The Design and Development of a Wireless ECG Monitor

Capstone 2 - Final Project Report
Florida Polytechnic University
Spring 2023

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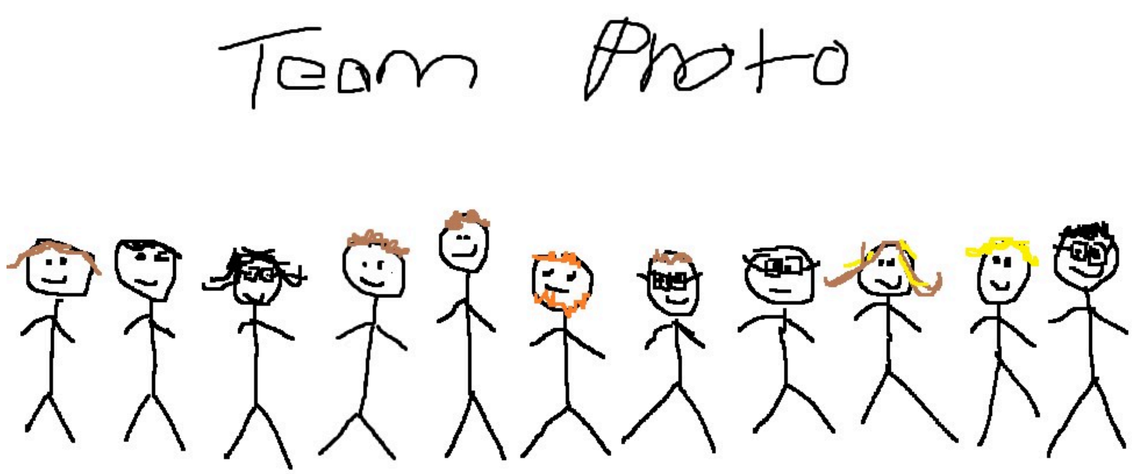


1. **Introduction [All Disciplines]**

This comprehensive report details the challenges, processes, trials, and solutions that the Wireless ECG Phase 2 team achieved in the semester of Spring 2023.

The goal of the Wireless ECG Phase 2 team was to provide a solution for Dr. Faeza Kazmier, a plastic and reconstructive surgeon at Watson Clinic, to create a Wireless ECG monitoring device that does not require a direct, wired tether to the patient and can sustain for up to 12 hours at a time.

Phase 2 originally received the product from Phase 1 to continue the development process from the preceding semester. Many issues were encountered when working with the acquired device. After much troubleshooting, the team made the decision to start anew, using a refresh of the client's needs.

To begin the designing process, requirements were drawn based on the customer's needs. After consulting with the sponsor, the device in mind needed to be ergonomic, sterile, secure, durable, and electrically stable on top of the wireless requirement.
Using these requirements, a few proof of concepts were made with most variants being placed on different parts of the body; wrist, neck, box(palm), and chest. All original variants used parts from Phase 1's product to try to repurpose microcontrollers and batteries. These parts ended up being removed from the designs due to impracticalities in component sizes.

The variant that became the Alpha Prototype was the box module. The Finalized Alpha Prototype depended on the use of the MAX86150 board by Protocentral to read the patient's heart rhythm through their fingertips. It would be comprised of two components: a Transmitter and a Receiver. Both components would connect via bluetooth on Arduino microcontrollers and the Transmitter would contain a rechargeable battery.

The Alpha Prototype had the issue of not having a feasible way to connect the bluetooth receiver to hospital equipment without a proper ECG cable converter specific to the ECG manufacturer. Making a single converter or wire from scratch for the ECG Receiver would have consumed a vast amount of time to develop. The battery was also not sufficient to provide the sponsor with the longevity required of the product.

Through design refinements of the Alpha Prototype came the Beta Prototype, which contained a more thorough awareness of the sponsor's needs. The housing was changed to fit the shape of a human hand and featured a tiered system to allow for individual components to be partitioned for easier management. The method of gathering patient data switched from fingertip contact to electrodes applied to the patient via ECG leads. These ECG leads were wired to the MAX86150 board. The microcontrollers in the Beta Prototype were switched to Arduino Nano BLE 33, which has low energy consumption and built-in bluetooth support. The battery was changed to a larger lithium ion battery with 5000 mAH that would be rechargeable through a port-slot in the Transmitter's housing. The method of sending signal to the hospital equipment from the Receiver changed to remove the need for a converter/wire. The method required 3 conductive buttons extracted from electrode pads to be soldered to the Receiver's Arduino Nano. These buttons connect directly to the hospital's pre-existing ECG Leads and transfer the output signal from the Receiver directly to the hospital monitor. This essentially is tricking the hospital equipment into believing that the Receiver is a human patient.

In the testing phase of the product, the initial challenge was getting a readable signal through the Arduino IDE. Through use of altering the sample rates and adding signal filters to the

existing libraries available in the MAX86150 library, a slightly noisy, but non-cacophonous signal was produced.
When it came time to test on a hospital monitor, much tweaking had to be done with the values in the ".ino" files for the monitor to acknowledge the signal being output to it. At the end of testing, the hospital monitor was able to successfully read the patient's heart rhythm, but, ultimately, could not interpret a BPM.

The finalized product Phase 2 created meets all of the sponsor's requirements: a sterile, durable, secure, ergonomic, wireless ECG device that has longevity for extended operations.
The product in its current state works, with improvements to be made on its communicative issues from Receiver to hospital monitor. These improvements are to be continued by the successors of the Wireless ECG project.

2. Customer Needs, Objectives and Team Interpretation [All Disciplines]

The sponsor is Dr. Faeza Kazmier, a plastic and reconstructive surgeon at the Watson Clinic. The problem presented was in regards to how the use of an ECG monitoring device on a patient is necessary, but is cumbersome to handle efficiently during operations that require moving of the patient. To move the patient, the patient must be completely untethered from the ECG leads to prevent any snagging on the patient.

2.1 Customer Needs

Our sponsor was very clear about the details of our task. We were told to create a wireless replacement for the ECG machines currently being used in hospitals. This replacement needed to be fully wireless, if possible, and needed to cast the patient's information to a screen in the operating room with little to no delay. We also needed to make sure the device that attaches to the patient is comfortable for them to wear during long hours of surgery.

2.2 Design Objectives

Our sponsor was very clear about the details of our task. We were told to create a wireless replacement for the ECG machines currently being used in hospitals. This replacement needed to be fully wireless, if possible, and needed to cast the patient's information to a screen in the operating room with little to no delay. We also needed to make sure the device that attaches to the patient is comfortable for them to wear during long hours of surgery.

2.3 Team Interpretation

In order to make the device ergonomic for both the patient and surgeon, learning of the many different placements was important to help make a conclusion to what device would be possible to make in each scenario.

We used the prototype from phase 1 to start with and kept in mind the most important factors based on our sponsor's needs: sterility, ergonomics, longevity, and function.

We analyzed each aforementioned need to come up with individual solutions:

-Medical grade silicone could achieve a soft body and be easily kept sterile between uses.

-Designing the device to be positioned on the fingers/hand would allow it to be placed comfortably within the restraint that is used to prevent the patient's arm from moving during surgery. Many ECG monitors for consumer use have been made in this fashion, as well as clinical use, such as the Blood Oxygen Monitors that are placed on a patient's fingertips.

-In order to make the device run for as long as possible, we had a few interpretations on how to fit in over 9 hours of battery life:

1) Use as little power in the wireless device itself by having most computation be done through the receiver. After all, less computation equals less power consumed.
2) Have a lithium ion battery that supports power over a lengthy period.
3) Have a port that may allow for the swapping of batteries between or during surgeries.

-For function, the interpretation was to have as simple of a device that could reliably transmit a heart signal to the ECG module/receiver. One electrode making contact with the patient would be sufficient to provide an accurate enough signal for its intended purpose. The function is the collection of solutions above placed within one unit, while accounting for the fact that simplicity is the goal.

Keeping one electrode contact means that no wires would need to be extended out of the device, nor would any bluetooth signals have to be paired if there were multiple wireless electrodes.

