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Medical Sound SimuVest

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Dr. McAllister,

The Echo Tech design team is pleased to submit the following Final Design Report for the *SimuVest System* project. Within the following document, you will find a comprehensive summary of our efforts in developing the design of a cost-effective, high-fidelity simulator of auscultation and palpation.

Based on the needs and wants that have been communicated to our team, our work has focused on thorough research and analysis of the technology that we believe to be the most feasible for satisfying the ambitions of all concerned parties. Relevant products, literature, and patents have been investigated for strengths and weaknesses, and key findings of this research have been applied to the formulation of a realistic design solution to the lack of affordable patient assessment simulation options. Design history, final design description, design evaluation, and suggested future work has been gathered and provided in this report. The Echo Tech Team has concluded that the produced system meets the requirements of the stakeholders with the production of a novel solution to the issues posed.

Thank you for trusting Echo Tech to complete this design for you. We appreciate your partnership in developing this technology and have adjusted our design based on the input provided throughout the development of this system. Please review the following report to assess the efficacy of the *SimuVest system* and direct any further feedback or comment regarding this document to our client coordinator Jordan Grant at jgrant34@vols.utk.edu. We hope you find this design to meet your expectations.

Sincerely,

Alex Barrett

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FINAL DESIGN REPORT FOR THE *SIMUVEST* PROJECT AND DR. MARCIA MCALLISTER AT THE UNIVERSITY OF TENNESSEE COLLEGE OF NURSING

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I. EXECUTIVE SUMMARY

Working alongside Dr. Marcia McAllister at the University of Tennessee College of Nursing, our team has designed a cost-effective simulation of basic patient assessment techniques through the creation of a three-part novel system: a wearable vest, a modified electronic stethoscope (called the *EchoScope*), and an html user interface. Altogether, we have titled this system the *SimuVest*. With regards to auscultation and palpation, the *SimuVest* project's primary focus is to achieve a high level of realism while minimizing costs. Other needs considered in making the system included wearer comfort, vest adjustability, system mobility and durability, easy sanitation, and user interface accessibility.

Existing products and research related to the aforementioned needs were evaluated to find design alternatives for the simulations included in this project. For auscultation, common approaches include installing either RFID tags or small speakers directly into a manakin at locations of importance. For palpation, most approaches are based on using layered, highly customized materials to build manikins with high tactile and visual realism. One researched method for simulating pulse employs flow loops, with pneumatic bladders placed at points of interest to help users differentiate between disease states and healthy function [1].

For the *SimuVest*, inexpensive approaches that required less hardware were prioritized. To simulate auscultation, a magnetometry grid was designed to read magnetic field changes caused by the movements of a magnet installed in the *EchoScope*. This novel approach is simple, inexpensive, and has the potential for greater functionality given its reliance on software as opposed to hardware. Users can add anatomical locations and sounds without adding tags or speakers and will be able to continuously track the *EchoScope* beyond just the specific locations programmed. To avoid the cost and space limitations of a flow loop, vibration motors programmed with a pulse waveform were installed at points of interest for palpation. A layer of silicone rubber with muscle definition was placed over a false rib cage made from PVC to give the *SimuVest* a realistic look and feel for simulation.

Assessments of the *SimuVest* project to date show great promise. Precise identification of the *EchoScope* at anatomical locations within 1 inch is replicable given proper operation of the system. The vest materials used give the system a qualitatively high level of realism, along with a satisfactory level of adjustability and comfort for different wearers. Sanitation and movement of the system are simple, and the various *EchoScope* and vest components all show promise in durability testing. Battery-powered components of the system allow for extended use with minimal charging time, and the system webpage is easy to use and understand. Finally, our simple, replicable manufacturing process created a prototype using just under $350 in materials, meaning that the further development of an inexpensive product is more than possible. Areas for improvement with the *SimuVest* are apparent, with adjustments to magnetometer grid sensitivity and the expansion and refinement of the sound library being the most so. In summary, our design incorporates novel technologies to provide a yet unseen combination of functionality and accessibility, with routes to prototype improvement clear. This report will serve to document all these points in greater detail.

II. BACKGROUND

As mentioned above, our primary motivation for this project was the need for a more cost-effective simulator of auscultation and palpation assessment methods. Similar training exercises have already been widely implemented for use in educational and training contexts, and have shown good outcomes in preparing healthcare professionals for real-life applications. Unfortunately, the systems that are currently available are either inadequate or too expensive for small programs with limited budgets. Two such systems that have been identified by our team's research are the SimShirt System from Cardionics Incorporated [2] and the Wearable Simulator for Enhanced Realism from the University of Wisconsin [3].

While both projects show conceptual value in their own way, it is our opinion that both also fail to accomplish the ambitions that we have set out for the *SimuVest*. Of the two projects, the SimShirt System shows more promise for a high-quality simulation of auscultation. RFID tags installed in the SimShirt at specific anatomical locations correspond to a large library of physiological sounds, which can be heard through a simulated stethoscope when a tag is properly located. Sounds are selected by a user from an external tablet included with the system. The system does not include any palpation features, and the price tag is fairly high ($8,500).

The University of Wisconsin project implemented a series of Bluetooth speakers at auscultation locations in a wearable vest. Pre-programmed sounds selected from an analog dial could then be played through these speakers, allowing a student to use a stethoscope to listen to the sounds being output. Limitations of this design include a lack of planning for visual realism, no listed method for dampening sounds from the wearer, a limited sound library, non-location-specific sound output, and no palpation simulation features. No documentation of the project's advancement beyond the conceptual stage could be found in our research, so the outcome of the project is unclear.

Based on these two designs, our team's assessment is that the current market does not have any device that can provide high-quality simulations of both auscultation and palpation for an affordable price. This project has been directed accordingly, with smaller healthcare programs and their students as the stakeholders in mind. Providing a high-quality educational tool for this audience is the main potential benefit. During the course of this project, the number of nursing students that do not have the proper training to give patients general assessments has been stressed to our team on several occasions. It is our belief that the system we have created has the potential to reduce technological inequalities between different healthcare programs, leading to an increase in healthcare professionals with the best possible educational background. In turn, this level of education will create the opportunity for more patients to receive the best possible care. With this wide scope in mind, we feel that the benefits offered by the *SimuVest* are extensive.

III. PROBLEM DEFINITION

The goal of our project can be summarized as the creation of a low-cost, realistic auscultation and palpation simulation device for nursing program educational use. The primary client and stakeholder of our product is Dr. McAllister, representing the College of Nursing at the

University of Tennessee. With her educational and professional background as a registered nurse, nursing administrator, and clinical instructor, she has provided our team with an immensely helpful wealth of information during the course of our project. Other sources of knowledge that have aided us in properly directing our efforts are varied in nature, including nursing students, medical journals, and online databases.

To satisfy the goals set out by Dr. McAllister and ourselves that have been previously described, a list of functions and requirements for our product has been developed and sought after over the course of these past nine months. General key functions include recognizing *EchoScope* contact with the surface of the vest, locating the *EchoScope* magnet on the vest, correlating magnet location information with auscultation locations, transmitting auscultation locations to the webpage, customizing manikin health, outputting sounds to the *EchoScope*, working vibration motors, adjusting vest fit, sanitizing system surfaces, overall system mobility, product operation time, product durability, and product accessibility. For each of these key functions, the requirements for a successful product were defined generally by Dr. McAllister, with her needs and wants used by our team to determine more specific aims.

To recognize the moment of contact with the surface of the vest, a push-button was incorporated into the *EchoScope*. The success of the button in satisfying its function could only be determined qualitatively, with the requirement being the consistent prevention of false positives and negatives during use. For locating the *EchoScope* magnet during operation, calibration of the magnetometers was required to ensure outputs were consistent, with our goal set to achieve an uncertainty in readings translating to ±0.125 in. Also required was the consistent translation of location information into positive/negative outputs for six different auscultation zones that were established in our program. zones 1-4 (circles with a 1-in. radius) correspond to four different heart sound locations, and zones 5 and 6 (whole chest, divided into left and right lung) correspond to breath sounds. zone 0 was set as the output for when zones 1-6 were not detected at the location of the *EchoScope*. Consistency in this area requires that our program can output the correct zone for each placement of the *EchoScope*, with heart zones given preference over breath sounds. Consistency aim in this area was set at 95%. Transmission of auscultation zone data from our program to the webpage that controls sounds outputs must be quick to preserve the realism of the simulation. Our expectation was to achieve a system that completed serial communication in less than 0.2 seconds. The ability to customize the physiological state of the manikin resides in this webpage, which must control the health, and therefore the sound output, of the system. Success in this regard is simply measured by the ability of the webpage to use auscultation zone data to play different sounds. To output these sounds to the *EchoScope,* the Bluetooth connection between the device running the webpage and the wireless headphones must be reliable. Reliability, in this case, would be satisfactory if pairing is possible with different devices and if the connection is present during all operations. Vibration motor function simply requires that each motor works and that the pulse pattern of vibration can be felt through the silicone rubber in the correct location. The adjustability of the vest would be measured by the ability of different persons to wear the vest in such a way that the functions of the vest are not compromised, with satisfaction being achieved with a working vest for men and women of heights between 5’8” and 6’2” and weights between 125 and 225 lbs. Sanitation of the vest requires that all external surfaces can be sanitized. Satisfaction would entail the entire system (silicone rubber, nylon vest, *EchoScope* components, Bluetooth earbuds) being easy to wipe down in a short period of time (<5 min) with a recommended clean solution without any possibility of damaging any components given appropriate care. System mobility refers to any difficulty associated with moving the *SimuVest* between different locations in a healthcare environment. Satisfaction in this area would require that the system be composed of three or fewer individual components with an overall weight of under 20 lbs. Product operation time is the ability of the system to be operated for extended training periods. Usual healthcare program operations would require the system to be capable of running for 2.5-3 hours on a full charge before any components would run out of battery, begin to malfunction, or cause any unwanted side effects. Product durability is a measure of the *SimuVest*’s ability to maintain its structure and function over time and in different environments. The performance of all system components in drop tests, normal and shear stress tests, heat and cold tests, and others would be assessed to qualify the system’s durability. Satisfaction would be determined by the product’s ability to withstand these tests in relation to the assumption that users would be responsible for negligent use and storage of the product. Finally, product accessibility refers to the ease with which new users are able to understand and operate the system, particularly the webpage. Satisfaction would require that the vast majority (>70%) of a moderate sample (15) of individuals unfamiliar with the program could learn how to interact with the user interface using only the instructions that are included on the page.

On top of the requirements listed, the primary constraint of this project is cost. Making a product that can satisfy every aforementioned need while also limiting expenditures is certainly a challenge, especially given the markup on the retail price that would be expected from outside investors that could make any sort of large-scale production possible. While the low amount of funds used by our team to produce our prototype is certainly to our satisfaction given the original goals for our project, any further development of the product will require additional expenditures. These additional costs are antithetical to our desire for an affordable final product, and therefore must be minimized.

