Wearables for Real-Time Health Monitoring

Final Report

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Revision Date: December 10, 2019

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List of Definitions

Android - The basic operating system by Google company

CNT - Carbon nanotube, it is 3D structure made of carbon

Graphene - Carbon 2D structure

Eco-flex - Stretchable substrate

ECG (electrocardiogram) - the test for medical which measure any problem in heart

BLE - Bluetooth Low Energy

iOS - The basic operating system by Apple company

Mobility sensor - the test for movement which measure any movement between two different locations

Optimization - It means how some program is working well at the particular environment

Sensor - A device which can measure the characteristics of particular tangible things

Nano - also known as Arduino Nano BLE 33 is a micro-computer

1 Introduction

1.1 Acknowledgement

Thank you to Dr. Dong for allowing us to use his lab and it's equipment. Due to his generosity, creativity, and support, we have been so fortunate to work on such an interesting project.

1.2 Problem and Project Statement

Currently there is a lack of options in regards to personal health monitoring, which can be troublesome for at-risk patients who wish to be in control of their health. Smartwatches provide some rough approximations in regards to cardiovascular data, however, smart watches are expensive and do not provide enough data for true personal health monitoring.

Our task is to design a thin wireless sensor with wearability comparable to a simple BandAid, and design and develop a low-cost fabrication process for the wearable sensor. We also are tasked with developing a mobile application which will communicate with the sensors using bluetooth technology.

Through the efforts of our team, we hope to develop an affordable and reliable fabrication process by which we can develop these ultra-thin wearables at a cheap cost and streamlined pace. We also hope to release a stable and user-friendly mobile application which allows a user to monitor their health information in real-time. In short, we would like to have a mobile application which allows a user to monitor real-time health information with the assistance of thin wearables.

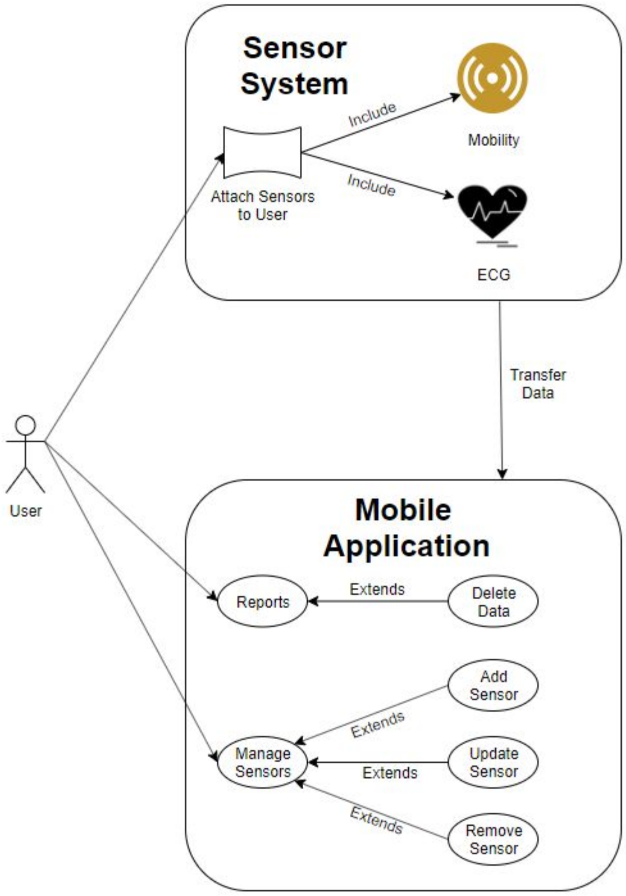

Figure 1: Use Case Diagram

The above figure is the use case diagram which is a helpful, high-level view of our entire project. It is a little unusual due to the nature of our project - as we have two products we are working on, a wearable sensor and a mobile application.

1.3 Operational Environment

The wearable is meant to be placed directly on the skin, under clothing. Flexibility is of paramount concern, along with strength and durability. Hence, the wearable must be conformable to the human body, and should be able to withstand a minimal amount of moisture (i.e. sweat). The wearable will not be subject to extremely harsh weather conditions, as it will be directly on the skin and under clothing of the user.

1.4 Intended Users and Uses

The wearable sensor is to be designed to track various important health and activity markers such motor functions and mobility, and electrical activity of the heart.

Electrical activity of the human heart provides information on heart rate and rhythm. It also shows if there is organ enlargement due to high blood pressure (hypertension), or evidence of a previous heart attack. Potential users of this functionality are people at risk of developing heart disease or strokes like hypertension patients.

The wearable is also intended to be used by elderly patients who do not have everyday contact with medical professionals. A common problem with seniors is their reduction in mobility; hence, having a wearable device that can analyze mobility would enable medical practitioners to perform an early diagnosis of potential issues. This, in turn, will increase chances of full recovery and help mitigate the possibility of a serious fall that could lead to long hospitalization and, frequently, death. The wearable can also be applicable for athletes who are interested in their performance data.

1.5 Assumptions and Limitations

Assumptions

- Client will provide lab access so that we can fabricate multiple variations of the thin wearable
- Each of the sensors will have independent channels of communication with the mobile application

Limitations

- Total funding of $500
- The existence of flexible/micro technology (i.e. bluetooth device) is limited and can tend to be costly

1.6 Expected End Product and Deliverables

The expected end product is a thin wearable which is placed on the skin and provides high quality health monitoring data via bluetooth to an iOS application. The device should be able to monitor various personal health related information such as cardiovascular activity, the data will be read from a patch placed on the skin, over the heart.

The fabricated sensors were developed as a proof of concept and this project is for research than an actual, commercialized product. The following final deliverables are a home-made on-skin sensor system consisting of multiple home-made wearable sensors described above (heart sensor, knee sensor) and a mobile application for monitoring the sensor systems in real-time.

Since the software aspect doesn't require a strenuous amount of work, we have decided to develop both an android and iOS application. The client has not specifically requested two mobile applications but we have been provided the freedom to develop two applications. So an expected deliverable is at least *one* mobile application - but we're aiming for two (Android and iOS).

The hardware aspect will be finished much later than our software aspect due to the complexities of research related work - so the software team must put focus on creating hardware using Arduino Nano BLE 33s in order to test the software we create. So, when we have the patches ready, we already have a proof of concept and we do not have to change much in regards to software. We may need minor tweaks but we expect the received signals (patches vs nanos) signals to be similar.

2 Design

2.1 Design Requirements

The following two tables are the functional requirements for the wearable and the mobile application respectively.

Wearable

- Shall use sensor placed on skin above heart to monitor heartbeat.
- Shall use accelerometer sensor placed on knee to monitor the movement of the body.
- Shall transfer data from sensors through bluetooth to mobile device.
- Shall be flexible, durable, and conform to the natural contortions of human skin.

Mobile Application

- Shall use bluetooth to communicate with ultra-thin wearable device
- Shall save health monitoring data locally for later access
- Shall provide accurate, readable data for the intended users by using medical algorithms provided

To completely cover and properly test the functional requirements/solve the problem at hand we followed a sequential path. First, we completed a prototype, which will be a rudimentary version of the sensor system to be designed and fabricated. The prototype was used to test the mobile applications and assure that we have a working and robust platform. Once the sensor system is finished, we will connect our mobile application(s) to the sensor system and once again compare the readings with our prototype to assure the sensor system is acting as expected. Once we assured the sensor system is acting as expected, the software engineers polished the applications and the electrical engineers began the fabrication process for their sensors; with the goal of finding a cheap and efficient method of reproducing the thin wearables.