2.4 Functional and Non-functional Requirements

First and foremost, the device must be able to read the cardiac rhythm of a patient and it must be fully wireless so as to not impede the patient or medical personnel. The device must also be able to interface with existing monitors and systems currently in place in the operating room. Optionally, we will consider providing support for popular handheld devices such as IOS or Android tablets and smartphones. The signals that the device emits must be encrypted to comply with HIPAA guidelines. The device must be sanitary and easily cleaned. The device must be able to hold an operational charge for at least 12 hours. Lastly, the device must be able to be worn by the patient comfortably for the operating time as well.

2.5 Limitations

The development of this device is being facilitated under the prospects that it will be used in conjunction with the Philips ECG monitors currently employed at the Mayo clinic. These monitors are equipped with an 11-pin GE/Marquette Connector which clasp directly to traditional electrode pads. The device will be used in an isolated operating room where the patient is under general anesthetic. The device cannot obstruct the abdomen of the patient or any procedure in this area.

To work around this limitation, 3 metal buttons (standard to connecting electrodes to ECG leads) will be connected to the Bluetooth Receiver's output. These 3 metal buttons will then connect to the single lead wire standard to most ECG cables. The signal will output through these 3 connectors to multiplex the signal into one.

This eliminates the need to make a new cable specifically for the device and allows for better standardization/implementation across the board with organizations that may use different ECG modules.

3. Concept Generation and Analysis of Alternatives [All Disciplines]

When building concepts to select for the initial prototypes, it was important to review products on the market that perform similar tasks. The goal in comparing related products is to get ideas of how to approach creating a solution: which components to consider, which functionality is required, and what can make the product unique from others in the market, such that it is not drowned out by the competition. Below are a few products that were examined to help guide the team in generating concept variants.

3.1 Literature Search

Biocare iE300

Pros

- Effective monitor that receives, interprets and displays up to 12 leads.
- Data management potential
- Properly Licensed and approved by the FDA and CE

Cons

- Large form factor
- Wires are still run on the patient
- Battery capacity of only 3 hours

Eko Duo ECG + Digital Stethoscope

Pros

- Very portable
- Pairs with IOS and Android devices
- Interprets the ECG signal

Cons

- Only intended for short term use
- Does not output to existing equipment

Omron BP + ECG Monitor

Pros

- Pairs with IOS and Android devices
- Interprets the ECG signal
- Also can read the patient’s blood pressure
- Truly wireless and unintrusive

Cons

- Intended for domestic use
- Does not output to existing equipment

Kardia Mobile

Pros

- Pairs with IOS and Android devices
- Interprets the ECG signal
- Very small unit
- Cost effective product

Cons

- Does not attach to the patient
- Outputs only to IOS and Android

EMAY Portable ECG

Pros
- Can be used on nearly any part of the body
- Very small unit
- Cost effective product

Cons
- Does not attach to the patient
- Outputs only to IOS and Android
- Can only record for 30 seconds at a time.

3.2 Concept Generation

The process of concept generation started with talking to the sponsor and understanding what she expected of our group. These expectations and deliverables have been largely discussed in the '*customer needs'* subsection, however, will be referenced throughout our concept generation as they become relevant.

Because our senior project is a "phase 2" project, meaning that we are building off of a project done previously by other students, we had an initial outline already laid out for us. The group who completed "phase 1" finished off the project with a prototype that was able to transmit a bluetooth signal for a heart rate.

Figure 1 shows the prototype that was provided. This is the unit designed and built by the "Phase 1" group from last year. Our initial concept generation plan was heavily influenced by this module and our primary prototype plans share a lot of similar features with it. This module includes three electrodes and was designed as a box that rests on a patient's sternum.

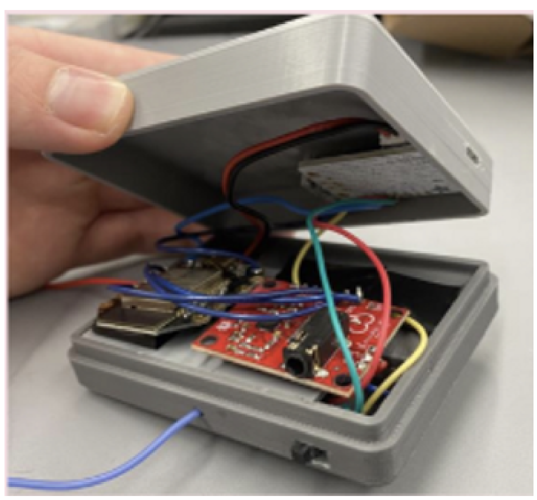


Figure 1: Phase 1 Prototype

One of the first modifications that we decided to make was based on a conversation we had with the sponsor, who informed us that having three electrodes was unnecessary and overcomplicated. Instead, we began working to diminish the requirement down to a single electrode.

The first variant below shows the first module designed. It contains only one electrode, and is redesigned to be worn as a necklace rather than being adhered to the chest. This module was also designed to be a rounded off pod, intended to be more comfortable and safer than the box with sharper edges and a bulkier body.

While the necklace module satisfied the requirement to diminish the number of required electrodes and kept the module close to the patient's chest, there were definitely concerns about the safety of the device. Having it hung around a patient's neck could become a strangulation hazard and cause serious injury or death if not monitored at all times. In response to this, we created the wrist module, seen in the second variant. This module aesthetically appears much more similar to the provided prototype than the necklace module, however, this one is intended to be worn around the wrist via a strap, similar to a smart watch. When presented to the sponsor, she expressed concerns about the signal that could be read through the wrist. We also were hesitant about the size of the module, since it would have to be a similar size to the (quite large) prototype but still fit comfortably on wrists of all sizes.

Since the sponsor was worried about the signal that could be read from a patient's wrist, we worked to move the module back to the chest where it began, but combined that prototype module we received with the initial necklace module concept. We came up with the pod module, shown in our third variant. This module uses only one electrode, which is what adheres the pod itself to a patient's body, eliminating the need for an additional wire connecting the module to the electrode. While this module satisfied the given criteria the most out of the ones generated thus far, we still had concerns about the practicality of it since it would be bulky, heavy, and only secured to the patient by a single electrode.

After much deliberating with the sponsor and rethinking the project from the ground up, we ultimately decided to abandon the prototype that was provided to us altogether. While the unit was successful in its task, we determined that there were simply too many design barriers to overcome and that we would make better use of our time if we started from scratch. After much research and even more speaking with our sponsor, we ultimately decided on the design shown as our alpha prototype. This design is much different from the others, and uses sensors situated on the patient's fingertips to read the signal circulating throughout the body rather than using electrodes to read the heartbeat directly from the source on the chest. The entire unit can rest freely on a patient's belly or pelvis area while each hand has a single finger touching on one of the sensors. To improve the comfort and wearability of the module, the whole thing will be concealed within a sanitary glove to prevent the patient from removing their fingers from the sensors. This final design concept has been approved by our sponsor.

Even though the alpha prototype design was approved by the sponsor as a working prototype, this was not the final design of the product. The final design for the beta prototype was done using the best features of the alpha prototype, and giving it a more ergonomic design. The final design not only included a case for the main components, but also a separate design for the receiver. The main module also maintained the opening for PPG reading through finger placement, and this is facilitated by the new ergonomic design, to avoid any patient discomfort.

3.3 Analysis of Alternatives

The team reduced the number of alternatives through their use in application, whether it was their wireless capability, ergonomics, or size/metrics. Refer to Appendix 2 to see the concept variant weight graph.

3.4 Flow Chart of Design Process

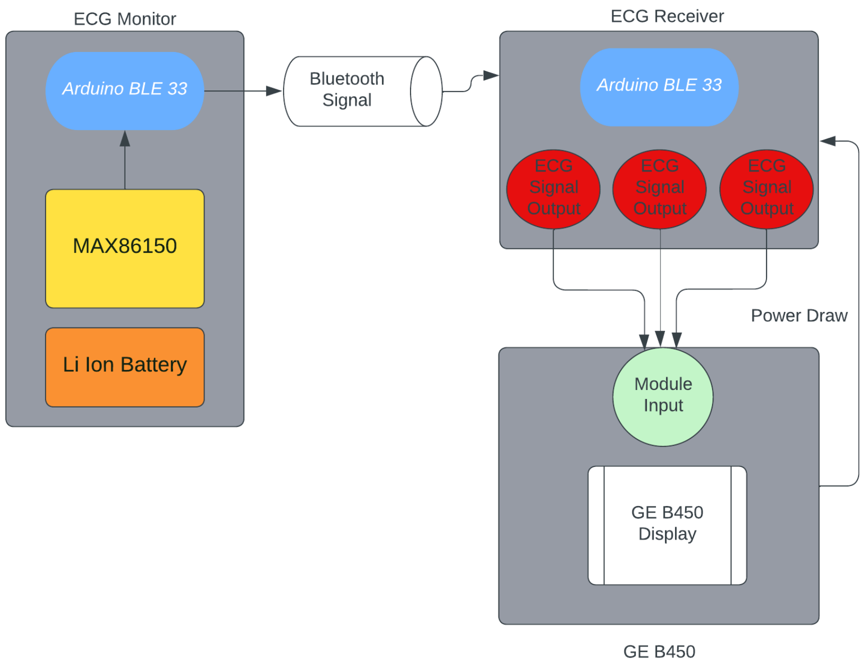


Figure 1: High View of Device Components

Using figure 1 as the example to explain, the design process began with the Transmitter, which contains the Arduino BLE 33, MAX86150, and a Lithium Ion battery. The parts were soldered together, then the MAX86150 board was tested in the Arduino IDE to ensure the board could acquire electric signals from human heartbeats.