IV. CONCEPT DEVELOPMENT

A table for the process of design concept selection can be found in Appendix A. To start developing our design concept, we conducted research on simulation models currently available to nursing and medical programs. The more expensive simulation models available are simulation manikins that range in cost between $20,000 and $100,000 [4]. These are not wearable designs, and not all provide feedback for students. A recent design project that we researched was a wearable simulator for enhanced realism made by a research group at the University of Wisconsin. This device was designed to be wearable by a standardized patient and used a series of speakers inside of a vest that could be auscultated with a stethoscope. Some limitations of this design included a limited sound selection for locations, limited realism, and the system had to include a method for blocking the sounds generated by the wearer/standardized patient. The device with the best quality and lowest price found in our research was the *SimShirt* by Cardionics.

Figure 1: *SimShirt* system by Cardionics [2].

This design, seen in the figure above, is a wearable shirt with 15 RFID tags used to mark anatomical locations, an electronic stethoscope called the *SimScope,* and a tablet that comes with an app that controls the system. The entire system sells for a price of $8,500. While this is more affordable than simulation mannequins, this cost still exceeds the budget of smaller programs. In addition, if more locations are needed, additional fees for both the RFID tags and added sounds are required. Using RFID tags to mark locations also allows only for discrete feedback for users of the system limiting location mapping to points marked by tags. Finally, while this device is a beneficial tool for learning auscultation techniques, it does not include any simulation of palpation for students.

From this research, we were able to ascertain which concepts we thought worked the best in the competing designs and conceive new concepts to improve upon current designs. In addition, we included new concepts to meet the functions and requirements provided by this project's Stakeholder: Dr. McAllister. From the University of Wisconsin project, the use of an adjustable vest as the base of the system was found to be beneficial for addressing the need for adjustability, comfort, and easy sanitation in our design. Including a list of specific auscultation sounds for anatomical locations and regions as with the *SimShirt* was also deemed appropriate. We quickly decided that installing speakers in the vest was not acceptable because it would limit both realism and the possible number of auscultation locations and would present the problem of having to block the wearer's breath and heart sounds. Building a system that could continuously track the location of a stethoscope was an ambition that our team possessed from the start. Using RFID technology was not appealing because of its limitation to discrete locations. As developing a system allowing for palpation was not listed as the stakeholder's primary concern, so developing a reliable continuous tracking system became the EchoTech team's priority. Additionally, high-fidelity manikins generally employ expensive combinations of different rubbers and plastics to simulate the varying density of the human torso. Many products did not disclose their method for simulating pulse, which is central to palpation assessments, and little research was available on the effects of varying material density. Projects that were unrelated to simulating palpation, however, suggested that most systems for simulating pulse fell into one of two approaches: one that builds a flow loop of either viscous liquid or air, pumping through pneumatic bladders in a pulse-like rhythm to simulate the rapid pressure changes in blood vessels, or one that programs vibration motors to mimic the pattern of a heartbeat. While the use of custom rubbers and plastic to create a vest that looked and felt realistic was our goal, the materials used in manikins that took this approach were generally beyond our constraints of costs and time. The electronic stethoscope included in the *SimShirt* system was interesting, as it presented the opportunity for more functionality and flexibility than the use of a traditional stethoscope. The battery life requirements for an educational setting of a custom wireless stethoscope were also considered at this point, with our intention being to use Bluetooth headphones to play simulated sounds to circumvent the need for dampening the actual sounds of the vest's wearer.

The initial design for the *SimuVest* included three magnetometers to allow for continuous location tracking during auscultation, with a magnet installed in a custom stethoscope to create measurable changes in the magnetic field surrounding the vest. To play heart and breath sounds, Bluetooth headphones would also be incorporated in this stethoscope, which we titled the *EchoScope*. For palpation, the initial design would also include a flow loop with bladders to model pulse. Control of the flow loop would be performed using a Raspberry Pi, which would also transmit magnetometer data to the computer running the program. Liquid silicone rubber mixes and custom molds would be to create a realistic torso that would incorporate all components needed for the magnetometers and the palpation flow loop. This circuitry and rubber assembly would be attached to a set of adjustable straps to allow the full assembly to be comfortably fitted to wearers of different shapes and sizes. A layer of food-grade neoprene would be used as the inner layer of the vest, serving as a non-porous, easily sanitized surface that would be in contact with all wearers. For a user interface, a web page built for sound selection at specific auscultation locations would be included. Based on these initial concepts, we developed our overall design concept of the *SimuVest* system, which is displayed in Figure 2.

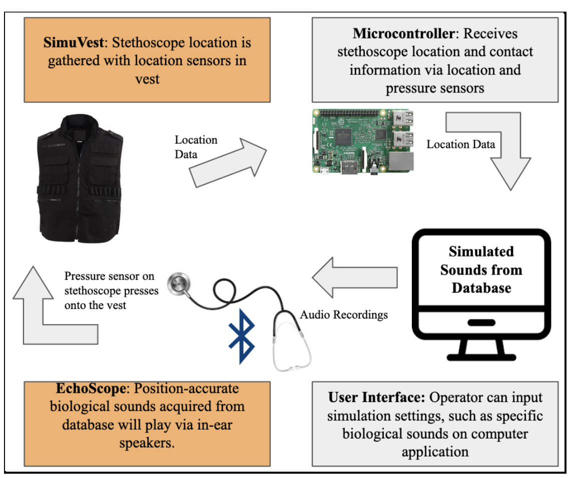


Figure 2: Original design concept for the *SimuVest* that used raspberry pi as the microcontroller to power the location sensors of the *SimuVest*.

Our solution for simulating palpation quickly switched to the vibration module method as a way to minimize costs and decrease the structural complexity of the vest. These vibration modules were to be inserted into the abdomen of the vest after feedback from Dr. McAllister. Furthermore, the process of creating large molds for silicone and curing actual silicone structures was found to be too expensive, complex, and time-consuming for a cast of this size. Prototype manufacturing plans turned to the acquisition and adjustment of a pre-manufactured silicone vest and a set of PVC ribs for building a realistic but inexpensive torso. The plan was for the torso to be attached to an adjustable vest that would be a men's size large and a women's size 14 in order to fit an average-sized person. This iteration of the *SimuVest* can be seen below in Figure 3.

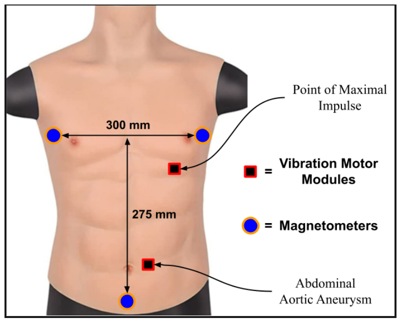


Figure 3: Second design concept for the *SimuVest*, showing magnetometer and vibration modules layout on silicone rubber vest

This second concept underwent further changes during the building process and prototyping. The Raspberry Pi was expensive and difficult to integrate with the magnetometry system, which led to the use of Arduino Nano as micro controllers. The Nanos were easier to program and less expensive, which allowed us to direct funding to other areas of the project. We were also able to achieve location tracking of a magnet using only two magnetometers which allowed for a decrease in system cost. An RF receiver was added to the electronics of the vest to allow for communication with the *EchoScope*, which contained an RF transmitter. The final design for the *SimuVest* is shown below in Figure 4. The diagram for the circuitry of the *SimuVest* can be found in Appendix B.

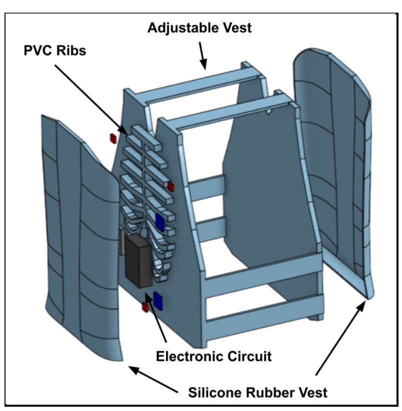


Figure 4: Final layered design concept for the *SimuVest*

The original concept for the *EchoScope* was to modify a stethoscope by replacing original hardware with new components developed for this design. For sound production, we wanted to use Bluetooth earbuds to reduce the number of wired connections and allow for mobility of the *EchoScope.* For these earbuds, we designed a set of earbud-adapters using CAD software to replace the original earpieces. The Bluetooth earbuds would then insert into these adapters and be easily removable for charging. An Arduino was to be attached to the yoke of the stethoscope with wires leading to a push button and RF transmitter in the original stethoscope head. A hole was planned to be drilled into the bottom of the stethoscope head for a metal rod to be run through and attached to a magnet on the bottom of the stethoscope head via a 3D printed button. A hole was also to be drilled in the top of the stethoscope head for a 3D printed button to be inserted into with a pressure sensor attached. Figure 5 shows more detailed drawings of these plans.

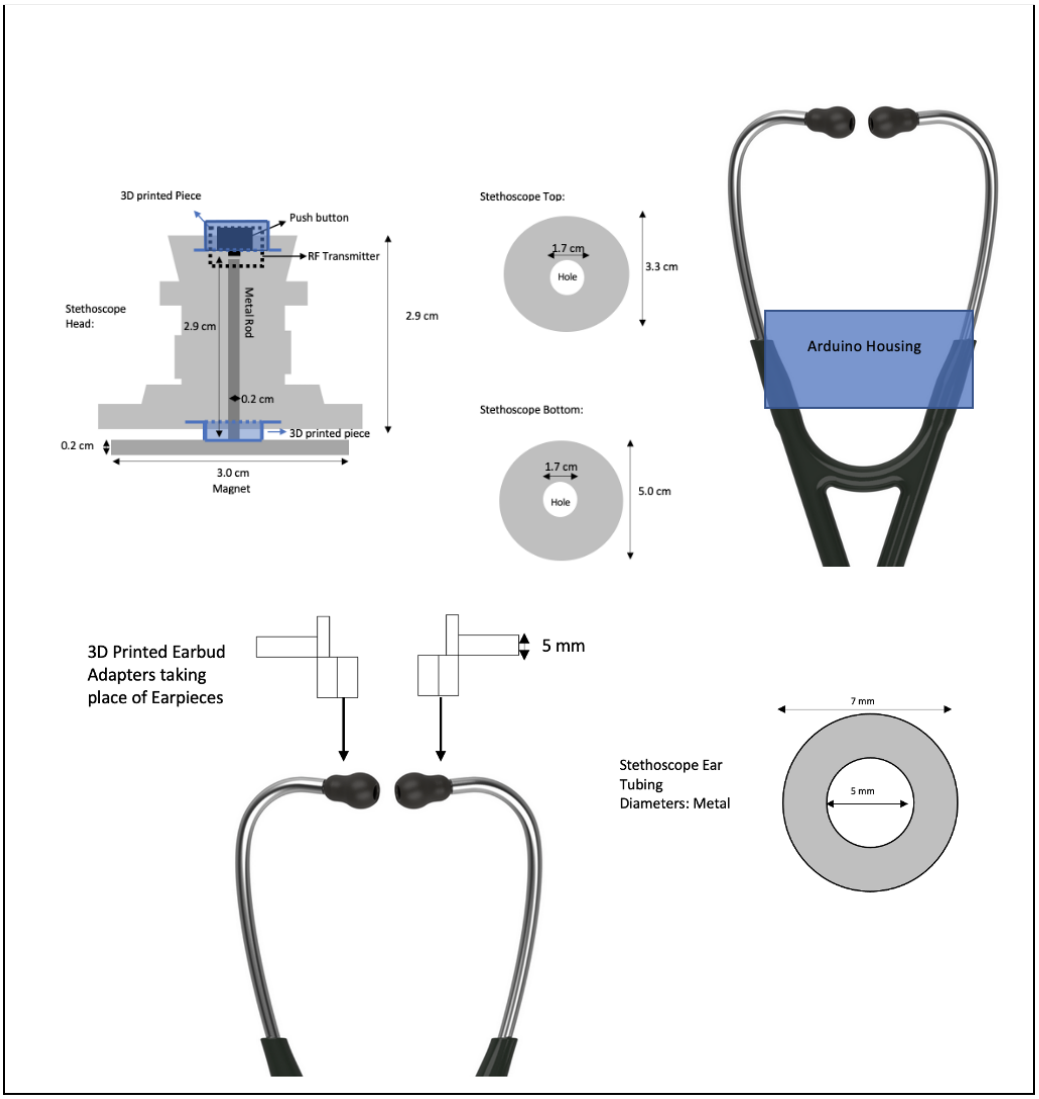


Figure 5: Original design concepts of the stethoscope head, housing unit, and earbud adapters for the *EchoScope.*

