

# Deployable Prototype Documentation

## ESG - Electrical Stethoscope

Team 9

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*Abstract – The physician shortage in the United States is a major issue in the medical industry. To help alleviate this societal problem, we are building an electronic stethoscope, the ESG, which aims to improve productivity. Our electronic stethoscope has five features that help differentiate it with current medical devices. Our Bluetooth feature provides the medical practitioner with more spacing that minimizes cross-contamination. The ESG also has sound amplification and noise reduction feature via selectable ranges of frequencies assist aging physician. The sample recordings and file transferring allowing tasks delegation and freeing more time for the physician. Additional, sound samples can be stored in a repository for analysis and research.*

*Keyword Index: Stethoscope; Electronic; Productivity; Medical Practitioner; Auscultation; Recordable; Signal Processing; Medical Device; Amplification; Filtering; Recordable; Bluetooth Technology; Signal Processing; Risk Assessment; Risk Management; Project Management; Critical Paths; Risk Mitigation Plan; RACI; Level of Effort*

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## EXECUTIVE SUMMARY

Shortages of the physician is a problem in today's society and we experience this when we are seeking medical attention. Hospitals and clinics are full of patients with all kinds of illness and doctors can easily be infected by those patients they help. Medical practitioner exam patients within arm's length while using a traditional stethoscope, this will increase the possibility of the cross-contamination and the likelihood if the medical practitioner does have time to properly clean their stethoscope. Patients usually need to wait weeks before they actually talk to a doctor and appointments only last about fifteen minutes. With our electronic stethoscope, we will be able to increase the productivity inside the hospital and reduce the cross contamination.

### Features/Components Discussion

- Live Sound Acquisition – This feature is achieved by performing the integrated system on the Raspberry Pi. Since Raspberry Pi does not have an input microphone jack, we used a USB audio adapter to complete a streaming audio signal.
- Noise Elimination – This feature is completed via Simulink platform. The Simulink model contains two IIR digital filters: low and high pass filter. In order to complete a standalone device, the Simulink model is being deployed to the Raspberry Pi as an execute file.
- Wireless Playback – When body sound is being recorded, the audio file can be saved as MP3 file. The file can be played back via Bluetooth device while the push button is being pushed.
- Audio Amplification – The adjustable gain has three modes: 40 dB, 50 dB and 60 dB. A toggle switch is used as an indicator to select between these gains.

### Testing

- White Box Testing – This section lists the methodology to test the sound acquisition feature. Among the tests to be considered are power, connectivity, and amplification test. Successfully achieving the amplification test would mean that the Pi can process live sound and generate an amplified output.
- Testing Results – This section describes the pass/fail progress results of our tests. The first two tests are successful, the integration of the amplification is still in progress. List of features section recaptures all the features to be integrated. This includes live sound acquisition, sound enhancement through amplification and filtering, and wireless connectivity. The interdependency section discusses the dependency of the components and features. Features such as amplification and filter require the live sound acquisition feature to work.

### Market Review

- The target audiences of our device are medical practitioners and medical students. The medical practitioner will be able to acquire a filtered sound and record the sound of patients for future comparison.
- The market analysis breaks down into three areas: the market condition, market size, and price point estimation. The traditional stethoscope holds the largest portion of the current market. The market condition points out the growth of the stethoscope is due to the public and private investments in the medical field, and growing will keep existing in the future.

## I. INTRODUCTION

The United States is facing a serious shortage of physicians, largely due to the growth and aging of the population and the impending retirements of older physicians. Healthcare Associated Infections (HAIs) is major factor that contributed to doctor shortages. The Center for Disease Control (CDC) estimates that one in twenty patients will contract an HAI every day, and some estimates suggested that the economic burden of HAIs reaches \$35.7 billion a year [1]. Hospitals are amongst the primary breeding grounds for infections. These HAIs can be transmitted in many ways, including, but not limited to, bodily fluid contacts, contaminated syringes, invasive medical devices, or simply by being within a close proximity to the patients. Not only does cross-contamination put doctors at risk, it also put other patients at risk as well due to the constant reuse of medical equipment. However, hospital doctors and nurses constantly work in extremely active environments, and not all of them follow the guidelines every single day. In order to solve this issue, we proposed for medical offices and hospitals to adopt a team-based healthcare by using our electronic stethoscope to increase patient-doctor relations, productivity and medical care. The Stethoscope is a medical device doctors used to listen to various sounds inside the patient's body. There are generally two types of stethoscopes: the traditional acoustic stethoscope and electronic stethoscope. The acoustic stethoscope operates on the transmission of sound from the chest piece, via air-filled hollow tubes, to the listener's ears [2]. Electronic stethoscopes convert the acoustic sound waves obtained through the chest piece into electrical signals which can then be amplified for optimal listening [2]. Our design goal is to apply modern technologies to the stethoscope, providing features that will allow medical practitioners to be more efficient in promoting productivity within medical offices and hospitals. Our electronic stethoscope offers wireless connectivity and allows doctors to be further away from the patients. The wireless feature will allow a distance of up to ten feet between doctors and their patients, thus significantly reducing their chance of contracting or

passing HAIs. It will be able to record and transfer body auscultations. The ability to record sound samples allows for tasks delegation. Similar to how nurses take the blood pressure readings ahead of time, the ESG recording feature allows nurses to perform initial auscultations and record the samples. The device will take samples readings of the faint heart and lung sounds and enhance it through digital amplification and noise reduction filtering. In addition, with multiple samples recorded from different visits, doctors can also review these samples chronologically, thus giving doctors a bigger picture of how these sounds have changed from one visitation to the next. The sound enhancing feature will allow doctors to obtain good sound quality with adjustable volumes and frequencies. With sound enhancing, the ESG can amplify the sound and filter the noise, thus improving their ability to diagnose the problem, and perhaps give incentives to aging doctors to continue their medical practices.

Filtering is an essential feature for the project and the goal of this feature is to reduce any audible induced electrical noises as much as possible. Since the lack of knowledge in the professional medical field, it is extremely challenging to distinguish important signals and unwanted noises. Therefore, the goal is to keep an acoustic signal as complete as possible. On the other hand, doctors have been using the traditional stethoscope for decades. Most of them are used to the noises in the background, and it is what they were hearing since the first day of using stethoscope. By filtering out certain segments of the sound, it will risk the diagnostic of the illness from the doctors. Meanwhile, this will also introduce a big learning curve for the current doctors.

This filtering process is executed after the acquisition of a real-time signal from patients. When an acoustic signal is acquired through the electret transducer, the signal will be fed into two filters. The difference between the cutoff frequencies for these two filters is the range of frequency that will be kept from the original signal. An amplifier is connected after this filtering process which allows user to adjust the volume of the

sound. At the end, a processed sound signal will be transferred to the earpiece via Bluetooth. Therefore, any failure during this filtering process will lead to a fault output signal. A misdiagnosis might be made due to this fault. It is important to select the correct transducers and accurate cutoff frequency for each filter. We chose our design features by adhering to the problems and situations explained earlier. The wireless feature will allow a distance of up to ten feet between doctors and their patients, thus significantly reducing their chance of contracting or passing HAIs. The sound enhancing feature will allow doctors to obtain good sound quality with adjustable volumes and frequencies. Like everyone else, doctors do grow old and their hearings become less effective with age. As such, multiple auscultations would be needed, thus losing productivity. Or worse, they may fail to identify all the heart sounds entirely. With sound enhancing, the ESG can amplify the sound and filter the noise, thus improving their ability to diagnose the problem, and perhaps give incentives to aging doctors to continue their medical practices. Another feature that we will implement with our design is the recording feature. The ability to record sound samples allows for tasks delegation. Similar to how nurses take the blood pressure readings ahead of time, the ESG recording feature allows nurses to perform initial auscultations and record the samples. This will free up time as doctors can study multiple samples at once. In addition, with multiple samples recorded from different visits, doctors can also review these samples chronologically, thus giving doctors a bigger picture of how these sounds have changed from one visitation to the next.

The Work Breakdown Structure (WBS) is a key project deliverable that organizes the team's work into manageable sections. Each level of the WBS provides further definition and detail. We have broken down the project into three levels. The first level covers our core features that were stated in our design feature contract. The second level talks about subtasks of that core feature. The third "sub-subtasks" embodies what we have to accomplish to implement the subtasks by breaking it down into individual size packages suitable for a single team

member to complete. When the tasks have been identified, we will be assigning team members to these tasks based on their area of expertise and other criterions.

Risks are unavoidable events in the project designing process but developing a framework to gauge known risks is a pathway to a successful project. But for any project, there are predictable and unpredictable factors or knowns and unknowns and having a strategy for both is imperative. It is our task to identify as many of these risks as possible while also providing solutions and strategies to tackle these factors. The risk assessment is a tool that provides guidelines for tackling these sources of failure by identifying both predictable and unpredictable risks. We used two types of matrix for our risk management plan, the risk matrix, and the RACI matrix. The risk matrix identifies the severity and probability of each activity as we view them. We can prioritize higher impact and probability activities as they are crucial parts of completing the project. For example, filtering is an important feature and will be prioritized higher than lower impact activities such as the dimension feature. The risk matrix was populated based on the work breakdown structure and the critical path identified in our project timeline.

The risk assessment contains four strategies to tackle risks, namely risk transfer, avoidance, acceptance, and control. Although, there are four strategies provided, only three are acceptable chooses on this project. We cannot transfer the risk to a third-party because the project is solely based on our performance. By recognizing these strategies and prioritizing how we handle each activity based on their severity, we can minimize the failure that could occur during the project development. We explore some risks that could happen and a risk mitigation plan to those events.

## II. PROBLEM STATEMENT

### A. *Societal Problem*

Doctor shortages have become a widespread problem in the American healthcare industry. According to a recent study released in March of

2017 by the IHS Markit on behalf of the Association of American Medical Colleges (AAMC), demand for physicians continues to grow faster than the supply. The findings predict that the U.S. will face a shortage of between 40,800-104,900 physicians by 2030 [3].

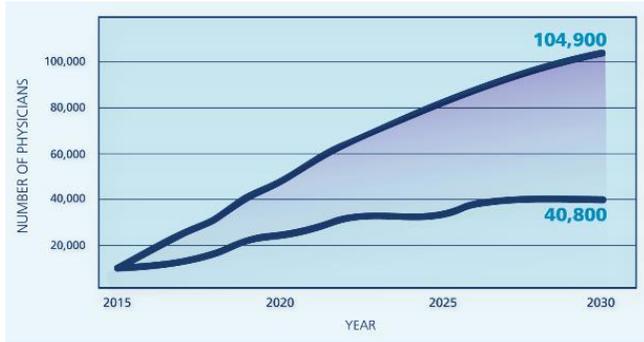


Fig. 1. AAMC Physician Workforce Projection 2015-2030 [1]

We experience this societal problem first-hand when trying to schedule a checkup or visit an emergency room. Doctors are overworked with the patients they have to see. Patients are made to wait weeks or months for their appointments which can cause their illnesses to worsen. Sicker patients mean expensive care like urgent care or ambulance which cost the taxpayers millions of dollars. Sicker patients also mean higher rates of cross contamination with other patients or medical practitioners like doctors. One obvious solution is to hire more doctors to meet the demand but finding doctors may be a difficult task. This requires hospitals and clinics to implement an alternative solution to deal with the shortages by increasing the workload of all medical practitioner. We aim to address this societal problem by designing an electronic stethoscope. We are initiating the first steps in increasing the productivity and reducing the cross-contamination in the medical industry. We are taking the design of the traditional stethoscope and modernizing with new technologies.

### B. Health Security

Although the wellbeing of the patients is important, the wellbeing of the doctors is critical to avoid understaffed hospitals and clinics. There are two problems with the design of the traditional

stethoscope. The traditional stethoscopes have terrible sound quality and are typically not long. Doctors are within an arm-length to their patients and risking contracting the patient's illnesses. According to a study on airborne influenza, the virus is known to be spread from person to person by at least two mechanisms: direct and indirect transfer of respiratory secretions and contact with large droplets that settle onto fomites. Additionally, the influenza virus may be transmitted by small airborne particles, but this potential route is not well characterized and remains controversial. Coughing, sneezing, talking, and breathing generates a cloud of airborne particles, some large, some small. Larger droplets settle on the ground while smaller particles, including droplet nuclei from evaporated larger particles, can remain airborne for hours and are easily inhaled deep into the respiratory tract [4].

