the previous cycle to finish in 4 hours rather than the normal 9 hours that it required.
- Launched an investigation to determine disparities in cooling times between bonding hot bars.
- Advanced the ETS Lab by investigating high-priority undocumented spare parts and properly storing them for future repairs.

Native American Program, Dartmouth College, Hanover, NH **August 2020-Present**
STEM Tutor

- Courses Taught: Introduction to Programming, Scientific Computing, Introduction to Calculus up to Accelerated Multivariable Calculus, Introductory Physics 1 & 2, Systems Engineering
- Developed program to help Dartmouth's Native American students looking to major in STEM with course selection and study routines
- Educate students on effective study habits and critical thinking skills

Tutor Clearinghouse, Dartmouth College, Hanover, NH **March 2021-June 2021**
Scientific Computing Group Tutor (Computer Science)

- Tutor 5 students weekly for a 2-hour group session to solidify the concepts taught in *Introduction to Scientific Computing*
- Guided students on weekly assignments and coding projects such as creating a board game or sorting data
- Utilize multiple teaching styles to accommodate each student's learning style
- All students reported an increase in project and exam grades after attending study sessions

ACTIVITIES

Hōkūpa'a - Hawai'i Club, Dartmouth College, Hanover, NH **April 2021-Present**
Treasurer

- Oversee the Hawai'i Club's finances, funding, and budgets
- Coordinate fundraising events and opportunities to give Hawai'i's community a sense of belonging so far from home
- Secure funds and create detailed budgets for events including the annual student-run Hōkūpa'a Lū'au that has a $20,000 budget and seats 350

Kamehameha Math Team, Honolulu, HI **August 2017-May 2019**
Co-President

- Coordinated practices, meets, socials, and travel plans throughout the year
- Led team to achieve a high ranking in the O'ahu Math League and a 12th place in Mu Alpha Theta national math competition

MACKENZIE GRACE GUYNN

195 N Harbor Drive Apt #3702 • Chicago, IL 60601 • mackenzie.guynn@gmail.com • (312) 513-0908

EDUCATION

DARTMOUTH COLLEGE Hanover, NH
BE Candidate, November 2023; BS Candidate, June 2023: Electrical Engineering and Computer Science *2019 – Present*
- ***Relevant Coursework:*** Engineering Systems; Software Design and Implementation; Digital Electronics; Linear Control Design; Introduction to Machine Learning and Data Mining; Embedded Systems; Distributed Systems and Fields; Linear Algebra; Computer Architecture; Cognitive Computing
- ***Honors/Awards:*** Citation in Sociolinguistics; Honors for the 2020–2021 academic year

TECHNICAL EXPERIENCE

NURO Mountain View, CA
Embedded Software Engineer Intern *June – September 2022*
Robotics company that develops autonomous delivery vehicles and robotic solutions for everyday life
- Designed, developed, and tested a driver for the second-generation Prius display using **embedded C**, **SPI**, and **CAN** communication protocols. The display will be a part of the vehicle's launch and integrated into hundreds of vehicles deployed in multiple states.
- Implemented and tested a check that doors are closed before moving in the third-generation robot's state machine

CLEARCOGS Remote
Full-Stack Software Development Intern *January–May 2022*
Tech start-up developing Machine Learning systems to reduce food waste in chain restaurants
- Built communications to inform and engage external users using **React, Typescript,** and **Python**
- Built and deployed an API and User Interface for a user onboarding tool using the **AWS Lambda Function** and **API gateway** tools, **Python** and **Typescript**

TEACHING ASSISTANT – THAYER SCHOOL OF ENGINEERING Hanover, NH
Selected Teaching Assistant for ENGS 22: Systems *January–March 2022*
- Help students solve problems and understand course concepts on modeling linear time invariant systems (electrical, mechanical, thermal, and fluid)
- Collaborate with fellow teaching assistants in weekly meetings to develop teaching strategies

SUSTAINABLE HEALTH LAB – DARTMOUTH COLLEGE Hanover, NH
Research Assistant for Lead Investigator: Inas Khayal PhD *September–December 2020*
- Conducted lab research and developed a Mental Health SMS Bot for members of the Upper Valley to provide access to mental health care at the Dartmouth Hitchcock Medical Center using **mySQL**, **Flask, Python,** and cloud communication platforms

GYST AUDIO Chicago, IL
Front-End Software Development Intern *June–November 2020*
Tech start-up that supplies professionally narrated audio to couple with text-based material for subscribing publishers
- Built and launched a settings page to enable each user to customize their inline player using **HTML**, **JavaScript, CSS**, and **React.js**
- Built internal dashboards connected to Gyst Audio's server to allow users to view their current statistics using **HTML, CSS, Python, Flask,** and **React.js**

PROJECT EXPERIENCE

RECYCLE REPAY Hanover, NH
Final Project for Computer Science 89.11: Cognitive Computing with Watson *Spring 2022*
- Designed, developed, and tested an app that captures images of recycled items and rewards users using **Typescript** and **React Native** with three teammates
- Connected the user interface with an API and a **Pytorch** Image Recognition model to minimize false classifications and enhance the performance of the app

DIGITAL VOICE RECORDER Hanover, NH
Final Project for Engineering Sciences 31: Digital Electronics *Summer 2021*
- Implemented, debugged, and documented a digital voice recorder using **VHDL**, **ADC** conversion, **SPI** communication, an **FPGA**, and an oscilloscope
- Planned the digital system using RTL-based design, block diagrams and sequential and combinational logic with a partner