The power source for the *EchoScope* was initially a set of AAA batteries. However, the AAA batteries were not able to provide sufficient power to the Nano and RF transmitter, so the design was adjusted to include a power bank that was attached to the backside of the Nano housing. Due to limited space on the stethoscope and surprisingly high power requirements, the design concept changed slightly, as the yoke and original stethoscope head did not have the necessary amount of space for all components. As a solution, we designed and 3D printed a housing unit for the Arduino Nano and circuitry for the *EchoScope* that would instead attach to the rubber tubing of the stethoscope. After feedback from Dr. McAllister, this housing unit was adjusted to a location on the tubing that would not interfere with students auscultating the vest. A stethoscope head was designed and 3D printed to replace the original one. Included with the stethoscope head were two housings that were also 3D printed. One housing was attached to both a magnet on the outside of the stethoscope head and a metal rod on the inside. On the opposite housing, a push-button was adhered with wires running to the Nano housing unit. This push-button replaced the pressure sensor functionally, as the binary feedback of the push-button was much easier to effectively use in the program than readings given by the pressure sensor. This new assembly allowed for force on the magnet to be transferred directly to the push-button, signaling contact with the vest. After further feedback on the loose feel of the button mechanism during use, a foam pad was added to give a more appropriate level of resistance. The CAD designs for all 3D printed parts and the circuit diagram of the *EchoScope* can be found in Appendix C. The final design concept for the *EchoScope* is shown below.

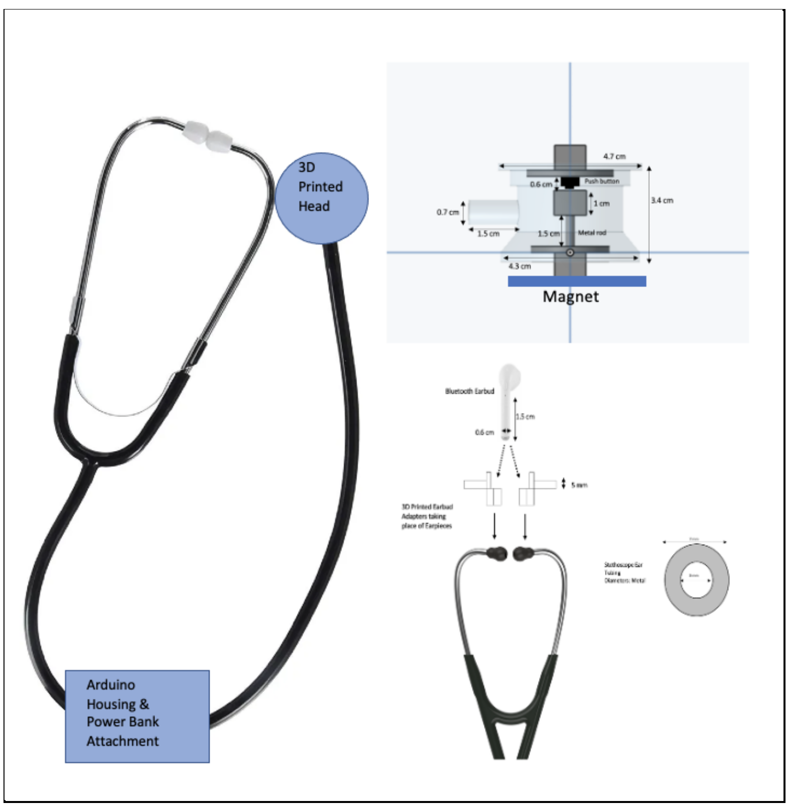


Figure 6: Final design concept of the *EchoScope.*

The concept for the user interface remained fairly constant throughout the design process. The concept was to create a webpage that would control the sound output of the vest and be user-friendly for instructors to use. The idea was to have a series of drop-down lists to select from a variety of sounds for each location. The sounds were obtained from a list provided to us by Dr. McAllister and a variety of open-source sound libraries. Six auscultation locations were to be programmed into the *SimuVest* with sound files specific to those locations. The initial concept was to be able to control the *SimuVest* wirelessly from the web page. Due to difficulties with programming and the serial output of the magnetometers, this idea was adapted to include a connection from the user's laptop to the *SimuVest* via a USB cable. The coding of the webpage required some open source libraries that were not included in the initial design concept. Figure 7 shows an abbreviated representation of the webpage interface.

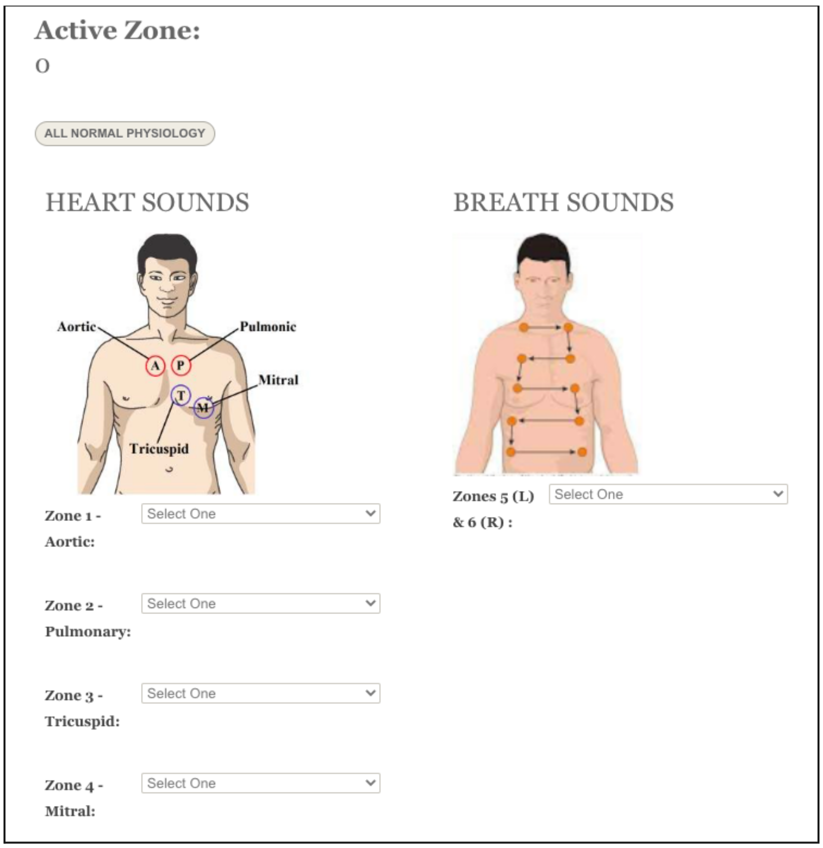


Figure 7: Design of sound selection of the user interface.

V. PRODUCT DESCRIPTION

A. *SimuVest:*

The *SimuVest* prototype is comprised of an adjustable vest, a false rib cage made from PVC, a layer of silicone rubber, and an Arduino circuit with magnetometers for location tracking and vibration motor modules for simulating pulse. Each of these main components serves a specific purpose determined by the requirements of the *SimuVest* outlined previously in this report.

As the most basic layer of the wearable product we have made, the adjustable vest serves as a source of structure for the other components that are attached. Aside from providing structure for the prototype, the nylon material of the vest also provides an external surface that is easily sanitized, as it does not easily absorb spray cleaners or the moisture from sanitary wipes. The velcro straps on the vest also give it the adjustability needed to allow different wearers to easily put it on and adjust it to size. Lastly, the vest is inexpensive and lightweight, making it an optimal fit for the cost and mobility requirements set for this project. Figure 8 below shows the original appearance and dimensions of the vest. It should be noted that all additional pockets shown were removed from the surface of the vest for the final prototype to allow for the adhesion of other components.

Figure 8: Adjustable vest dimensions (from Amazon)

To create tactile landmarks for auscultation and palpation, the creation of a false ribcage was suggested early in the design process by Dr. McAllister. To accomplish this, a set of full-size disarticulated ribs was acquired from Fisher Scientific. The ribs were shaped as they would be for an adult, so some modification was required so that the new “ribcage” would fit around the outside of the vest without constricting the wearer. Each rib was heated with a blow dryer and then bent to the desired shape. The first seven ribs, which can all be felt when palpating the front of a patient’s torso, were then adhered to the front of the vest using cyanoacrylate adhesive that was already in our team’s possession. Once the construction of the rib cage was complete, the creation and addition of the *SimuVest* circuit could be completed. Figure 9 shows a representation of the false rib cage as it is attached to the front of the adjustable vest.

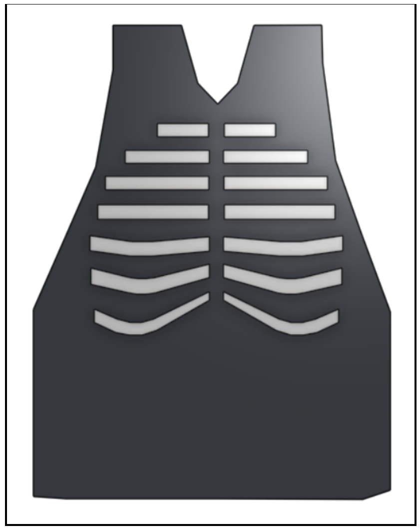


Figure 9: Drawing of PVC ribs on vest

The location of the *EchoScope* is determined in this system by integrating a magnet onto the auscultation head of the *EchoScope*. Using magnetometers, the location of the *EchoScope* could be determined by measuring changes in the magnetic field generated by the movement of the *EchoScope* magnet. Magnetic field readings are processed using an Elegoo Nano V.3, and when the changes in the magnetic field place the magnet within one of the previously defined zones, the *SimuVest* transmits the zone value by serial communication to the user's computer for sound selection and transmission. The *SimuVest* also receives RF transmissions from the *EchoScope* indicating when vest contact is made as determined by the push-button installed in the head of the *EchoScope*. Though the system can collect magnetic field readings when the *EchoScope* is not in contact with the *SimuVest*, the system defaults to a "no contact" state when *EchoScope* is not sending a signal indicating contact. Only when the *SimuVest* receives RF transmissions indicating *EchoScope* contact with the vest is data sent to the computer. This novel system of using magnetometry to track auscultation movements has not been seen in any other medical simulations. As mentioned previously, this method poses several advantages, as it is relatively inexpensive, easy to modify, and allows for continuous tracking of the user's movements of the stethoscope at all points on the surface of the vest.

