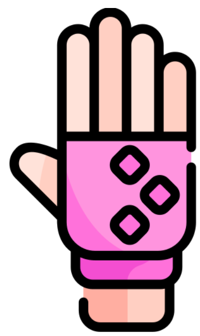
Project N.I.H.M.S.
(Non-Invasive Health Monitoring System)



University of Central Florida

Senior Design 2 Documentation

College of Electrical and Computer Engineering

College of Optics and Photonics

<u>Group E</u>

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Total Pages: **145**

1. Executive Summary

Technology has always played an important role in the administration and progression of medical care, now more than ever in the wake of the COVID-19 pandemic. In order to properly get diagnosed and treated, a patient would need to enter a clinic or hospital and risk exposure to the virus. However, with the advent of telemedicine doctors are better prepared to take care of patients from the comfort of their own home. The main issue that comes about with this method of clinical care is that many people lack access to proper diagnostic equipment, such as a means to measure heart rate. Without the appropriate tools for a patient to check their own vitals, the effectiveness of an off-site doctor decreases. Another obstacle to overcome in telemedicine care is that many people do not know how to effectively take their own vitals with the equipment available to them. Diagnostic tools that are easy to use and understand are then important to aid a doctor in making a proper diagnosis of the patient.

There are also times when having a method of continuously measuring vitals is important, such as determining trends in a patient to help prevent future medical emergencies from occurring. Many diagnostic tools, especially those available commercially, only measure an instance at a time. By having continuous measurements taken, a better profile of the patient will be available to the doctor.

Our proposal was for a piece of non-invasive wearable tech that will measure the featured medical vitals of the user and transmit them to an app. This will allow both the user and any healthcare professionals to see the data and any trends therein. The device aims to focus on ergonomics and accuracy for the user, to ensure a positive experience while under use. Heart rate, blood oxygen, and skin temperature will be recorded by the device, with an alert system built in to let the user know if an irregularity in vital signs is detected. It should be lightweight and easy to use, so that the user can utilize the device without much instruction or hassle.

This device aims to be used mainly for medical use, but the applications for self care are also understood, as many people would be interested in monitoring their own vitals on a day to day basis. Users could then be better informed of their own health, with the possibility of altering life habits based on pressing needs, such as making changes to help prevent heart problems or better sleep habits based on lower blood oxygen levels at night. The included ability of recording vitals on a day to day basis would also allow the user to create an E-Diary to record what activities were done during an episode of irregular vital measurements.

With new methods of diagnosing illnesses and taking care of patients, a better way to facilitate accurately reading vitals is necessary, and so our goal is to make it easier for users to get proper readings and relay the data to relevant healthcare professionals. By encompassing varying methods of measuring vitals into a simple to use device, our hope is that we can do our part to help everyone take better care of themselves, and to help prevent future emergencies from occurring through trends found in continuous measurements.

2. Project Description

This section of the document discusses the team's motivation for coming up with Project N.I.H.M.S. As well as share our goals and objectives we set to meet for this device. We will further go in depth into our team’s requirement specifications and engineering and market requirements for our device. Included in this will be block diagrams portraying the components and software that can be found at the end of the section. The block diagrams, engineering and market requirements inevitably help meet our team's goals and objectives for our device.

2.1 Project Motivation and Goals

The motivation for this project was to not only demonstrate our engineering abilities through a group project, but to also create a project that would be beneficial and used in the medical field. In the midst of a pandemic, we wanted to create a device that would make it easier for those who are unable to reach a hospital. Our non- invasive wearable device is meant to be an alternative way to measure and track daily vitals and also be able to transmit them to a medical professional without needing to visit them in person. Via an application that ties to our device, users can read their vitals from up to a period of a year, so that in case they needed to know any of their old records they would have those accessible to them.