NUGGETS VIDEO-GAME Hanover, NH
Final Project for Computer Science 50: Software Design and Implementation *Spring 2021*
- Implemented, tested, and documented a modularized and scalable multi-player video game with a team of four using **Github**, **C** and Scrum
- Enhanced the user's experience by debugging and implementing the display of the game with the **C** library, **ncurses**
- Implemented the client-server model by writing the client program using **C** and the TCP/IP protocol

THE PHONEPACK Hanover, NH
Final Project for Engineering Sciences 21: Introduction to Engineering *Winter 2021*
- Developed the concept, designed, and built a prototype for a portable, software-enabled device to keep teenagers off their phones when doing work, using an agile development process
- Optimized the product design based on our specifications using **SolidWorks** to model prototypes of the portable device and **Figma** to design the software component**;** Conducted **Specific Tests** at different stages of development

LEADERSHIP & ACTIVITIES

DARTMOUTH CHI DELTA MEETINGS CHAIR Hanover, NH
- Plan weekly meetings with active members; Facilitate icebreakers, community building and strengthen leadership and public speaking skills *2021-Present*

DARTMOUTH SAPA Hanover, NH
- Provide support and guidance to Dartmouth students who have been impacted by Sexual Violence through 1:1 interaction *2020–Present*
- Strengthen personal relationship skills through leadership and communication training; Led small groups through training in 2020-2022 school years

DARTMOUTH VARSITY WOMEN'S ROWING TEAM Hanover, NH
- Balance a minimum of 20-hour per week practice schedule in the fall, winter, and spring with a rigorous academic course load *2019-2022*
- Strengthen leadership and time management skills through relationships with coaches and teammates

TECHNICAL SKILLS

Technical Skills: Java, C++, MATLAB, R, VHDL, Python, C, HTML, CSS, JavaScript, Typescript, React, Y86 Assembly, Logisim, Flask, mySQL, Ruby, SolidWorks

Di Luo

Hanover, NH · (207) 830-1280 · di.luo.th@dartmouth.edu · linkedin.com/in/diluo1999

Education

Dartmouth College, Hanover, NH **06/2023**
Bachelor of Engineering, with Computer Engineering Concentration
- *Relevant Coursework:* Engineering Design Methodology and Project Initiation, Software Design and Implementation, Digital Electronics

Colby College, Waterville, ME **05/2022**
Bachelor of Arts: Major in Computer Science; Minors in Mathematics and Physics
- *Relevant Coursework*: Empirical Software Engineering, Software Engineering, Analysis of Algorithms, Data Structures and Algorithms, Data Analysis and Visualization, Web Programming, Programming Languages
- *Honors*: Phi Beta Kappa, Sigma Pi Sigma, Dean's List, Davis United World College Scholar

United World College Costa Rica, Santa Ana, Costa Rica **05/2018**
International Baccalaureate Diploma

Technical Skills

Programming Languages: Python, C, VHDL, Java, JavaScript, HTML, CSS, PHP
Technologies: Git, Bash, JSON, Jupyter Notebook, Numpy, Matplotlib, pandas, jQuery, AJAX, Node.js, MySQL, Flask, Heroku
Project Management: SDLC, Agile, Scrum, Kanban, UML, Risk Management

Projects & Experience

Low-Cost Boothless Audiometry—Engineering Design Team Project, Dartmouth College **09/2022 - Present**
- Decreasing the cost of boothless audiometry by 83% by replacing noise dosimeter with customized open-source audio platform TYMPAN to help community health workers (CHWs) and people, especially children, in low-income countries
- Leading the customization of open-source hearing assessment mobile app TabSINT by developing Bluetooth connection with TYMPAN in **JavaScript** and improving UI/UX and database of hearing test protocol written in **JSON**
- Managing product backlog and organizing sprints as **Scrum Master** of a 5-person team according to **Agile** model
- Collaborating with specialists from Creare LLC, doctors from Dartmouth Hitchcock Medical Center, and faculty advisors to collect technical suggestions and user stories, and to adjust the product accordingly

Blackjack & Search Engine—Software Design and Implementation Projects, Dartmouth College **09/2022 - 11/2022**
- Engineered reinforcement learning-based Blackjack game as part of a 4-person team, in which player module learned to play optimally by training with dealer module (150K games) through TCP/IP communication, all written in **C**
- Developed a search engine in **C** comprised of crawler, indexer, and querier modules (all tested and integrated)
- Managed the projects through **GitHub** and conducted version control with **Git**

Video Game Development—Digital Electronics Final Project, Dartmouth College **06/2022 - 08/2022**
- Created the classic tic-tac-toe game in **VHDL** with Basys 3 FPGA board that was displayed on a VGA monitor
- Implemented and tested minimum viable product with Player vs. Player functionalities in a 2-day sprint
- Improved UI/UX and game logic through evolutionary prototyping based on feedback from professors and 10+ classmates

Code Comprehension Platform—Empirical Software Engineering Team Project, Colby College **02/2022 - 05/2022**
- Developed a web-based educational platform neatCode with **Flask** and **Heroku** to implement interactive **Python** code checking, **Python** tutorial, and leveling systems
- Designed an experiment for novice CS course students divided into treatment group (neatCode) and control group (Pylint) that evaluated the improvement of code comprehension quantified by the scores of experiment quizzes
- Employed **Agile** with **Scrum** and **Git**/**GitHub** for project management and version control