The *SimuVest* system was additionally designed to include a pulse for palpation. Because the circuit in the vest only transmits data to the computer, the pulse cannot be controlled by computer input. Because palpation and auscultation are not conducted synchronously, the pulse vibration pattern was integrated into our program such that the pattern plays only when the *EchoScope* is not in contact with the vest. The electronic systems of the vest are also powered through the USB connection of the system and user computer. The *SimuVest* system can then run indefinitely if the computer used is powered by a wall outlet or for the battery life of the user's computer. While further development of this pulse simulation is to be desired, the simplicity and low cost of the design adhere to the time and cost constraints of this project.

Once the Arduino circuit composed of the magnetometers and the vibration motors was constructed, the modules were then attached to the vest and rib cage assembly created previously. The magnetometers were the first components attached to allow for the necessary calibrations of our program once their position was set. The first magnetometer was attached just to the left of the midline of the vest, near the bottom. This module established the X- and Y-axes of the magnetic field to be read. To take readings along the Z-axis, the second module was attached to the side of the vest, with an extra section of PVC shaped and used to form a solid “bridge” between the front and back of the vest that the magnetometer could be attached to. Both modules were attached using the same cyanoacrylate adhesive used previously, with small sections of neoprene rubber also being adhered to cover the modules and protect them from possibly damaging forces or environments. The two vibration modules were then attached as well, with one being placed at the point of maximal impulse, and the other at the point of abdominal aortic aneurysm. With all electronic components in place, the layer of silicone rubber was attached to the front of the assembly using nylon thread to cover the ribs and circuitry underneath. This final layer of silicone completes the realism of the system as it pertains to the assessments that can be performed on the front side of a patient. While the ribs serve as tactile landmarks that can be felt underneath the silicone, the silicone reinforces the benefit provided by the look and feel of the prototype. Not only does the layer stand to help users visually identify the locations of interest for auscultation and palpation, but it also serves as a step toward a simulation that fully reflects the tactile sensations that can be expected when palpating a healthy or ill patient. The technology that provides the pulse pattern can be improved to more accurately represent the pressure changes felt when touching a blood vessel, but for now, the tissue that covers said blood vessels is in place. To finish the prototype, the Arduino microcontroller was secured inside of a plastic housing and wire covers were used to conceal all wiring between the vest assembly and the microcontroller. Figure 10 is a picture of the completed vest prototype.

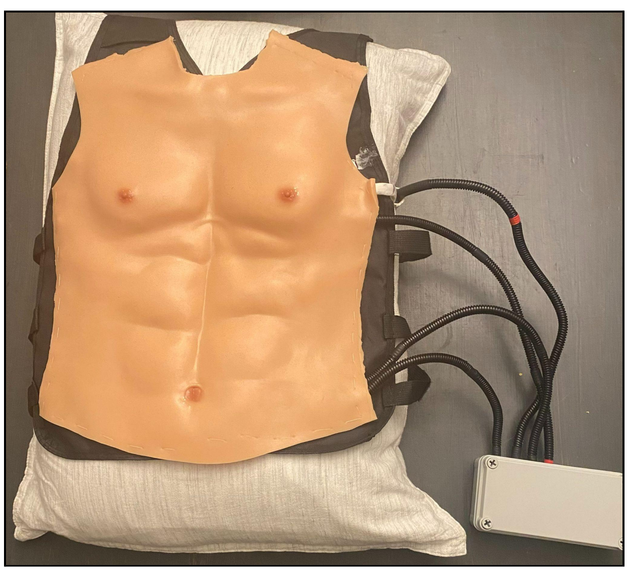


Figure 10: Vest prototype fully assembled

B. *EchoScope:*

The final design of the *EchoScope* was briefly described in the section above. The first notable aspects of the *EchoScope's* final design were the earbud adapters and BlueTooth earbuds. The advantage of this is that we did not have to concern ourselves with dampening the sounds of the wearer of the *SimuVest*. The earbud adapters were designed to take the place of the original earpieces of the stethoscope and have a tight enough connection to hold the earbuds in place. The earbuds could also be easily removed from the adapters to allow them to be charged after use. Another advantage of this design is that students could choose to use their own Bluetooth earbuds if they were similar to the earbuds that come with the *EchoScope.* Additionally, it would be easy to design multiple different earbud adapters that would fit popular earbud models on the market. The earbuds used would have to be compatible with a variety of laptops because different programs have access to different computers. A specification given to us by our stakeholders was that the *EchoScope* would have to be able to be used multiple times in a teaching setting. Tests were conducted on the earbuds to determine if they could meet the criterion of 3 hours of use in one battery life. Incorporated with the *EchoScope'*s design was a 3D-printed Arduino housing unit with a compartment for a power supply. This housing unit was attached to the rubber tubing, where wires were run through the tubing down to the 3D printed stethoscope head. The housing unit did not interfere with auscultating the vest. The battery life of the power bank was also tested to ensure it could meet the 3-hour requirement.

Figure 11: Assembled prototype of *EchoScope.*

Other electronics used for the *EchoScope* included an Arduino Nano, RF transmitter, 10 k-ohm resistor, solderable breadboard, wires, and a push-button. The RF transmitter, Arduino Nano, resistor, and solderable breadboard were contained within the Arduino housing. A novel aspect of the circuitry for the *EchoScope* was the use of the RF transmitter. The RF transmitter communicated with an RF receiver located in the *SimuVest.* The purpose of this was to transmit when the push button was pressed when contact was made with the *SimuVest.* The state of the button was used to control when location tracking in the *SimuVest* was initiated.

The final component of the *EchoScope's* design was a 3D printed stethoscope head with two 3D printed buttons, a metal rod, and a push-button located on the inside. On the outside of the stethoscope head, a magnet was adhered to the bottom of one of the 3D printed buttons. The dimensions of the stethoscope head were taken from measurements of a stethoscope and slightly scaled up to contain the necessary hardware components. A novel aspect of the stethoscope head was the push button mechanism and the magnet. The push-button mechanism allows for either side of the stethoscope head to be used for auscultation. For the current design, only one side of the stethoscope head is used for auscultation but has the potential for both sides to be used in further development. The push-button initiates location tracking of the position of the *EchoScope* on the *SimuVest.* The magnet provides the changes in the magnetic field needed for the magnetometers to triangulate position. This allows for continuous location tracking of the *EchoScope* as opposed to discrete methods currently used in products on the market. Images of the assembly, wiring, and components can be found in the section above and in Appendix C.

C. User Interface:

The final design of the user interface includes JavaScript and html files to create communication from the Arduino, to the local machine, to the html page, and finally to the *EchoScope*. Each intermediate step is necessary to extract output data from the Arduino to the user, as shown in Figure 12. The interface is a one-time, front-end development that would become available to all clients upon purchase of the *SimuVest* System.

First, software packages must be downloaded by the user on the local machine that is intended for use. These instructions will be provided to the user and can be found in the Appendix D. First, node.js is used to compile the packages that we use for communication between the Arduino, JavaScript, html, and *EchoScope*. Serialport.io is used to establish the connection from the Arduino to the computer via USB. This requires the input of the name of the USB port used for the *SimuVest*. When the design.js script is running, the output data from the Arduino correlates to the zone that the *EchoScope* is placed in, Serialport.io extracts this output and allows these data to exist on the local machine. These data are then accessible in the terminal as well as in JavaScript. Socket.io is then used to create an HTTP server used to emit data from the local machine to an html script. The zone number then exists as an input in the html script. This transfer is made in a negligible amount of time, creating an instant connection between the *SimuVest* and the user interface. This fulfills the need for limited latency in data transfer in order to preserve the realism of the simulation.

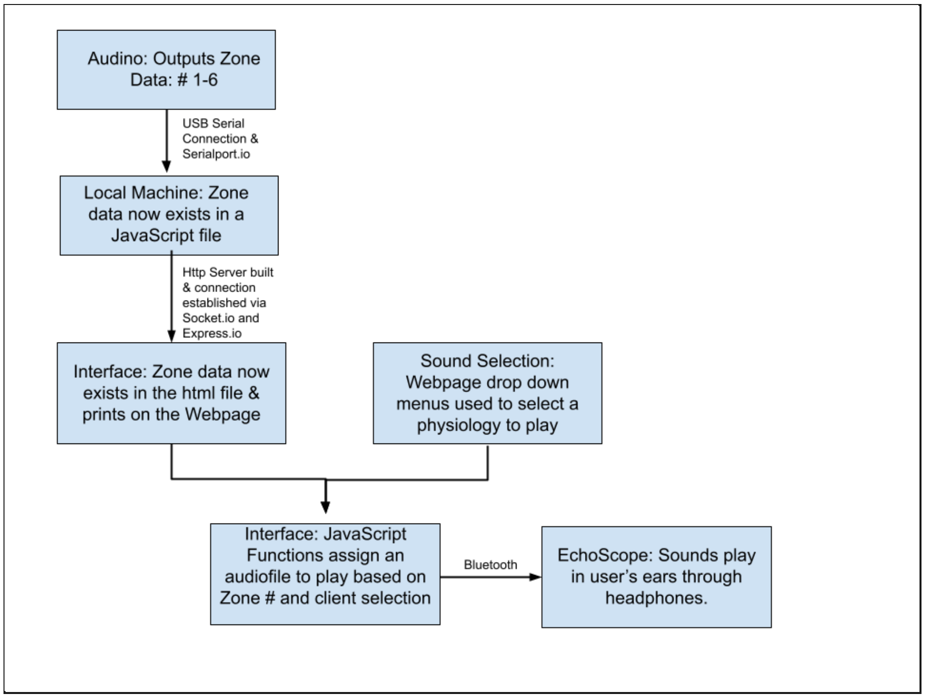


Figure 12: Flow chart of software pipeline.