2.2 Objectives

To design a fingerless glove that will be able to check heart rate/telemetry, pulse oxygenation, and skin temperature. The fingerless glove includes an alert system built in to let the user know if an irregularity in vital signs is detected, and if said alert is triggered, the user will have the option to alert local authorities for any emergency help if they need to. It is lightweight, comfortable, and easy to use, so that the user can utilize the device without much instruction or hassle. The user can transmit any of their health data to their desired medical professional. They should be able to also read data collected previously via an e diary on our application that can go back to up to a year from the day they are accessing the application. This should be useful for not only the user but the medical professional recipient so that they can keep track of any updates in the medical e diary and/or past alerts made from the device.

2.3 Requirements and Specifications

Shown below in Figure 2.3-1 is our Requirements and Specifications Table which specify the numerical values of how we want to measure success on the functions we want our product to implement during use. Each requirement is also categorized by level of priority based on how important it is to us to have that requirement working properly for when the time comes for us to demonstrate our final product. Highlighted are the 3 main requirements that we would be able to demonstrate in our final demo at the end of the semester of our Senior Design II class.

Table 2.3-1: Requirements and Specifications Table

#	Requirement	Specifications	Description
1	**Wi-Fi Connectivity**	20 seconds	The device will boot and begin to connect to Wi-Fi within a specific time frame.
2	**Data Transfer**	Under 20 seconds	Fast data transfer to allow for a more continuous view of vitals shown on the database, time taken for each reading should be less than the time listed.
3	**Weight**	Less than 2 pounds.	Allow users to easily wear the fingerless gloves without additional weight
4	**Battery Life**	Up to 8 hours battery life	Goal for overall battery life of the device.
5	**Wearability**	Fit a hand of 7.6 inches	Allows the average user to comfortably use our product.
6	**User Friendliness**	Less than 2 minutes	Teach users to use the product in less than the time mentioned.
7	**Application speed**	Under 45 seconds	Mobile application shows overall user results before the time listed.
8	**Emergency Detection**	Within 60 seconds	Alert to call proper authorities is triggered if the product detects major irregularity in data within a specified time period.

2.4 House of Quality Analysis

Shown below in Figure 2.4-1 is the House of Quality chart which depicts the project's needs and how they all correlate to an engineering requirement. This chart helps to see which features of the project are most important. Since the primary focus of our device is to create a non-invasive device, this is stressed in the engineering requirements to make sure the strongest positive correlation was comfort and user friendliness. With any successful medical device or piece of engineering, the ultimate goal is the accuracy of measurement. This unfortunately affects the cost as the strongest negative correlation for our device. One goal for the device is to be of low cost with 100% accuracy of measurements.