Teaching Assistant, Computer Science Department, Colby College **09/2021 - 12/2021**
- Mentored 30+ students in *Analysis of Algorithms* course in 10+ weekly TA sessions
- Graded weekly assignments and provided written feedback to students on the implementation and complexity of algorithms
- Advised visiting professor on course pace and progress to ensure a smooth transition to a tenure-track role

ADDITIONAL EXPERIENCE & INTERESTS

Chinese Drill Instructor, Dartmouth Asian Societies, Cultures, and Languages Program **09/2022 - Present**
- Tutoring 8 students in *Intermediate Modern Chinese* course to raise their speaking and listening skills

Circulation Desk Assistant, Colby College Libraries **09/2018 - 05/2022**
- Provided customer service for 2K+ students and faculty members, using Sierra Library Services Platform

Languages: Fluent in Chinese

Interests: Singing Mandopop, soccer, consumer electronics, dogs and cats, Chinese cooking

DANIEL SOLOMON ABATE

Hinman 0285 Hanover, NH 03755 • +1(603)359-6699 • Daniel.S.Abate.23@dartmouth.edu
linkedin.com/in/Daniel-Solomon-Abate • github.com/DanielAbate

EDUCATION

Dartmouth College, Hanover, NH **June 2023**
Bachelor of Engineering in Electrical Engineering
- *Honors:* **Rufus Choate Scholar** (top 5% of freshman class), **E.E. Just Scholar** ($3,500), **Presidential Scholar** ($2,000)
- *Relevant Coursework:* Introduction to Scientific Computing (C, MATLAB), Data Structures and Algorithms (Java), Embedded Systems (C, Arduino), Human-Computer Interactions (Figma, React Native), Digital Electronics (VDHL, FPGA, Vivado), Machine Learning and Statistical Data Analysis (Winter 2023), Statistical Methods in Engineering (Spring 2023)

SKILLS AND PROJECTS

Technical Skills
- *Programming Languages:* Java, C, Python, SQL, MATLAB, VDHL, OrCAD, PSpice
- *Experience with:* UI/UX Design, Arduino, IoT, Figma, React Native

Technical Projects
- **Speech Tagger (Java):** Implemented a Viterbi Algorithm that used a Hidden Markov Model to tag parts of speech of a sentence or sentences in a text file with **96%** accuracy.
- **Collaborative Graphical Editor (Java):** Built a graphical editor that could handle actions of multiple users over a network simultaneously using a clients/server configuration.
- **Record Manager (C):** Built a record manager that could accept user queries/commands, and then save, display, add, delete, sort, and search records of data about African Nations accordingly.
- **Trivia Game (C):** Created an interactive trivia game that involved two players answering random trivia questions of various difficulty levels. Scores would be tallied, and a winner would be declared after 5 rounds.
- **IoT Smart AC Model (C, Arduino, Wi-Fi, SPI):** Built a system that measured ambient temperature and changed the speed of a fan accordingly. Thermistor readings were displayed on an Adafruit IO dashboard using an IoT connection.
- **Digital Calculator (VDHL):** Designed and created a SCI-enabled calculator on an FPGA Board using a PuTTy display.
- **Heartbeat Monitor (OrCAD, PSpice):** Designed a heartbeat monitor and implemented it on a circuit board.

RELEVANT WORK EXPERIENCE

Meta Inc., Menlo Park, CA **June 2022 - Sept 2022**
Data Scientist
- Analyzed the organic sharing of Virtual Reality (VR) related content by Oculus owners on Instagram Reels using SQL.
- Inferred correlations between Oculus activity and viewership, leading to recommendations to increase viewership by **5%.**
- Highlighted tools to focus on in the Reels composer using available data to inform Bridges-to-the-Metaverse team on optimal strategies to enhance the VR content sharing experience.

Meta Inc., Menlo Park, CA **June 2021 - Aug 2021**
Data Analyst
- Identified logging gaps in Android and iOS for a novel Meta product still in testing (Facebook Reels) using SQL.
- Analyzed tool usage and creator trends in the market across various markets and operating systems.
- Delivered **4** high impact data-backed suggestions about the music picker functionality in the product by identifying areas with the highest improvement potential.

Dartmouth Center for the Advancement of Learning, Hanover, NH **March 2020 - June 2020**
Learning Fellow for Introduction to Scientific Computing
- Monitored the progress of students and reported to the professor, along with improvement suggestions.
- Instructed students on strategies to debug their code and clarified concepts which they found confusing.
- Mentored students as they developed their programming knowledge by setting aside **3** hours weekly to host help sessions.

LEADERSHIP & SERVICE

National Society of Black Engineers, Hanover, NH **March 2022 - Present**
Senator
- Attended regional meetings of the NSBE as a representative of Dartmouth's NSBE chapter and reported back.
- Hosted forums on campus to discuss ways to support black/African American students in Engineering at Dartmouth.

Dartmouth African Students Association, Hanover, NH **March 2022 - Present**
President
- Presided over the executive board meetings of DASA to discuss projects and events for the term.
- Coordinated with the Office of Pluralism and Leadership to secure spaces on campus for DASA events.
- Appealed for $12,000 from Dartmouth successfully to fund a week-long Afrocentric event in the Spring term.