Day	No. of patients reporting influenza-like symptoms	Total no. of stationary samplers	Total no. of personal samplers	Samplers showing results positive for influenza virus	No. of TCID <sub>50</sub> -equivalent RNA particles detected in the sampler			
					First stage	Second stage	Filter	Total
1	4	9	4	Waiting room (lower sampler) Waiting room (upper sampler) Reception and triage room Personal sampler (physician 1) Personal sampler (physician 2) Personal sampler (physician 3)	460 0 0 3160 309 0	0 13,426 1941 0 0 4623	0 2852 0 0 0 0	460 16,278 1941 3160 309 4623
2	0	13	0	Waiting room, (upper sampler)	1114	0	0	1114
3	5	13	1	None	...	...	...	...
4	3	13	0	Children's waiting room (lower sampler) Children's waiting room (upper sampler) Waiting room (lower sampler) Waiting room (lower sampler)	4025 5762 15,532 0	11,040 <100 0 1367	0 0 0 0	15,065 5762 15,532 1367

Fig. 2. Statistics on Influenza Virus [4]

With doctors being an important resource in hospitals, it is a no-brainer that we keep the doctor as healthy as possible. Outdated equipment such as the acoustic stethoscope creates this risk for doctors as well as other patients receiving their care. Our design will solve both issues with the traditional stethoscopes. The wireless design will separate the microphone from the device that will process the signal, thus creating greater distance between the doctor and the patient. Due to privacy issues, the wireless communication will send and receive a one-to-one pairing with the docking station, ensuring that the listening piece is only connecting to the matching diaphragm in that room. The devices could be prepared and checked for readiness by the attending nurse within seconds. By being electrical, the device will have the capability of amplifying, filtering and digitizing the sound.

The wireless technology provides the doctor distance from the patient, decreasing the chance of receiving germs and viruses from ill patients. Some patients may feel more secure by placing the microphone on themselves.

### C. Increase Productivity

Productivity could increase if nurses could record abnormality in the preliminary readings prior to the meeting with the doctor. According to BMC Health Services Research, nurses spend about 37.0% of their time with patients [5].

With whom	Period	Number of tasks	Mean task length (seconds)	Percentage* (%)	95% Confidence intervals	
Alone	Year 1	2630	41.37*	27.52	24.45	30.59
	Year 3	2288	50.48*	39.38	34.90	43.87
Patient	Year1	2394	61.01	36.95	34.55	39.34
	Year 3	1666	62.77	35.66	33.29	38.03
Relative	Year 1	401	59.69	6.05	5.27	6.84
	Year 3	282	57.45	5.52	4.71	6.34
Nurse	Year 1	2665	80.64*	54.36	49.05	59.67
	Year 3	2229	53.87*	40.95	36.93	44.97
Doctor	Year 1	327	44.19	3.66	3.26	4.05
	Year 3	240	43.37	3.55	2.96	4.14
Allied Health	Year1	83	55.67	1.17	0.88	1.46
	Year 3	67	34.48	0.79	0.60	0.98
Pharmacy	Year 1	31	46.23	0.36	0.20	0.52
	Year 3	35	40.49	0.48	0.37	0.60
Health professional <sup>A</sup>	Year 1	2976	76.57*	57.64	52.30	62.98
	Year 3	2518	52.34*	44.94	40.88	49.00
Other	Year1	416	51.87	5.46	4.82	6.10
	Year 3	290	38.52	3.81	3.18	4.44

Fig. 3. Hours Nurses Spend with Patients [5]

Doctors spend a limited time with each patient, so it is important to make this valuable time as productive as possible. While some patients are easier to diagnose, others may prove difficult, requiring the medical practitioner to take multiple readings. Doctors may not be certain of what is heard from the traditional stethoscope may require multiple reading or be unable to diagnose. With our design capability to record sound bites, doctors will have an option to study these samples further and provide a thorough diagnosis. The medical practitioner may also seek their colleague's opinions by sharing the samples and may improve the chance of a correct analysis. This promotes job delegations, and productivity.

### D. Patients and Medical Practitioners

Having readings from multiple visitations could help the doctors identify many current problems and

prevent futures ones. According to studies, having multiple samples from a spanning time frame will improve the doctors' chance of finding irregularity early on. By detecting problems early, treatments could become more effective and has the potential to save lives. A good example of a disease that could benefit from early detection is heart disease. According to heart attack treatment by Alex Samuels, heart disease is included in top five global cause of death [6].

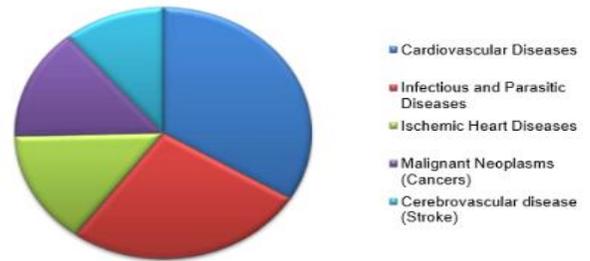


Fig. 4. Charts on Heart Disease Assessment [6]

Our design will allow for early detection, allowing the doctors to review multiple samples of his patients' auscultations. Once an irregularity is detected, the patient can be informed for a checkup as soon as possible. Many doctors do not remember their patients' illness and often rely on medical records provided to them by the nurses. By uploading the patient's readings onto a database, doctors could easily review these samples with simple clicks of a mouse and thus save more lives. Medical offices are often equipped with a computer within the consultation room, and doctors often took notes on the computers

## III. DESIGN IDEA

### A. Design Details

Wireless technology will promote a more sterile environment, reduce cross-contamination between patients and the medical practitioners. According to a study on bacteriological contamination of stethoscopes by Thapa and Sapkota, out of 122 diaphragms used by healthcare workers, 88 were colonized, and only 71 bells and 152 earpieces were contaminated [6]. The distance that the Bluetooth

create should help minimize the medical practitioner's risks of airborne pathogens. Additionally, the risk that the doctors will spread more illnesses to other patients is also reduced. Such reduction in cross-contamination will lead to less sick days amongst all the medical personnel and achieve full productivity.

- Hardware
  - Raspberry Pi3
  - Bluetooth module
  - Batteries
  - Electret Microphone
- Software
  - Python
  - C/MATLAB
  - Simulink
- Metrics for Outcome
  - Establish and maintain a Bluetooth connection on the microcontroller.

Sound quality is one of the core features of our project. Unlike the acoustic stethoscope that does not have sound amplification, our device will focus on noise reduction through filtering. The human auditory system is not automatically attuned to the intensity and frequency of heart sounds. An electronic stethoscope can overcome the low sound levels by amplifying the sounds below the threshold, the use of specialized filters limits the bandwidth by filtering out frequencies that are not within the required range [7]. Adult hearing ability ranges from 50 to 1500 Hz, with the best discrimination frequency between 1000 and 2000 Hz. Heart sounds begin well below this audible threshold and do not reach 1000 Hz.

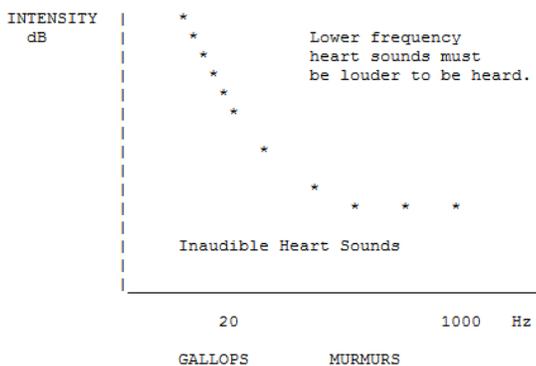


Fig. 5. Audibility Threshold [8]

The stethoscope will work with a variety of frequency ranges to measure different types of heart sounds. We will also, use hardware components to filter to lessen the amount of noise present in the system.

- Hardware
  - Raspberry Pi3
  - Electret microphone
  - Wires
  - Passive components
  - Batteries
- Software
  - C/MATLAB
- Metrics for Outcome
  - Provide good sound quality under different ranges of frequency. High fidelity signals with minimal noise.

The ability to record heart sounds and playback will improve any doctor's productivity. By delegating the task of performing the auscultation to an attending nurse, doctor's time can be better utilized to compare and analyze the current sound sample to the previously recorded samples. The nurse could prepare the patient's heart sound history in their preliminary testing. Once available, the doctor could quickly review the patient's multiple recordings consecutively and chronologically to find any anomalies amongst all the sample. According to the National Institute of Health (NIH), early diagnosis and treatment can help people who have heart failure live longer, more active lives [9]. By detecting the problems early, the patients can receive the treatments sooner and be cured faster. Such feature is not available with the currently traditional acoustic stethoscope.

As sounds samples are recorded onto the MicroSD card that situated inside the piezo contact microphone, the medical staffs have an option of transferring these samples onto their own database or onto a desktop computer. Once the files have been loaded on the repository, the device will also delete the original contents from the MicroSD card, freeing up the memory for the future recordings.

- Hardware
  - Microcontroller

- Speaker
- Batteries
- Software
  - Python with Bluetooth libraries
  - C/MATLAB
- Metrics for Outcome
  - Ability to record a sound file, store it and transfer it.

#### A. Physical Design Features

##### Lightweight Design

- The device dimensions are 13.56mm x 31.5mm x 25mm. It will have a flat surface to help reduce pathogens and make it easier to clean.

#### B. Required Skill Set

- Edward Isham  
Responsibilities include design and circuitry, focusing on amplifications and filtering features. Edward also have a minor background in Computer Science and networking. He will also provide support to Gustavo with wireless feature in the file transferring and establish connection. Also, he will be the liaison to our 3D-drafters, contributors, advisors, and sponsors.
- Guangyao Chen (Simon)  
Responsibilities include circuitry design and decide on the electronic element of the digital stethoscope. He is familiar with PSPICE and Multisim circuit simulation software's, so his tasked with testing our circuit design and MATLAB codes. Simon's experience working on project designs will be crucial to organizing and creating our prototype.
- Gustavo Martinez  
Responsible include file transfer, wireless connectivity and record feature. Also, he will assist with testing the circuit design along with Simon.

#### A. Laboratory Prototype Device (2017)

The budget of the project was funded by all the team members. At the beginning of the semester, we decide on a budget of 200 dollars for the fall term. The budget would include the microprocessor, electronics elements like capacitors and resistors, microphone, and any additional hardware or software components. Additionally, on the Purchased List Table we list all the items purchased or owned and the cost.

TABLE I

Funding (Fall 2017) [18]

Team 9	Fall 2017 Budget	Fall 2017 Money Spent	Fall 2017 Money Saved
ESG	\$ 200.00	\$ 134.64	\$ 65.36

TABLE II

List of Purchased Parts (Fall 2017) [19]

Item(s)	Cost
(2) Raspberry Pi 3	\$ 0*
AA Batteries Bundle	\$ 12.34
32GB MicroSD Card	\$ 14.80
HC-05 Bluetooth Module	\$ 9.99
HC-06 Bluetooth Module	\$ 8.99
Prototype Board	\$ 0*
Arduino	\$ 23.64
Micro SD card adapter reader SPI module	\$ 9.28
SRA #99-20 Rosin RMA soldering flex pen	\$ 8.09
Breadboard Jumper Wire kit	\$ 14.99
Adafruit MEMS Microphone Breakout	\$ 11.99
Adafruit Silicon MEMS breakout	\$ 8.58
Total:	\$122.69

## IV. FUNDING

TABLE III  
Labor Hours (2017) [20]

Team Member	Primary Task(s)	Hours
Edward Isham	<ul style="list-style-type: none"> <li>• Research (Areas in societal problem, filtering, and signal processing)</li> <li>• Interviews (Carrington College professor and doctors at the Well)</li> <li>• MATLAB and Simulink</li> <li>• Report Writing</li> </ul>	141 Hours
Simon Chen	<ul style="list-style-type: none"> <li>• Research (Areas in societal problem, amplifiers, and signal processing)</li> <li>• Interviews (Carrington College professor, doctors at the Well and a nurse at Mercy Clinic Infectious Disease)</li> <li>• MATLAB and Simulink</li> <li>• Report Writing</li> </ul>	145 Hours
Gustavo Martinez	<ul style="list-style-type: none"> <li>• Research (Areas in societal problem, Bluetooth, and signal processing)</li> <li>• Interviews (Nurse at Mercy Clinic Infectious Disease)</li> <li>• MATLAB and Simulink</li> <li>• Timeline, PERT and Gantt Chart using MS Project</li> <li>• Report Writing</li> </ul>	114 Hours

Team Total Hours (Fall 2017)	400 Hours
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### B. Deployable Prototype Device (Spring 2018)

The Spring 2018 budget of the project was funded by all the team members. At the beginning of the semester, we decide on a budget of 100 dollars for the Spring term [TABLE IV]. The budget for the spring semester is smaller because we purchased the bulk of the components in the fall semester. The budget would include an Electret Microphone amplifiers, case, cables, and other components to finish the project. As seen in [TABLE IV] we spent 87.45 dollars and had a savings of 12.55 dollars of our budget. Additionally, on the Purchased List Table we list all the items purchased or owned and the cost.