By following these requirements, the final top-down view of our project is pictured below

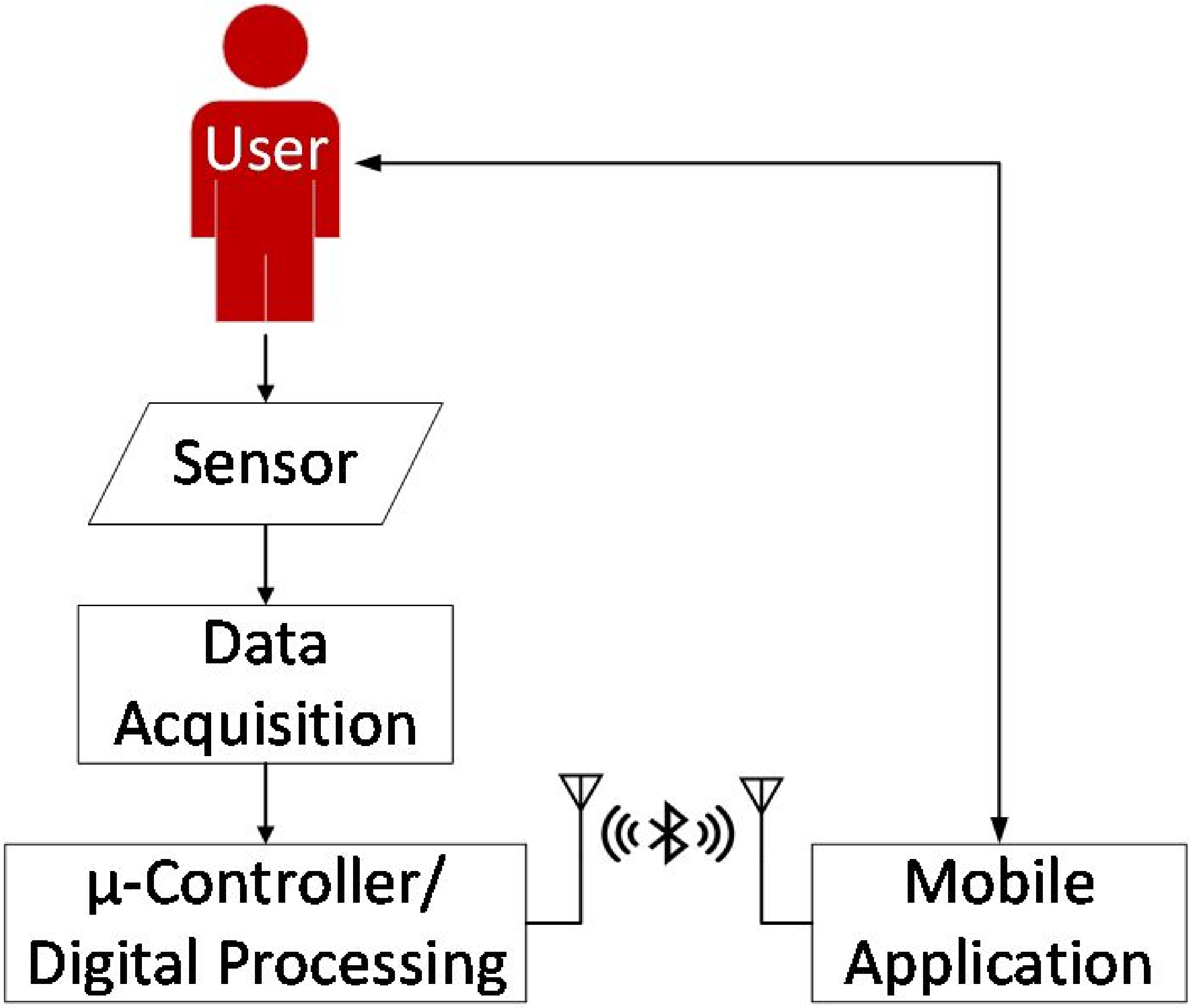

Figure 2: Top-down view of entire system

The wearable is subject to IEEE standards due to the adhesive patches we are using, the standards are discussed at length in the paper: Adhesive RFID Sensor Patch for Monitoring of Sweat Electrolytes [2]. Since the wearable is to conform to the human skin, the chemicals of the wearable/adhesive must not be chorosive or an irritant to the skin. Also, the wearable must have a low enough voltage as to not injure the user.

2.2 Sensor Design

A flexible mobility sensor was to be designed to have static dimensions of 0.2x3.2 inches the ends of the sensor are to be connected to a conductive material; possibly, copper tape. As for the electro-cardiogram sensor, the sensor should have dimensions of 0.5x1 inches and only one side of the sensor connected to a conductive end. Comparing two sensors mobility sensors designed longer than ECG sensors since through mobility sensor we are measuring resistance depending on length change. However for ECG we are measuring voltage level through sensor so it's length is shorter than mobility sensor but slightly wider width to ensure voltage stability. The following figures show the sensor design and real fabricated sensor.