The interface allows for the *SimuVest* system to be programmable. The stakeholder established that the instructor ought to have the ability to program a specific sound to play at a specific anatomical location. This is accomplished via drop-down menus on the Sounds Selection page of the website, as shown in Figure 7. Each zone has its own menu to select what sound the student will hear at that specific anatomical location. Each sound can be previewed on the Sounds Library tab on the left-hand menu of the web page. These sounds were procured from open source educational libraries and gathered as audio files in the html script. The mp4 files are included in the download in step 1 of the README instructions (found in Appendix D). Sounds will not play unless a selection is made. The sounds offered are as follows:

Heart Sounds:

Aortic Area: Normal, Aortic Stenosis, Atrial Septal Defect (ASD), Atrial Regurgitation, Aortic Stenosis with Regurgitation, Aortic Insufficiency, Aortic Coarctation.

Pulmonic Area: Normal, Pulmonic Stenosis, Patent Ductus Arteriosus (PDA), Right Branch Bundle Block.

Mitral Area: Mitral Normal, Stenosis, Mitral Prolapse, Mitral Insufficiency with Prolapse, Mitral Regurgitation, Left Ventricular Hypertrophy, Cardiomyopathy.

Tricuspid Area: Normal, Ventral Septal Defect, Tricuspid Regurgitation, Pericardial Rub (2 Component), Pericardial Rub (3 Component).

Breath Sounds:

<u>Left and Right</u>: Normal - Vesicular, Coarse Crackles, Bronchiectasis Crackles, Bronchiectasis Crackles and Wheezes - Cystic Fibrosis, Pulmonary Edema Crackles, Asthma Wheezes, COPD Wheezes, Rhonchi, Rhonchi with Pericarditis, Pleural Friction Rub, Bronchiolitis Wheezes, Stridor Inspiratory

Finally, the machine that is being used to power/control the SimuVest System is also connected to the *EchoScope* via Bluetooth (as shown in Figure 12). The machine is what is housing the audio files so they can play through the wireless headphones and directly into the student's ears. This accomplishes the need that the existing abdominal sounds of the vest's wearer will not interfere with the sounds selected and diminish the simulation quality.

VI. DESIGN EVALUATION

A. *<u>SimuVest:</u>*

Integrating the location-sensing technology into a realistic representation of a patient chest and abdomen, The *Simuvest* met stakeholder criteria and passed evaluation assessments for design efficacy. With the use of magnetometry, locations for auscultation were easily programmed into the system. Accuracy tests were additionally completed to assess the accuracy of location reading. Placing the stethoscope on the left lung, right lung, A, P, T, and M locations as shown in Figure 13 below. The A, P, T, and M locations correspond to zones 1-4 as they are named within our program, while the left and right lung correspond to zones 5 and 6.

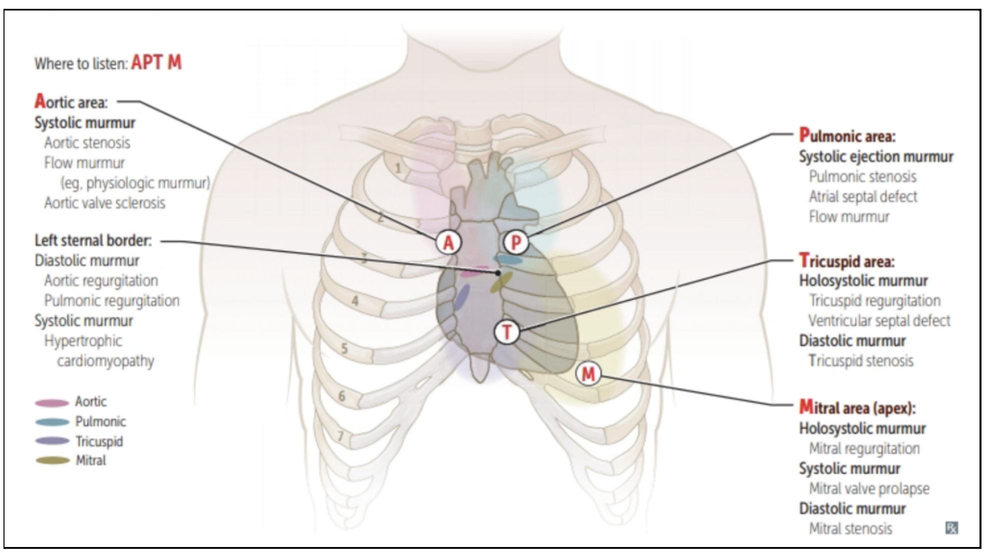


Figure 13: Locations of Identifiable Cardiac Abnormalities by Auscultation [5]

When moved more than an inch away from these locations, the location value returned to a "no location" state (zone 0) except in the case of locations T and M, where the location returned was "left lung" (zone 5). Deviation from location accuracy was observed, however, when ferrous or magnetic objects were brought near the system after initial power-up and calibration (automatically performed during power-up). Adjustment of the *SimuVest* position/orientation had similar effects on location sensing, as the magnetic field experienced from the earth's poles impacts the readings from the magnetometers. To counteract these issues, the vest must be restarted by unplugging and then reconnecting the USB connection to the laptop after moving a ferrous/magnetic material in close proximity to the system or after the vest orientation is adjusted.

System electronics temperatures were also evaluated during use. Average temperatures observed on contact points with the standardized patient using an infrared thermometer were observed over a 20-minute span, with average temperatures shown below in Table 1.

Table 1: Electronics Temperatures on *SimuVest*

Time (min)	Magnetometer 1	Magnetometer 2	Microcontroller
0	23.9 °C	24.2 °C	24 °C
5	23.9 °C	23.1 °C	23.5 °C
10	23.7 °C	22.7 °C	23 °C
15	23.7 °C	22.9 °C	23.4 °C
20	23.8 °C	23.1 °C	23.4 °C

There was no indication of a significant temperature increase over the 20-minute assessment period. Additionally, electronics did not reach the threshold of pain found to be 44 °C [6]. The temperature, therefore, did not adversely impact the efficacy of the system.

Latency was also an important factor in ensuring simulation accuracy and user ease. Measuring the period between location data transmissions from the system by assessing the timestamps from serial communication, the average period between communicated values was 0.101 seconds. The measured noticeable latency between humans and computer interfaces was reported to be 0.100 seconds in "Response time in man-computer conversational transactions" by Robert Miller. [7]. Though ample time must be maintained for the processing of magnetometer values, this delay may be decreased in future optimizations of microcontroller code. With the rapid implementation of a pulse system, the current prototype has an additional delay in presenting locations after initially coming into contact with the vest as the full pulse cycle must complete before location data can be collected and reported. Further work must be completed to decrease this delay for improved latency following contact with the vest.

To assess the *SimuVest*'s reaction to sanitation, the external surfaces of the vest were cleaned with three different cleaning compounds and examined for any signs of reactivity or deterioration in response. Observations were recorded immediately after the application of cleaning solutions and after 30 minutes. Table 2 below summarizes the results observed for the silicone rubber and the nylon vest for all three compounds.

Table 2: Vest materials observations after sanitation test

	Silicone (0 minutes)	Silicone (30 minutes)	Nylon (0 minutes)	Nylon (30 minutes)
Lysol wipes	Slightly tacky, but dries quickly	No observable change	No observable change	No observable change
Spray & Forget sanitizer	Moderately tacky, but dries quickly	No observable change	No observable change	No observable change
Zep disinfectant cleaner solution	Moderately tacky, but dries quickly	No observable change	No observable change	No observable change

To determine the battery usage of the *SimuVest* system for a laptop disconnected from its power supply, three separate tests were performed by observing the battery life of a Mac laptop while the system was in use for 30 minutes. All three trials showed approximately 12% battery loss over the duration. More testing to determine the battery usage for other laptop models could be beneficial in this area.

B. *EchoScope:*

Throughout this project, we had several meetings with Dr. McAllister to evaluate the design as it was being developed. She provided us with a series of criteria that she wanted the *EchoScope* to meet. The expectations were for the battery life of the *EchoScope* to be able to last multiple instruction times (minimum of three hours), be mobile, be able to connect with a variety of laptops, and be durable. A series of tests were conducted on the prototype of the *EchoScope* to ensure that our design met or exceeded these criteria. The *EchoScope* contained two components with battery life: the earbuds and power bank. Both were subjected to battery testing where the battery life (both the earbuds and power bank) and voltage (just the power bank) during maximum use. The purpose of these tests was to determine if the battery life of the earbuds and power bank could last a minimum of three hours.

Table 3: Recorded battery life of earbuds during maximum use.

Trial #:	Recorded Battery Life of Earbuds (Hours: Minutes):	Pass/Fail:
1	4:01	Pass
2	3.:58	Pass
3	4:00	Pass
4	4:02	Pass
5	4:00	Pass

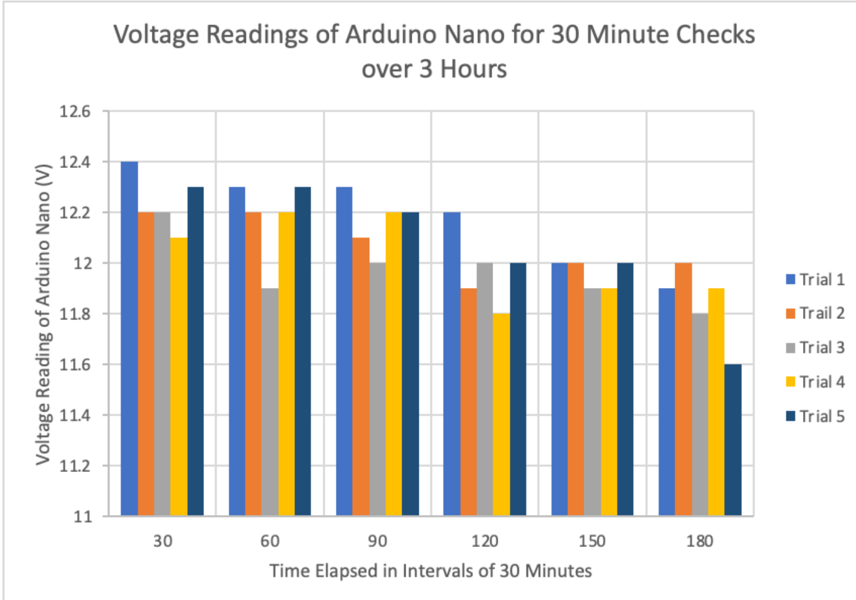


Figure 14: Recorded voltage readings every 30 minutes of Arduino Nano from testing the battery life of the power bank for 3 hours of maximum use.

Based on Table 3 and Figure 14, both the earbuds and power bank have a battery life that met or exceeded three hours. The power bank was also able to maintain a voltage above 5 Volts during the three-hour testing period for all trials. This is important because the Arduino Nano and RF transmitter in the *EchoScope* require a voltage of 5 Volts to function. Bluetooth connection to the earbuds was also tested. Universities will have access to laptops with either Mac operating systems or Windows operating systems. For this test, a MacBook Pro and HP laptop were used to test the Bluetooth connectivity of the earbuds. Both laptops were successful in establishing a connection to the earbuds. Thus, we can conclude that the *EchoScope* will be able to be used by any program so long as they have access to laptops with Bluetooth capability. Because a power bank and Bluetooth earbuds were used in the design, we were able to design the *EchoScope* to not require any external connections. All components of the *EchoScope* are contained within itself, which allows it to be mobile without external connections limiting movement. The durability of the *EchoScope* was tested by conducting drop tests. The drop tests were also used to determine if the *EchoScope* could withstand a force of 3 pounds (typical force applied when auscultating a patient). After 20 drops simulating 3 pounds of force, no structural failures (cracks, bends, or dents) were recorded. Thus, we were able to conclude that our design did meet durability criteria. When auscultating an actual patient, sounds are heard instantaneously through a stethoscope. To maintain realism, the response time of the *EchoScope* would also have to have a fast response time. After testing, the response time for the entire system was found to be 0.1 seconds. This is an acceptable response time but could be improved. Replicating the *EchoScope* is projected to cost $82. This includes all materials used and prices obtained from ordering in bulk.