Once the basic functionality of the Transmitter was confirmed, the second Arduino was introduced, such that the Bluetooth connection could be acquired between both microcontrollers. This was also tested by attaching the receiving Arduino in the Arduino IDE and confirming the Bluetooth signal could be captured.

Then the team began testing the device's ECG signal in the Arduino IDE to improve the consistency of the PQRS waves. Digital Signal Filters had to be implemented in the Receiver to reduce the sheer noise that was visible in the IDE.

The team then realized that in order to connect the Receiver to the hospital monitor, a wire would need to be connected to the hospital monitor, which would have required either a converter or a cable to be made just to connect between the Receiver and the specific model of ECG monitor that the hospital uses. The solution was to connect the hospital monitor to the Receiver by using the metal buttons from electrode pads to directly link up to the hospital monitor's ECG lead cable.

3.5 Functional Decomposition

Using figure 1, the functional decomposition of the project is seen within each component:

The MAX86150 is the driver of the device. Without it, there is no functionality. The MAX86150 is responsible for converting the patient's electric heart signals into a processable data.
The MAX86150 communicates with the Arduino BLE, such that it can send data from the Transmitter Arduino to the Receiver Arduino.

The Transmitter Arduino's purpose is simply to act as the communicative bridge between the MAX86150 and the Receiver's Arduino, since the Arduino on the Transmitter does no calculations in order to use less power.

The receiving Arduino is the only component within the Receiver and it executes all the calculations and signal filtering, since it is attached to the hospital monitor's power supply. The Receiver then communicates to the hospital equipment via ECG leads directly connected to it.

3.6 Data Flow Diagrams

The data flows in a unidirectional path as is depicted in Figure 1:
Patient Heart Rate -> Converted from Analog to Digital Signal by MAX86150 ->
Passed to Arduino BLE 33 -> Send digital signal via bluetooth to Receiver Arduino ->
Receiver Arduino performs Signal Processing -> Converts digital signal back to Analog ->
Pass output signal to Hospital ECG monitor via ECG leads

4. Prototyping Process [All Disciplines]

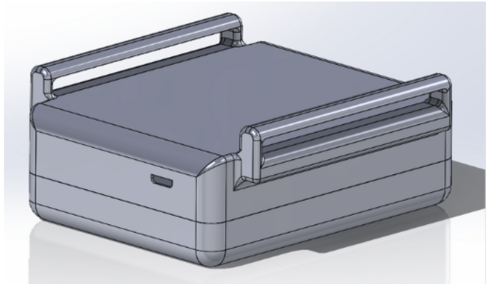
When designing the first proof of concepts, the main focus was on the patient's ergonomics and their effects when placed on different locations on the patient's body.

4.1 Proof of Concepts

Variant 1 - Necklace Module:

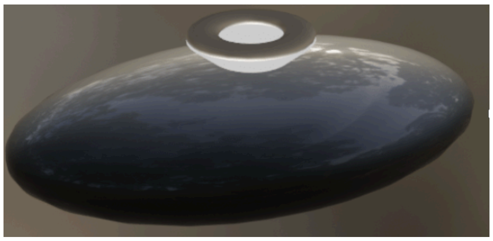
This variant had the chance of strangulation as well as the possibility of the electrode pad being pulled off if the necklace module were to shift during surgery.

Variant 2 - Wrist Module



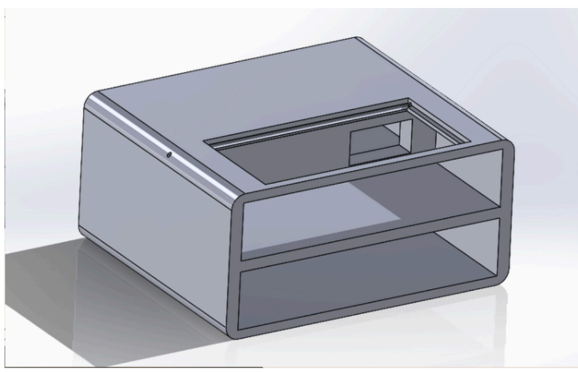
Built on the idea of other products, such as the apple watch, but proved to not fit the patient restraint on the surgery table.

Variant 3 - Electrode Inclusive Module:



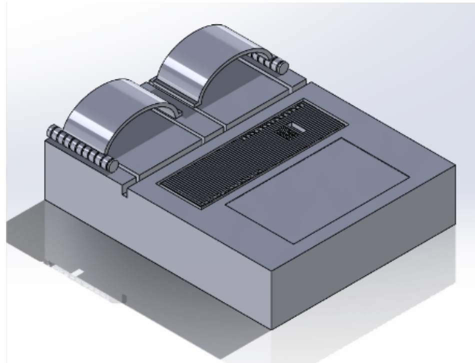
The electrode inclusive variant would not adhere well enough to the patient without some form of extra binding to the patient, which would be discomforting.

Variant 4 - Tiered Module:



The tiered module was referred to later when building the tiering system in the Beta Prototype.

Alpha Prototype:



The ECG alpha prototype comprises two Arduino BLE 33 microcontrollers, a MAX86150 board, and a 5000 mAH Li Ion battery. The device is designed as a transmitter module, with a casing that encloses the circuitry. The transmitter is equipped with clamps that securely hold the patient's fingers to obtain measurements of the patient's heartbeat. By measuring the voltage difference across the upper body, the prototype can accurately read the voltage output of each heartbeat. Specifically, the clamps hold a finger from each hand to obtain a reliable measurement of the ECG signal.

4.2 Design Details

The power requirements of the Device's current design is based on the power draw from both the MAX86150 and Arduino BLE 33 boards within the Transmitter. The purpose of analyzing the power draw is to gauge how many mAH the Transmitter's Battery would require to stay active for 12 hours sustained. Below is the calculations performed to understand the lifespan of the 5000 mAH battery that was placed within the Transmitter Housing:

The battery will supply power to an arduino nano and our ECG board (MAX86150). Below are the power draws from their respective datasheets.

```
clear
Ah = 5000; %battery mAmp Hours
ard_PD = 2.4; %arduino nano power draw mAmps
MAX_PD = 100; %MAX86150 power draw in mAmps
T = Ah/(ard_PD+MAX_PD) %maximum battery life in hours
```

```
T = 48.8281
```

We also tested the power draw experimentally, we found that the unit operates at 4.7 V and has a resistance of 138 ohms. Via Ohms law we can find the current.

```
R = 138; %measured resistance
V = 4.7; %measured voltage
I = V/R %current in A
```

```
I = 0.0341
```

```
T_exp = Ah/(I*1e3) %battery life in hours
```

```
T_exp = 146.8085
```

The Receiver does not require an analysis of the power draw, as it receives an overabundant supply from the hospital monitor.