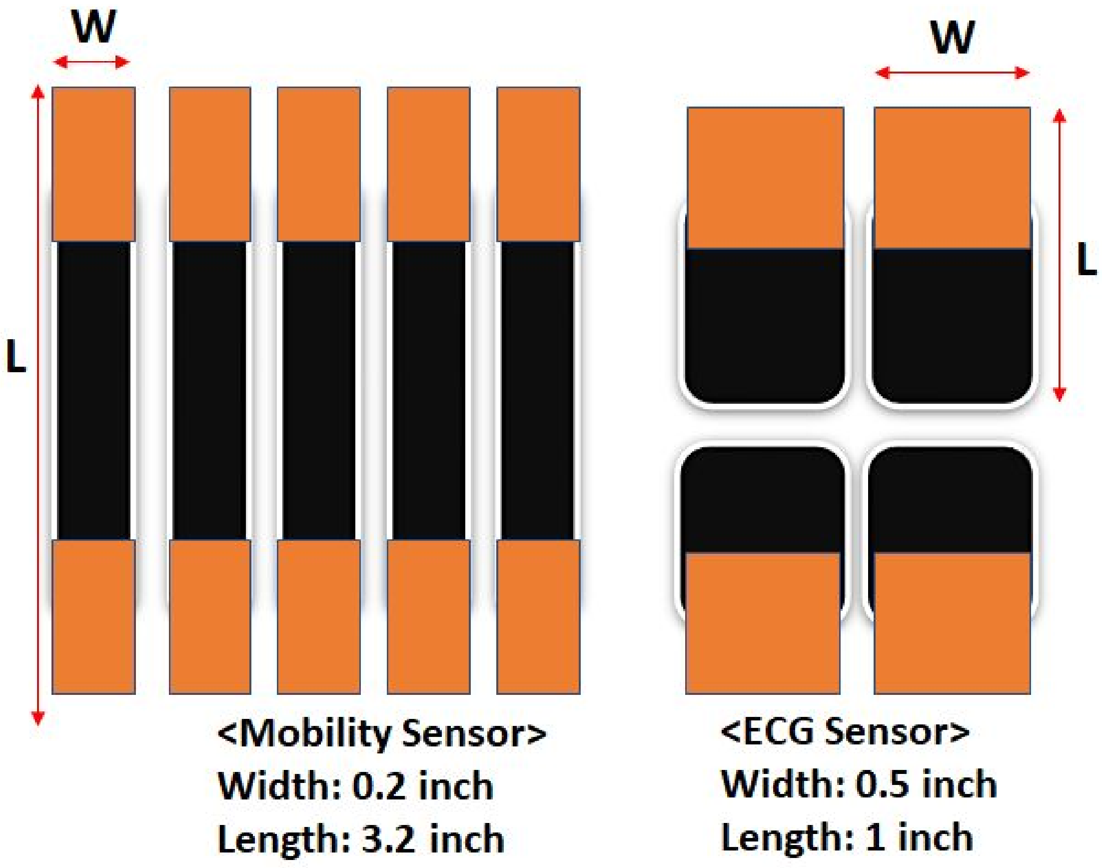

Figure 3: ECG and mobility sensors design

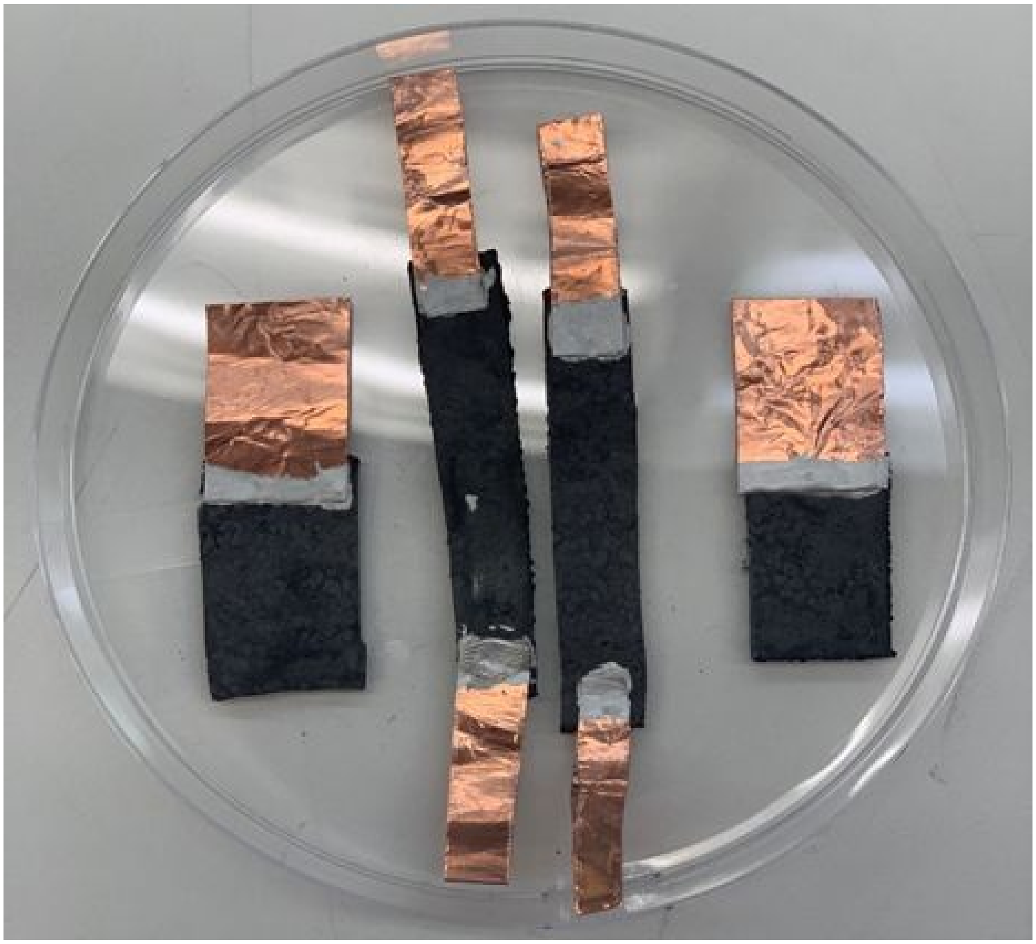

Figure 4: Finished ECG and mobility sensors

2.3 iOS Design

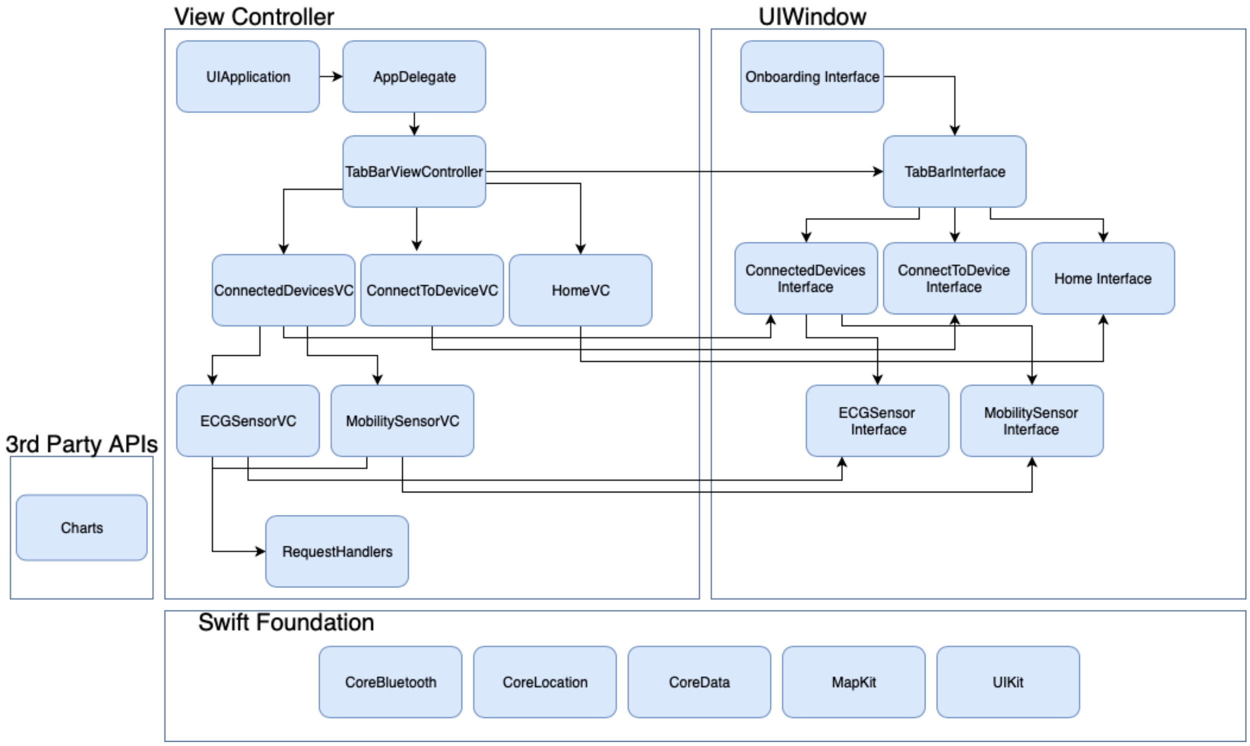

Figure 5: iOS System Design

2.4 Android Design

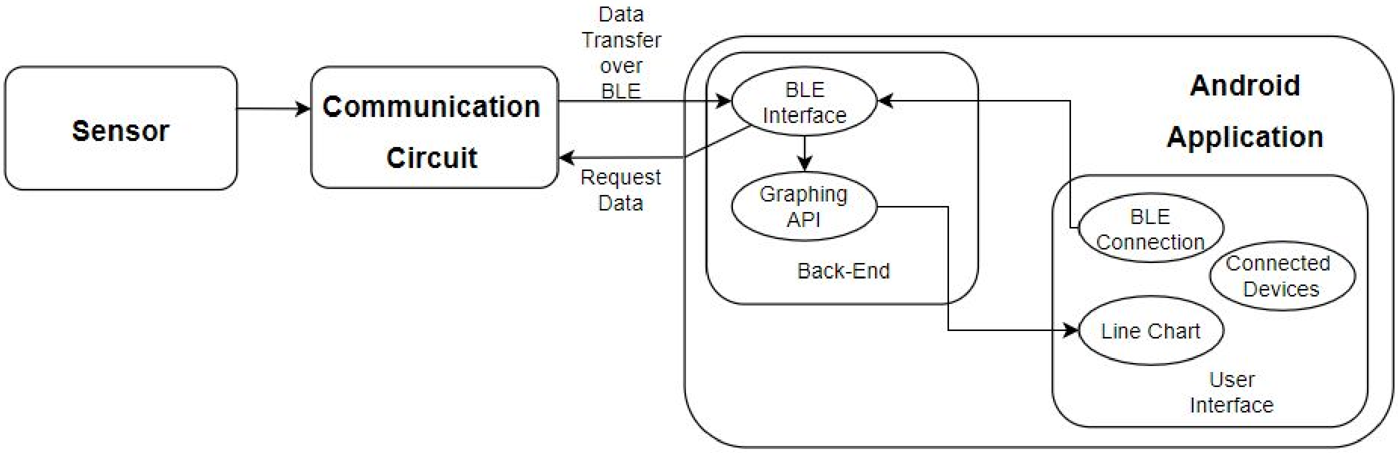

Figure 6: Android system design

2.5 Hardware Design

2.5.1 Mobility Sensor Mechanism of Transduction

The mechanism of transduction of each of the fabricated sensors is different. The mobility sensor utilizes the change in sensor resistance due to sensor deformation to sense changes in mobility. The change in resistance arises because the as the sensor is deformed (stretched), its length and cross sectional area are altered according to $R = \rho \frac{l}{A}$, where ρ is the resistivity of the sensor, and is constant for the sensor. l is the length of the sensor and A is its cross-sectional area. When the sensor is stretched, its cross-sectional area A is decreased, and its length is increased. Hence the resistance of the sensor is increased, as presented in figure 7.