C. User Interface:

The user interface was important to validate because it acts as the connection between the instructor and the user. Our goal was to create a user-friendly interface that is useful to those with a dense clinical background while not requiring any technical expertise.

First, we validated our sound library by utilizing our stakeholder's expertise. The sound library was shared with Dr. McAllister to ensure that it would suffice for auscultation simulation. We were specifically wanting to know if the recordings that we obtained were accurate to what physiology they were labeled as. Our sounds were validated to ensure that students would hear sounds in specific anatomical areas that they would encounter in their clinical careers. This ensures that our goal to create a useful simulation was met.

Finally, we had to evaluate that each sound plays when it is assigned and its zone is triggered by the *EchoScope*. This was the last test to ensure that each element of the *SimuVest System* is working properly and together. This was determined by one-by-one testing that each of the 33 different sounds plays when their respective zone is triggered. This requires the *EchoScope's* transmitter to be properly communicating with the *SimuVest's* receiver to record when the button is pushed, the magnetometers of the *SimuVest* to correctly identify the location of the *EchoScope's* magnet and for the Arduino to output the corresponding zone number, the USB connection to extract the zone number and to push it to the interface, the sound selection on the interface to correctly assign an audio file to play, and finally for the sound to play through the headphones of the *EchoScope* when triggered. This process ensured that we met the needs of the stakeholder by creating a product that is programmable, easy to use, and a valid simulation tool.

VII. RECOMMENDATIONS & FUTURE WORK

Through the validation of the *SimuVest* system, areas of improvement were identified as the system presented limitations during evaluation. Future work must focus on enabling movement of the vest without impacting the measurement of the *EchoScope*'s magnetic field, enabling greater control of the pulse functionality, editing audio files, establishing a pause in the audio files, and refining the materials and final presentation of the *SimuVest.* To enable vest movement without impacting the measurement of the system's magnetic fields, three approaches have been suggested by the EchoTech team. The first approach would be to investigate alternative magnetic field measuring chipsets that are less sensitive. As the *SimuVest* is repositioned, measurements of the system's magnetic field are altered as the earth's magnetic field interferes with the identification of auscultation zones. Should a sensor have a range excluding the magnitude of the earth's magnetic field, but still measuring the field of a magnet, new sensors could resolve the issue of changing magnetic field with vest orientation. The second proposed solution involves tracking the position of the vest by accelerometer or using an additional magnetometer that is placed far enough from the *EchoScope* to identify vest orientation change by magnetic field change and allow for data collection adjustment. By tracking the movement and new location of the vest, the magnetometers used could be adjusted to track their new orientation. The final solution would rely on the user or instructor resetting the system after each change in patient/vest orientation. Systems relying on manual reset could be improved by adding a physical button on the system or a virtual reset command through the user interface. This would enable rapid system recalibration and could be assisted by an accelerometer to prompt system reset upon detection of orientation change.

The pulse, implemented using vibration motors, could be improved by allowing user control of pulse characteristics and presence. This could be conducted manually using physical controls to enable the pulse and adjust its strength and speed. If communication from the user webpage can be accomplished, user control would be much more efficient, enabling an instructor to adjust all aspects of the system in a single location. The realism of the pulse was also questioned given the vibrating nature of the motor modules used, so further investigation into different methods of pulse replication should be conducted.

Also, the sounds that we have compiled in the sounds library of the *SimuVest* system all come from different sources (the University of Michigan, the University of Washington, Teaching Heart Auscultation to Health Professionals, thesimtech.com, and Hawaii COPD). Therefore, inconsistencies between the recordings such as length and volume could interfere with the realism of auscultation simulation. In the future, we would like to either use additional software to edit these audio files or ideally record our own files. We could edit these files to all be a reasonable length of time, approximately 15 seconds, and program them to loop if the simulation requires any longer than that. This would save on storage space, as some of the current files are as long as 2 minutes. We could also normalize the volume of each sound so the student is not struggling to hear one sound while others are too loud to be heard comfortably by headphones. Ideally, we would record our own sound files. This would be in collaboration with the College of Nursing with their equipment and expertise. That way we could ensure consistency across the sound library and maintain the integrity of the simulation. All of the sounds would then appear to actually be produced by the same individual under the same circumstances.

The audio files in their current state will play until completion once triggered. In the future, we would like to establish a command that would stop the playing of the audio when the *EchoScope* is lifted from the *SimuVest*. This would further enhance the realism of the simulation, as biological sounds are only heard when a stethoscope is in contact with a patient. However, our design focuses on the student's ability to locate the correct anatomical location to hear auscultation sounds. This is established by only playing a sound when a zone has been triggered by the *EchoScope's* magnet.

Finally, further work on the selection of materials and construction of the *SimuVest* must be conducted. Though some reviewers of the *SimuVest* were off-put by the realistic construction of the chest and abdomen, the EchoTech team feels it is important to maintain the silicone molded face of the chest to enable anatomical navigation to auscultation areas. Improvements, however, can be made by selecting a similar material to that of the fabric vest to more smoothly transition from silicone chest to fabric vest. With these two adjustments to the *SimuVest*, a more finished product can be presented to increase the realism for users.

The *EchoScope* functioned properly in the *SimuVest* system but could be improved by decreasing the size of the current system's electronics. The size of the *EchoScope*'s electronic systems significantly increased the mass of the stethoscope causing user fatigue for long periods of use. Another improvement to the *EchoScope* would be to contain the wired connection between the Arduino Nano and power source and reduce the length of the connection. Future improvements could also include providing multiple earbud adapters to allow students to use their own earbuds when auscultating the *SimuVest.*

VIII. APPENDICES

Appendix A: Summary of Design Concept Selection

Table A: Design concept selection.

Design Concept:	Description:	Limitations/Challenges:	Advantages:	Sound:	Location Marking:	Realism:	Palpation:	Ease of Use:	Adaptability:	Low Cost:	Sanitation:
Potential Concept 1 - Wearable vest adustable to different sized with speakers embedded for auscultation	Sounds produced at speakers placed at specific locations in the vest. An actual stethoscope would be used for auscultation. User interface (website) to select from sounds to be played through each speaker.	Auscultation locations limited by number and placement of speakers. Requires method for dampening sounds produced by the wearer. Challenges with including additional auscultation locationns. Limited realism. Challenges with sanitation for fear of damaging speakers.	Simple to use. Likely less wiring. Would allow for students to practice with their own stethoscope.	☑	☑	☐	☐	☑	☐	☐	☐
Potential Concept 2 - Design a wearable vest with RFID tags, an electronic stethoscope, webpage, and include palpation simulation	Include RFID tags at anatomical locations. Would require a stethoscope to be designed to read the tags. Inclusion of a pump to simulate pulse at the two required locations. Webpage for sound control.	Sounds would be limited to discrete locations, which decreases the adaptability of the design. More components to this design, raising the cost. Bluetooth speakers used to play sounds through an electronic stethoscope.	Better realism for palpation and auscultation. Would not have to be concerned about how different stethoscopes would perform with the vest because we would be providing one. Easily sanitized.	☑	☑	☑	☑	☑	☐	☐	☑
Initial Design Concept - SimuVest & EchoScope	Vest made of silicone and neoprene layers. 3 magnetometers used for tracking the location of the electronic stethoscope (EchoScope). SimuVest also includes 2 vibrationn modules to mark location of palpations, but would not model realism. Silicone layer would be made from a mold to demonstrate anatomical accuracy. EchoScope would use bluetooth earbuds for sound production, have a magnet for tracking in magnetometry grid, battery powered, and a pressure to signal when contact is made with the vest. A webpage to remotely control the sound selection and provide location feedback.	Limited by battery life of *EchoScope*. Palpation would not be simulated for realism but rather only to mark where students should be palpating. Expensive because Raspberry Pi used as microcontroller of *SimuVest.* Also high cost due to materials of the vest. Challenging coding for the user interface.	High realism for auscultation. High adaptability for adding additional auscultation locations and different bluetooth speakers. Designed stethoscope would also be realistic because it would be a stethoscope modified with 3D printed parts. Easy to use user interface that provides direct control for intructors. Silicone and neoprene easily sanitized by alcohol based cleaners. Would not have to be concerned about how different stethoscopes would perform with the vest because we would be providing one.	☑	☑	☑	☑	☑	☑	☐	☑
Final Design - Adjsuted *SimuVest* and *EchoScope* design	Vest with silicone overlay taken from a premade piece, set of ribs underneath this layer, and vest with adjustable straps. Number of magnetometers reduced to 2 with 2 vibration modules. Similar design for the *EchoScope,* but powered by a power bank and 3D printed stethoscope head. Webpage control of the *SimuVest* but with required connection between user's laptop and the *SimuVest.*	Auscultation locations limited to the front of the vest. *EchoScope* still limited by battery life. Required connection between laptop and the *SimuVest.* Palpation would not be simulated for realism but rather only to mark where students should be palpating.	Lower cost than initial design concept while maintaining realism and adpatability. Webpage is local which would not require wifi to operate the system. Arduino Nano's are smaller and easier to program. Materials of the vest are still easily ssanitized by alcohol based cleaners. Sounds and locations easily added to the program.	☑	☑	☑	☑	☑	☑	☑	☑