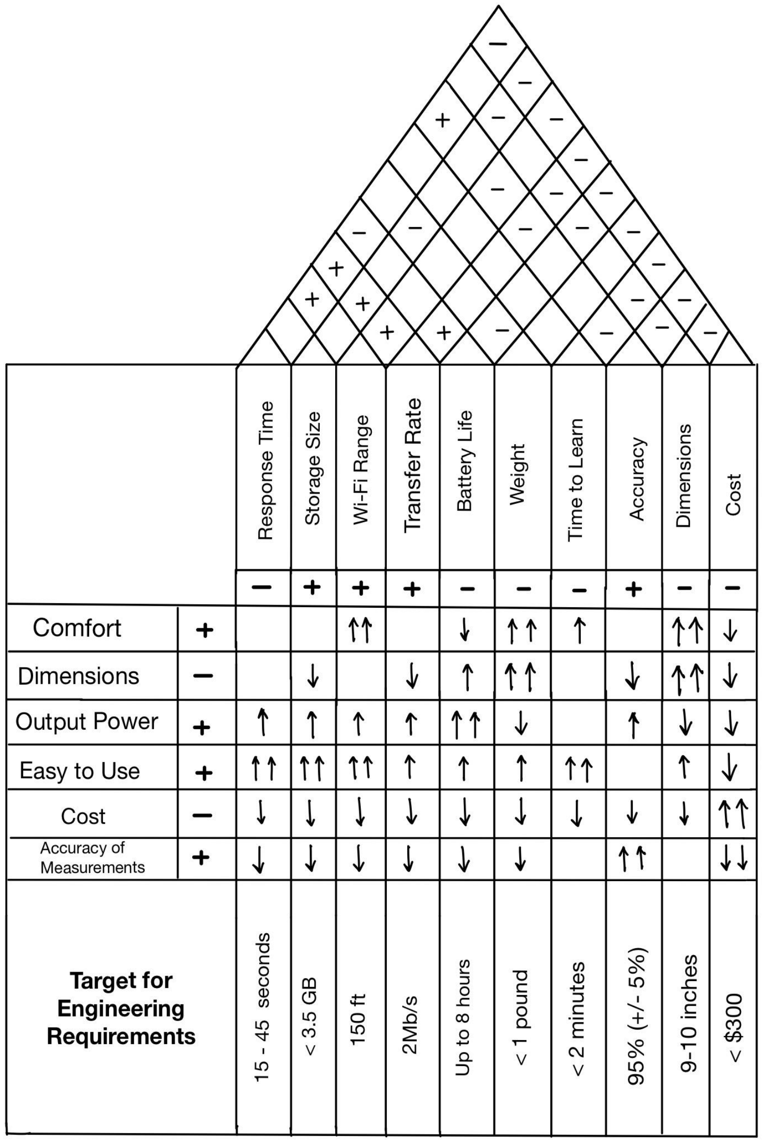


Figure 2.4-1: House of Quality

Table 2.4-1 below shows how to read the House of Quality chart in regards to the correlation between the needs of the project and the engineering requirements. We have mainly focused on ensuring all positive correlation relationships within our device are well done so that our device is considered to be functioning properly.

Table 2.4-1: House of Quality Legend

↑	Positive Correlation
↑↑	Strong Positive Correlation
↓	Negative Correlation
↓↓	Strong Negative Correlation
+	Increasing Requirement
-	Decreasing Requirement

2.5 Block Diagrams

The following block diagrams display the principal parts and functions of the hardware and software systems. We have based our development process around these charts to achieve building the working prototype at the end of our Senior Design 2 course.

Fig. 2.5-1 Shows the updated hardware flowchart of the current project. As we got to the testing and development phases in Senior Design 2, we realized that some of the components that we had planned to use in our original design were new parts that were just released earlier in the year and therefore did not have as much documentation online or used parts that were not documented at all. An example of that is that the PPG sensor was only able to work and display answers via a microcontroller that was already on a PCB and programmed with a software by Analog Devices. The datasheet on that microcontroller was not available anywhere and even after emailing Analog Devices for that documentation, we did not receive any answer back. Thus, we were forced to start all over with our design and think about parts that we were able to buy right away and breadboard so we can start programming it up and testing an alternative design that was still able to do the same things we desired for our project. This time, we made sure to have parts that were very well known and well documented so that we could make progress on our project.

The Software flowchart, Fig. 2.5-2, is a visual displaying how our application we built works alongside with our device. One of our goals was to make this application easy to learn so that any user could be able to use our device without little to any assistance. In order for our application to work, it must be connected to WiFi to send or receive any results from the server holding all of the information transmitted from the device. We used Google's Firebase to store a year's worth of data, as the device itself resets as often as every month to not overload the internal memory it has. To protect the user's private medical data, all users must login with a username and password in order to use the application and see any records that are stored with that account. The user can also pick and choose from a list of results that the device has taken and decide whether to just view them for themselves on their smartphone or decide to send it straight to their medical professional by generating a PDF that could be sent via email.

Fig. 2.5-3 is our Hardware Flowchart for our original design that was planned in senior design 1. It depicts all of the components that we were planning to use to build our device. Each component was assigned to a member of our team, which will be the main person in charge to research that part and collaborate with the team to describe how it interconnects with the rest of the system. Regardless, all team members agreed to work with one another if they have trouble with solving an issue with a component they are focusing on.