SKILLS & INTERESTS

Languages: Swahili (Fluent), French (Basic)
Interests: software engineering, embedded systems, data science, integrated circuit design, signal processing

Zhanel Nugmanova
Zhanel.r.nugmanova.23@dartmouth.edu

Education:

Bachelor of Engineering & Arts: Dartmouth College, Hanover (NH), USA
September 2019 – June 2023
Major: Biomedical Engineering & Computer Science
Courses with Citations: Machine Learning, Protein Engineering
National School of Physics and Math, Nur-Sultan, Kazakhstan
Graduation Date: June 2018. GPA: 5.0/5.0

Experience:

- **Biomedical Research Fellow, Haigis Lab, Harvard Medical School**

(February 2021 – now)
In Haigis Lab, I'm developing deep learning frameworks to conduct quantitative image analysis of whole-slide images (WSI) of lung samples taken from old and young cohorts of transgenic Cre-dependent mice to study lung tumorigenesis in the context of aging.

1) Invited to present a poster on the Annual Harvard Medical School Cell Biology Retreat in October 2022
2) Methodology paper in progress on quantitative histopathological analysis of mouse lung cancer and aging using QuPath and applied machine learning frameworks.
3) Hosted Cell Biology joint lab presentation and journal club

Lab skillset: Omero database management, QuPath for quantitative histopathological analysis, MSI and CyCIF analyses (currently training), mice room training, mice dissection, organ harvesting, and survival surgery; LC-MS analysis, FACS, FlowJo analysis, GraphPad Prism

- **Machine Learning Research Assistant, Dartmouth College**

(December 2021 – March 2022)
Under Professor Preum's supervision, I assisted with engineering better medical data annotation methods and frameworks to aid in the design of ML models that would support the medical literature analysis and medical advice recognition and classification.
In addition, I worked as a Machine Learning Teacher Assistant for 3 terms in the 2021-2022 academic year.

- **Undergraduate Intern, Dartmouth Innovations Accelerator for Cancer Research (DIAC)**

(September 2021 – now)
The DIAC Accelerator provides entrepreneurial support for Dartmouth-based biomedical research related to cancer studies to deliver their innovations from the lab bench to patients. DIAC is working with Simbex and Celdara Medical to provide a 10-week-long businessacceleration program for startup teams. As part of the DIAC team, I'm the only undergraduate intern supporting the Accelerator in communications with startup teams, marketing, and meetings with External Review Panelists who make funding decisions.

- **Women in Science Project and Sophomore Summer Scholars Research Intern**

(December 2019 – August 2020)
Immunology research on the classification of human antibody repertoire (to Influenza virus, HIV, and cystic fibrosis) at the Dartmouth Hitchcock Medical Center at Lee Lab.

- **CTO, SuperEEG (Hanover, NH) under TuckLab program**

(December 2019 – April 2020)
Launch of a biotech startup that provides a software solution with a machine learning approach for reconstructing full brain recording based on patient ECoG data.

- **Software Intern, SAP Kazakhstan**

(July 2018 – October 2018, June 2017 – September 2017)
Software testing and integration of SAP systems to existing solutions in compliance with the local government requirements.
Honored 3rd place by the end of the intern competition of Summer 2018.

Honors and Fellowships:

- Dartmouth Cancer Scholar (2022)
- Certificate of Excellence at Dartmouth Management and Leadership Development Program (2022)
- Yale Summer Institute in Bioethics Fellow (2021)
- Dartmouth Founder Grant Winner (2021)
- Dartmouth Global Health Fellow (2020-2021)
- Dartmouth Tuck Business School Startup Incubation Program Certificate (2020)
- Finalist of Dartmouth Magnuson Center for Entrepreneurship 3DStartup competition (2019)
- International Science Conference NCSSS USA (2017): BEST Mobile Application (out of 100 projects)
- International Science Conference ISSC Hong Kong (2017): Hydro-Turbine Project (83 projects)

Activities:

- Advanced Topics in Patent Law (drug discovery adapted) webinar from Morrison Foerster (2022)
- Executive Board Member of Dartmouth Undergraduate Research Association (2020), Dartmouth Women in Business (2019-2021), Dartmouth Society of Women Engineers (2020-2021)
- Writer at Dartmouth Undergraduate Journal of Science (2020-2021)
- Venture Capital Investment Competition Training Certificate by Tuck Business School (2019)

Other skills and Interests:

- Languages: Kazakh (native), Russian (native), English (professional), German (professional), Chinese (pre-intermediate)
- Skill areas: Deep Learning, certified iOS programming, Project Management, PyMol, NetNGlyc, Matlab, Python, Swift, JavaScript

Appendix M
Emails with Stakeholders

A portion of email receipts from our liaison with Dr. Niemczak at DHMC provides the arrangements to conduct testing at the Space Medicine Innovations Lab.