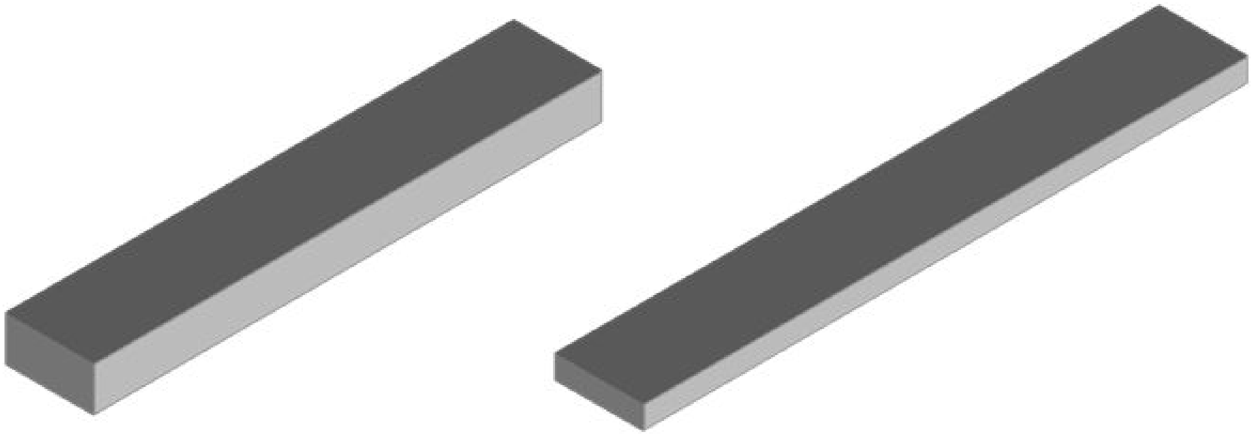

Figure 7: Sketch of the mobility sensor static (left), and deformed (right)

2.5.2 Electrocardiogram (ECG) Mechanism of Transduction

Although the electrocardiogram sensor is made of the same material, as described in section 3.1: Sensor Fabrication, the mechanism of transduction is completely different from that of the mobility sensor. In order to understand how electrocardiograms operate, one must have a minimal understanding of the biological process of heart.

The human heart has chambers and one-way valves which circulate blood around the body. The top chambers of the heart, the *atria*, contract to load the bigger hollow chambers of the heart with blood. The bigger hollow chambers are called *ventricles*, and are much stronger than the atria. When blood is squeezed into the ventricles through the atria, one-way valves in the heart are slammed shut and the ventricles push blood throughout the body. The one-way valves opening and shutting are the source of what is heard if a stethoscope is placed on the chest.

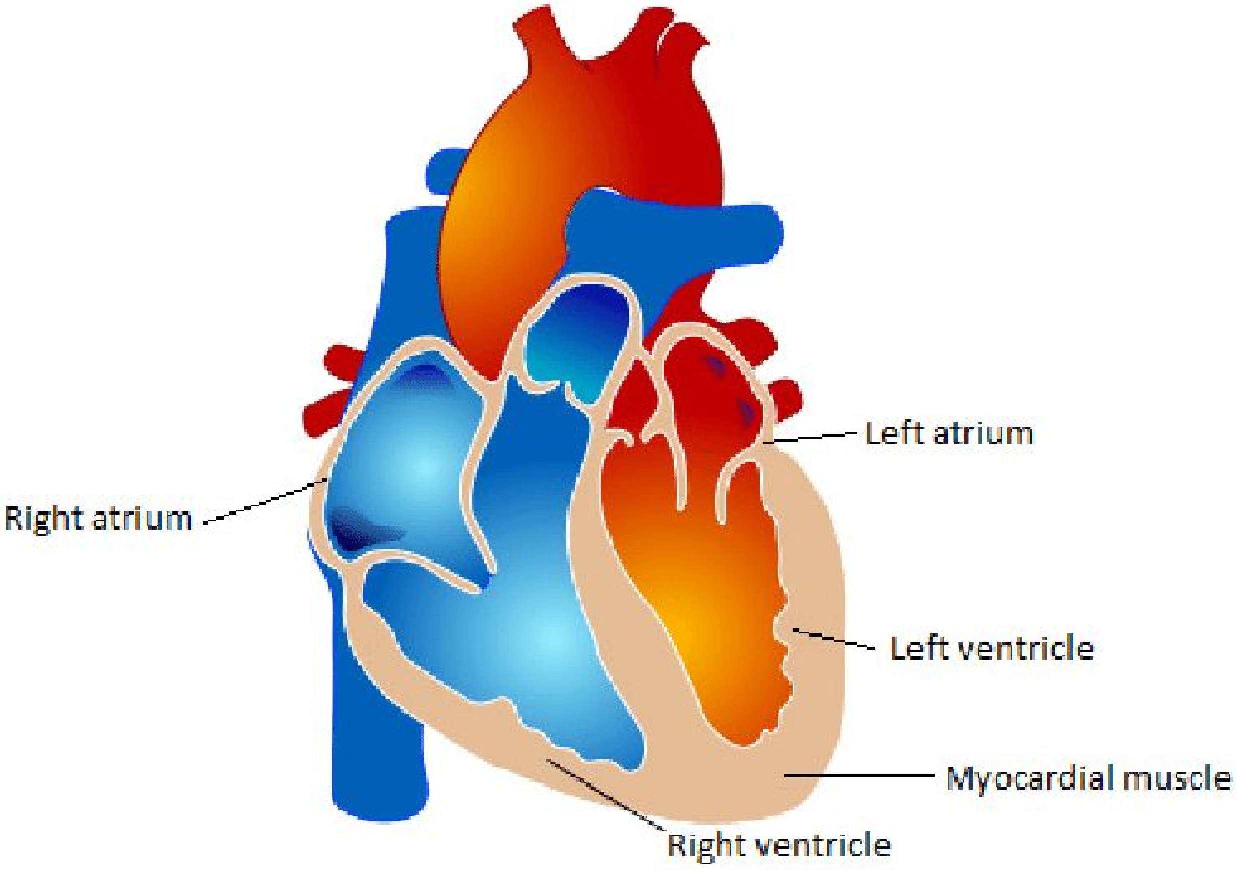

Figure 8: Sketch of the heart chambers and muscles

Different regions of the heart need to contract in the right sequence for the heart to function properly. From a high-level system perspective, this contraction is controlled by the brain; however the brain only sends biopotential signals to the heart. The actual contraction and relaxation of the heart are controlled by neurons within the heart itself, called *ganglia*. These neurons are the reasons why if a heart is removed from a living being, it continues to beat on its own for a short while.

The ganglia sends messages to the heart muscle cells, which in turn open sodium and calcium channels allowing positive ions to rush inside the cells. The flow of ions in and out of the cells leads to polarization and depolarization of the cells. This polarization process is what gives rise to the electrical signal measured using electrocardiogram machines shown in figure 8. This waveform is picked by the ECG sensing electrodes which get polarized and depolarized as the heart pumps blood to the body.

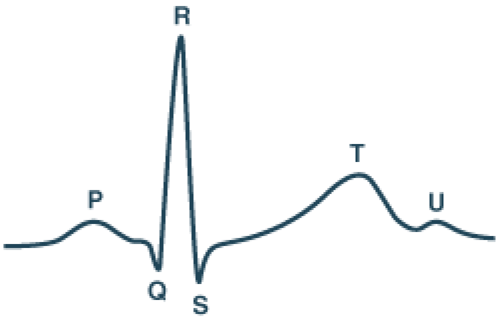

Figure 9: PQRST wave produced by polarization of the heart muscles

2.5.2 Electrocardiogram (ECG) Mechanism of Transduction

The data acquisition circuits should be able to translate mobility, and heart beat into a single voltage output that would then be sent to the microcontroller (Arduino Nano) as shown in figure 10.

Figure 10: System diagram of the interface between the sensor and the microcontroller

The data acquisition circuits are presented as the white box in the system diagram in figure 10. The mobility sensor data acquisition circuit is shown in figure 11. It is a simple voltage divider circuit, and the output voltage could be processed to calculate the resistance of the sensor using $Rsensor = \frac{200k\Omega \times 3.3V}{V out} - 200k\Omega$. This resistance could then be correlated to sensor deformation.

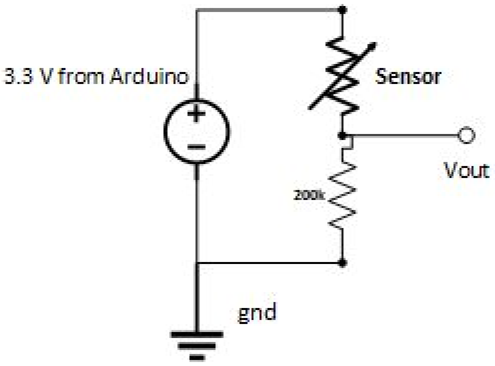

Figure 11: Mobility sensor data acquisition circuit

Moreover, the ECG data acquisition circuit should be able to detect the polarization of the heart muscle cells, which produce a voltage signal with an amplitude around 1mV. The voltage between the two sensor leads are subtracted from each other to obtain the waveform in figure 8, this is achieved using a differential amplifier structure. It was expected that there would be inherent noise present in the circuit owing to the fact that the heart produces a signal with a very low amplitude. The main source of noise the circuit is expected to pick up is the 60 Hz signal powering every building, hence two 60 Hz notch filters are included in the circuit.