Appendix B: *SimuVest* Circuitry Diagram

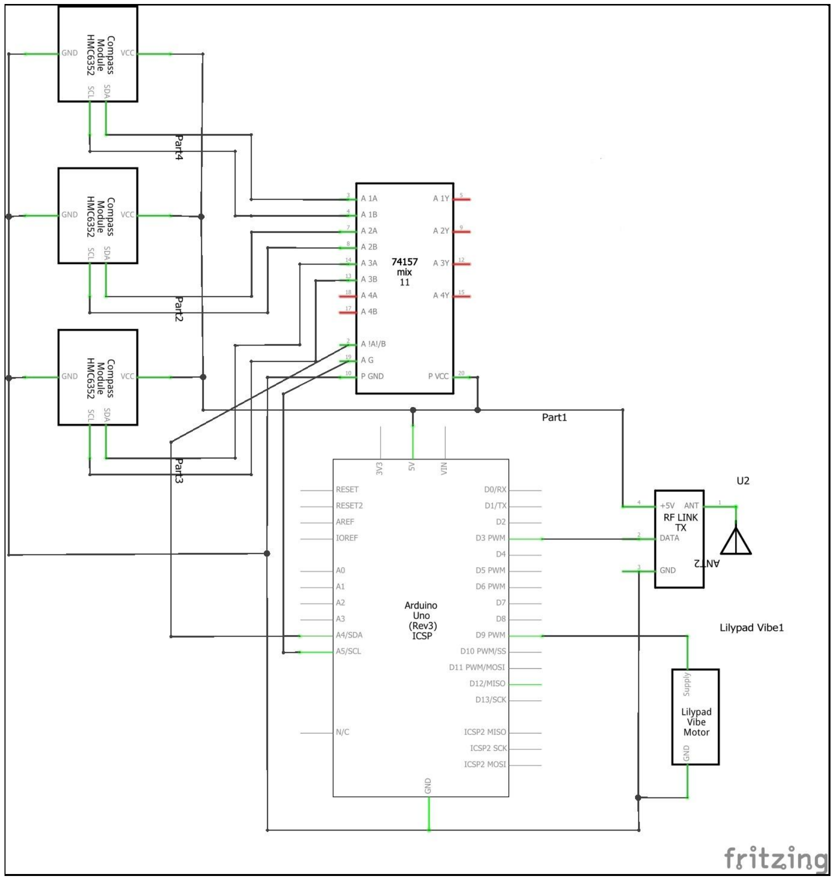


Figure A: Circuit diagram for the *SimuVest.*

Appendix C: *EchoScope* Circuitry Diagrams and CAD Drawings

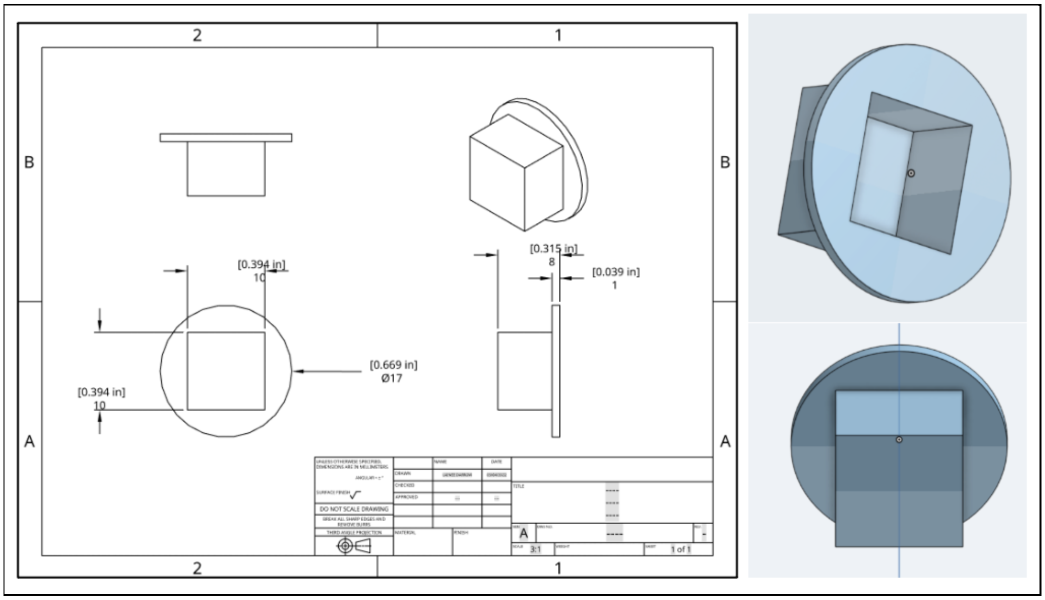


Figure A: Initial CAD designs for the 3D printed buttons.

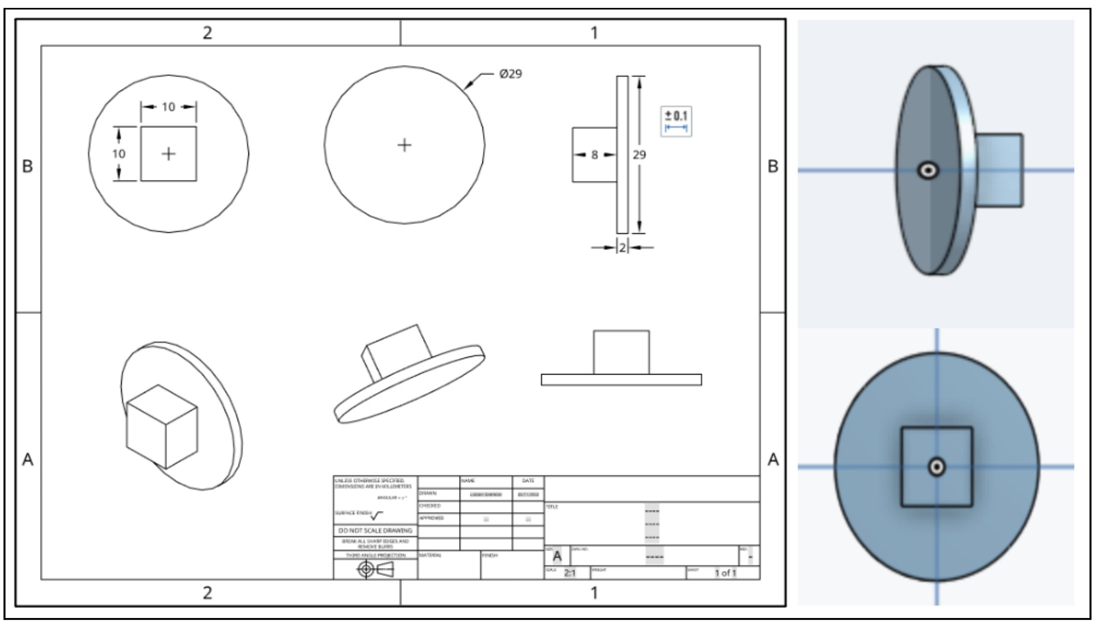


Figure B: Finalized CAD designs for the 3D printed buttons of *EchoScope.*

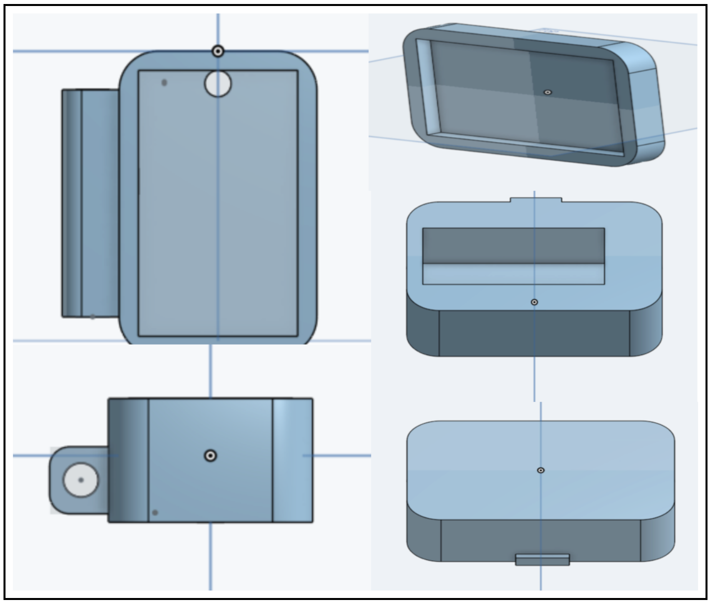


Figure C: Starting CAD designs for Arduino and battery housing of *EchoScope*.

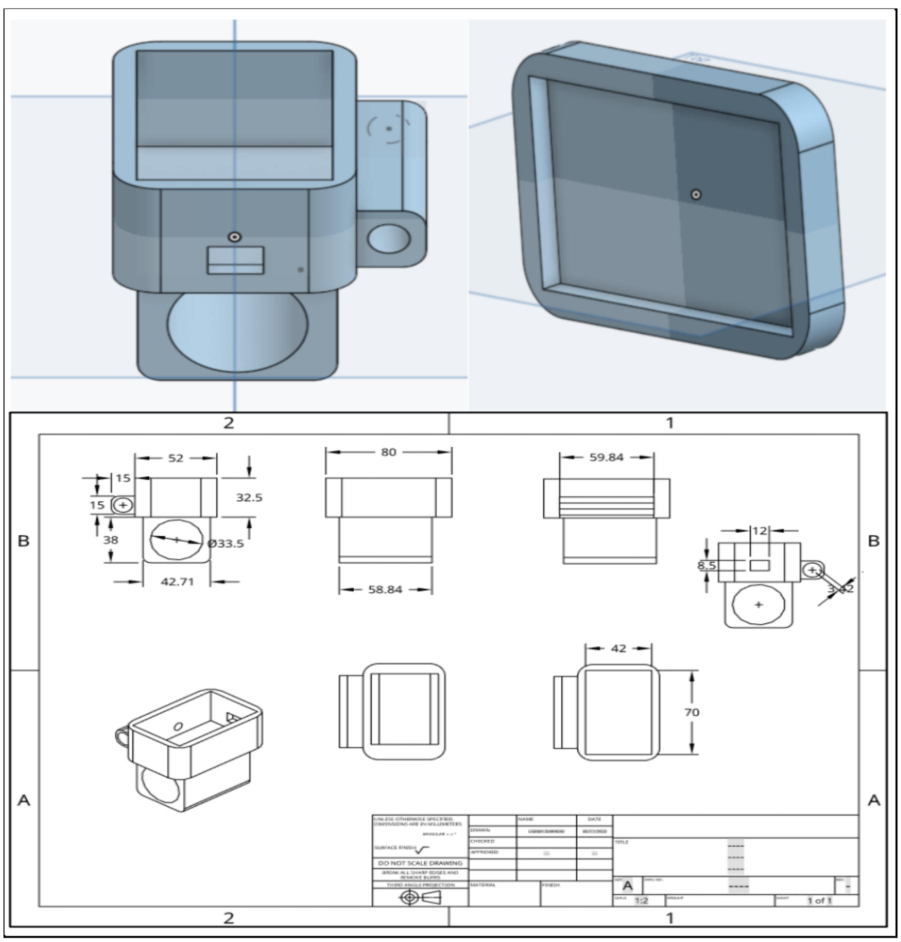


Figure D: Finalized CAD designs for the Arduino housing and power bank attachment of *EchoScope.*