TABLE IV  
Funding 2018 [43]

Team 9	Spring 2018 Budget	Spring 2018 Money Spent	Spring 2018 Money Saved
Electronic Stethoscope	\$ 100.00	\$ 87.45	\$ 12.55

TABLE V  
List of Purchased Parts (2018) [44]

Item(s)	Cost
Adafruit Electret Microphone Amplifier – MAX9814	\$ 7.95
Raspberry Pi 3 Case	\$ 20.00
HDMI cable	\$ 6.99
Double Sided PCB Board Prototype Kit	\$ 6.99
Toggle Switch	\$ 1.22
Sony Bluetooth Speaker	\$ 38.00
Screws and washer	\$ 6.30
Total:	\$ 87.45

TABLE VI  
Labor Hours 2018 [45]

Team Member	Primary Task(s)	Hours
Edward Isham	<ul style="list-style-type: none"> <li>• Work on System Integration</li> <li>• Testing</li> <li>• Order Components</li> <li>• Consult with Dr. Smith</li> <li>• MATLAB and Simulink</li> <li>• Documentation</li> </ul>	185 Hours
Simon Chen	<ul style="list-style-type: none"> <li>• Work on System Integration</li> <li>• Testing</li> <li>• Consult with Dr. Smith</li> <li>• MATLAB and Simulink</li> <li>• Documentation</li> </ul>	185 Hours
Gustavo Martinez	<ul style="list-style-type: none"> <li>• Work on System Integration</li> <li>• Testing</li> <li>• Order Components</li> <li>• Python Scripts</li> <li>• Timeline, PERT and Gantt Chart using MS Project</li> <li>• Reporting Assignments</li> </ul>	112 Hours
Team Total Hours (Spring 2018)		482 Hours

## V. PROJECT MILESTONE

### A. Project Schedule (Fall 2017)

- Problem Statement

- In this project, we explore the physician shortage issues by offering a solution that will increase productivity and reduce cross-contamination. This solution is accomplished by design an electronic stethoscope.
- Design Idea Contract
  - Created a punch list of the features available on our stethoscope. The features include wireless connectivity, amplification, filtration, and a simple design.
- Work Breakdown Structure
  - Design a template where we divided the project between the team member. These divisions were then subdivided into three levels with a smaller working package.
- Risk Assessment
  - We identified potential risks with our stethoscope project. Then, we created a mitigation plan for those potential risks.

### B. Milestones and Other Significant Events (Fall 2017)

- MATLAB/Simulink – The filtering and amplification feature is accomplished using Simulink.
- Bluetooth Configuration – The wireless connectivity will be done using Bluetooth.
- Real-time Data Acquisition – Real-time signal processing provides a complete and accurate WAV sound file.
- 3D physical Design – Some parts of the device will be 3D printed in order to achieve a small dimension lightweight design.
- Laboratory Prototype Documentation and Presentation – Was able to acquire and filter heart auscultation. We created a Simulink block that acquired and filtered the acquisition of a microphone plugged into a pc.

### C. Project Schedule (Spring 2018)

- Problem Statement Revisions
  - In this report, we re-exam the physician shortage issues. We look at how to improve the electronic stethoscope from the previous semester. Again, this solution will increase productivity and reduce cross-contamination.
- Device Test Plan
  - We devised a three-level device test plan where we tested each unit, integration of components and the whole system. The main purpose of the test plan is to test at the component level and each feature from the punch list. These features include wireless connectivity, amplification, filtration, and a simple design.
- Market Review
  - The market review is a report where we research the marketability of our medical device. We explored the medical device industry and current implementations of the electronic stethoscope. We concluded that our device could enter the market because it offers features that current implements do not offer.
- Feature Presentation
  - Each team member presents their respective feature and the test results for the device test plan.

### D. Milestones and Other Significant Events (Spring 2018)

- MATLAB/Simulink – Post-filtering and amplification feature is accomplished using Simulink. There is also pre-amplification with the electret microphone with an adjustable gain.
- Bluetooth Configuration – We used Bluetooth technology to playback the recorded auscultations via a wireless speaker.

- Real-time Data Acquisition – Real-time signal processing provides a complete and accurate WAV/MP3 sound file.
- 3D-printed Case – A 3D-printed case was ordered to achieve a small dimension lightweight design.
- Laboratory Prototype Documentation and Presentation – Was able to acquire and filter heart auscultation. We created a Simulink block filtered the acquisition of a microphone plugged into a pc.

## VI. PROJECT WORK BREAKDOWN STRUCTURE

### A. Wireless Connectivity

The wireless design in the electronic stethoscope will give medical practitioner freedom to interact with the patient without worrying that they are too close to the patient. The wireless connectivity will use Bluetooth technology to make the device portable and convenient. This technology will allow the user to sync any Bluetooth ready device with our electronic stethoscope. The first task to be complete is to install an operating system on the Raspberry Pi. We chose the Raspberry Pi 3 because it is Bluetooth ready and its computational performance. As seen in [TABLE VII], the wireless connectivity has three levels, and each level is subdivided. The level 2 has three sections: installing the necessary drivers, establish a connection and automation [TABLE VII]. We chose Raspbian because it is a lite version of the Linux distribution Debian. Next, we installed the Bluetooth and audio drivers. We installed Bluetooth Bluez and PulseAudio. The level 3 also, has three sections: configuring Bluetooth through Bluez driver, verifying pairing through settings and main a connection within a range of 10 feet [TABLE VII]. Bluez provides support for the Bluetooth protocol stack for Linux distribution. PulseAudio is a sound server that helps with transferring audio to different machines and change sample format.

TABLE VII  
Wireless Connectivity [21]

<u>Level 1</u>	<u>Level 2</u>	<u>Level 3</u>
Wireless Connectivity	Installing Bluetooth	Configuring Bluetooth module
	Establish wireless connection	Verifying pairing
	Script to automate process	Maintain a wireless connection with device at a range of up to 10 feet

### B. Sound Enhancing

The amplifying feature eliminates the need for multiple devices by allowing each doctor to adjust the gain output. It also eliminates the need to manually switch between bell and diaphragm chest piece. These adjustments to the stethoscope enables the medical practitioner to be more productivity which helps combat the societal problem of doctor shortages. As seen in [TABLE VIII], the amplification is divided into two sections for level 2 – the circuit design and unit testing. As seen in [TABLE VIII], the amplification is divided into two sections for level 2: the circuit design and unit tests. Amplifying circuit design subtask will strictly be achieved through hardware, utilizing electret microphones, prototype board, amplifier, and other passive circuit elements. Once the circuit is completed, we will test the design based on three specific ranges as specified in the table above. The level 3 describes the two frequency ranges of the stethoscope with adjustable gain [TABLE VIII].

TABLE VIII  
Sound Enhancing [22]

<u>Level 1</u>	<u>Level 2</u>	<u>Level 3</u>

Sound Enhancing	Amplifying circuit design or MATLAB coding	Low frequency – range of 20 Hz to 500 Hz, with adjustable gain
	Test Design	High frequency – range of 100 Hz to 1000Hz, with adjustable gain
		Simulation

### C. Noise Elimination

The noise elimination is the most important feature because distinguishing the input signal and from background noise is fundamental for high fidelity. As seen in [TABLE IX], the breakdown of the filtration is between the design and test case. The digital noise filters pre-process will be a software solution that will simulate on Simulink. We tested our filters on a computer-aided program then simulated on Simulink. We used a Butterworth topology to benefit from the flat passband frequency response and normalization of the low pass filter. High fidelity is measured by the signal-to-noise ratio (SNR), so one of the objectives of our filtering process is having high SNR. The signal-to-noise ratio is the ratio between the power of the signal over the power of the noise.

TABLE IX  
Noise Elimination [23]

<u>Level 1</u>	<u>Level 2</u>	<u>Level 3</u>
Noise Elimination	Filtering circuit design within MATLAB	Digital filtering process to eliminate noise (Low/High pass Butterworth)

	Test Design	Simulation
--	-------------	------------

files to WAV format then it is store to a secondary storage.

#### D. Lightweight Design

The device design must improve the usability, performance, and versatility. As seen in [TABLE X], there are two sections for level 2 – designing a small device and testing the prototype. Designing a lightweight stethoscope makes the device easier to move and use. The surface area of the device also plays a critical role to reduce cross-combination. A flat design helps reduce contamination and it makes it easier to disinfect

TABLE X

Lightweight Design [24]

<u>Level 1</u>	<u>Level 2</u>	<u>Level 3</u>
Lightweight Design	Small and portable	One-piece design that will be 13.56mm x 31.55mm x 25mm (or less)
	Breadboard for prototype	Flat surface

#### E. Storage and File Transfer

The record and store feature will enable the medical practitioner to transfer the audio recording to a paired device or transfer manually by removing the microSD. The ability to record auscultation allows for research, studying patient’s history thoroughly, and telemedicine. We identified that by delegating auscultation tasks to nurses so doctors can spend more time with patients. Nurses could use our lightweight stethoscope to take initial readings and have the results transferred to the doctor remotely. As seen in [TABLE XI], this feature is subdivided into two sections: the record and storage. First, we encode the raw sample sound

TABLE XI

Storage and File Transfer [25]

<u>Level 1</u>	<u>Level 2</u>	<u>Level 3</u>
Record	Encode raw sample into WMA format	Script to automate process
Store	Store into a secondary storage	

#### F. Responsibility Chart

TABLE XII

Individual Responsibility Chart [26]

Feature	Team Member	Hours
Wireless Connectivity	Gustavo	25 Hours
Amplifying	Simon	50 Hours
Filtering	Edward	50 Hours
Record and Store	Gustavo and Simon	20 Hours
Lightweight Design	Edward and Simon	10 Hours

## VII. RISK ASSESSMENT

The risk management plan we created to mitigate or deal with potential risk. Our framework consists of four steps: identifying the risk, determining risk factors and impacts, strategies for risk and possible mitigation or monitoring. The first step involves identifying risks in our deliverables. We use a RACI matrix to assign responsibilities, manage accountability, and consulting or informed with other team members [TABLE X]. The following step is to determine the risk factors and impacts of the all the tasks. We use a risk matrix to analyze the probability and impact of the work packages. This matrix also serves as a visual

representation that correlates the critical path and the impact of each work package. The following step is to determine the appropriate strategy to deploy. There are two factors that determine the strategy: impact of the control measures and the effects of the order of prioritization. Lastly, it is the mitigation or monitor strategy we will likely implement in the event of an unpredictable outcome or risk. We will only get to this step if we choose to avoid or control the identified risk.

The risk management for the deployable prototype is strictly following the risks that we identified last semester. We trying to avoid every risk that we defined on the risk matrix. However, risks will happen no matter how hard we are trying to avoid it. One of the risk that we realize is that the interface between each component of the device during the system integration. How we can make sure that our device will not get major damage if any of the subcomponent has a short circuit. Another major risk that we met is switching to a whole new platform for the system integration. At the beginning stage of the design, we all agreed on using Arduino Uno as our integration platform. However, as we have a better technical understanding of the project along the way, we found that Arduino Uno might not be the best option for us. Not only it will give us a great challenge about the wireless connectivity feature, but also it is really to hard deploy the Simulink model onto Arduino Uno while the modeling is running externally. Therefore, we decided to change the platform and use Raspberry Pi3 after a compressive consideration. By taking this step, we fully understand that we are risking our entire project because all the works we have done are based on Arduino Uno. Therefore, we need to put extra hours into the project to ensure that all features will still be accomplished while we switching to Raspberry Pi3.

#### A. Identify Risks

Identify the risks associated with the individual task is the first step in our risk management.

Identify risks was our first step because if we could identify possible issues before they happen, we would have a better hold on our project. On the work breakdown structure, we took our design feature list and broken them down into smaller more manageable activities. We then were able to identify and assign these activities to our team member based on their strengths. We concluded that based on the feature list we were likely to experience issues with hardware because of failures, component issues, or overheating.

Wireless Connectivity: Bluetooth wireless is crucial in our design. The earpiece receiver must properly receive sounds from the chest piece device before other tasks can be implemented.

- Issues with Connectivity
- Latency
- Issues with Pairing
- Issues with Bluetooth module

Sound Enhancing: With the connection established, sound enhancing must work so that doctors can understand the sounds clearly and to the desired volume.

- Circuit Failure
- Electrical Component Failure
- Analog-to-Digital Conversion
- Negative feedback
- Power Management Issues

Noise Elimination: As the auscultations are amplified with the adjustable gain, the noise must also be kept at minimum. Many issues can go wrong during the filtrations.