Further, commercial ECGs usually incorporate a band-pass filter to eliminate any low frequency noise and any higher frequency noise. A wide range of cut-off frequencies are present in commercial products; however, in our circuit, cut-off frequencies of 0.5 Hz and 60 Hz are designed, according to industry standards [1]. After filtering, a non-inverting amplifier is included to amplify the signal to a detectable range. A schematic of the initial circuit is presented in figure 12. Finally, diodes are used to between the electrode terminals to short and surge in current that might arise.

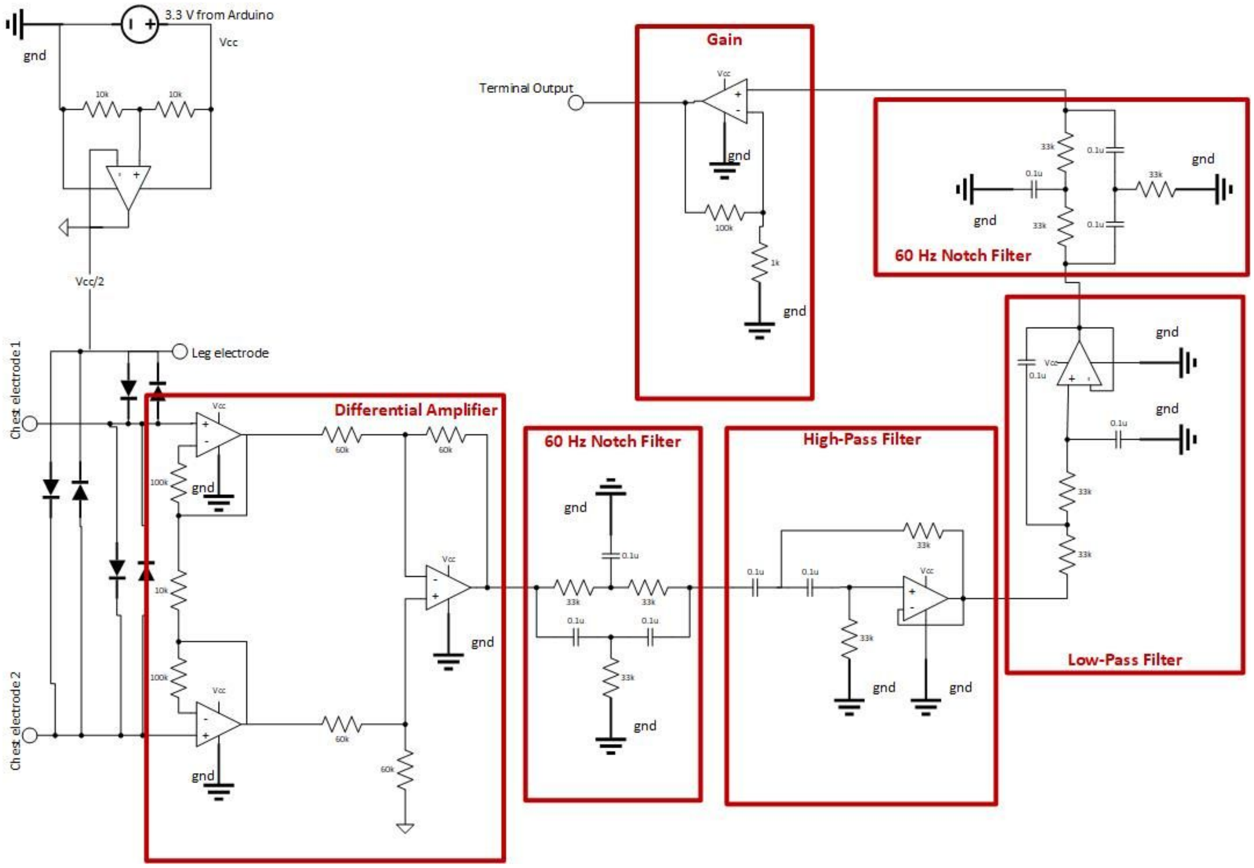

Figure 12: Electrocardiogram Data Acquisition Circuit

3 Implementation Details

3.1 Sensor Fabrication

For fabrication dry electrode, first, we prepared a 3-D mold which is designed by Auto-CAD software and printed by a 3-D printer. The width and length of mold are 2 and 3 inches respectively, and height is 1 mm. We pour the eco-flex which is a stretchable substrate, then before it is fully cured, we put the graphene solution (20mg graphene powder + 700 µl ethanol + 300 µl DI water). This is because we want some fusion effects like much bonding between the substrate and 1layer material. Graphene is a 2D material, so it can be flexible. After drying graphene, for a uniform layer, we did rolling on the surface. Once we finished rolling, we put the Carbon nanotube solution (20mg CNT + 700 µl ethanol + 300 µl DI water). The carbon nanotube is a 3D structure, so it cannot be flexible, but it can increase the conductivity of our sensor. We did rolling again after drying CNT. Our structure is like Islands (CNT) and bridge (graphene) structure. After cutting it in pieces, we could put connector (copper tape) using Ag/AgCl paste. In the case of a mobility sensor, we need to measure resistance, so we need to connectors to measure resistance. However, for the electrocardiogram (ECG) sensor, we need to measure biopotential. We need to electrodes, and for each electrode, we need one connector.