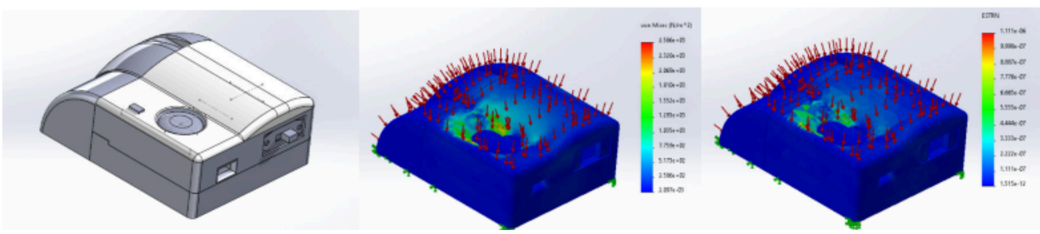
The Transmitter housing itself underwent a structural requirements analysis to ensure that the forces acting on it will not cause damage to it. Below is a stress analysis by using an FEA study in SOLIDWORKS:

The unit must withstand the force of a finger/hand strapped to it. Lets assume that the surface area of a finger is ~3 cm^2 and the maximum force it will be exerting is ~20 N, the device will have a factor of safety of 4.

```
clear
A = 3e-4; %surface area in M
F = 20; %force in N
FoS = 4; %factor of safety
stress = (F/A)*FoS %maximum force to be withstood by the unit in Pa
```

```
stress = 2.6667e+05
```

We also ran an FEA study in solidworks with our model. We applied a distributed load of 10 Pa on the top of the unit and here are our findings.



The materials used to fabricate the housing are also of importance, since sterility is paramount in a medical facility. Thus, an analysis of how the housing material should react to the cleaning compounds found in sterilizing agents was done by researching the variety of ways the FDA recommends to sterilize medical devices.

According to the FDA, 50% of medical devices are sterilized with an ethylene oxide solution. It is a commonly used solution due to its unlikeliness to damage equipment that are sensitive to heat or moisture. Fortunately, after testing at the sponsor's office, it was discovered that the disinfecting agent used by their office is also ethylene oxide based.

Another material consideration is how the material used can interfere with the wireless signals, but it has been researched and proven that 3D printed materials and Polymeric materials are very compatible with wireless communications, as they allow most electromagnetic waves to pass through them rather than shielding from them.

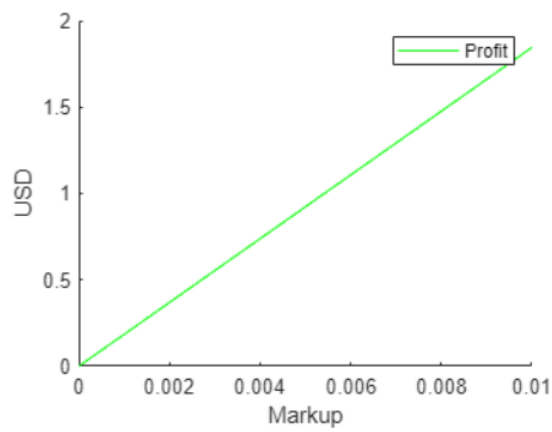
Pricing based on component and expected labor cost were performed in order to calculate a cost analysis of the ECG device from an Engineering Economics standpoint. Below is the analysis of the device's economics:

```
clear
partcost = 159.52;
laborcost = 20;
```

```
pdcost = 5;
totalcost = partcost + laborcost + pdcost %total cost in USD
```

```
totalcost = 184.5200
```

```
markup = zeros(1,100);
profit = zeros(size(markup));
for i = 1:size(markup)
    markup(i) = i/100; %markup in %
    profit(i) = markup(i)*totalcost;
end
figure(1)
hold on
plot(markup, profit,'g')
xlabel('Markup')
ylabel('USD')
legend ('Profit')
```



4.3 Beta Prototype

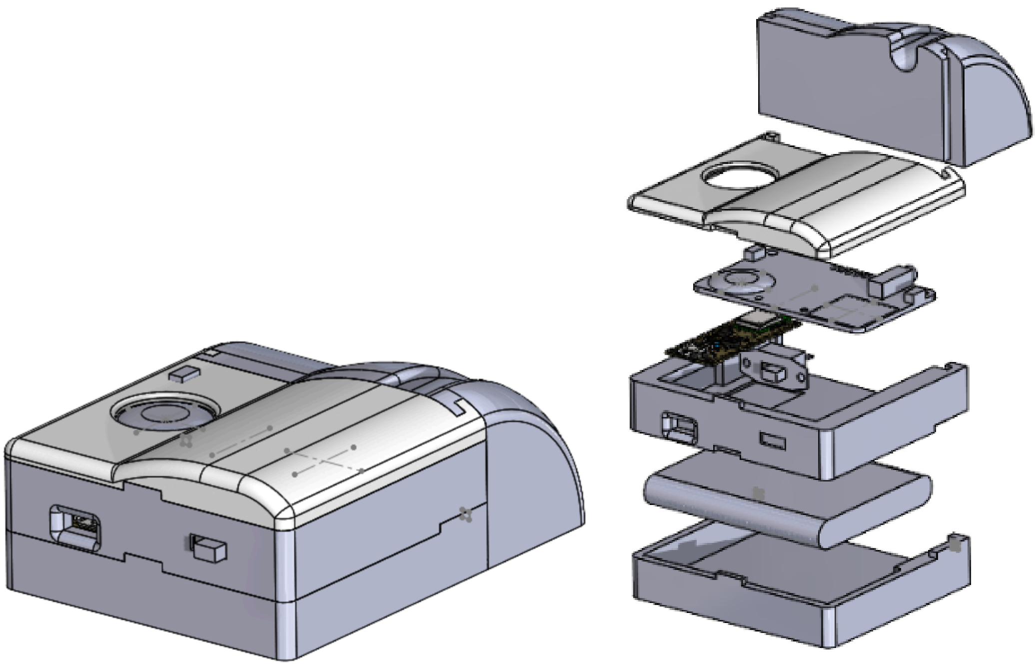


Figure 2: Tiered housing with components

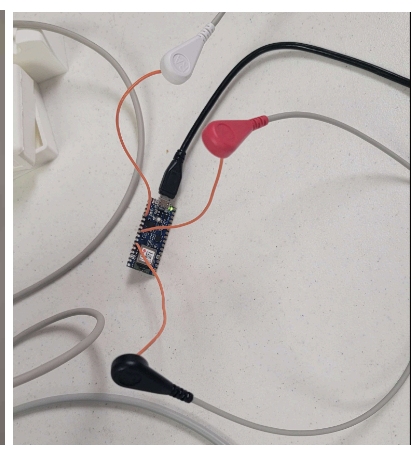


Figure 3: Final Beta Housing

Figure 4: Exposed view of how Receiver connects to hospital ECG

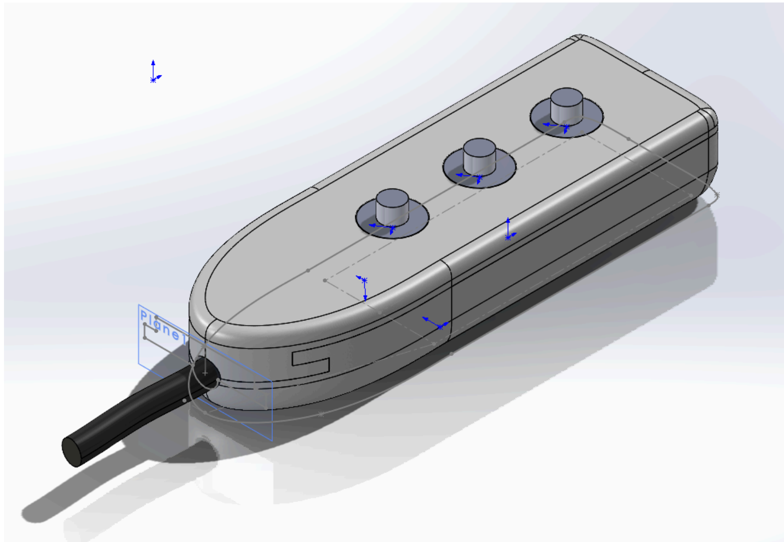


Figure 5: Wireless Receiver Model

The Beta prototype is a significant improvement over the Alpha prototype in several ways. One of the most important changes is the incorporation of a receiver design that is compatible with any hospital monitor using ECG cables. The receiver design comprises an Arduino microcontroller that converts the signal from the max86150 into a pulse-width modulation (PWM) signal that emulates an actual analog signal. The PWM signal is then transmitted through the positive end of the ECG monitor cable, while the ground and negative ends are connected to ground. The hospital monitor can then read the PWM signal as if it were directly connected to a patient. Although the hospital monitor does not display the BPM, with some changes in the signal, the monitor appears clear and accurate, providing real-time information on the patient's heart activity.