From: Chris Niemczak <Chris.Niemczak@dartmouth.edu>
Sun 10/30/2022 3:55 PM
Hi MacKenzie,
We have a class 1 SLM and an audiometer which could give you pure tones from 125-16,000 Hz. But the SLM is used periodically to validate sound levels for our fMRI audio system and the audiometer is hooked up to our audio booth (it's not mobile). If you came to the lab, you could potentially use both.
Let me know when you would like to come in or find another option.
Sincerely,
Chris

From: MacKenzie Guynn <MacKenzie.G.Guynn.23@dartmouth.edu>
Mon 10/31/2022 10:24 AM
Hi Chris,
That would be great! We were planning on testing this wednesday (11/2) evening around 5:30pm. If this is too late, we can find a time to come in earlier. What is the general timeframe that would work for us to come in?
Thank you,
MacKenzie

From: Chris Niemczak <Chris.Niemczak@dartmouth.edu>
Mon 10/31/2022 11:08 AM
Hi MacKenzie,
We are generally available from 8-5pm Monday through Friday.
Cheers,
Chris

Appendix N:
Tympan device

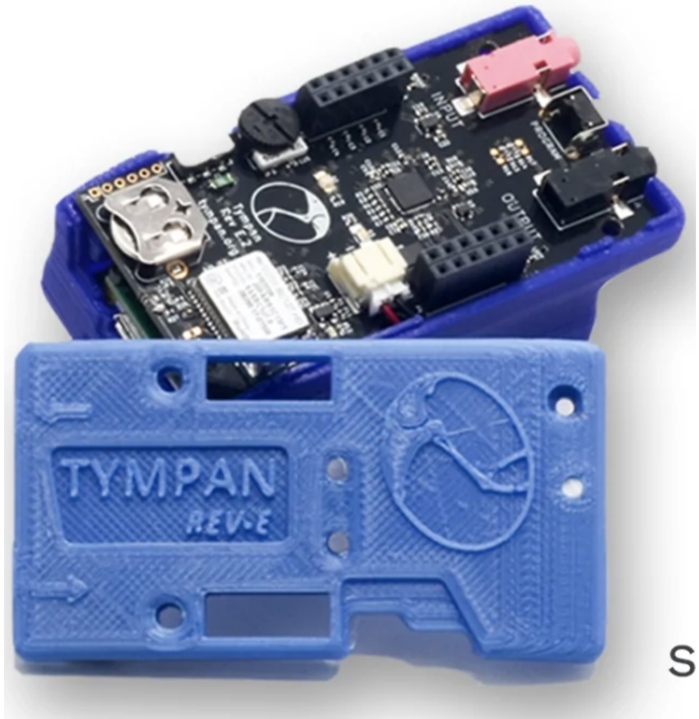

Figure L1: Tympan Rev-E opened to show the Teensy 4.1 inside

Figure L2: Tympan Rev-E closed

Figure L2 shows the Tympan Rev-E as it would be used. You can see the arrows on the left-hand side of the device, which help make it clear where the microphone and headphone jacks are located.

Appendix O:
Common abbreviations

- SPL: Sound Pressure Level
- WAHTS: Wireless Automated Hearing Test System
- ANSI: American National Standards Institute
- OSHA: Occupational Safety and Health Administration
- SLM: Sound Level Meter
- SV 104A: Svantek 104a Sound Level Meter and Dosimeter
- MPANLs: Maximum Permissible Ambient Noise Levels
- CHWs: Community Health Workers
- SDLC: Software Development Life Cycle
- RMS: root mean squared
- DHMC: Dartmouth Hitchcock Medical Center
- dB: decibels
- IDE: Integrated Development Environment

Appendix P
User Interface Sketches

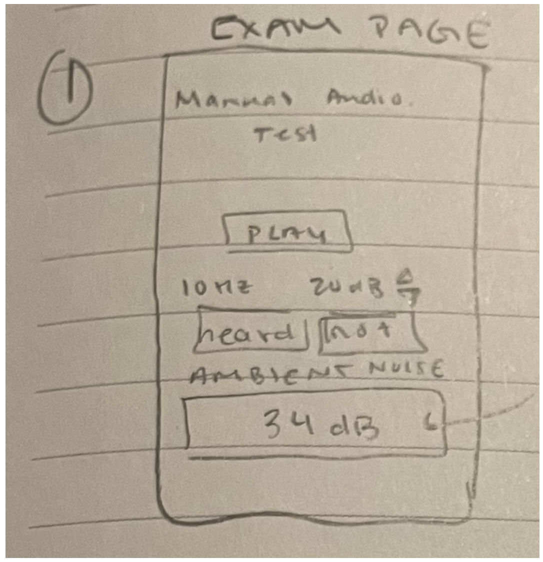

Figure P1: Exam page with a live ambient noise reported

The value would be updated every second and the color of the box would change according to whether the value was below the MPANLs or not.