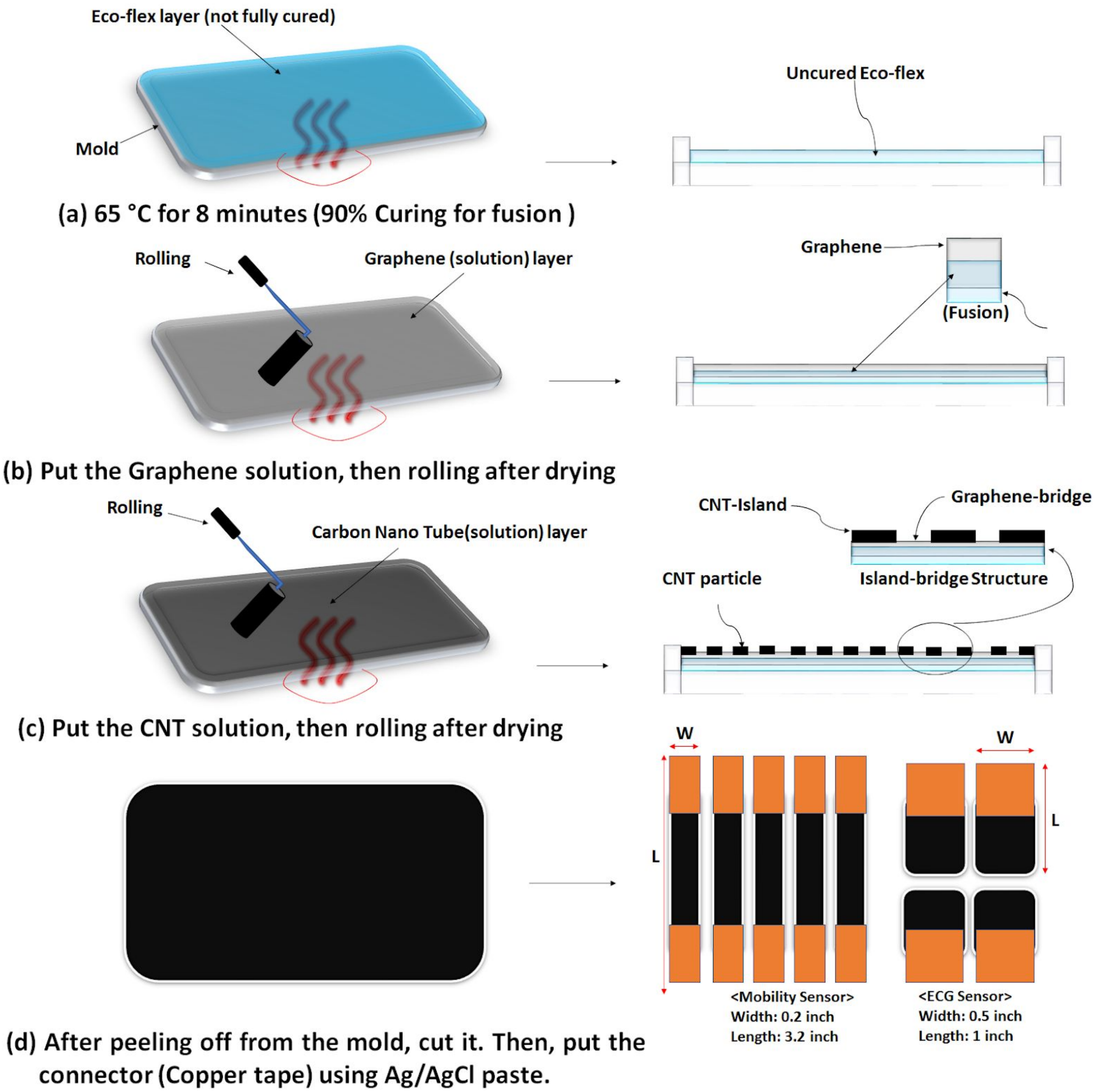

Figure 13: Sensor fabrication process

3.2 Android Design Implementation

The android application was designed in android studio using java. Android studio provides an easy to use and customize application designing interface and is the main platform used in developing android mobile applications. Java and Kotlin are the main languages supported in the android studio IDE. We decided to use java since it is more widely known and available whereas kotlin is a fairly new language. MPAndroidChart and SimpleBLE were two APIs that were used within the application as well. MPAndroidChart is a very popular charting library used to produce graphs from data, while it does not support "live" graphing it circumvents this weakness by dynamically adding and removing points on the graphs. SimpleBLE was used in place of typical BLE interfacing which can become very hard to follow and becomes rather large when implementing.

3.3 iOS Design Implementation

The iOS application was designed using XCode IDE in the Swift programming language (specifically Swift 5.1). Most of the design was implemented using internal frameworks, such as CoreBluetooth for BLE communication and CoreLocation for location of the user. The only 3rd party API used was for the graphing of user data. Swift does not provide a native graphing framework so it was necessary to use a 3rd party API, which was called Charts. Using this framework we were able to achieve live graphing of data.

3.4 Hardware Design Implementation

The data acquisition circuits were initially built on breadboards for initial testing purposes, then a prototype was fabricated on a perfboard after successful testing using the bread board. The circuits are shown in figures 14 and 15 respectively.

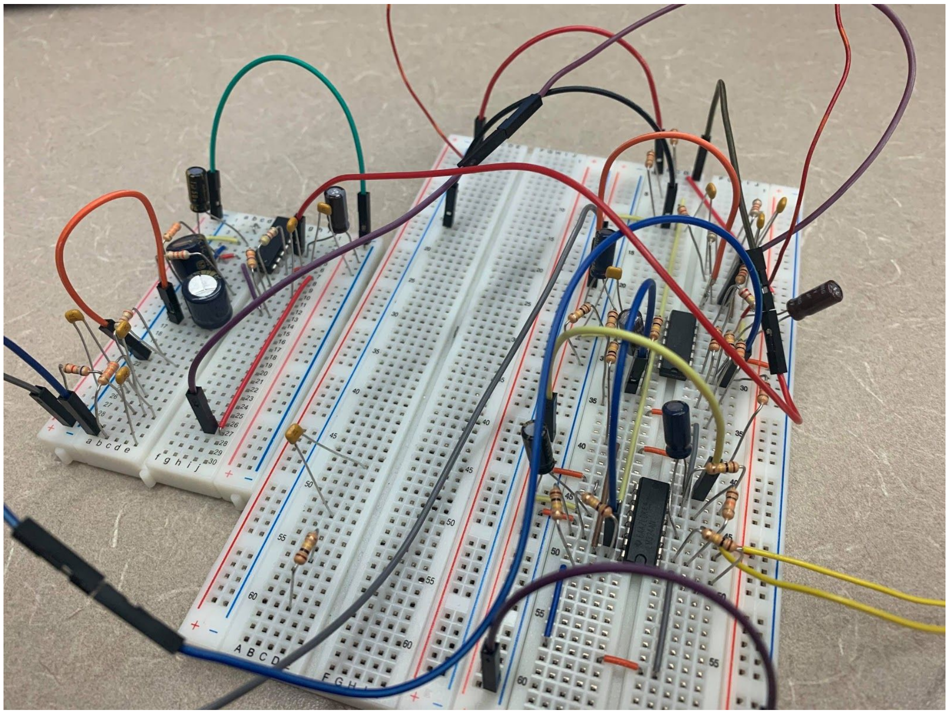

Figure 14: Data acquisition circuits implemented on a breadboard

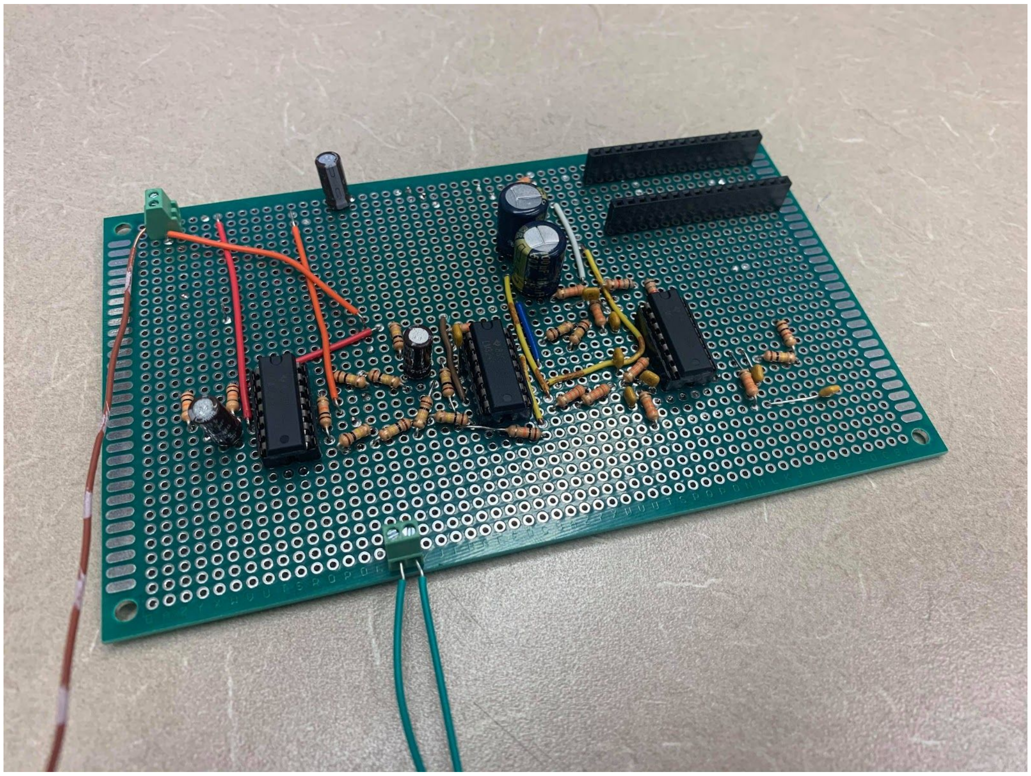

Figure 15: Prototype of data acquisition circuit fabricated on perfboard

4 Testing

4.1 Process

Testing the system design has been done using several methods. For the sensors we used lab equipment provided by our client Dr. Liang Dong. We used a multimeter with a bench view to test our ecg and mobility sensors in a lab setting. The data we got from these tests was used with further testing from purchased sensors that were utilized by the same machine to compare the outputs of our sensors to accurate values given by proven technologies on the market.

Testing the software and the hardware was done somewhat in tandem. While the hardware was being built the software used similar methods of data transfer with mock sensor data in the beginning steps of development. This gave us the ability to narrow in on potential problems with our applications as well as a feel for how they would be communicating with the sensors that had been fabricated. Once the hardware was nearing completion we began to test our software with the communication circuit produced. We tested the sending and receiving of the data from the sensors to the application through BLE.

4.2 Functional Testing

The functional requirements are listed in Tables 1 and 2 and will be referred to in the following section.