Another significant improvement in the Beta prototype is the integration of the battery into the transmitter. In the Alpha prototype, the device was powered by a 500mAh Lithium-ion battery, but there was no method for integrating the battery into the device. During testing, the transmitter was plugged into one computer while the receiving Arduino was plugged into another via a micro-USB cord. However, in the Beta prototype, the battery is now integrated into the transmitter using a TP4056 Lithium-ion battery charger and protection module. This component enables the battery to be charged without damaging it and allows the device to be powered by the battery without fully depleting it. When plugged in, the battery is in charge mode, and the device can still function. When unplugged, the battery powers the device, enabling it to operate for up to 10 hours.

Additionally, the Beta prototype includes a power switch, which was not present in the Alpha prototype. The power switch allows users to turn the device on and off, making it more user-friendly and convenient to operate. The switch is located on the exterior of the device and is easily accessible, making it simple for healthcare professionals to use.

In summary, the Beta prototype represents a significant improvement over the Alpha prototype in terms of functionality, portability, and ease of use. The integration of a receiver design, battery integration, and power switch make it a practical and user-friendly device for monitoring a patient's heart activity in real-time. The Beta prototype offers real-time ECG data that can be read by any hospital monitor using ECG cables, making it a versatile device for healthcare professionals.

4.4 Agile User Stories

The two main epics that occurred during the development cycle were:

1: Device Housing Changes and Fabrication

User Story 1: Sponsor needed housing to be within specific size metrics.

Task 1: Get measurements of surgery table's clearance space for patient arms [10].

Task 2: Decide how to organize components within the new parameters [6].

Task 3: Create model in SolidWorks of new design [10].

User Story 2: Sponsor needed housing to be resistant to chemical compounds.

Task 1: Research a variety of different 3D printer materials, specifically those durable to impact and chemical wear [8].

-The material chosen was PC-ABS, which is Allergen Friendly, cheap, electrically insulating, temperature and impact resistant.

Task 2: Print housing with best fitting material [8].

-Housing had to be printed twice due to thinning of material during fabrication.

Task 3: Test housing in a solution made of same ingredients found in the disinfectants used in the hospital [8].

-After soaking the housing in solution, the material proved resistant.

User Story 3: Sponsor required the housing to be easily disassembled.

Task 1: Design a tiered housing model that could partition components [8].

Task 2: Organize in which tier each component would be set within, while maintaining the ability to keep the battery charging port and ECG Lead port accessible from outside of the housing [10].

2: Adding Filters to Receiver Code.

User Story 1: When testing device on Team laptop in Arduino IDE, raw signal was very messy.

Task 1: Find root cause of signal distortion [10].

-Determined to be caused by noise and lack of signal filtering.

Task 2: Research on existing filters within the MAX86150 board [6].

- An FIR filter was already existent within the example code.

Task 3: Repurpose the existing FIR filter to help clean the signal.

User Story 2: Heartbeat peak amplitudes on the monitor were smaller than expected.

Task 1: Create a new high pass filter to amplify peak amplitudes without amplifying the noise [8].

-An FIR filter was used to pass signals that are 0.5-150 Hz and amplify them so they were observable on the monitor.

Task 2: Modify the output voltage of the PWM signal [10].

Task 3: Create signals to send through the negative and ground node to prevent the monitor from getting confused [10].

User Story 3: The hospital monitor could not interpret a BPM from the Receiver's signal.

Task 1: Research if the monitor is capable of reading BPM from a PWM signal [10].

-The MAX86150 library does not have a method to differentiate signals.

Task 2: Test output to monitor with positive and negative signals [8].
- Didn't provide much change to results.

5. **Related Design Activities [ME and ECE]**

The main design process started with embodiment design. Once we decided on the form we wished our product to take, we (as mechanical engineers) coordinated with the other members of our group to reach a mutual understanding of the approach for success. By the time of the beta semester, we had acquired all of the major parts that would be used in the final product.

These parts and the way that they were oriented, interfacing and connecting were the defining aspects of the design. To create a housing for them we first began by modeling them. The ideal way to accomplish this would be to find a premade CAD file online to use, but unfortunately, not all of our parts gave us this luxury. For the majority of our components, we ended up measuring them with calipers and sketching them in SOLIDWORKS.

Once all of our parts were modeled, we created an assembly that included all of these parts. They were then oriented and positioned in an ideal manner for operation. From this configuration, we decided on a layout to hold them with. The switch, Arduino micro USB port, MAX board PPG and 3.5mm jack must be accessible from the outside for use.

From this, we developed a bottom piece that contains the battery, a middle "shelf" that connects the cable from the battery to the switch and Arduino, and a lid that fixes the MAX board in place. To ensure all of these parts stay firmly locked together, we added notches and grooves to parts that interfaced with each other.

One issue with the previous group's unit was it was awkward to disassemble and reassemble. If this was a fully production ready unit, this wouldn't be necessary. However, due to the nature of prototyping, the unit must be both serviceable and sturdy simultaneously. To accomplish this, we opted for a 4th part in the main assembly that can easily be slid in and out to allow for the layered assembly to be taken apart without undoing any permanent fixtures.

This solution keeps everything together snugly with a friction fit. The tolerancing of the parts were very tight however. Somehow, we managed to print an acceptable set of parts on our first attempt, resulting in a well operating assembly.

The process for developing the receiver housing was very similar, albeit much more streamlined. The receiver consists of a single Arduino powered by a USB micro cable and 3 ECG electrode buttons. We used another rail system for fitment again, but this time our tolerance was not good enough. We had to manually machine our parts as we were in crunch time at that point. In the end, we created a very compact unit that fulfills all of the requirements.

5.1 Risk Examination/Codes Standards

Because we are designing for a medical environment, the unit should be hypoallergenic and be able to be sanitized frequently. Due to its ease of production we employed FDM printing for the housing. This should allow for a prototype unit that is capable of being used in this context.

In addition, in order to ensure the device is safe, we must ensure the electrical components are properly insulated, the battery is not exposed to an environment that would cause it to combust, the surface of the unit cannot harbor bacteria or
contaminants.

Medical devices are sterilized in a variety of ways and according to Sterilization for Medical Devices | FDA, 50% of medical devices are sterilized with an ethylene oxide solution. It is used because it is a method that will not cause damage to devices and equipment that are sensitive to heat or moisture. In order to ensure the usage of ethylene oxide is safe for human interaction, two commonly accepted standards are to be followed, ANSI AAMI ISO 11135:2014 and ANSI AAMI ISO 10993-7:2008(R)2012.

According to https://doi.org/10.3928/01477447-20191031-07 and https://doi.org/10.1016/j.stlm.2022.100045, if properly cared for and treated as a standard medical device, the potential for sterility and bacterial resistance of FDM printed parts is applicable for a medical environment. According to these articles, our FDM printed device is compliant to these standards and should be safe and durable enough to be used in an operating room environment.

One additional consideration would be how the FDM printed material interacts with electrical components inside and bluetooth communication. According to https://doi.org/10.1007/s00170-014-5717-7, 3D printed materials are an ideal material for housing and interacting with electrical equipment. This is because these devices can
be incorporated into a housing as an integral component as they can be fitted and designed around these parts.

Another consideration to make would be that the polymeric nature of FDM parts is that they make for good insulators, both electrically and from contaminants and corrosion. Polymers used in FDM printing are also compatible with wireless communication as they allow for most electromagnetic waves to travel through them
and do not act as shielding.

6. Results:

6.1 *Final Product Testing*

Figure 6: Results from final day of testing with hospital ECG monitor
(noise and no BPM, but stable signal)

As the project neared its "final" version multiple meetings were scheduled with the sponsor to go to her office and test the wireless ecg's integration with the current equipment that is in use. While there the signal manipulating algorithm was tweaked until it produced a signal that the sponsor was happy with. This took three meetings and around 5 hours of testing before the sponsor was happy with how the output looked. Overall it was a great success as it met the objectives of the device from the sponsor. The device is able to disconnect the patient from having to be directly connected to the ecg monitor. There is a single issue with the signal structure which will be discussed in the future work section below.

7. **Conclusions and Future Work [All Disciplines]**

The product the Wireless ECG created satisfied all requirements the sponsor set for us, with improvements to be made.