- Issues with filters
- Electrical Component Failure
- Nonlinear filtering issues
- Power Management Issues
- Issues with N-stage filter system

Lightweight Design: As more measures are in placed to mitigate the above risks, the designs may become larger or heavier. We need to keep the weight and dimension within the range of our feature list specification.

- Issues with weight

- Issues with dimensions
- Issues with materials used

Record and Storage: As the stethoscope attained good sounds and connectivity, the recording and storage feature completes by adding more productivity to the device. A few things can still go wrong here.

- Electrical Component Failure
- Software Failure
- WAV Conversion Issues

### B. Risk Management

TABLE XIII  
RACI Matrix [27]

Task/Name	Gustavo Martinez	Edward Isham	Simon Chen
Wireless Connectivity	RA	I	I
Amplifying	I	RA	C
Filtering	I	C	RA
Record and Store	RA	I	I
Testing and Simulations	AI	A	A
Circuit Design	ACI	A	A
PCB Design	AI	A	A

RACI Matrix:

- R: Responsible for the task
- A: Accountable for completing the task
- C: Consulted before completing the task
- I: Informed about tasks results

### C. Risk Impacts/Factors

Analyzing the risks factors and impacts is the second step in our risk management. The risk matrix was created to identify the likelihood and the probability of risk [Fig. 6]. This matrix has three colors the blend together where red is the most critical, yellow is the mild, and green is the least critical. As seen in [Fig. 6], the vertical axis represents the probability of risk, and the horizontal axis represents the impact of that risk.

	Software issues	Accuracy	Circuit failure	Filtering
Probability	Wireless connectivity	Power Distribution	Amplifying	Various ranges of frequency
	Simplicity	Record and Store	Function failure	Processing time
	Cost		Hardware Failure	
	Physical Design	Human Failure		
				Impact

Fig. 6. Risk Impacts [28]

### D. Strategies

We have four control measures that we could use: risk transfer/contracting, avoidance, control and acceptance. Depending on the severity of risks we will choose the appropriate control measure. We will also, prioritize events with higher impact on the project which are those events in red. In the filtering and amplifying feature, we will order parts with a lower failure rate. These types of order will reduce the occurrence of a defective circuit. Also, we will keep communicating with a medical professional to ensure that the sound quality is acceptable. By consult medical professionals we will reduce the occurrence of the risk for unacceptable sound. Various actions will be taken during our project to minimize the possibility of a risk occurring.

1. Risk Transfer/Contracting
2. Risk Avoidance
3. Risk Control
4. Risk Acceptance

5. Fully understand the characteristic of Raspberry Pi3
6. All the ground wire for the subcomponents will connect to one single termination. Therefore, any short circuit happened to subcomponent the device will shut off to prevent future damages.
7. Calculate the power consumption for each component. Make sure that no overload circuits in the device.
8. To achieve a much more stable device with less electrical induced noise, the electret transducer will be powered separately instead of taking 3.3V directly from GPIO pins.

#### E. Mitigation Plan

We have a mitigation plan for high or unavoidable risks. Should such high risks occurred, we will still be able to achieve the final product in an alternative way. The following plan covers several of high risks in our project such as filtering/amplifying circuit failure and safety aspect of the project. We created a RACI matrix in order to identify the responsibility of each team member [Fig. 6].

#### Possible Mitigation Plan:

- Choosing components that are more reliable without worrying about cost. In other words, by using more of the budget to get good quality components reduces the chance of failure.
- Revising the feature set. For example: if we only have a gain of 6dB instead of the proposed 8dB, we will have to revise the feature set to 6dB.
- Using nonconductive materials for device ensure that it is absolutely safe to have directly contact with human.
- Using components that have less power consumption for a longer lasting operating period.
- Have all spare electrical components that we used in the device
- Have back up software for the Raspberry Pi

- Keep all the codes and design from previous project
- Work on new design little step at a time

## VII. DESIGN DOCUMENTATION

### A. Hardware

The General Concepts: In the case of the acoustic stethoscope, doctors would place the chest piece's diaphragm against the chest of the patients to obtain heart sounds. From the diaphragm, body sounds would travel through a sealed tube, and traverse through it until it reaches the ear piece. The design of the ESG is aimed to be similar, and it will have a diaphragm and a tube. The most important component of sound acquisition is the transducer. According to Wikipedia, the generally accepted standard range of audible frequencies is from 20 to 20,000 Hz [10]. The following table lists how these frequencies are broken down.

An electret microphone is a type of electrostatic capacitor-based microphone, which eliminates the need for a polarizing power supply by using a permanently charged material. An electret is a stable dielectric material in which, due to its high resistance and chemical stability, will not decay for hundreds of years. The following picture from Wikipedia shows a typical electret microphone preamp circuit using an FET in a common source configuration. The FET is externally powered by a supply voltage  $V_+$ . The resistor sets the gain and output impedance. The audio signal appears at the output, after a DC-blocking capacitor. [11]

- Electret Transducer  
Specification:
  - Output a few millivolts peak-to-peak voltage
  - Bandwidth: 20-20,000 Hz
  - -44 dB sensitivity
  - Operating Voltage: 3V
  - 6mm diameter x 4.5mm depth
- Implementation:  
In a nutshell, the ESG will utilize a diaphragm as contact for picking up the sound initially. The sound will traverse

through a medical tube right to the microphone, which will be tightly sealed inside the tube. From the microphone, the output will be soldered onto the receiving wires of an audio jack. The jack is then plugged into the Raspberry Pi 3, our microprocessor, for further processing.



Fig. 7. Adafruit Electret Microphone [12]

To receive the best sound, we used a single tube diaphragm. All body sounds that are picked up will go through this single tube right into the microphone. Next, a 6mm diameter microphone is inserted into the tube of the same size. While the microphone fits snugly inside a medical tube, the contacting surfaces were also sealed to minimize sound loss and to ensure that the microphone is always in place and not moved around inside the tube. The two pins of the electret microphone are then connected to two wires of an audio jack.

We have shown during our lab demonstration that live sound acquisition worked flawlessly via a desktop computer. This is not exactly the case with the Pi 3. The Raspberry Pi 3 version b does not have an input jack. Thus, we are currently using a USB-to-jack adapter to provide input from our transducer. We became aware of this limitation late due to our fixation on the earlier processor, the Arduino Uno. Although not how the device will look at the end, the following picture shows how device will be connected to the Raspberry Pi.



Fig. 8. Raspberry Pi Connectivity [13]

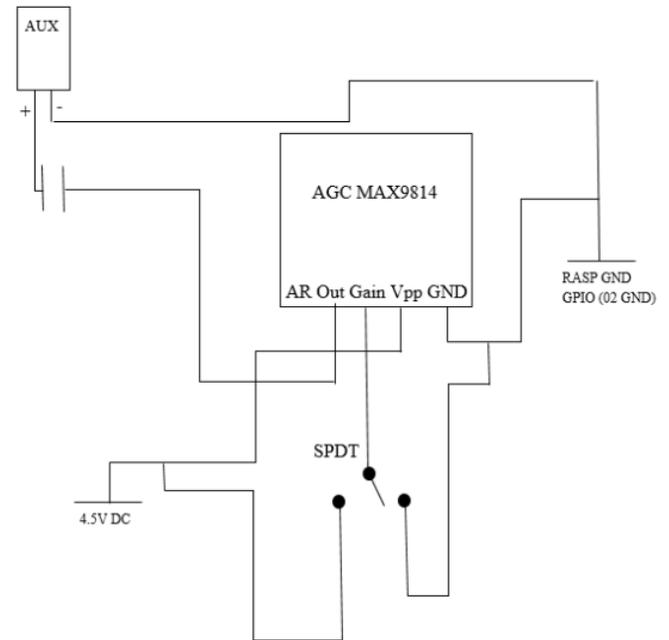


Fig. 9. Circuit [14]

### B. Software (Noise Elimination)

There were two approaches had been planned at the beginning stage of the design. One of the approaches is hardware based, this requires a filtering circuit design with several passive electrical components. The other approach is software based, the filters will be programmed within software and signal will be processed digitally. The team discussed and evaluated for both options and decided to process the signal digitally within Simulink software. By choosing this approach, it minimized the failure of electronic components and has a higher time efficiency. Although a digital software programmed filter will have a few seconds of delay at the initial stage due to the minimum requirement for data collection, the process will still be more stable than hardware filters with our current skill level. Meanwhile, other features' approaches will be planned based on filtering, because it is the main part of the entire signal process. For example, amplification of the signal need to be hardware based if filtering is performed through a designed circuit board. All features of the device are chained together. With a limited amount of time, it is easier to keep all the features under the same environment. After doing research of Simulink software, all features of our

device can be achieved within Simulink. Meanwhile, Simulink models are compiled on many hardware. This will help system integration in the future to complete a stand-alone device. Therefore, this will be the best option for this project.

#### *Audio System Toolbox (Simulink)*

- Algorithms for designing and prototyping audio processing system
- Enable low-latency signal streaming from and to the audio interface [15]
- Support C and C++ code generation
- Real-time generator

#### *Digital Signal Processing Toolbox*

- Provide algorithms for digital signal processing
- Design and analyze FIR filters
- Support fixed-point modeling and code generation from filters, FFT and IFFT.

#### *High-pass Filter*

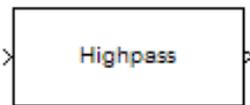


Fig. 10. High-pass Filter [16]

- Filter type: FIR or IIR
- Minimum order with specified passband and stopband frequency
- Specified passband ripple and stopband attenuation
- Input sampling rate
- Viewable filter response

#### *Low-pass Filter*

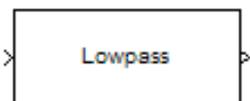


Fig. 11. Low-pass Filter [17]

- Filter type: FIR or IIR
- Minimum order with specified passband and stopband frequency
- Specified passband ripple and stopband attenuation
- Input sampling rate
- Viewable filter response

During the designing stage of the filters, a single bandpass filter was considered at first. The reason of this is a shorter processing time comparing with two separate filters. However, it is hard for Simulink to generate a minimum order bandpass filter with such low frequency range such as heart sound. It took a lot longer time to just generate the filter and even longer to start the simulation. Due to this problem, I decided to change the approach. Instead of using one single bandpass filter, two separate filters will be implemented into the design. One of them is a high pass filter, and the other one is lower pass. With the combination of a high and low pass filter, it will also achieve the functionality as a bandpass filter. By running the simulation, it is obvious to tell that the time takes to generate the filter is getting shorter. Meanwhile, simulation runs a lot smoother than the previous design.

Filter Parameters:

#### *1<sup>st</sup> High-pass filter parameter:*

- Filter type: FIR
- Minimum order design
- Stopband edge frequency: 22Hz
- Passband edge frequency: 30Hz
- Minimum stopband attenuation: 1dB
- Sampling rate: 44.1kHz

#### *2<sup>nd</sup> High-pass filter parameter:*

- Filter type: FIR
- Minimum order design
- Stopband edge frequency: 90Hz
- Passband edge frequency: 100Hz
- Minimum stopband attenuation: 0.7dB
- Sampling rate: 44.1kHz

### 3<sup>rd</sup> High-pass filter parameter:

- Filter type: FIR
- Minimum order design
- Stopband edge frequency: 15Hz
- Passband edge frequency: 20Hz
- Minimum stopband attenuation: 2dB
- Sampling rate: 44.1kHz

### 1<sup>st</sup> Low-pass filter parameter:

- Filter type: FIR
- Minimum order design
- Stopband edge frequency: 520Hz
- Passband edge frequency: 500Hz
- Minimum stopband attenuation: 1dB
- Sampling rate: 44.1kHz

### 2<sup>nd</sup> Low-pass filter parameter:

- Filter type: FIR
- Minimum order design
- Stopband edge frequency: 1.2kHz
- Passband edge frequency: 1 kHz
- Minimum stopband attenuation: 1dB
- Sampling rate: 44.1kHz

### 3<sup>rd</sup> Low-pass filter parameter:

- Filter type: FIR
- Minimum order design
- Stopband edge frequency: 22 kHz
- Passband edge frequency: 20 kHz
- Minimum stopband attenuation: 1dB
- Sampling rate: 44.1kHz

## C. Software (Wireless Connectivity)

Having a medical device that is wireless is one of the major selling points of the device. Most electronic stethoscope is not fully wireless and those that are cost a lot. What we try to target is a reliable and simple device that is allowed to communicate wireless to some computer system. As illustrated in, our design will allow users to use Bluetooth speakers or headphones to listen to the playback auscultations. Additionally, the standalone device will be able to be programmed wirelessly through internet protocols. Currently, we are able to link the Raspberry Pi with a static IP addresses and

bind a connection between the microcontroller and a laptop. Using Simulink, we can load various executables into the controller and then automate using Python. The fact that our design uses internet protocols mean that it can be integrate with any current network infrastructure. The device can be accessed remotely and load a new program within a local network.