Test	Required Result	Corresponding Requirement
UTWT.1	Sensor placed on over left breast detects heartbeat and transmits data	UTW.1
UTWT.2	Sensor placed over knee shall transmit different readings when the knee is moved	UTW.2
UTWT.3	The bluetooth chip on each of the respective sensors shall be transmitting data constantly while connected to mobile device	UTW.5
UTWT.4	Flexible enough to match the natural contortions of human skin without damaging sensors	UTW.6

Table 1: Table for the functional tests of the ultra-thin wearable (hardware)

Test	Required Result	Corresponding Requirement
MAT.1	Data shall not be transmitted outside of the communication between mobile app and sensors	MA.1
MAT.2	Data shall be read when connected to sensor via bluetooth (up to 3 simultaneous connections allowed)	MA.2
MAT.3	Infographics on mobile application shall contain real-time data interpretations	MA.3
MAT.4	Data shall be saved locally	MA.4

Table 2: Table for the functional tests of the mobile application (software)

UTWT.1 Procedure, UTWT.2 Procedure, UTWT.3 Procedure:

1. In a lab environment, place sensor on the designated area (breast, knee)
2. Assure data is being read from sensor by viewing raw data on raspberry pi terminal

UTWT.4 Procedure:

1. In a lab environment, place accelerometer sensor on a subject's knee
2. Instruct user to move knee with sensor at specific time intervals (i.e. user bend knee at t0 and unbend knee at t1)
3. View the log for the accelerometer sensors to assure that the data at the specific time intervals is indeed different

MAT.1 Procedure:

1. In a lab environment, place sensor on the designated area (breast, knee)
2. Attempt to access data outside of bluetooth connection with mobile device (Bluetooth sniffing)

MAT.2 Procedure:

1. In a lab environment attach the 3 sensors to a person in their respective areas
2. Connect each sensor individually to a mobile device
3. Observe data output from sensors

MAT.3 Procedure:

1. Attach sensors to respective areas on a subject
2. Observe data output within mobile application
3. Ensure data is being transmitted in real-time through time logs of received data

MAT.4 Procedure:

1. Gather and store data through other tests
2. Access data stored through mobile application

4.3 Non-Functional Testing

Test see	Required Result	Testing Category
UTWT.5	The sensor should not shock the user	Security
UTWT.6	The sensor should never irritate the skin (due to chemicals in the adhesive)	Security

Table 3: Table for the non-functional tests of the ultra-thin wearable (hardware)

Test	Required Result	Testing Category
MAT.5	Mobile application shall be accessible from iOS or Android mobile devices	Compatibility
MAT.6	Data shall be saved locally for x amount of time (x is decided by user)	Security
MAT.7	Data shall be deleted at user discretion	Security
MAT.8	Mobile application shall not hang during computations	Usability

Table 4: Table for the non-functional tests of the mobile application (software)

UTWT.5 Procedure, UTWT.6 Procedure:

1. Review our design of the sensors
2. Assure that our product follows the IEEE standards of biomedical devices [2] (these standards provide guidelines to avoid issues of user hazard for our device)

MAT.5 Procedure:

1. Download application from both iPhone and Android devices
2. Access the application and the various features

MAT.6 Procedure:

1. Save data for x amount of time (user specified)
2. Attempt to observe data past x point of time

MAT.7 Procedure:

1. Save data to users mobile device
2. Request to delete data (stored locally)
3. Attempt to view data which was deleted

4.4 Testing Results

By testing the previously discussed functional and non-functional requirements - we were able to develop applications which can support multiple devices and provide live data to end users. Also, we were able to deliver a solid proof of concept for the fabricated sensors. The fabricated sensors use dry electrodes and can potentially be the future of wearable technology. The tests for the proof of concept allowed us to determine their safety and the viability of future products using this fabrication method to develop lasting, wearable technology.

5 Related Products

There are commercial related products such as Apple Watch and Android wear which use biosignal that calculates the beat rate. Comparing with our design, it can only calculate the rate of heart beat. However our design can trace the entire signal through mobile device application. Also cost of device is much cheaper than these wearables. These devices also do not contain a mobility sensor.

Many wet electrode wearables exist in the market, however, they do not last long due to the fact that they are gel-based wearables. Our wearables use dry electrodes which can sustain multiple uses, our wearables are not perfect, but they are a promising proof of concept.

6 Related Literature

[1] R. Kher, "Signal Processing Techniques for Removing Noise from ECG Signals," *Journal of Biomedical Engineering and Research*, vol. 1, pp. 1–9, Mar. 2019.

[2] D. P. Rose, M. E. Ratterman, D. K. Griffin, L. Hou, N. Kelley-Loughnane, R. R. Naik, J. A. Hagen, I. Papautsky, and J. C. Heikenfeld, "Adhesive RFID Sensor Patch for Monitoring of Sweat Electrolytes," *IEEE Transactions on Biomedical Engineering*, vol. 62, no. 6, pp. 1457–1465, 2015.

[2] W. Zijlstra and K. Aminian, "Mobility assessment in older people: new possibilities and challenges," *European Journal of Ageing*, vol. 4, no. 1, pp. 3–12, 2007.

Appendix I - Operation Manual

To operate the application, simply open the application and navigate to the *Connect Sensors* tab. Once selected the application will scan neighboring BLE devices. Find the device you wish to connect to, in this case either *Mobility Sensor* and/or *Heartbeat Sensor.* Once connected you can navigate to the *Connect to Sensors* tab. To remove and disconnect a sensor, simply swipe left on the sensor and select delete. This will remove the device. Otherwise, you can tap the sensor's name to view the respective sensor page. On this page the user will be able to view real-time data from the devices.

To view the history of your sensors, you must have used the application previously and connected sensors before - otherwise there will be no history. To locate the history, select the

Home tab and there are various boxes to select from with the respective names of the sensors above. To view a sensors history, simply select one of the boxes which has the sensor you wish to view labeled above. From there the user can view previously recorded data from the sensors.

To properly operate the mobility sensor, put the sensor on the knee area with the eco-flex substrate side facing outwards. Then, connect wires from the circuit to each side of connectors very softly. Once we connected wires, open the application on the mobile device and connect to the sensor *MobilitySensor*. Then select the connected devices tab. On the selected devices tab, choose the sensor which was connected to the mobile application. From there the user can view real time data from their mobility sensor. In order to remove the sensor, simply navigate to the *Connected Sensors* tab and swipe left on the *Mobility Sensor* and select *Delete,* then the sensor will be removed and disconnected.

To test the mobility sensor, navigate to the sensor's page by following the instructions detailed in the above paragraph. Once the user is on the Mobility Sensor page, the user can move their knee which contains the mobility sensor. During this movement the user can watch the application and see the data in real time.

To properly operate the ECG sensor, there are two parts:

1. The first part is the proper placement of the reference potential sensor the sensor must be placed on the ankle area with the top surface side facing outwards. At this time, the connector should be insulated with skin, because of skin impedance.

2. Then, we put the electrodes on the skin for the active potential. The most ideal location is to place two sensors on both sides of the breast, above the heart. Connect wires from circuit to each side of connectors very softly. Once the wires are connected, the user can now open the application.

Open the application on the mobile device. Navigate to the *Connect Devices* tab and select Heartbeat Sensor. Once the sensor is selected, navigate to the sensors page by clicking the *Connected Sensors* tab. Then select the Heartbeat Sensor from the list and from that page the user can view real time data from the heartbeat sensor. In order to remove the sensor, simply navigate to the *Connected Sensors* tab and swipe left on the *Heartbeat Sensor* and select *Delete,* then the sensor will be removed and disconnected.

To test the heartbeat sensor, navigate to the sensor's page by following the instructions detailed in the above paragraph. Once the user is on the Heartbeat Sensor page, the user can view their ECG and heart's BPM in real time. Once a connection is established the user can try various activities such as pushups, jumping jacks, and jogging in attempt to raise their heart rate. Using the live data they can see their heart's data change with every strenuous activity.

To test the BLE aspect of the system the user could connect two sensors by navigating to *Connect Sensors* tab and select both a mobility and heartbeat sensor. Once connected they can navigate to the *Home* tab and wait a few minutes. The user can then disconnect the sensors by navigating to the *Connected Sensors* tab and swiping left on each sensor and then clicking the delete button. Once the sensors have been removed, the user can view their sensor history by selecting the various history boxes on the home tab and see if the data was collected in the previous minutes and assure no data was collected after disconnecting the sensors.

To remove data from the application, simple delete the application from the device. All storage is saved on the device's local persistent database, thus giving the user complete control over their data and once the application is deleted, all data in the local persistent database pertaining to the application is deleted.