7.1 Conclusions and Project Summary

Through multiple design iterations, the team achieved a functioning product that could produce reliable results by the end of testing. The biggest setback encountered in this project was the inability and fixation to get the Phase 1 ECG device to work. Another setback compounded by the first was not having the time to devise a solution to differentiate signals well enough for the hospital ECG to interpret a heart BPM. Otherwise, the work done is substantial and would be considered a success.

The next team to be passed the torch will have to resolve the issues remaining on the current solution. To summarize for the next group: The noise caused seen in Figure 5 is most likely caused by one or more of three actors:

1: The MAX86150 board only outputs one signal for the ECG, whereas the hospital ECG monitor expects 2 differentiating signals and a ground, such that it respects Einthoven's triangle.

2: The hospital monitor may expect a true analog signal, yet the device is converting from Analog to Digital, then from Digital to Analog again. Data loss can occur during sampling.

3: Signal filters will need tweaking or require additional filters

7.2 Individual Contribution

Team Member	Contribution
1. Aradia Mauras	9.09%
2. Krister Lawlor	9.09%
3. Travis DiDonato	9.09%
4. Travis Rau	9.09%
5. Rylee Pilat	9.09%
6. Kel Nielsen	9.09%
7. Angelo Rivas Plata	9.09%
8. William Friend	9.09%
9. Kendrick Washington	9.09%
10. Erik Delaney	9.09%
11. Alan Platt	9.09%

7.3 Reflection Report

The overall reflection of the project is a positive one, with some self-criticism to be given from hindsight. Much time was spent analyzing the device from Phase 1 to attempt to get it to work. Following whatever documentation at our disposal to achieve a working prototype ended in failure. Even with help from a member from Phase 1, the device was unresponsive.

It was an unfortunate outcome, as the results from the Phase 1's device were promising. Building off of it would have expedited the development of the wireless component. For between one to two months, the team was preoccupied trying to get the device to work, when the team should have simultaneously been brainstorming the contingency plans in the event that the Phase 1 device would not work.

The team was very close to figuring out a solution to the final issue encountered, which was the hospital monitor not interpreting a patient's heart BPM. Had the time been spent working on the same product the team currently has, the product may very well be finalized.

The problem the team encountered within the final testing stages was a noise in the signal that was preventing the hospital ECG monitor from acknowledging the Receiver's output as a human with a beating heart. This was potentially caused by an oversight in component selection, yet none of the team members could be aware of how the MAX86150 board's ECG capture method could inhibit the hospital ECG monitor's ability to read the Receiver's output. In retrospect, having multiple models of ECG boards available would have proven beneficial in this instance, yet would have been a waste of sponsor funding, had the other boards not been used.

Beyond these issues, the team worked well together to ask in thoroughness to the sponsor what was required of this project. When given requirements, the team gave many examples to receive the sponsor's input on each example. This led to many proof of concepts to be written up.

Each member worked both individually and as team players to collaborate to create a better version of the product than before. With a mixed discipline team and a good ratio of each discipline, the team could divide work and allow members to be covered for in the event that they were unavailable to contribute for a time. Research involvement was performed by every discipline, even if it didn't align with their own expertise. No single problem belonged to a single individual.

In conclusion, more went well with the project than not, considering Phase 2 built a functional Beta Prototype despite the tribulations the project suffered.

Appendix 1 - Customer Needs, Requirements and Objectives

1.A Customer Needs

The sponsor's needs did not change from the first semester to the next. It remained true that our device had to be durable and efficient in order to be used in the hospital environment. Our sponsor specifically asked for a device that was as fast as a wired machine in a similar hospital setting and should be able to last during a twelve hour surgery.

1.B Design Requirements

For design requirements, we decided that the device must be able to interface with existing hospital equipment, be universal for all patients, and be capable of repeated sterilization. To make sure we were consistent with the customer's needs, we had to make sure the device was fast, efficient, and safe to use for long periods of time.

1.C Objectives

The objectives remained the same as well, since the customer needs remained the same from the previous Phase.

Appendix 2 - Concepts and Analysis of Alternatives

	Box Module	Wired Pad	Wrist Device	Pillow Module	Necklace Unit
Patient Comfort (2)	-2	0	+2	+2	-2
Battery Capacity (2)	0	+2	-2	0	-2
Economics (1)	+1	+1	-1	0	0
Durability (2)	0	-2	0	+2	-2
Sterility (3)	+3	0	+3	0	+3
Complexity (2)	+2	0	-2	-2	-2
TOTAL	+4	+1	0	+2	-5

The image above was the original criteria ranking of the variants.

Appendix 3 - Prototyping Process

The prototyping process began with choosing a concept variant. The concept variant that was chosen was the one that resembled the Phase 1 device most closely. From there, the components were decided, then put together without a housing for the sake of being able to pull things apart quicker, since soldering wasn't successful every time.

Testing the ECG board with the Arduino IDE to ensure a signal was produced was next. Once the board was proven to work, the Arduino's bluetooth capabilities were implemented. After bluetooth, signal filters had to be implemented due to the noise occurring in the ECG.
The testing on the filters was iterative to keep making small improvements every adjustment.

Appendix 4 - Patent Search, and Risk Examination

No patents exist that would directly jeopardize the current project model.

The only risk that was assessed and resolved is the potential violation of HIPAA, where any data lost to a 3rd party would result in a direct violation and possibly a hefty fine. This was mostly applicable only to the use of Bluetooth in the device, but this has been tested and proven to not be an issue.

Appendix 5 – Individual Contributions

[Aradia Mauras]

My role in the Wireless ECG team was to design and create a mobile app that would connect to the device and display the signal output. I handled making the mockups and prototypes of this tablet design, as well as creating the finished app for a tablet.

During the first semester, I did research for how to output the arduino signal to a display and just generally worked on the mockups for the app design. I also worked on sifting through the code of the team before us to understand what they had did to create a signal.

During the second semester, my team decided they did not want to go through with the tablet design, so while that was shelved I helped with bug fixing the arduino code. During a presentation, we received feedback from Dr.Park stating that we should continue work on the app as a backup in case the connection to the monitor did not work. After that I continued working on it and made changes to the design to be more streamlined.

[Krister Lawlor]

My role in the Wireless ECG team was to manage the team meetings and to communicate with our sponsor, Dr. Faeza Kazmier. With my knowledge in Computer Science, I was able to, as an individual, communicate some possible issues and solutions to our sponsor during our semi-regular meetings. When I could not answer a question for our sponsor, I would consult with the team for their expertise in their respective disciplines. Then I would return to discuss further with our client to get input.

I was responsible for determining times and setting up for the Wireless ECG team to meet digitally via Google Meet as well as when we had to begin testing our product in person with the hospital equipment. Although fitting in 11 (plus our sponsor) people to meet all within one time slot was near impossible, I made sure to always include one of every discipline to meet, as their advice during testing would be invaluable.

My contribution to the device itself comes from designing the form-factor of the device, where an issue to be addressed was the compatibility between multiple hospital ECG devices. Since every manufacturer of ECG devices has different cables/ports, a cable converter would simply not be feasible.

A solution I provided to the problem was to connect the hospital's ECG leads directly to the Wireless ECG Receiver by means of wiring the conductive, metal electrode buttons to the Wireless ECG Receiver's Arduino Nano BLE 33.

I provided research on components to be used in the Beta Prototype, as well as research into the Digital Filters implemented into the Wireless Receiver and confirming they were compatible with our software and our Use-Case. I also provided information that helped troubleshoot the device during testing, particularly during the final stages of testing.

[Travis DiDonato]

As a Computer Science student on this project I spent much of the first semester working on trying to get the previous year's project to function and to understand how the Arduino IDE and its language functions. In the end the previous year's project did not function, but we decided to abandon their setup and go a different direction.

Once the CE/EE students had decided on the boards that we were going to use in semester 2 for the project I began researching bluetooth and specifically bluetooth low energy since that's what the boards we decided on were going to use. I looked into the functionality of bluetooth connections along with how Arduinos connect and the properties of the sent data. Very early on one of the problems I helped solve was to get the bluetooth connection to be able to send a number larger than 255 as the test code from Arduino was only able to send shorts. Very quickly I was able to typecast the value and have the connection able to send long values, which we kept using in the final version of our project.

Around this time in the project I became the primary holder of the physical device and its components while we were waiting/assembling it. I was always available for anyone on the team to message and have me bring the parts down to the lab/meeting spot for them to work on if they needed it. Early on in this semester Cole and I spent a Saturday testing the board connections to ensure we had a method to graph and record data as an example.