We needed to choose a storage medium that was non-volatile and large enough to store a couple of recordings. We decide on flash memory because of its ease of use, simplicity, and modular form. The Raspberry Pi requires a large enough microSD card to house the operating system and will enable us to store our auscultations. Currently, we are using a 32GB San Disk microSD card which should be large enough for our system. We could also expand the amount of memory by using USBs to store more information. The deployable prototype system uses python scripts to automate some of the processes. One example of these scripts is the push button action. This code sets up the Raspberry Pi's GPIO pins to use a push button to automate a certain process. These processes are accomplished by running a script that executes commands from the terminal.

### Special Code Examples:

1. `GPIO.setmode (GPIO, BCM)`  
This piece of code numbers the IO pins on the Raspberry PI within the `Rpi.GPIO`. There are two ways of numbering the IO pins: using Board or BCM. The board argument refers to the pin layout on the P1 header of the board. The argument BCM refers to a low-level method to channel numbers on the system-on chip's microprocessor.
2. `GPIO.setup (23, GPIO.IN, pull_up_down=GPIO.PUD_UP)`  
The code then attaches a pin from the Raspberry Pi and specifies the attributes of that pin. These attributes setup the channel as either an input or output pin. In this case, we want an input pin changes the state of the system when pressed.

3. `cmd = "/home/pi/Desktop/untitled.elf"`  
The script needs the path or location of the executable. The location we chose is the desktop because it is the easiest to locate.
4. `process = subprocess.Popen (cmd, stdin = subprocess.PIPE, stdout=subprocess, 0)`  
This `popen` constructor creates a child program from a new process. The `popen` constructor takes several arguments but in this case we only need four: `args`, `stdin`, `stdout`, `stderr`. The `args` argument is a string that holds the path of the new child program. The defined `stdin` as `subprocess.PIPE`, `stdout` as `subprocess` and `stderr` as zero. The stream data going to the new child program, `stdin`, we defined as a new pipe for communication. The stream data output is defined as the process and the return status is zero.

## IX. DEPLOYABLE PROTOTYPE STATUS

As the status for the project, we are currently 90% complete the desired final deployable device. However, there is a feature in our feature set that is not accomplished. The filtering feature is programmed in a Simulink environment. Simon was assigned to this feature at the beginning of the project. He built a model with two digital filters with different cutoff frequency to achieve this feature. Edward is assigned for sound enhancing and live sound acquisition. Since Raspberry Pi does not have a sound input jack, Edward found out that a USB adapter can help us to achieve this feature. With the investigation of Raspberry Pi, Edward was able to acquire a real-time signal through the USB adapter. Me and Edward are both in EEE field, we designed a circuit board with a single pole double throw toggle switch to provide user selection of gain for the signal. Meanwhile, we found out that the sound file can be easily recorded and saved within Raspberry Pi and transfer the file to another PC with the microSD card. A standalone device was achieved by deploying the Simulink model on Raspberry Pi. Gustavo is assigned to the wireless connectivity of the device because he is the only CPE member in our team. He mentioned that it is

feasible to establish a wireless connection between Raspberry and another wireless device. However, we were told that it is extremely difficult to achieve such a feature toward the end of the semester by him. However, Gustavo found out that he can play back a recorded sound file through a wireless connected device. With a push button that he connected to the GPIO pins on the Raspberry Pi, he was being able to execute the command line and achieve a wireless playback. Originally, we want to have a streaming playback signal through a wireless device. Even though this is not what the original scope of the project is, he still implemented the wireless feature on the device.

### A. Hardware Test Plan and Results

- **Power Testing:** The Pi should be able to supply enough power to all the ports to run all the features, and not just limited to the Microphone.
- **Audio Connectivity:** The Pi should be able to record the sound live using a built-in or commercialized software such as Audacity. It should be able to play back the recorded sound with all noise intact, and ready for processing.
- **Audio Amplification:** The Pi should be able to process the live sound acquisition and generate an amplified output in real time.

### Results:

- **Power Test: PASS**  
The Raspberry Pi 3 could power and boot itself into its own Raspbian Operating System using its own AC power adapter. All ports were functioning as indicated by lights on all plugged-in devices. The diaphragm/microphone could generate sound.
- **Audio Connectivity: PASS**  
The Pi could record live sound and recording using a built-in recording software on the Raspberry Pi. Due to the poor quality of the built-in software, the sound obtained from the recording was subpar. Recommended by Pi users, third party software such as Audacity could not be

properly installed and led to multiple errors when installing, thus no results was obtained at present.

- **Audio Amplification:**  
While we could transfer Simulink function blocks onto the Pi as executables, we are still working on getting good recorded sound from non-live source so that we can gauge the amplifications.
- Based on our desktop yield, we expect our gain to be similar when the function is completely integrated onto the Pi.

#### *B. Software Test Plan and Results*

- Launch Simulink software with no error messages: PASS
- Both filters are generated successfully during compiling stage: PASS
- Code simulated successfully without warnings or errors: PASS
- Verify that the sound acquired through transducer, waveform observed on spectrum analysis and time scope: PASS
- Compare original and processed signal, observe a smoother and flatter frequency graph: PASS
- Filters load on raspberry with no errors, and process start performing: PASS
- All features performing smoothly with each other: PASS

## X. DEPLOYABLE PROTOTYPE MARKETABILITY FORECAST

### *A. Target Audience*

The target audience of our product will concentrate on two groups: professional medical practitioner and students in the medical field. The stethoscope is one of the most commonly used tools in the medical field and a requirement to learn how to use in this field. Some specialties will use stethoscopes more often such as cardiology and pulmonology. These specialists use a stethoscope as their first tool to detect any abnormalities in vital organs like the heart and lung. Therefore, it is

extremely challenging for medical students who just started in these two fields to catch these tiny abnormalities in the sound. Unlike books, students cannot take the sounds back home. Even though they might be able to get those sounds files online, but those files have already been processed for teaching purpose. With our recording feature of the device, professors will be able to acquire a sound from a real patient and record the sound file. With the sound being recorded, students can easily access those files for future study. Meanwhile, doctors can also record the sound for each visit of the patients and store the sound file under the database.

Therefore, the sound samples could be used for the comparison of several visits in order to see the changes of a patient. On the patient's side, patients would love to know how their bodies are reacting to the medical treatments. While hearing the file by themselves along with explanations from the doctors, it will be easier for them to better understand their condition and see how their bodies are reacting. As mentioned before, all the abnormalities of the sound are really hard to catch especially in a noisy environment. With the filtering feature of our device, students will be able to hear a filtered sound and catch the abnormalities much easier comparing to the traditional stethoscope. They can simply switch the modes of the device by using push buttons while they are listening to different locations of the body. For those low frequency sounds, doctors and students can adjust the volume by using a potentiometer in order to have a better listen for those sounds.

### *B. Current Economic Environment*

The price of a product that people can accept nowadays will be significantly higher than the past. It is obvious to tell that the price of any products has increased in today's society. Students pay hundreds of dollars for classes, therefore, the price of the ESG stethoscope is acceptable in the current economic environment. There are more new products invented each day, and the prices for the majority of these products are not cheap. However, consumers are still willing to purchase these products. Therefore, the current economic

environment has the ability to accept the high-priced products, proving that now is a viable time to introduce new products to the market.

### *C. Demographics Segmentation*

The main approaches for marketing the ESG stethoscope will be via social media and school. Since social media are widely used for all ages, it is a great strategy to expand the market. Social media has influenced today's society in many different ways as information are rapidly passed along via social media. Another approach that we can take for marketing is through school. Since students are one of our largest potential users, introducing the ESG stethoscope to the medical department should be the most efficient way to reach this specific group. By introducing the device during lectures or posting information in the bookstore, many medical students will be interested in learning more about the device and opt to try the new product. Our last approach to marketing is to introduce the ESG to hospitals, the place with the highest demands for the products. Doctors are more likely to afford our device than students, and they are required to have a stethoscope with them. By promoting the device within the hospital, this will bring the device to the professional medical field a lot faster.

### *D. Market Conditions*

The stethoscope is growing market because of investments from the government, private companies, and schools [29]. According to Selectusa, the United States remains the largest medical device market in the world, representing about 40 percent of the global medical device market in 2015 [30]. The medical devices industry will continue to grow with constant innovations and R&D investments. Also, with the approval by the FDA, the development of digital stethoscope should rise. As an example, Eko Devices had closed a two-million-dollar deal for its digital stethoscope attachment [29].

### *E. Market Size and Price Estimations*

There are currently five types of stethoscope in the market: acoustic, electronic, fetal, Doppler, and 3D-printed. The acoustic and more notably

electronic are dominating the market. The price for ESG will be lower than the existing similar products, the estimation will be between 100~125 dollars.

### *F. Market Barriers*

Analyzing the potential barriers to market entry is a critical part of the market analysis. Becoming familiar with the market becomes one of the major points in the market review. Here, we will be analyzing certain pitfalls and costs in entering this growing market. We will also analyze any weakness that our product will face when entering the stethoscope market. Then, we discuss the window of opportunity and government regulations.

- **Economies of Scale**  
This happens when there is a decrease in the unit cost of a product as production volume increase. Common sources include purchasing, managerial, financial, marketing and technological. We do see this as our biggest challenge to market entry because of the advantages that big stethoscope companies have and their dominance in the marketplace.
- **Product differentiation**  
We believe that our product lives in a different niche than the other because of the features we offer in our device. table 1 shows several of our competitor and the features and price point they offer.
- **Capital Requirements**  
We are currently not worried about capital requirements because we are still in the product development stage.
- **Switching Costs**  
We are currently not worried about switching cost because we are not transferring between markets.
- **Access to Distribution Channels**  
Because this market relies upon other industries like microelectronics, telecommunication, instrumentation, biotechnology and software, having access to a distribution channel will not be an issue [30].

- **Government Policy**  
This is the second biggest challenge to market entry and it revolves around patients and copyright. Government policy also includes compliance with HIPAA.
- **Competitor Analysis**  
According to Grand View Research, the major players in electronic stethoscopes include 3M, Medline Industries, Welch Allyn, GF Health Products, Rudolf Riester GmbH, American Diagnostic Corporation, Cardionics, Heine Optotechnik GmbH & Co. KG, and Smiths Medical [31]. From Scalar Market Research, newer companies such as Eko Devices, ThinkLabs Medical LLC, and SensiCardiac are also considered as key players [32]. The following chart breaks down the more common electronic stethoscopes of 2017 and their features in comparison to the ESG:

TABLE XIV

Feature Comparison [31]

	Eko Device: Eko Core	3M: Littmann 3200	Thinklabs: One	ESG
Amplification	40x	24x	100x	10x
Freq Range	20-2KHz	-	4 levels	3 levels
Bluetooth	Yes	Yes	No	Yes
Recordable	Yes	12 x 30s	External	Yes
File Transfer	Wired	Wireless	Wired	SD-Card
Battery Life	9 Hrs.	10+ Hrs.	~125 patients	10+ Hrs.
Acoustic/Dig	Both	Both	Digital	Digital
Price	\$200	\$400	\$599	< \$125

- **Market Share: Finding Information** regarding the Market Share of electronic

stethoscope has been difficult. Almost all the reports were conducted by profession business research group, thus consumers will need to pay a fee to review each company’s finding.

- **Sales Strategies:** To reach as many people as possible, these digital stethoscopes can be easily purchased online, either directly from the manufacturer’s website or through a third party. While Thinklabs One and the Eko Core are rather new in the market, 3M’s involvement in stethoscope technology goes back to the 1960s, with the acquisition of a company founded by Dr. David Littman. Littmann innovative design for a two-sided chest piece greatly improved the stethoscope acoustics, and help make 3M Littmann Stethoscopes the benchmark of the industry. As being a trusted name, the Littmann stethoscope often performs well in the market, and own the largest share of the digital Stethoscope industry [30].

Newer companies aim to break this trend by offering new features or design that shows modernity, as we can see from the modern design of the Thinklabs One. The Eko Core, however, reflects the dominance of acoustic stethoscope in the market. Thus, the Eko Core works as an add-on to the legacy device rather than replacing it completely. This design approach is aimed at users who are not entirely ready to change the look and feel of the original acoustic stethoscope. While all companies do try to reach out to their intended audience: doctors, nurses, medical students, their main advertisements are mainly through their company websites, or as advertisements on popular web pages and social media such as YouTube or Facebook. Videos showing the new sleek design and features is a very common way of advertising the new products.