Appendix II - Previous Designs

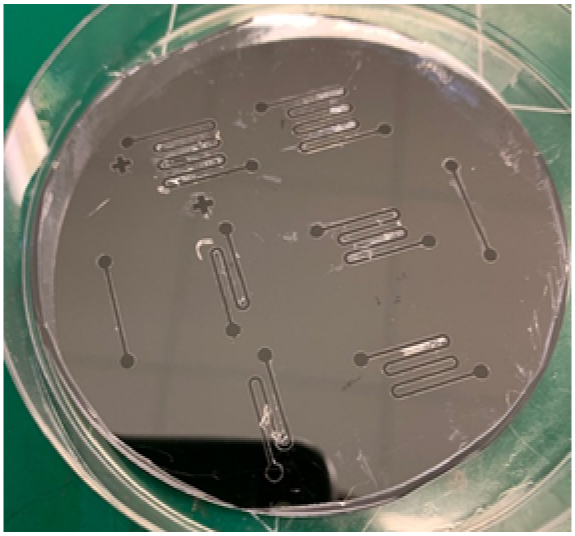

Figure 16: Patterns printed on silicon wafer

For sensor fabrication, we initially used a photolithography on a silicon wafer to get the desired sensor pattern using the SU-8 negative photoresist. After getting the pattern on the wafer, a PDMS solution is poured over the wafer. When the PDMS cures, and is detached from the wafer, the end result is a PDMS negative feature mold.

Figure 17: Graphene patterns

Once the mold is fabricated, a graphene solution is poured into the mold, which is then dried on a hot plate. Then, using scotch tape, undesired (excess) graphene is stripped away. Finally, using polyimide tape, the sensor structure is transferred onto the tape.

This fabrication process was not adequate for our application, because no substrate was durable enough for the stretchability needed to be employed in a mobility sensor. For the ECG sensor, the fabrication process produced adequate sensors. Thus due to lack of stretchability, this fabrication process was not used.

For the ECG data acquisition circuit, a simple design was initially used to mitigate the complexity of hardware material. Moreover, given the varied values in components due to the inherent tolerance of the circuit components, it was preferred to implement a digital filter as opposed to a hardware filter to remove any noise. The circuit was comprised of a single op amp, and its output was to be fed into the microcontroller, and the digital filter would be implemented using the Arduino. The schematic is presented in figure 18.

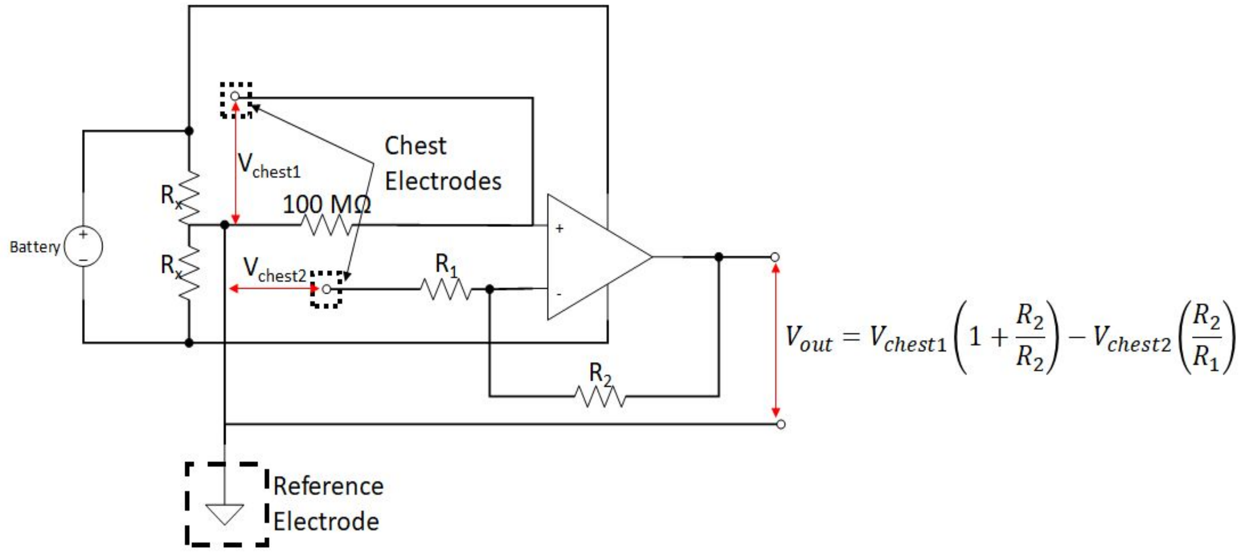

Figure 18: Initial ECG data acquisition circuit

The digital filter presented a huge challenge, and we successfully implemented it using Python, plotting the output on a computer screen. However, the filtering process was not as good using the Arduino, so this circuit was not used in our final prototype.

Appendix III - Other Considerations

Given that this senior design project was research driven, the end-goal was not clear since the beginning. The project was initially very ambitious, and the final outcome was not well defined. This brought upon this Team a tumultuous process of switching gears, which equipped us with the necessary skills to perform academic research. However, since the scope of this project was bigger than what could be implemented in two semesters, more research is needed to produce a viable commercial product. In light of this, one of our Project Team members will be pursuing his master of science degree under the supervision of our client and adviser Dr. Liang Dong where this research project will be further investigated.

This investigation will be built on what was not feasible to be achieved in a mere two semesters. For example, the bluetooth low-energy transmission module adds a significant cost to any product. This could be mitigated by using other transmission techniques; one of the methods we failed to implement was an NFC module, which would incorporate the built-in NFC readers in smartphones. Since we knew, this would require a longer duration for a project than two semesters, we tried to implement it as a proof of concept. In this proof of concept, an NFC antenna would be attached to the user’s clothing which would be in the vicinity of the sensor. The sensor itself would be connected to an NFC chip which has an analog-to-digital converter and a transmitter. The transmitter would transmit the data to be picked up by the NFC antenna, which would be connected to the microcontroller. The microcontroller would then send the data to mobile application using the BLE module as in our current design. A system diagram of this implementation is presented in figure 19. This was very difficult to implement given the inherent complexity of antenna design and microwave communication. Similar investigation are more suitable for graduate research, which this project has inspired.

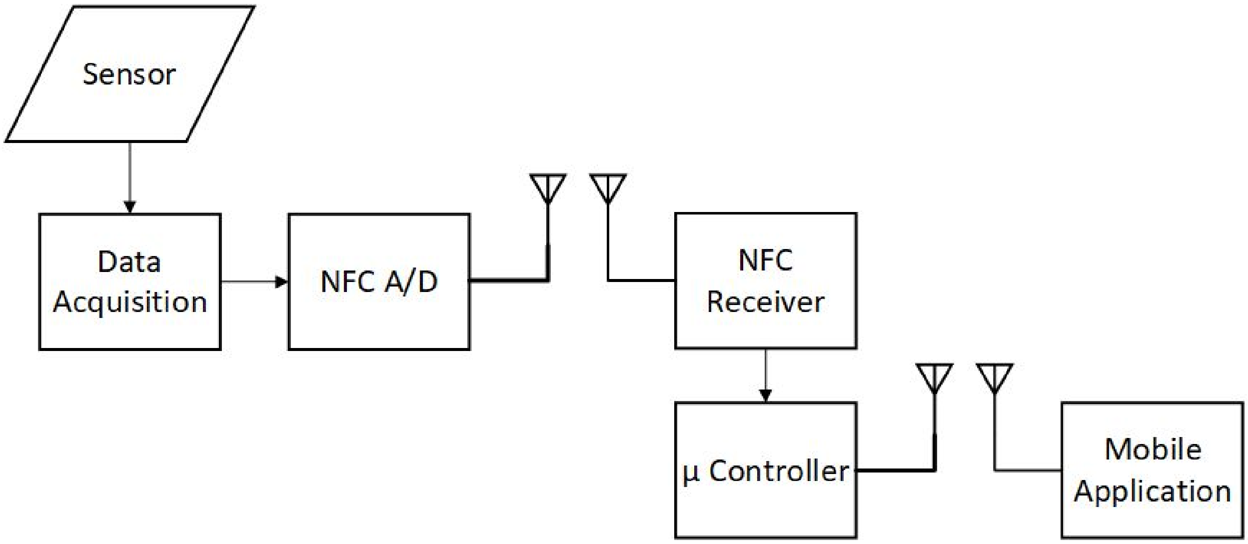

Figure 19: System diagram using NFC as a means of signal transmission