Once the components were soldered together I was there every meeting to help test the device and make filtering options for it, I specifically helped with the averaging filter and later the limiting filter. The limiting filter is an important part of our data manipulation in order to get a reasonable quality output on the hospital ECG monitor. These two filters combine to make the data be normalized and then re-scaled to 0-4096 as that's the number we can actually output to the ecg monitor. Then another algorithm that doesn't have a name separates out the single value we have into a positive and negative while constantly changing the ground value in order to trick the ecg monitor into believing it's plugged directly into the patient.

The last notable thing I contributed to the team was writing a documentation document for next year's team, while it is a group effort and other teammates have added to it, I started the document and wrote a sizeable amount of useful insights that won't be immediately apparent to the next team that I think they would benefit from knowing off the start of the project. So that they don't have to figure it out on their own while testing as my team had.

[Travis Rau]

During the first semester, I focused on understanding the prototype given to us by the previous team. After analyzing the entire program from the prototype device, we determined that the device was not able to meet the requirements and decided to begin our project from scratch. During the second semester my contributions to the Wireless ECG team consisted of programming and debugging the devices along with researching ECGs. I also researched parts that could improve the current state of the project.

The receiver device contained code sections for the bluetooth connection, the filter implementations, and the connection to the hospital's ECG. The bluetooth connection had to be programmed to quickly begin and receive one number at a time from the transmitter device during each loop. The filters implemented in the code were the filters created by the team so that we could use them in various orders and with different coefficients, allowing us to quickly check multiple different filtering effects. Connecting the receiver to the hospital's ECG had many problems that were difficult to solve.

The first issue with the hospital ECG was that the monitor believed our device was not a patient and would not display the graph or heart rate. We tried various values to get the ECG to accept our device's output signal and eventually managed to find a graph that the ECG accepted most of the time. One value would be the original ECG graph, the second value would be an inverted ECG graph, and the third value would be a number between the first two for ground. The ground is constantly rising until it reaches the top graph. Then, the ground is reset to the bottom graph. This traps it between the graphs and seems to trick the ECG monitor into believing it is a real person. After researching ECG lead types we understand why the inverted graphs work well for the ECG, however, we're not sure why the ground moving between the positive and negative makes the ECG work.

The second issue with the hospital ECG was that the monitor would not show the heart rate of the patient. While we were still experiencing the first issue, we assumed it was likely because it could not have the graph operating for long enough to determine the heart rate. Once we had fixed the first issue we realized that the ECG monitor had a marking for a noisy signal any time the graph was running. We performed a couple tests with the real ECG to see if we could create a noisy signal. These included shaking the lead wires, disconnecting the leads partially while still maintaining contact, and moving the patient. The graph on the ECG monitor looked incredibly noisy, however, the monitor was still able to read the heart rate and did not give a marking for noise. Our graph looked much cleaner than the fake noise graph but couldn't be read due to noise. After these tests it became clear that the issue is most likely being caused by PWM. The Nano 33 BLE device that we had only supported analog outputs as PWM, meaning we would need to buy another part to be able to fix the problem. By the time we discovered this, it was already too late to buy, install, and program a new part.

[Rylee Pilat]

My contribution to the project consisted mostly of the design and modeling of the housing. During the initial prototyping, the mechanical engineering majors focused on brainstorming different types of units that could eventually be implemented. We discussed modules seen earlier in the report including the necklace variant, wrist variant, electrode-inclusive variant, and the tiered variant.

In order to decide on which housing unit was best, I paid attention to what electrical components the other majors were considering putting into the device. If the components were relatively small and compact, then one of the smaller units that adheres to the patient such as the necklace variant or the electrode-inclusive variant could be utilized. Conversely, the wrist variant and tiered variant had more stability and therefore more ability to house and support larger or heavier components. The mechanical engineers also took into consideration the sponsor needs and concerns as a housing type was finalized.

To help with the proposal and selection process, I personally contributed by pitching some of the proposed ideas and creating some of the models seen in this report in order to present the ideas to the sponsor. A visual aid is very important to help clarify communication and understanding between parties, so I emphasized the need for models and blueprints along the duration of the project. I personally proposed the tiered module housing that we eventually determined to be the best choice for our application, and I also created the models for both the alpha and beta prototypes.

After the mechanical engineers settled on using the tiered module, I spoke directly with the other majors to ensure that we knew exactly which electrical components were being finalized to go into the project. Knowing exactly what was going to be put into the module and how it all connected was crucial because it allowed for the module to be as space-efficient as possible. Once the exact components were known, I used the sizing specifications for each piece to design the housing around them. Using my knowledge of tolerancing and slip-fitting, I designed and modeled the first printable prototype for the final housing module. The design was effective and Kel made minor modifications to it in order to create our final housing.

While the initial prototype housing was being printed out of PLA for testing purposes, I did research on what material we would eventually want the final housing to be. I focused my efforts on materials that could be 3D printed and that would satisfy the needs of this project. I eventually proposed pure polycarbonate because it is able to be 3D printed, it is not an allergen, and it is not susceptible to deterioration after repeated sterilization. After speaking with the 3D printing lab at Florida Poly, I green-lit the use of PC-ABS, a polycarbonate mixture, in order to make the printing process easier.

Aside from working with the housing, I also tried to spend time on this project supporting the other majors and helping to keep the group structured. I created a lot of the group documents, such as the presentations and feedback sheets, and monitored them in the group chat. I also assigned the presentation slides to people to present them in order to make sure that everyone had the ability to speak during presentations and all of the powerpoint slides were accounted for. I was also largely responsible for making sure that our documents were submitted on time.

[Kel Nielsen]

As a Mechanical Engineer, my role in this team was to create a housing that fulfills the needs of the device. To begin, our initial conversations with our sponsor informed us of what was expected of us. I worked with the sponsor and all of my peers during this time to brainstorm an embodiment design. As seen in the alpha prototype report, we explored many potential ways we could solve the problem set in place, but we ended up settling on our hand unit design. Reflecting back on this time, I realized that we didn't make much headroom in the way of tangible progress. In my position, we were unable to start drafting a design for the housing until we had a unified idea of what we were making.

What I was able to accomplish during this time in addition to the previous work was material selection. I did research on what standards we would need to follow to comply with medical device requirements. I discovered that our device needs to be tolerable of repeated and long term exposure to solvents and other sanitizing agents. Thus I decided that we needed to use a polycarbonate based material for its outstanding resistance to chemical exposure, high strength and cleanliness. For ease of production and manufacturing, we opted for our housing to be additively manufactured. I found and purchased a polycarbonate/ABS blended filament for our prototype.

For the second semester of our project I worked closely with Rey to design the housing for the hand unit and receiver in SOLIDWORKS. Work began when we finally had our hardware chosen and in our possession. I was able to find a premade CAD model for the Arduino Nano, but I had to create models for each of the other components. To do this, I measured all of the relevant dimensions of the components and created models for them. From there, based on our preliminary work and my ideas from the alpha phase, I modeled the components to be printed with considerations to our actual hardware.

I then was able to get a test print of our initial hand unit design for fitment and tolerance checks. Based on these considerations, our next print was the final model housing. I was then able to solder and assemble all of the components to fit within the case, resulting in our final product. I also had the receiver housing printed and I soldered and assembled it as well. Overall, I was in charge of most of the physical design and manufacture of the product, and I was a big part in the electrical/mechatronic aspect of the product as well.

[Angelo Rivas Plata]

Because the purpose of the project was to design a completely functional and wireless ECG device, one of the first things I started doing was research on what an ECG was and what was already out in the market. By researching trade studies, we could have a better idea on how to design our device. I found several different designs, some of them were very simple and looked almost like the chip we ended up using, but with an outer layer that covered the chip's components. Some other devices I tried researching were wrist devices, which is what gave me the idea for the wrist module. Also, I researched boards that were used in these devices to see if we could find one that could work for us.

After doing the initial research, I also tried helping how to figure out the device that the previous group had left us. After spending some weeks with it and realizing the case was very simple, the MEs started coming up with some concept variants that might work a little better. I designed the wrist module variant, which would be worn with a strap around the device to secure it in place. This design helped the device stay in place and allowed for the patient to be moved, and have the electrodes at the same distance from the patient at all times. This design was a little too bulky and could have been slightly uncomfortable if the patient had to be on its back.