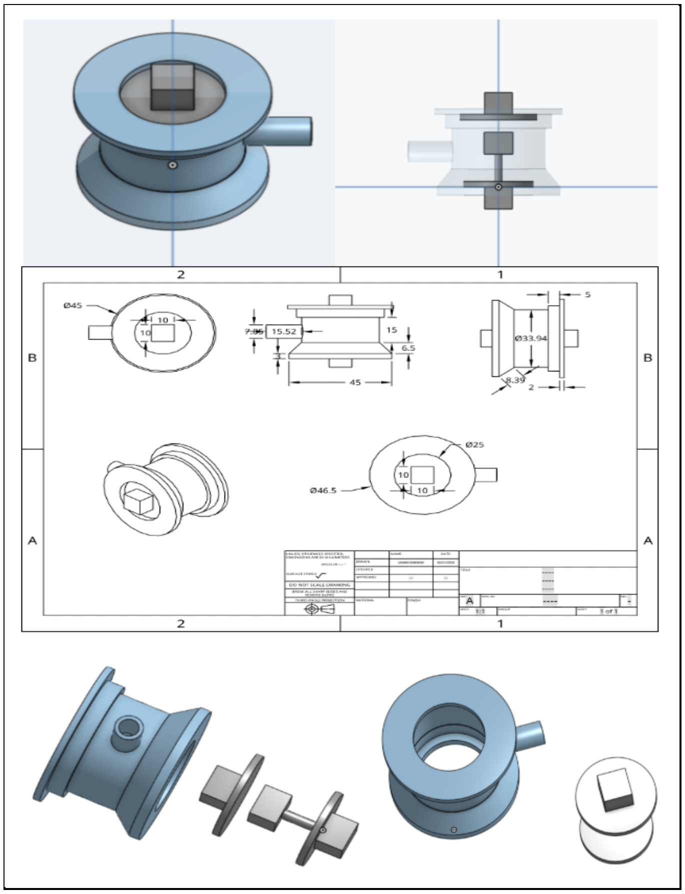


Figure E: Finalized CAD designs for 3D printed stethoscope head

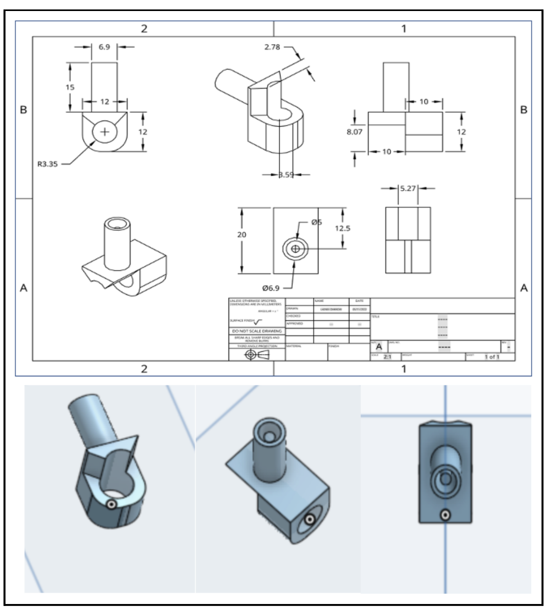


Figure F: CAD design of the earbud adapters

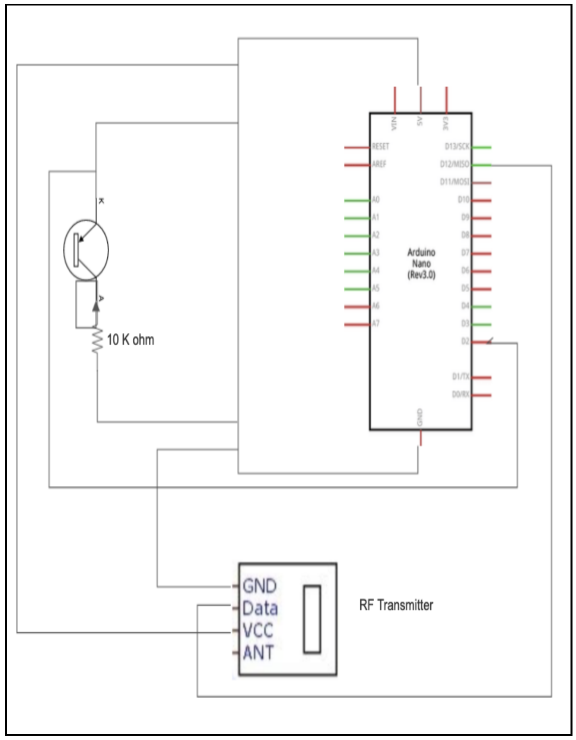


Figure G: Circuit diagram of the *EchoScope*

Appendix D: Setup Instructions for the *SimuVest* System

In order to use the *SimuVest* system, software packages must be installed on the local machine that you intend to use the system with. The following instructions show how to install each of these packages and how to begin using the *SimuVest* system.

1. Download the "**SimuVest_System**" provided upon purchase to your computer. Place this file in the "Documents" directory, found in the Finder (Mac) or File Explorer (Windows)

2. Open the Terminal (Mac) or PowerShell (Windows), and navigate to the "SimuVest_System" folder that you just placed in the "Documents" directory. You can do this by entering the following command according to your machine's path:

   ```
   cd Documents/SimuVest_System
   ```

3. Follow this link to install **node.js** according to your OS (Windows vs Mac): https://nodejs.org/en/download/

4. Then, use the "npm" command to install the packages that are necessary to run the SimuVest System. Do this by placing the following commands in the command line one by one:

   ```
   npm install serialport
   npm install socket.io
   npm install socket.io-client
   npm install express
   npm install ejs
   ```

5. Plug in SimuVest to a **USB port** on your computer. Ensure that you use the same port for each session. Find the **name** for the port by placing the following command on your command line:

   Mac:
   ```
   ls dev/tty*
   ```

   It will look something like this:
   ```
   /dev/tty.usbserial-1410
   ```

   Windows:
   ```
   Get-PnpDevice -PresentOnly | Where-Object { $_.InstanceId
   -match '^USB' }.
   ```

It will look something like this:
`COM1`

6. Open a text editor. If you have one that you prefer please use that one, but if not you can use “nano”, it comes standard on all devices. Type this in the command line:

```
nano design.js
```

7. In nano, navigate to line 4 of the `design.js` script and where it says `‘path:’ENTER YOUR PATH HERE’`, change it to the path that was found in step 5. So now line 4 looks something like this:

```
const port = new SerialPort({ path: '/dev/tty.usbserial-1410', baudRate: 9600})
```

8. Now you can use the SimuVest System! In the command line, type the following command:

```
node design.js
```

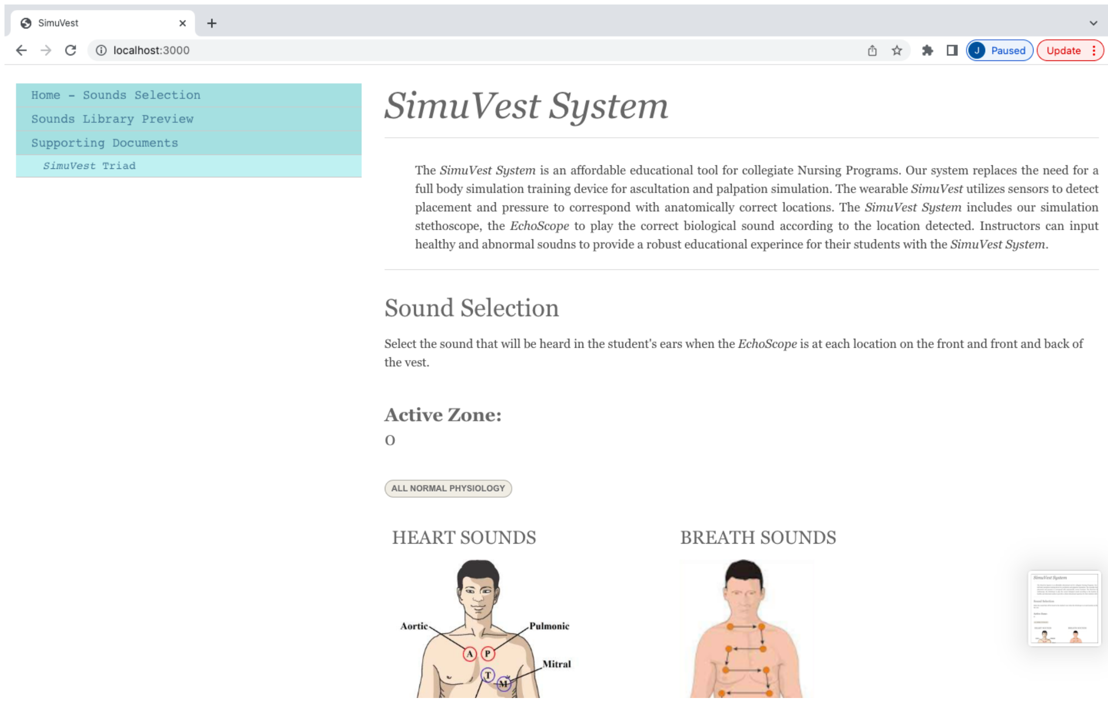
You should see the following:

```
listening on *:3000
a user connected
Button: 0
Button not pressed
```

9. Turn on the EchoScope. When a connection is established, the output should change to:

```
Button: -1
```

10. Open a Browser and typer “localhost:3000” in the search bar. The home page for the SimuVest System interface should appear:



11. That's it! Use the dropdown menus to select which sounds you would like to hear at which locations, or to auto-fill to all normal sounds, press the "ALL NORMAL PHYSIOLOGY" sounds button. No sounds will play until a selection is made. When the EchoScope button is pressed and in a zone, your sound will play!

****

If any issue arises with any of these steps, start at the beginning to ensure that the order is maintained. If further issues arise, contact SimuVest support here.

IX. REFERENCES

1. Talhan, A., & Jeon, S. (2018) Programmable prostate palpation simulator using property-changing pneumatic bladder. Computers in Biology and Medicine, 96, 166–177. doi.org/10.1016/j.compbiomed.2018.03.010

2. SimShirt® System. 3B Scientific. (n.d.). Retrieved September 10, 2021, from a3bs.com/simshirt-system-size-l-1021552-cardionics-718-3420m,p_148_30050.html.

3. Neumann, E., Snyder, G., Tolia, R., McCoy, E., Tran, T., & Gervolino, C. (2020). Wearable Simulator for Enhanced Realism. UW BME Design. Retrieved September 10, 2021, from bmedesign.engr.wisc.edu/projects/f20/sim_vest/file/view/ed82a52b-dcea-40a7-9682-59c5cae92235/Wearable%20Simulator%20Preliminary%20Report.pdf

4. *High-Fidelity Nursing Education*. Minority Nurse. (2015). Retrieved May 9, 2022, from https://minoritynurse.com/high-fidelity-nursing-education/

5. Asprey, D. (2018) Evaluation of Cardiac Murmurs. Retrieved May 12, 2022 from https://www.iapasociety.org/images/stories/CMEPowerPointPDF/Fall2018/Evaluation-of-Cardiac-Murmurs-Handouts.pdf

6. Dirler, J., Winkler, G., & Lachenmeier, D. W. (2018). What Temperature of Coffee Exceeds the Pain Threshold? Pilot Study of a Sensory Analysis Method as Basis for Cancer Risk Assessment. Foods (Basel, Switzerland), 7(6), 83. https://doi.org/10.3390/foods7060083

7. Miller, R. (1968) Response time in man-computer conversational transactions. (Poughkeepsie, United States) https://yusufarslan.net/sites/yusufarslan.net/files/upload/content/Miller1968.pdf