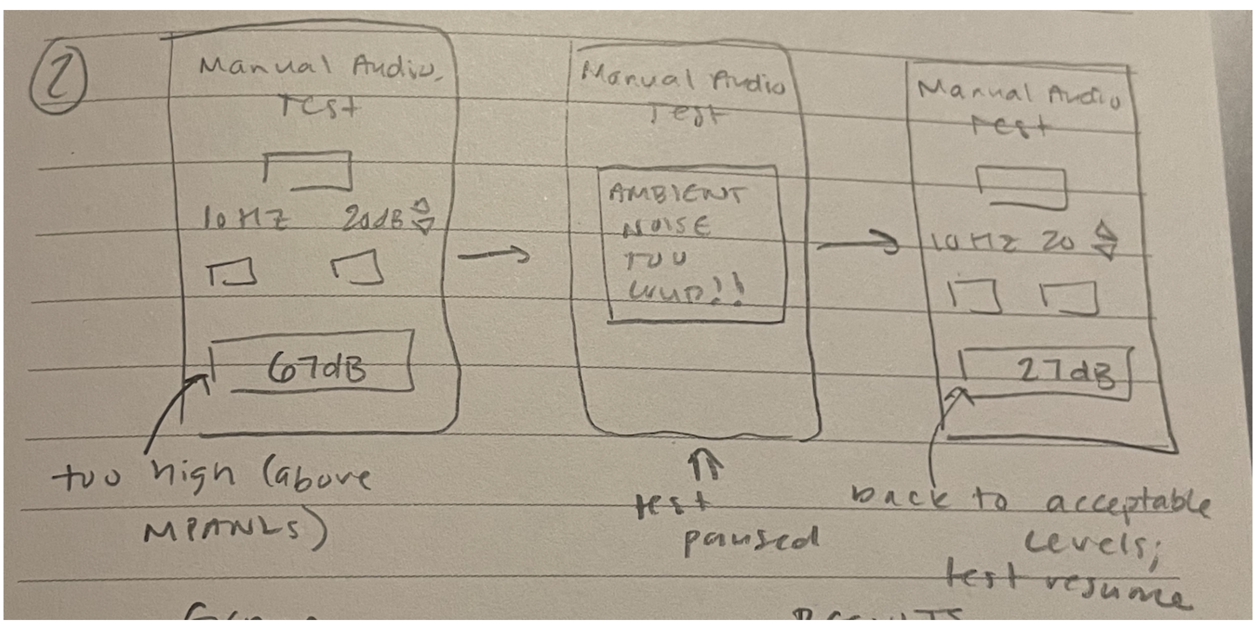

Figure P2: Exam pages with a pop-up

The live value would be displayed on the exam page. Once it exceeds the MPANLs, a pop-up would appear and the test procedure would be paused until the ambient noise drops to an acceptable value. When this happens, the pop-up will go away and the test can resume.

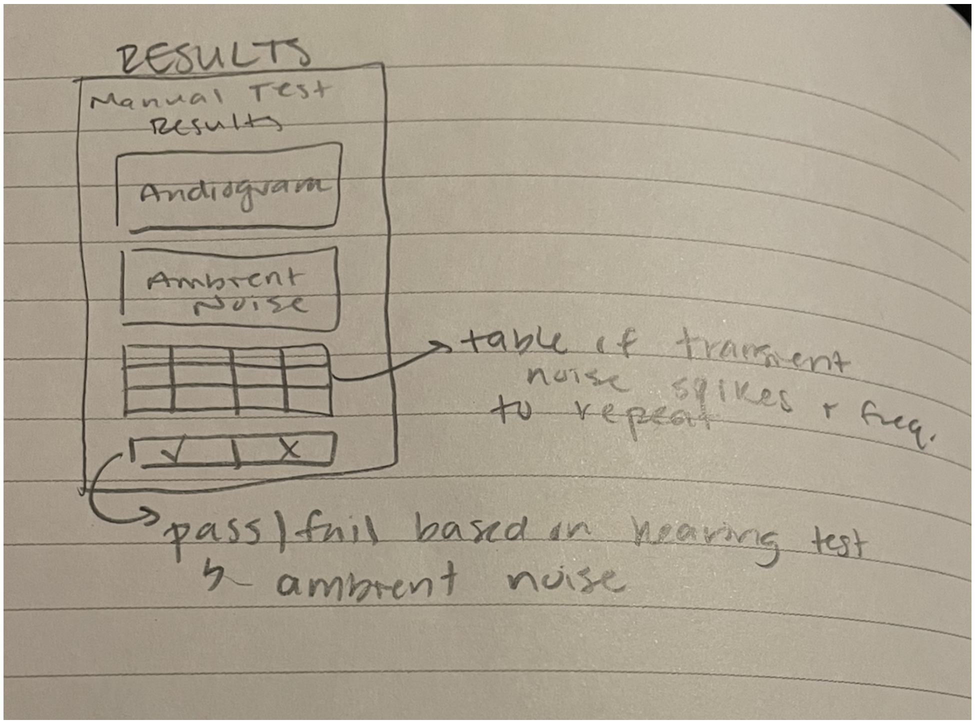

Figure P3: Results page with ambient noise data

The results page could have a table of transient noise spikes, whether it invalidated a certain tone or not, and how loud the spike was. It could also have two indications of pass/fail. One which only takes the audiometry into consideration and another that factors in the ambient noise.