During the second semester we had most of our needed components and I had suggested we use the Arduino nano BLE for our project since it was small, had enough capacity for what we needed and had a bluetooth connection. We tested with an Arduino Uno board I had because it was easier to connect and disconnect the cables during testing. Once we were close to obtaining our final result, we moved to the nanos. At the end I also tried helping with the final design of the case but Rylee and Kel had already done a wonderful job on it.

[Erik Delaney]

Throughout the duration of the ECG project, I played a crucial role in various aspects of the development process. During the first semester, I was responsible for researching the components that comprised the previous year's device. I meticulously studied the inner workings of the previous device and actively participated in brainstorming sessions to generate ideas for new concept variants.

After identifying the shortcomings of the previous device, we decided to start from scratch. As a team, we needed to carefully select new parts that would meet the requirements we were given. I recommended the MAX86150 Kit sensor board to the team after it was brought up during a meeting. This sensor board was equipped with a microcontroller that paired well with the MAX board. However, after evaluating our options, we ultimately decided to use Arduino nanos instead due to their Bluetooth capability.

Using my expertise, I designed the alpha prototype that was capable of reading a patient's heartbeat wirelessly using only their fingertips. The prototype featured clamps that would securely hold down the patient's fingers onto the MAX board. I also created detailed drawings of the potential housing unit for the device. These drawings were instrumental in helping the mechanical engineering majors design a case using AutoCAD, as shown below.

In the second semester, we began the physical process of assembling the device. I soldered multiple receiver units together, and we used them for testing purposes. However, one of the units got burnt out due to repetitive soldering. We decided to purchase two more of each part, as we had only put a small dent in our budget.

During the waiting period for the new parts, I designed the battery module, which safely implemented our lithium battery into our device. To achieve this, I used the TP4056 Lithium-ion battery charger and protection module. This component allowed us to charge the battery without it exploding and use it without fully depleting it. When the new parts finally arrived, I soldered another unit together for testing purposes while Kel soldered together the final unit. The device was now functional without a power outlet.

One of the key challenges we faced was getting rid of the noise on the signal. To overcome this, we put together multiple filters that were designed to remove the noise while amplifying the peaks. We first used a low-pass filter to eliminate the noise on the signal. However, after testing the device on the hospital monitor, we realized that the peaks were too small and needed an FIR filter to amplify the peaks without amplifying the noise. I contributed to this process by providing my knowledge of digital signal processing to the team.

As one of the individuals the device seemed to work best on, I was frequently used to test the device during the development process. I also explained the workings of the device on an electrical level to my peers to ensure everyone was on the same page. Additionally, I was present during all but one meeting with the sponsor, where we tested the device on the hospital monitor and discussed feedback and other requirements.

During the capstone showcase, I played a vital role in demonstrating the device's functionality. I was hooked up to the ECG the entire time and helped explain the project to individuals passing by. Overall, my contributions to the project were influential in its success, and I am proud to have played a significant role in its development.

[Alan Platt]

My contribution to the project was to help research and design the backend of the backup display app. Initially, our plan was to display the ECG's output on a tablet through an app. Later, we decided to instead display it on the hospital's own monitors. We decided we would still try to make the app just in case though.

The first part I had to do was determine how to get the app to connect to bluetooth, as well as decrypt the signal that the arduino sends. The second part was to get the signal to display correctly as an ECG. The signal that the arduino outputs is quite different from what a standard ECG looks like. I did research on what kinds of filters to apply to the signal so that it would be more in line with what we were expecting.

[William Friend]

The main goal for this design project was to create a wireless ECG that can be used in a surgical setting. The primary objectives regarding the device were to minimize wires, display an accurate ECG signal, establish a bluetooth connection, and create a sanitized and reliable housing. My primary responsibility was designing assorted filters to establish a legitimate ECG signal and testing the device.

When designing the ecg, we needed a series of filters to remove any distortion of signal. My first thought in the previous semester was to use a series of analog filters. These included a notch filter to remove the common 60Hz frequency, and a bandpass filter to attenuate frequencies outside of the 0.5-150 Hz range which is the industry standard. However, the added passive active components to the overall design would make the device less practical and create more room for error. To simplify this problem we decided to simply go with an FIR and low pass filter. The purpose of the lowpass filter was to remove high frequency noise by any outside interference such as body movement or breathing. The purpose of the FIR filter was to pass signals that are 0.5-150Hz and further amplify them so that they can be observable.

A FIR was presigned in the example arduino code that came with the device, we simply repurposed it for our design. However, there are resources online that can be used to design the coefficients for an FIR filter, as well as ways to program this process in Matlab or in Python. We designed the digital low pass filter through a trial and error process when finding the coefficients. However, a more mathematical process can be done by using the reverse euler method.

After implementing the filters the ECG signal had varied results, where sometimes the signal looked great and other times it looked incredibly noisy. Inconsistency and troubleshooting was a common theme for this project throughout the year. It was discovered multiple times that the soldered connections between the MAX86150 and the bluetooth Arduino Nano were loose or potentially not connected at all. This caused a voltage short which explained why our signal would work one day and then look terrible the next day. The device was indeed very delicate, and in hindsight needed proper connection and handling when testing.

Another issue that took place during the design process was establishing the connection between the bluetooth receiver and the GE machine that was used in the hospital during our testing with the sponsor. The ECG signal of course had its issues with having a consistent reading, but another issue was the ECG signal was rather small. In hindsight, it would've been ideal to implement an instrumentation amplifier or using a digital filter that provides gain for the signal. Implementing a proper PPG signal would also be a good addition to the device given the MAX81650 capabilities. This of course was not a mandatory objective, but it could be something added in the next phase.

All in all, the device did meet the minimum requirements for the project, but has room for improvement and tweaking in future works. Ideally, if I could do the project over again, I would start on the project earlier and do more research on the implementation of digital filters. I would like to have made multiple devices with different ECG signal blocks to see which worked the best overall.

[Kendrick Washington]

My individual contribution for the project was performing research on finding the perfect filtering to use for the Maxboard ECG Sensor. The main issue for finding the correct filter for the ECG sensor is the datasheet did not have the cutoff frequency which in designing a Low Pass filter you will need to have a cutoff frequency to get rid of the high frequency from the signal. Communicate to William Friend and Erik Delaney that the Maxboard does not have cutoff frequency in the datasheet.

William Friend communicated to Dr.Toker about the issue that we were having and Dr.Toker provided us with a filtering so the filtering was used in the code. William, Erik and I analyzed and interpreted the ecg sensor and discussed the different options to remove the noise and fix the erratic wave of noise in the system.

I provided a basic electrical quantitative test on the maxboard to see the voltage going from the transmitter. The voltage from the transmitter to the maxboard gave a reading of .02V. The current was so small it did show up on the voltmeter while conducting the electrical quantity. It was not a steady voltage unless the device is being used because when the device is not in use it is in a power saving mode. After analyzing the datasheet the reason the device was not having a steady voltage because in the datasheet it only works when the EPG is being touch for (for the EPG sensor) for the ecg sensor it works within 13 to 15 feet without the casing of the device on and with the casing of device it is 5 to 6 feet. The device is getting a signal off the surroundings of the device when it is attached to the patient.

My contribution is to go to the meeting with the sponsor Dr, Kazmier, if William Friend can not make it to the meeting, I will make it to the meeting just to make sure there is representation of the electrical engineer team. It can be an electrical engineer to answer the sponsor concerns and needs on site while performing the test on the test patient Krister. My contribution is to report all the issues that the electrical engineers and computer engineers need to achieve to meet the standard of the sponsor concern and needs for the project. Erik, William and I would discuss the different ways to achieve the different approaches to solve the filtering issue.The device does have a constituent ecg sensor signal from the patient without any distortion. It meets the sponsor expectation within the time frame given but it has more instrumentation to make it better. The improvements for the device are listed below and potential ways to achieve those issues in the project.

If the project wants to be continued it would need a PWM or create a differential amplifier or instrumentation amplifier to have the heartbeat display on the hospital monitor. The differential amplifier is to amplify the difference between the two input voltage sources. Another advancement of the project could be to get the EPG to work on the maxboard. Another advancement of the project can be extended the range of bluetooth signal by using a different arduino with higher power consumption and higher bluetooth range so we can use it if we have to push the monitor out of the room or further distance from the patient.