In order to achieve an advantage over our competitors, the ESG must first target a smaller market. The product must contain the features that customers want at the price that they are willing to pay. It will definitely be more difficult, if not

impossible, to compete with the already established companies such as 3M. We aim to differentiate our product features from those already in the market. We must also ensure that the similar features we are offering are flawless and has the same standard as our competitors. Finally, we can set a price that will swing customers to purchase our product.

### *G. Product Differentiation*

Table 14 Feature Comparison shows how each of the three company differentiates their products. The ESG was also designed to be different. The ESG main goal is sound quality. Our engineering goal is to create an algorithm that produces the clearest amplified sound for our product. We are also offering wireless connectivity between the chest piece and the earpiece, thus reducing cross-contamination and the intrusive nature of performing an auscultation. Our recording features allow for more than twelve samples, and the recordings can easily be reviewed with generic software or database repository. Finally, the price of the ESG will be much lower than our competitors.

#### **Feature need to be improved:**

- Better electrical noise elimination, which includes an actual hardware passive component filtering circuit. While we are using software filtering we realize a few seconds delay to the actual audio signal playback. However, this is not the problem of a real-time system such as Raspberry Pi. This is because the Simulink model needs seconds to collect enough numbers of data in order to analyze and playback the sound signal. With an actual hardware circuit, this delay can be improved.
- Wireless connectivity needs to meet our desired requirement. Being able to wireless stream and play back a sound signal from the electret transducer.
- The size of the device can be designed smaller to achieve an easy access and storage.

## XI. CONCLUSION

The problem of doctor shortage in the United States is real and needs immediate attention. To improve the situation, we must tackle the problem from different perspectives. As engineers, we are using modern technologies to redesign the stethoscope to offer features that can improve the productivity within medical offices and hospitals. Our ESG digital stethoscope uses Bluetooth wireless connectivity. This feature provides doctors with some distance from their patients, thus lowering the risk of cross-contamination that could sideline any doctors. The ESG will also provide sound enhancing through amplification and noise reduction, a feature most useful to aging doctors who are losing their hearings. The ESG recording feature allows nurses to record samples from auscultations that can be transferred onto a repository for further analysis. This feature promotes productivity through task delegation, freeing extra time for doctors to examine other patients. It also shields doctors from more direct contact with ill patients. In addition, doctors can study these recorded samples to detect any anomalies or patterns, and perhaps catches the source of the problems early. Finally, the design of the chest piece is aimed towards simplicity to encourage the switch from the acoustic stethoscope.

As of this writing, the project is almost at its halfway point. We have achieved our sound amplification target by obtaining at least a 4dB gain. Through graphical visualization, we were able to identify that noises are being filtered out. We also have a Bluetooth module ready to achieve Bluetooth connectivity. First, we decided what approach we want to take to complete the feature. This decision is made based on discussion with other team members and evaluation of the feasibility with our current skill level. After a comprehensive consideration, we decided to develop all feature in Simulink software. Lots of researches have been done afterwards including possible function blocks that will be implemented into the system. We decided to use two separate filters (high-pass and low-pass filter) to build a bandpass filter. The reason of this is to reduce

processing time, and easier filter generation. We used an existing product in the market: Thinklabs One as reference to select the cutoff frequency for each filter. With multiple experiments, a best fitted passband frequency and stopband frequency has been selected. The feature passed the majority of the testing, and the integration part of the testing is still in progress. Lastly, the model will compile on Raspberry Pi3 for an independent device. Through researches and testing, we chose an electret transducer to pick up body sounds. The electret microphone can pick up sounds ranging from 20 to 20KHz. This is the exact range audible to humans. We then built our chest piece based on this microphone and integrated it to the Raspberry Pi 3 for digital sound processing. Instruction for this processing was first created on Simulink and then uploaded onto the Pi. It currently acts as an executable, but can be run automatically upon startup using a batch file. Thus, this is the process of my assigned features. Our goal in the next two weeks is to finalize our integration, create a housing, and finish all documents for our product,

After a comprehensive consideration, we decided to develop all feature in Simulink software. Lots of researches have been done afterwards including possible function blocks that will be implemented into the system. I decided to use two separate filters (high-pass and low-pass filter) to build a bandpass filter. The reason of this is to reduce processing time, and easier filter generation. I used an existing product in the market: Thinklabs One as reference to select the cutoff frequency for each filter. With multiple experiments, a best fitted passband frequency and stopband frequency has been selected. The feature passed the majority of the testing, and the integration part of the testing is still in progress. Lastly, the model will compile on Raspberry Pi3 for an independent device.

To achieve our objective, we subdivided the project into a set of deliverables that each team member would accomplish. The set of deliverables incorporate the core functions that our electronic stethoscope will have. We used a RACI matrix to assign a feature to each team member along with his supporting member(s) who would help track the

completion of the task. Each level-3 packages in the WBS will complete a piece of the core feature set. The report also covered our risk assessment plans in which we explored potential issues with our feature design and developed a risk matrix from these features. Our risk management plans were broken down into four sections. In summary, one to identify the problem, another to analyze the factors and impacts, another to explore control measures and how to prioritize those issues and the last to mitigate or monitor the issue.

Market Review provides insights and strategies to showcase our product commercially. By considering the smaller market and the current economic health of the country, the price of our product will be affordable and acceptable to students and educators. Thus our initial target audience will revolve around those in educational institutions, with a future outlook that the product will expand to clinics and hospitals. From the market analysis, the United States still has the largest medical device market in the world. Growth in the medical device industry will also continue to increase as both public and private sectors are supporting new innovations and R&D investments. The current market for the ESG is quite promising.

With the market looking bright ahead, many companies are competing for their market shares. In this report, we identified our distribution channels by analyzing our competitors and differentiating our product. The report identified top companies that are producing electronic stethoscopes and listed the leading products and their associated features. Famous and popular digital stethoscope brands such as 3M's Littmann, the Eko Core, and Thinklabs One, all offered many excellent features. To compete with such companies, we designed the ESG to be different in both technology and price.

When the ESG becomes available to consumers, we will be tracking and monitoring its progress in the market. Through continuous analysis of sales orders and feedbacks from our users, we would obtain valuable information to improve our product as well as our market share. We are expecting our market share to be slow during the first quarter,

however, projecting that the number will increase as the consumers become more accustomed to our product. Overall, we succeeded our project and the device is functioning the way we are designed at the beginning phase of the project. We learned that teamwork and an objective consideration will benefit the project in a long term.

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## Glossary

**Acoustic Stethoscope:** The more common type of stethoscopes without built-in electronic circuits.

**Bluetooth:** A wireless technology standard for exchanging data over short distances from fixed and mobile devices, and building personal area networks (PANs).

**Product Differentiation:** The process of differentiating a product or service from others in order to make it attractive in a target market.

**Competitor Analysis:** The process of identifying competitors and evaluating their strength and/or weaknesses of their product or services in a particular market.

**Distribution Channel:** A chain of business or intermediaries through which a good or services is passed until it reaches the consumer.

**Market Barrier:** Obstacles that prevent new competitors from entering a particular industry or area of business.

**Demographic Segmentation:** Segmentation according to age, race, religion, gender, family size, ethnicity, income, and education.

**Target Audience:** a particular group at which is the aim of a particular product or service.

**Diaphragm.** The listening device of the stethoscope, capable of listening to high level frequencies. It is usually the larger side of the chest piece resonator.

**ESG:** Project name based on our names Edward, Simon, and Gustavo.

**FDA:** Food and Drug Administration

**HIPAA:** (Health Insurance Portability and Accountability Act of 1996) is United States legislation that provides data privacy and security provisions for safeguarding medical information.

**Level of Effort:** (LoE) is a support-type project activity that must be done to support other work activities or the entire project effort. It usually consists of short amounts of work that must be repeated periodically

**Bell.** The listening device of the acoustic stethoscope, capable of listening to low level frequencies. It is usually the smaller cylindrical side of the chest piece resonator

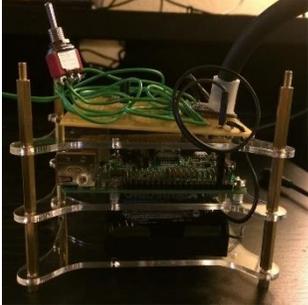
## Appendix A. User Manual

## Parts:

- 1 x ESG Main Unit
- 1 x Sabrent USB to jack adapter
- 1 x HDMI Cable
- 1 x AC Adapter 3V 2.1 A
- 1 x Battery Pack
- 4 x AA Duracell Batteries

TABLE XV

List of Parts [36]

<p>ESG Main Unit</p>  <p>Fig. 12. ESG Main Unit [37]</p>	<p>1 x HDMI Cable</p>  <p>Fig. 13. HDMI Cable [38]</p>	<p>1 x AC Adapter</p>  <p>Fig. 14. AC Adapter [39]</p>
<p>1 x Standard AA Battery Pack</p>  <p>Fig. 15. Battery Pack [40]</p>	<p>1 x Sabrent USB to jack Adapter</p>  <p>Fig. 16. Sabrent USB to jack Adapter [41]</p>	<p>4 X AA Batteries</p>  <p>Fig. 17. AA Duracell Battery [42]</p>

## HARDWARE SETUP:

**Step 1:** Connect the HDMI cable to the ESG unit. Plug one end of the HDMI cable to the ESG's HDMI socket, and the other end to the HDMI socket of the HDMI TV or HDMI Monitor.

**Step 2:** Insert 3 Alkaline batteries to the battery-pack holder, leave the fourth one for spare. Align the battery according to the etched drawing inside the battery pack.

**Step 3:** Connect the single ESG microphone jack into the **pink** input jack (microphone) of Sabrent USB-to-jack adapter. Then, plug this USB adapter into one of the four USB 2.0 inputs of the ESG.

**Step 4:** If you have an ear buds or speakers, simply plug the device's audio jack into the **green** Audio output jack of Sabrent USB-to-jack adapter. The green input jack supports numerous types of "**wired**" audio output. The ESG is currently not supporting **wireless** real-time streaming.

**Step 5:** Power the ESG by plugging the AC Adapter to the device, and plugging the adapter against the North American Standard (110V) wall socket. When the AC power adapter is properly plugged into the wall socket, the ESG should light up, and starts the boot loading process of the unit's Raspbian operating system.

**Note:** If there is nothing displayed on the screen, it is possible that you did not choose the correct input channel for your input device. Consult your TV manual on how to switch the input channel of your TV.

**Step 6:** Once the loading is complete, the ESG should be ready to go. Test your device by tapping the diaphragm of the ESG chest piece while listening for a real-time response on your chosen audio output. If you can hear the taps on your listening device, then the ESG is set up properly. Place the diaphragm at your chest, and you should be able to hear a faint heartbeat.

**Note:** If you cannot hear any sound, it is possible that the jacks are incorrectly plugged in. The microphone jack from the ESG main unit should be connected to the pink audio jack. Your listening device should be connected to the green audio jack.

**Step 7:** You can adjust the volumes of the ESG by flipping the switches. There are three settings associated with the switch: high, medium, and normal. Choose the settings that you are most comfortable with.

## SOFTWARE SETUP:

The ESG runs on a free Linux Raspbian operating system and can be easily configured for multiple applications. ESG acts like a regular stethoscope when the hardware setup is completed. However, the software installation allows the ESG to record the sounds and display the waveforms right on the screen using free third-party software such as SLV and Audacity. To run these programs,

**Step 1:** Click on Program → Audacity

or, Program → SLV

**Step 2:** Click on the **red** recording button to begin the recording process. You should be able to see a red recording button. While pressing the diaphragm firmly against your chest (auscultation), press this red recording button to begin the recording process. Once you are done with gathering the samples, press the stop (small square) button.

**Step 3:** Should you want to save this file for reviews, you can simply go to

File→Menu→Save as→

**Note:** A window will open with default location to store the recorded file. You may choose to save your recording into another folder by navigating to that new folder and enter the new filename for the file you just created.

**Step 4:** To retrieve this file for repository or for later viewing, you can select all the files and drag them into your USB drive in File Manager. Also, your office may already have a network setup, so you can simply highlight the new files, and drag the files to the designated network drive. If you do not see your designated drive to deposit these new sound recordings, contact your IT support to help set up the Raspberry Pi to your network. The ESG is similar to a Windows-based computer in terms of networking. Your IT support should be able to provide the ESG with passwords to connect to your own network.

**Note:** While the ESG does not work with real time wireless playback such as via Bluetooth speakers or earpieces, it can be configured to listen to audio recordings via Bluetooth. The ESG's Raspbian OS has a Bluetooth at the top right of the screen. By clicking it, a list of automatically detected Bluetooth device would appear. Choose the device that is yours to complete the pairing. Please consult your Bluetooth device's manual for to set up your listening device for pairing.