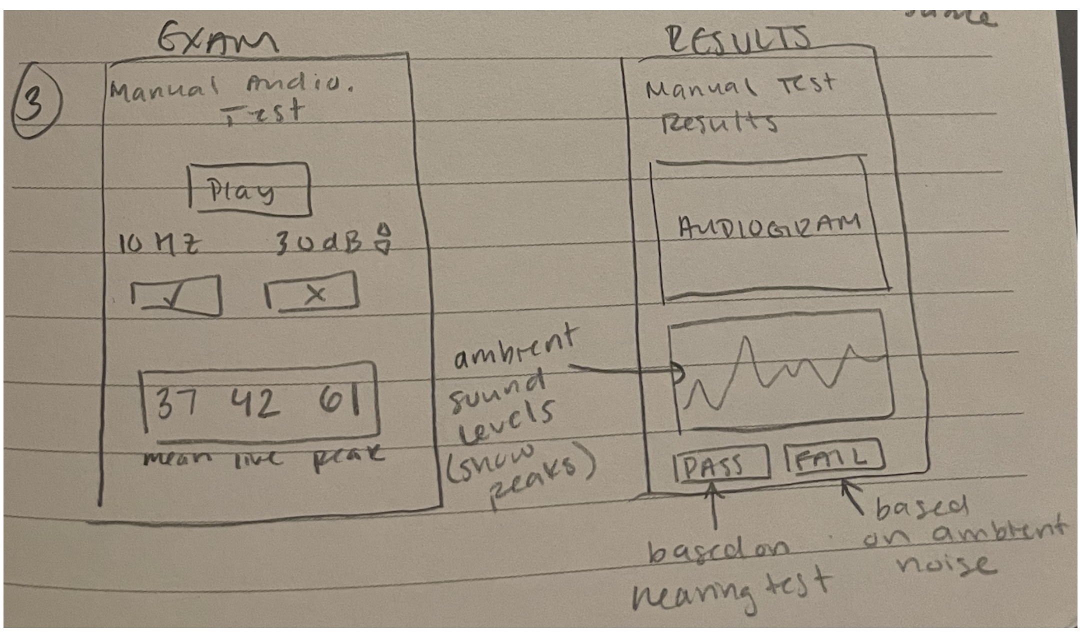

Figure P4: Exam and Result page with ambient noise data

This example shows the exam page that includes the mean, live, and peak ambient noise values. It also shows the results page with a graph of the ambient noise so that transient peaks can be tracked. It also includes the two indicators of pass/fail, based on the same conditions as figure H3.

Appendix Q

Risk severity matrix

Likelihood	Harm Severity			
	Negligible	Marginal	Critical	Catastrophic
Certain				
Likely		Change in software requirements		
Possible			Overtime	
Unlikely	Over budget		Integration failure	
Rare				

Figure Q1: Risk severity matrix of software development of TabSINT

Statement of Work Dated 11/14/2022
Project No. 648

ENGS 89-90 STATEMENT OF WORK

I. Project Organization

TITLE: Low Cost, Open Source Audiometry

DARTMOUTH TEAM:

Name	Role	Email
MacKenzie Guynn	Student Team Member	mackenzie.g.guynn.23@dartmouth.edu
Daniel Abate	Student Team Member	daniel.s.abate.23@dartmouth.edu
Di Luo	Student Team Member	di.luo.th@dartmouth.edu
Azariah Javillonar	Student Team Member	azariah.a.javillonar.23@dartmouth.edu
Zhanel Nugmanova	Student Team Member	zhanel.nugmanova.23@dartmouth.edu
Peter Chin	Faculty Adviser	pc@dartmouth.edu
Nikki Stevens	Faculty Adviser	nikki.stevens@dartmouth.edu
Emily Monroe	CEDC Director	emily.h.monroe@dartmouth.edu
Sol Diamond	ENGS 89/90 Course Director	solomon.g.diamond@dartmouth.edu
Rafe Steinhauer	ENGS 89 Course Director	rafe.h.steinhauer@dartmouth.edu

SPONSOR:

Company: Creare LLC

Websites: creare.com, shop.tympan.org, tabsint.org

Industry: Medical Technology

Sponsor Names: Odile Clavier

Sponsor Job Title: PhD Principal Engineer

Sponsor Address: 16 Great Hollow Rd, Hanover, NH 03755

Sponsor Phone: (603) 640-2463

Sponsor Email: ohc@creare.com

Technical Partner Names: Eric Yuan, Blaine Ayotte

Technical Lead Job Title: Research Engineer, Software Engineer

Technical Lead Phone: N/A

Technical Lead Email: eyuan@creare.com, blainejayotte@gmail.com

II. Project Specification

A. Essential Context and Background

There are around 360 million people worldwide experiencing mild to moderate levels of hearing loss. The majority of people with hearing problems come from developing countries with poor access to appropriate hearing diagnostics tools and services. One of the most common birth defects is hearing loss, and children born in low or middle-income countries are almost twice as likely to have hearing issues compared to infants born in wealthy states (6 cases/1000 children versus 2–4 cases/1000 children).[1] However, due to a lack of resources, early-stage hearing defects in children are constantly overlooked, leading to developmental delays and poor educational outcomes. These disabilities economically disadvantage people and perpetuate cycles of poverty in developing countries.[2]

Currently, the immediate solution to the problem of early-stage hearing diagnostics in low-income countries is regular screening in local schools and through children's health organizations. However, conducting hearing tests in low-resource conditions can be challenging due to the scarcity of audiologists to conduct the hearing tests. There are also fewer audiometric booths in which hearing tests may be conducted, thus tests have to be conducted in the open where ambient noise may invalidate results.

B. Problem/Need Statement

Boothless audiometry is a technology that promises to increase access to hearing examinations in low-income regions. However, there is a need for the technology to be more informative, reliable, and easy-to-use to aid audiologists in making more accurate and informed hearing loss diagnoses.

C. Previous Work and Proposed Solution

Previous work: Wireless Audiometry Hearing Test System (WAHTS) with attenuating Amplivox Audiocups, the Svantek 104A dosimeter to monitor background noise, and TabSINT software interface. Tympan is an open-source device which has been implemented as a hearing aid, cochlear implants, and sound level meter, but its performance as a sound level meter has yet to be documented. This is because its use as a sound level meter has only been a topic for research, rather than a marketable function of the device.

Proposed solution: A modified WAHTS with attenuating Amplivox Audiocups, the TabSINT software interface, and the Tympan acting as a sound level meter for ambient noise. The entire system would be integrated so that the Tympan can send ambient noise data to be displayed in a helpful and coherent way on TabSINT.

D. Objectives to be Addressed in the Final Deliverable (prototype)

The planned deliverables for ENGS 90 include a fully-functioning WAHTS with the Tympan as the sound level meter, as well as a detailed report analyzing our system's performance in the field. In particular, we would like to verify that the Tympan is an appropriate sound level meter by testing its noise floor, frequency response, and accuracy. The noise floor will determine if the Signal/Noise ratio of possible microphones is high enough that self-noise will not impact sound measurements. The frequency response should be flat across the human hearing range (20 Hz to 20 kHz), since we want to be able to accurately measure sounds across that whole range. Lastly, the accuracy of measurements made by the Tympan should be accurate within 1 dB.

Next, we will integrate the Tympan with TabSINT so that ambient noise data can be displayed for technicians during hearing exams. This data can be displayed in a number of ways, which will be explored with our stakeholders, but it should offer indication of whether the ambient noise is loud enough to invalidate results. Lastly, we want to upgrade the TabSINT interface to be completely compatible with Tympan and have the ambient noise data fully integrated into the testing procedure. The three main objectives along with milestones are listed below.

Objectives and Milestones: The main objectives of our project are listed below with their corresponding milestones.. To avoid difficult to track errors, we should accomplish them in the order they are listed.

1. Research the problem and familiarize ourselves with potential solutions
    a. Obtain all the components of our modified WAHTS
    b. Familiarize ourselves with the Tympan and TabSINT code bases
    c. Familiarize ourselves with audiometry
    d. Research state of the art solutions
    e. Research societal context
    f. Determine potential solutions and select most promising one
2. Test the Tympan and validate it can function as an appropriate sound level meter.
    a. Run example programs
    b. Test self-noise floor
    c. Test frequency response
    d. Test accuracy
    e. Determine best hardware pairing and finalize our specifications
3. Integrate the Tympan into the already existing WAHTS.
    a. Study existing connection between the Tympan and TympanRemote app
    b. Study existing connection between the Svantek 104a and TabSINT
    c. Connect Tympan and TabSINT via Bluetooth
    d. Test the connection
4. Design a UI in the TabSINT software which displays all the data requested by our clients.
    a. Setup development environment on our local computers
    b. Study related programming languages
    c. Collect user stories for the backlog
    d. Analyze backlog and setup sprints
    e. Sprints 1-3: 2 weeks long each and organized so that Sprint 1 will give a minimally viable product and sprint 3 are things that would be nice to add to the system
    f. System test of all software components
    g. (Time-dependent) Explore the automation of WAHTS to minimize the amount of oversight required of an audiologist.
5. Test the integrated system as one unit
    a. Get CPHS trained
    b. Finalize a testing protocol with DHMC doctors
    c. Submit protocol for approval
    d. Find a pool of participants
    e. Conduct user testing of our whole system

Changes to the project deliverables must be propagated here as updates to the objectives and milestones.

III. <u>Timeline of Milestones</u>

		Sept ‘22	Oct ‘22	Nov ‘22	Dec ‘22	Jan ‘23	Feb ‘23	Mar ‘23
Research and brainstorming		******	******	******				
	Familiarize with Tympan code base		X					

	Familiarize with TabSINT code base		X					
	Familiarize ourselves with audiometry	X						
	Research state of the art solution	X						
	Research societal context	X						
	Determine potential solutions and select the most promising one	X	X					
	Pre-Proposal presentation and report		X					
	Proposal presentation and report			X				
Validating Tympan			******	******				
	Obtain and set-up Tympan		X					
	Run example programs		X					
	Test noise floor of the internal and external microphones			X				
	Test frequency response of both microphones			X				
	Test accuracy of Tympan with both microphones			X				
	Determine best pair and finalize hardware specifications for the system			X				
Tympan - TabSINT integration			******	******	******	******		
	Study existing Bluetooth connection between TabSINT and SV104A			X	X	X		
	Study connection between Tympan and TympanRemote App			X	X	X		
	Connect Tympan and TabSINT via Bluetooth					X		
	Test the Tympan and TabSINT connection					X		
TabSINT software development				******	******	*****	******	******
	Setup development environment of			X	X			

	TabSINT on local computers							
	Study related programming languages			X	X	X		
	Collect all user stories into product backlog			X				
	Analyze product backlog and setup Scrum sprints				X			
	Sprint 1 (topic & duration TBD)					X		
	Sprint 2 (topic & duration TBD)					X	X	
	Sprint 3 (topic & duration TBD)						X	
	System test on software						X	
Full System Testing			******		******	******		******
	Get CPHS trained and approved[3]		X					
	Finalize a protocol with DHMC doctors				X	X		
	Submit protocol for approval					X		
	Find a pool of participants and conduct user testing of our whole system							X

IV. <u>Reference Documents</u>

1) Czechowicz, Josephine A et al. "Hearing impairment and poverty: the epidemiology of ear disease in Peruvian schoolchildren." Otolaryngology--head and neck surgery: official journal of American Academy of Otolaryngology-Head and Neck Surgery vol. 142,2 (2010): 272-7. doi:10.1016/j.otohns.2009.10.040
2) Saunders, James E. "Mobile Smartphone Audiometry to Improve Hearing Outcomes in Nicaraguan Children." *Grantome*, NIH, 15 Aug. 2017, https://grantome.com/grant/NIH/R21-DC015133-01A1.
3) https://www.dartmouth.edu/cphs/

Sponsor Agreement
Student Agreement