Appendix B. Hardware

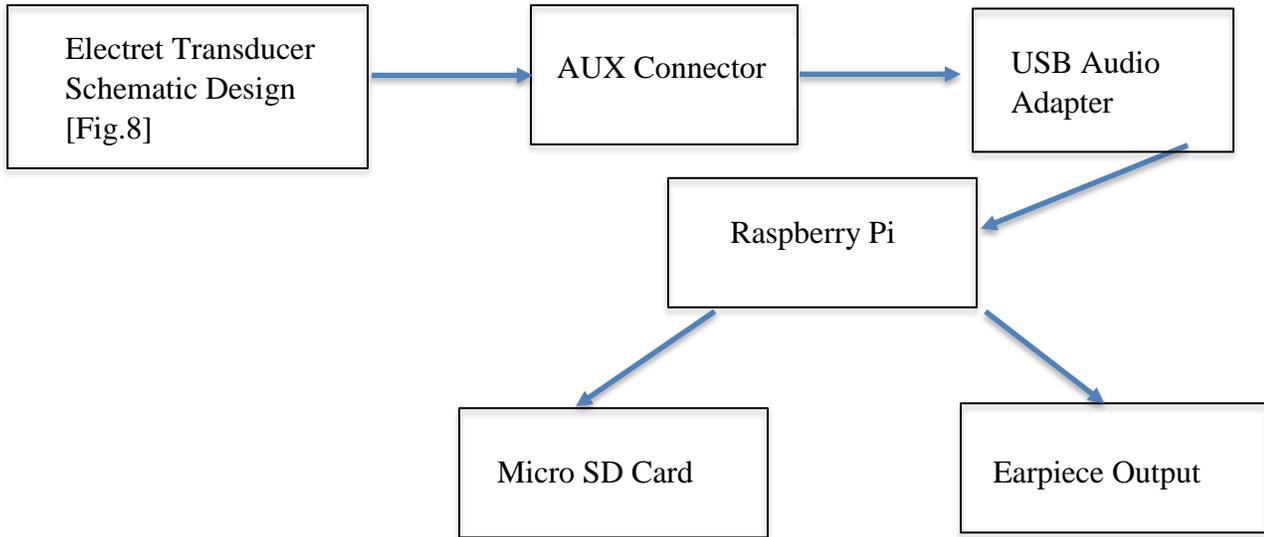


Fig. 18 Hardware Block Diagram [32]

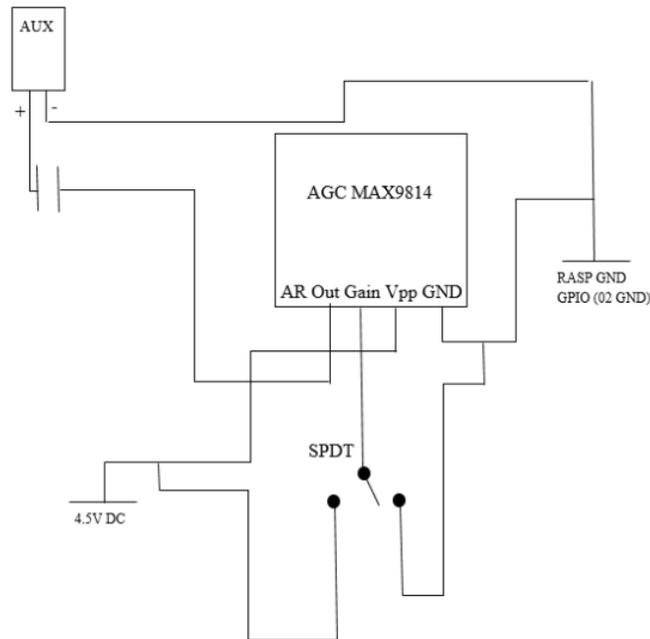


Fig. 19. Schematic Design [8]

**Technical Description for Electret Transducer (MAX 9814) and Sabrent USB Audio Adapter:**

- The default 'max gain' is 60dB, but can be set to 40dB or 50dB by jumping the Gain pin to VCC or ground [33].
- Attack/Release ratio, from the default 1:4000 to 1:2000 or 1:500 [33].
- The output from the amp is about 2Vpp max on a 1.25V DC bias, so it can be easily used with any Analog/Digital converter that is up to 3.3V input [33].
- Adapter has stereo output mode [34].
- 1 x USB 2.0 - 4 pin USB Type A 1 x headphones - mini-phone stereo 3.5 mm 1 x microphone - mini-phone 3.5 mm [34].

**Hardware Test Plan:**

- *Power up designed circuitry verify the input voltage is 4.5V which is supplied from three AA batteries from the battery pack.*  
**Result: PASS**
- *Connect the HDMI cord between Raspberry Pi and connect the power cord for the Raspberry Pi. Verify that the Pi is powered up successfully, and the monitor shows no error messages during the booting process.*  
**Result: PASS**
- *Connect the USB Audio Adapter in to the USB slot on Raspberry pi, verify that the LED indicator on the adapter has lit up and microphone indicator is not on mute mode.*  
**Result: PASS**
- *Plug the electret transducer circuit into the input jack on the USB adapter, and plug the output jack with earpiece. Verify a streaming sound signal can be heard via ear piece.*  
**Result: PASS**
- *Verify that all ground connection of the subcomponents has been connected to the ground GPIO pin that is located on Raspberry Pi. No observation of overheating components and over load circuits.*  
**Result: PASS**

All test results show positive as we are proceeding the test step by step. The test is designed to verify that no fault message has shown on the monitor. Meanwhile, all circuits are powered within its nominal operating voltage along with safe operation. The test results are acceptable for a prototype project, however for market purpose the testing procedure need to design in a much more industrial and professional way in order to complete all medical regulations and electronic devices exam and regulations.

**Revision:**

One of the major revision has been made to the device after testing is the connection of the circuits. We found out that we can hear clear induced electrical noises while we power up the transducer circuit with the 3.3V GPIO pin from Raspberry. The original idea is we can save the size of the device by powering subcomponents from Raspberry. However, we realized that the noise gets reduced while we trying to power the circuit up with a separate external battery pack. Weighing the good and bad side of the solution, we decided to accept the tradeoff for a better-quality sound. All ground connections are tied at the same GPIO pin, any short connection on the wiring will shut off the Raspberry Pi for preventing future damage.

## Appendix C. Software

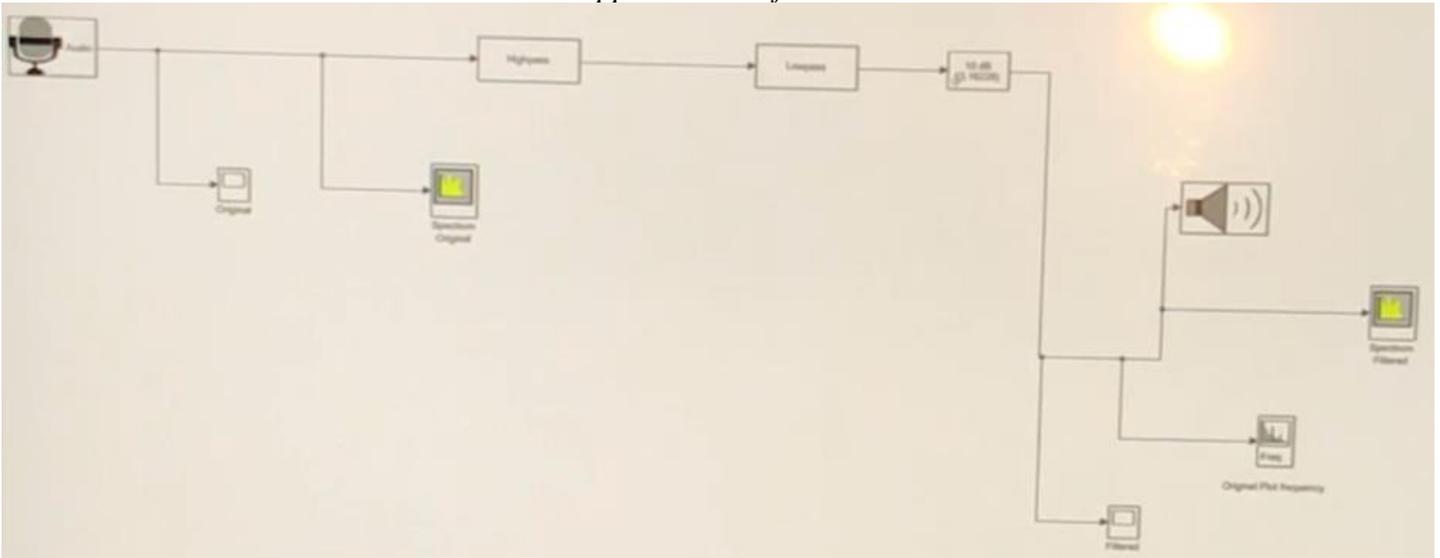


Fig. 20. Simulink Model [35]

**Simulink Model Testing Procedure:**

- *Launch Simulink Model on PC, verify that the model is loaded successfully without any error message.*  
**Result: PASS**
- *Change the sampling time of the model to infinite to achieve a continuous streaming and run the simulation of the model.*  
**Result: PASS**
- *Verify that all time scopes and spectrum analyzer has launched successful with no errors*  
**Result: PASS**
- *Select the target hardware (Raspberry Pi), and verify the IP address of the Raspberry Pi is correct*  
**Result: PASS**
- *Deploy the model to target hardware, verify the model has been loaded successfully*  
**Result: PASS**

All test results for the Simulink software turn out to be positive, it confirms that our model has been deployed onto the Raspberry Pi successfully. It is a positive outcome for our prototype device. Same as hardware testing, the procedure needs to be improved in order to meet the requirements and standards for market use.

**Revision:**

We did not make too many revisions to the Simulink Model except two function blocks. From previous laboratory prototype, we used “Audio Write” and “Audio output” functions blocks to achieve a streaming audio signal. Since we are switching to Raspberry Pi towards the end of the project. Minor corrections for the model need to be made. Instead of Simulink function block, we need to using Raspberry Pi hardware toolbox instead. We implemented “ALSA Capture” and “ALSA output” function blocks in order to access the sound card of Raspberry Pi. ALSA Mixer is the sound processing software that Raspberry Pi uses. The model maintains the method of solving via discrete time along with fixed point. Overall, we are able to pass all testing procedures with minimum modification to the model.

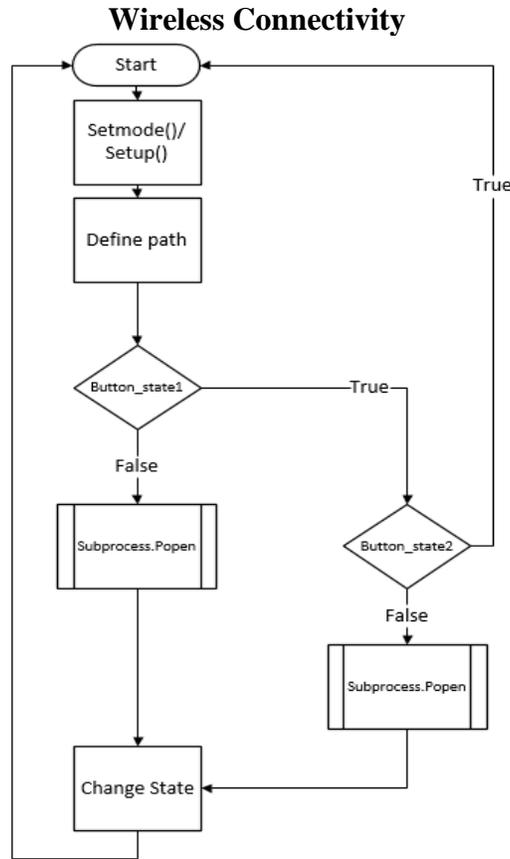


Fig. 21. Software Block Diagram [42]

**Block diagram & documentation at the block level:**

The procedural transitional block diagram is shown in [Fig 48]. We start from the point of view of the microcontroller where we defined a path to the location of the executable. For simplicity, we chose the desktop of the Raspbian Operating System. From the command line, we continuous execute the script in [Fig 50].

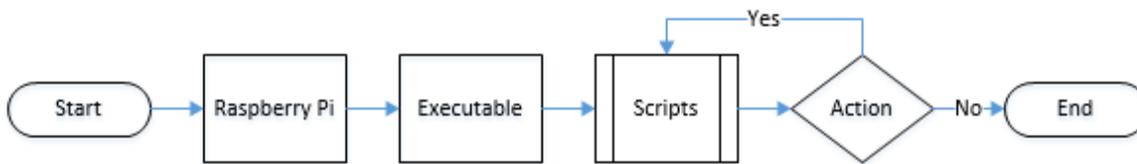


Fig. 22. Block Diagram 1 [47]

At the subroutine level the diagram is details the flow of the scripts [Fig. 3]. In the beginning of the script, we have to define and initialize the pins used for the push buttons. We also, chose the location of the path as describe before. Next, we initialize the states of the variables to true in the while-loop. We used reverse logic to define the action on the button, so true means the button is not pressed and false means the button is being pressed. Then, depending on the button pressed we spawn a child process that will execute a set of commands, sleep for a few seconds, and terminate.

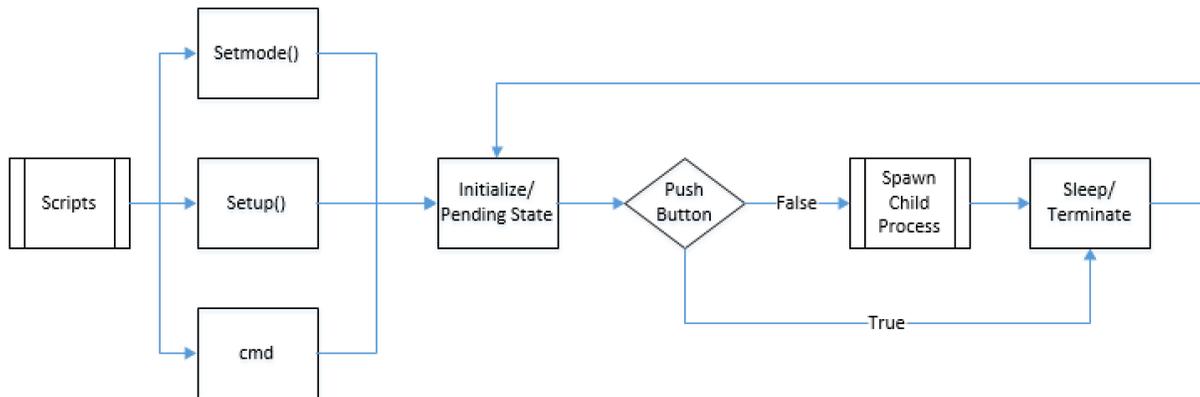


Fig. 23. Block Diagram 2 [48]

```

1  #!/usr/bin/python
2  import subprocess
3  import RPi.GPIO as GPIO
4  import time
5
6  GPIO.setmode(GPIO, BCM);
7  GPIO.setup(23, GPIO.IN, pull_up_down=GPIO.PUD_UP) #executable
8  GPIO.setup(24, GPIO.IN, pull_up_down=GPIO.PUD_UP) #bluetooth
9
10 cmd = "/home/pi/Desktop/untitled.elf"
11
12 print("Press command..")
13 while True:
14     button_state1 = GPIO.input(23);
15     button_state2 = GPIO.input(24);
16     if button_state1 == False:
17         print('Button Pressed...')
18         time.sleep(0.3)
19         process = subprocess.Popen(cmd, stdin = subprocess.PIPE, stdout=subprocess, 0)
20         #process.wait()
21         time.sleep(15)
22         process.terminate()
23     elif button_state2 == False:
24         print("Work Work Work")
25         time.sleep(0.5)
26         button_state2 = True
27

```

Fig. 24. Example Code [49]

The software test plan was simple for this script. We research different python constructors that could spawn child process and methods. The objective of the plan was for the Raspberry Pi to take in the state transition of the defined pins. The software testing results are suitability to the market because most industry try to automate different processes. The typically approach is to write batch files in a scripting language like Python, Ruby, or Perl and automate certain actions. In our case, we simplified the electronic stethoscope by having push buttons and toggle switch. There was no revision after software testing, but we did expand on the script by adding an addition push button that will play the saved auscultation sound file.

*Appendix D. Mechanical Design***Qunqi Acrylic 4-layer Clear Case Box Enclosure For Raspberry Pi [46]:**

Fig. 12. Raspberry Pi Enclosure [46]

**Specifications/Dimension:**

- 6 x 3.9 x 0.8 inches [46]
- 6.4 ounces [46]

**Revision:**

At the beginning stage of the design, we decided to 3D print a single box shape enclosure in order to achieve a light weight compact device. However, we realize the problem of this approach during our final device testing. We found out that we need to have a better isolation for each circuit and component of the device to reduce electrical noise. Based on this approach, we purchased the spacer as show. Each subcomponent of the device will have its own slot, maximize the distance between each component. We found out that this mechanical design will benefit our design the most.

*Appendix E. Vendor Contacts*

**Warren D. Smith, Ph.D.**

Professor of Communication Theory & Bioengineering at California State University, Sacramento  
6000 J St, Sacramento, CA 95819

**Julie Meylor, RN, MS, CIC**

Infection Control Practitioner at Mercy San Juan Medical Center  
Coyle Avenue, Carmichael, CA 95608  
[mercysanjuan.org](http://mercysanjuan.org)

**Debra Pepper, MHA, CCMA**

Program Director, Medical Assisting at Carrington College  
8909 Folsom Boulevard, Sacramento, CA 95826

## Appendix F. Resumes

## Guangyao Chen (Simon)

OBJECTIVE

To obtain an Engineering Full-time position in Electrical and Electronic Engineering field

EDUCATION

Bachelor of Engineering, Electrical and Electronic Engineering  
California State University, Sacramento, CA Current GPA 3.114

Expected: May 2018

SKILLS

Scripting/Programming Languages: C++, C, VBA, Python, Verilog

Computer Experience: Microsoft Office

Engineering Tools: PSPICE, Oscilloscope, SolidWorks, FPGA, Microprocessor, MATLAB

Language Skill: Chinese (Mandarin)

Organization and Communication Skill: Participate in a team of 4 in school's projects and working with the engineering team at Siemens Mobility Division. Commended on great attention to details and ability of collaborating with others. Have leadership qualities and abilities to adapt to new environments in a short time. Have passion for learning new things and great sense of responsibility.

RELATED PROJECT

- Skittle Sorting Machine: This project aimed at constructing a well-designed, fully-functional electronics system using a combination of various sensors and electrical components. It was decided that a machine that could sort candy. The machine would serve the purpose of reading each skittle candy through the use of a color sensor and output the skittles into color-specific containers.
- ESG Electrical Stethoscope: Design and build an electrical stethoscope with features like recording, electrical noise reduction, sound enhancing, and wireless connection. The device is programmed via Simulink and integrated on Raspberry Pi. The project requires knowledge of digital signal processing and electrical circuit design.

WORK EXPERIENCE

Electrical Engineering Intern at Siemens Mobility.

Jun 2017 - Present

*RESPONSIBILITIES*

- Testing Equipment Design: Design and build test boxes for overhaul units with simple user interface to achieve a clear testing procedure for future performance. The project includes circuit design, unit wiring and develop test procedure document. Build a database with simple user interface in Microsoft Access for the projects to record all testing performance and results. The database records and organizes all the input data for future reference.
- Equipment Wiring: Wiring the equipment based on schematics and troubleshooting defective components. Searching for best fitted parts for the equipment and creating BOM. Develop a detailed building procedure documentation for future reference.
- Software Loading: Loading software on different cards for the vehicle control unit. Writing batch files and designing database to achieve future automated procedure.

## Edward Isham

### Objective:

Dynamic Electronics and Electrical Engineer with concentration in Digital Control device, Robotics, and Machine Vision. Resourceful and dedicated with team player mentality and extensive knowledge of electrical engineering concepts as well as a creative aptitude of new product designs. Additional backgrounds in Computer Science, CISCO Networking, and Mathematics.

### Education:

B.S. Electrical Engineering | Dec 2018 | Sacramento state university

Major: Electrical engineering

Related coursework: EEE concentration in Digital Control System, Robotics, Computer Vision

A.S. Physical science and mathematics | June 2016 | American River College

Major: Electrical Engineering

Related coursework: STEM related courses, GE

CCNA, CCNP certifications | June 2006 | Pasadena City College

Major: Cisco Networking via Academy

Related coursework: Cisco related networking class, CCNA, CCNP, Cisco Security

A.S. Computer Education information | June 2003 | Kaplan college

Major: Computer Networking

Related coursework: Microsoft Certified System Engineers, A+ Repairs, Network+

### Skills:

Programming in MATLAB, C, C++, Python, OpenCV

Digital Signal Processing, filter designs, Laplace, frequency domain, time domain, Z-transforms

Analog circuit: designs, wiring, soldering

SPICE(s), Multisim, ADS, LineCalc, Solidworks, VISIO

Microprocessors: Raspberry Pi, Arduino, Parallax Propeller, Chipkits, Picket.

VMWare, Windows, Linux, MS Office: Words, Excel, PowerPoint

Microsoft and Cisco Networking

Networking: TCP/IP, EIGRP, RIP v2, EIGRP, OSP, IS-IS, BGP, Multilayer switching, firewalls

### Experience:

Tutor | Private | 2014-2016

Privately worked with students, teaching mathematics from Algebra to Calculus

Technical counselor | Esperanza | 2004 - 2006

Responsible for training and preparing a high-function autistic client to become a CISCO networking professional. Successfully taught different clients to achieve CISCO CCNA certification.

Telephone technical support | Teletech | 2003 - 2004

Responsible for DSL customer supports via call center. Assist customers in setting their new DSL models/routers and troubleshoot modem connectivity.

Assistant manager | Big John's Gas station | 1997 - 2000

Responsible for setting up surveillance cameras and theft monitoring system for a mid-size gas station.

Assisted the manager with book-keeping and data entry along with inventory pricing, cashiering, and maintenance of the gas pumps and electronic equipment's.

Cashier | Fred Meyers | 1997 - 1998

Worked as cashier and sales agent in the Electronics Department. Responsible for assisting customers with electronic equipment's/components purchases, floor maintenance, cashiering, and photography development.

Technical counselor | Esperanza | 2004 -2006

Responsible for training and preparing high-function an autistic client to become a CISCO networking professional.

Hobbies and Interests

I enjoy playing soccer, basketball, racquetball, and bicycling. Besides playing, I also like to watch team sports, especially among other fellow fans at a restaurant or a bar. I am also interested in traditional martial arts such as Aikido and Muay Thai. I love to travel, especially to my hometown in Thailand. I also enjoy cooking and love to experience different cultures around the world.

REFERENCES – Available upon request

## GUSTAVO A. MARTINEZ

### OBJECTIVE:

Seeking an internship position in an organization where I can maximize my computer science and engineering background.

### EDUCATION:

California State University, Sacramento — B.S. Computer Engineering, Spring 2018

### TECHNICAL SKILLS:

**Programming:** C, Verilog, Java, VHDL, Python (Familiar with MIPS and IA-32 Assembly)  
**Operating System:** macOS, Windows 7/8/10, Linux  
**Software:** Matlab, Simulink, Microsoft Office Suite, Visio, Project, Visual Studios and SharePoint, jGRASP, Eclipse, SPEDE/GNU Compiler, Icarus Verilog, Scansion  
**Hardware:** Raspberry Pi and Arduino Platform

### PROFESSIONAL EXPERIENCE:

#### Student Assistant – Department of General Services, 05/2017 to current

Assist in creating, documenting, updating, and organizing Visio network designs, including but not limited to procedural, rack elevation, topology, flowchart and server build forms. Responsible for updating and designing new SharePoint content, modifying InfoPath templates, and handling escalation management using BMC Remedy and Printer Logic. Analysis technical documents, prepare weekly VMware Snapshots Reports and build reports using SSRS Report Builder.

### RESEARCH:

#### Senior Design Project, California State University, Sacramento, 08/2017 to current

As a team of three, we designed and implemented a wireless electronic stethoscope using a Raspberry Pi. We created a Simulink model that would load an executable into the microcontroller using TCP/UDP protocols. Our feature set included wireless connectivity, amplification, filtration, and storage.

#### Group Project, California State University, Sacramento; Sacramento, CA 08/2014 to 05/2017

**Linux Based Operating System (in progress):** In a group of three, we created an OS that currently has a timer for time-sharing, service calls, semaphore for IPC and device driver for Terminal Display and I/O. The current service calls include getting the PID, sleep, write, read, semaphore wait and post.

**MIPS Pipelined Datapath (16 bit):** In a group of two, we designed and simulated the datapath and control unit for a 16-bit pipeline MIPS CPU for a given instruction set of 16 instructions. These instructions include load, store branching, multiplication, bitwise and arithmetic operations. We used a 5-stage pipeline system that included hazard detection, forwarding, and exception handling.

### HONORS AND ACTIVITIES:

Dean's Honor List Spring 16', MESA Engineer Program Mentor, Society of Hispanic Engineers (SHPE) member, Association for Computing Machinery (ACM) member

#### Intel Training Workshop, 03/02/2018

Introduction to Static Timing Analysis of Digital Circuits