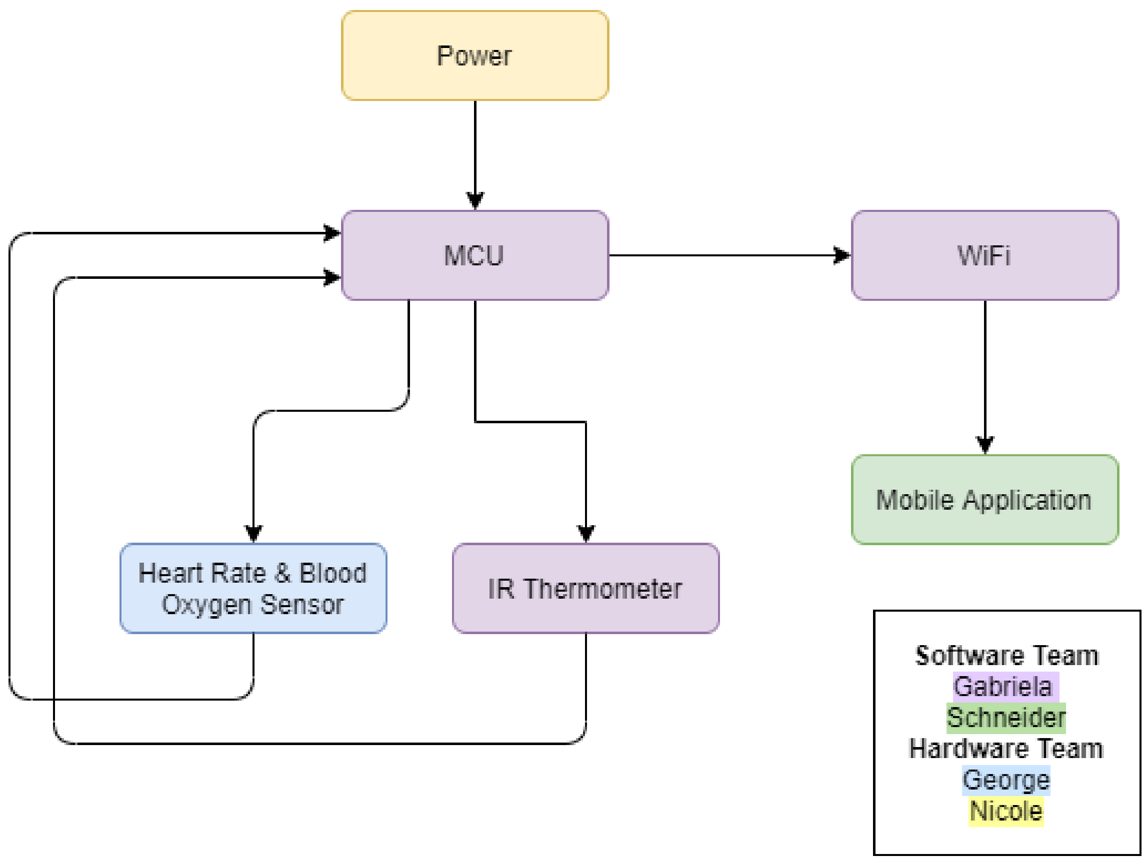


Fig. 2.5-1 Current Project Hardware (Plan B) Flowchart

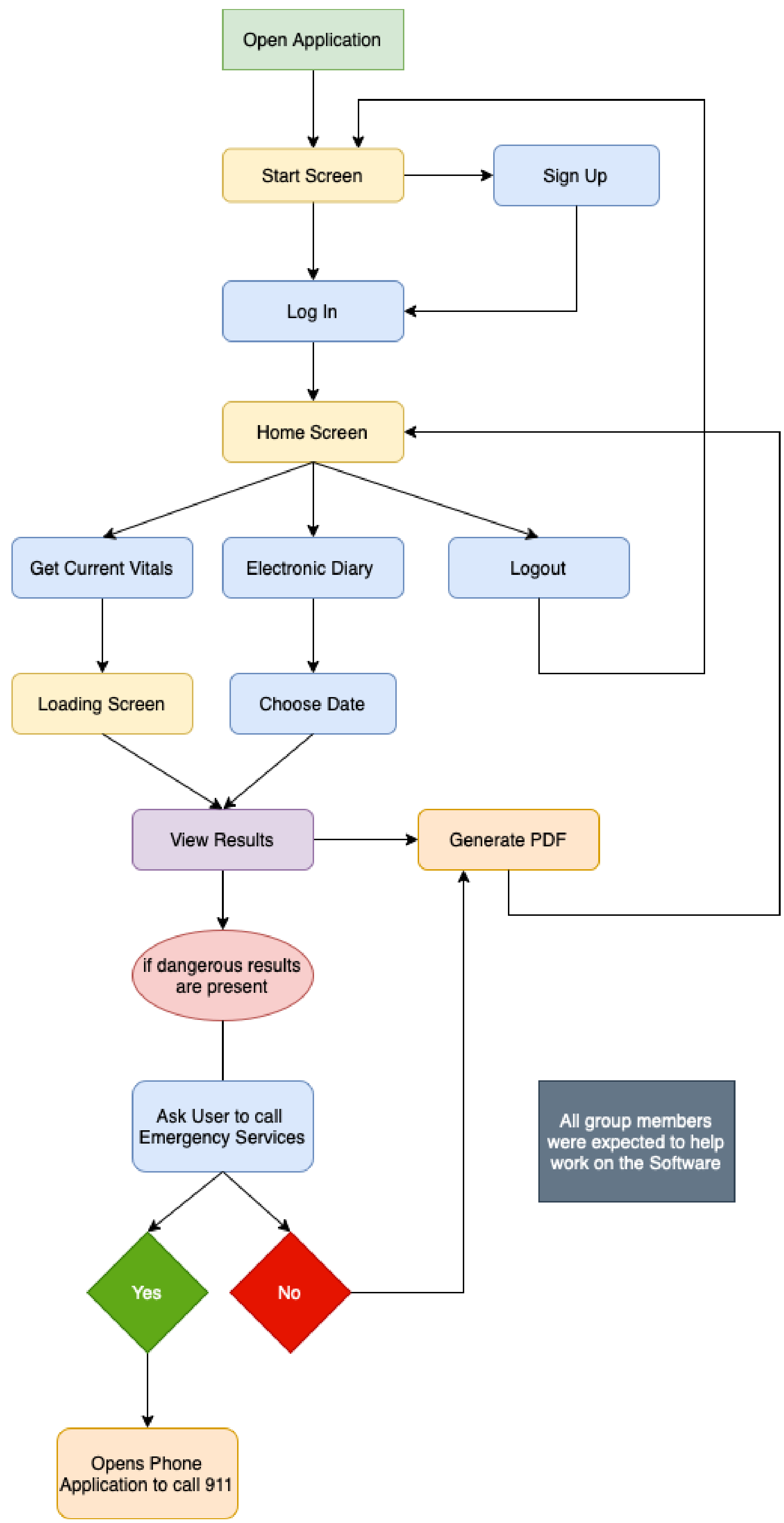


Fig. 2.5-2 Current Project Software Flowchart

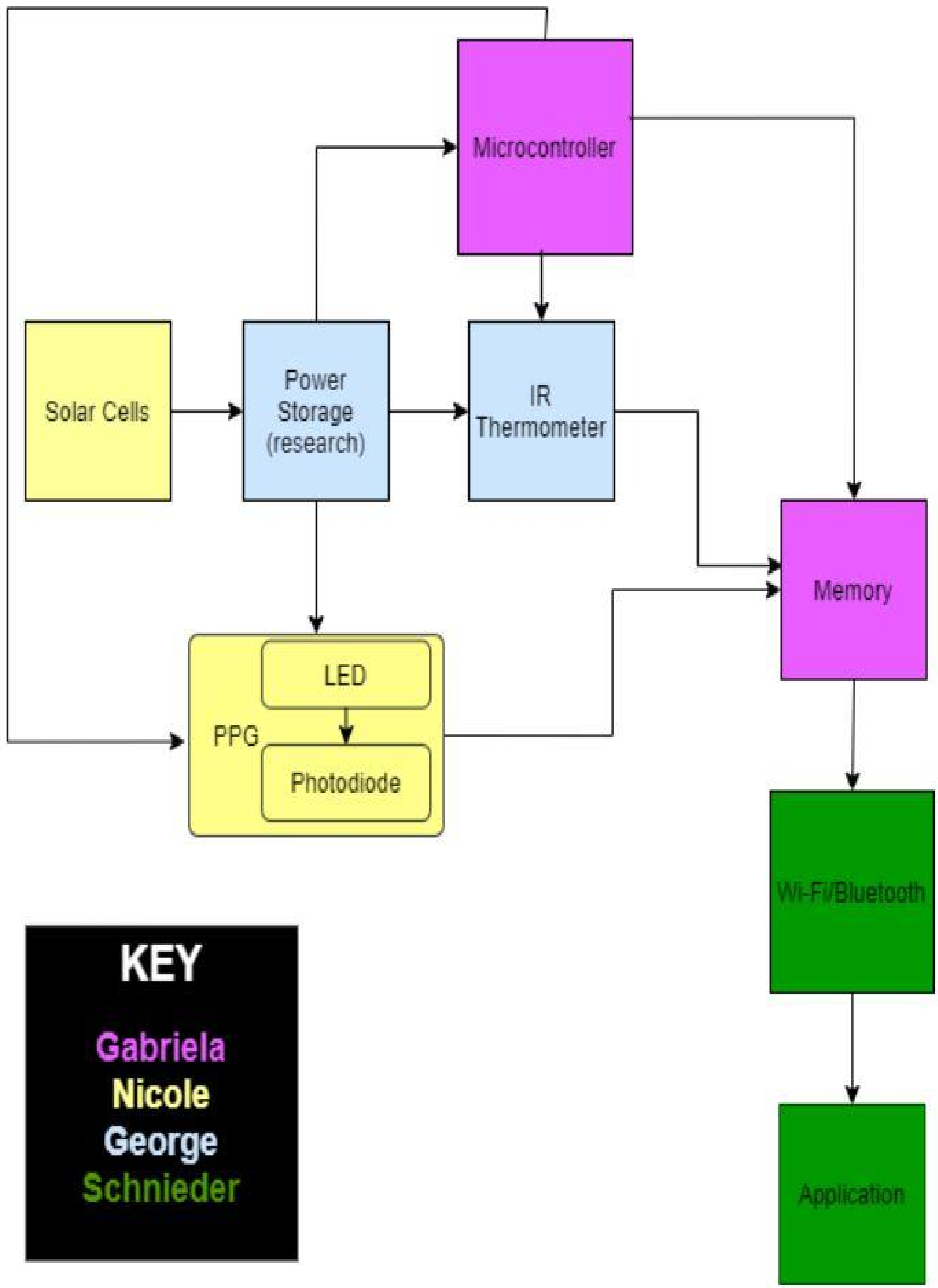


Fig. 2.5-3: Original Project (Plan A) Hardware Flowchart

2.6 Roles and Responsibilities

Gabriela Pinedo

Held the responsibility of working with the microcontroller and backend programming aspects of the overall project. Worked for the entirety of the semester alongside Schneider to build the mobile application that reads all of the data that the glove retrieves. Together, Schneider and I have spent several days working in the Senior Design lab in person to interface the hardware to work properly with the software and have frequently tested on a breadboard and a physical mobile phone to see how the results are being displayed with our application. I have also achieved on programming the microcontroller to interact with WiFi to be able to write to our database which is where data is transferred over to be able to be read on the mobile application whenever vitals are being retrieved. I have also implemented a way to ensure that data is stored so that our database does not reach maximum storage capacity and at the same time be able to keep as many daily entries as possible. To accomplish all that I have worked on, I have done extensive research and have participated in contributing to the documentation and every other assignment that has been required of us throughout both Senior Design I and Senior Design II.

George Ruiz

Focused on the power supply and IR thermometer components of our project. Other responsibilities included working with Nicole on the conception and implementation of the PPG sensor into the overall design. I focused on ensuring that our PCB design has the proper flow of current for each part, as well as making sure the appropriate circuitry components (such as resistors, capacitors, etc.) are used in the design. Documentation and citation of research is a facet of each of our contributions to this project, and so was also included in my responsibilities. The majority of the medical research was also a part of my role within the project, and so the generalized scope of information presented in this report concerning medical research was my work.

Nicole Fossenier

The responsibilities of the photonics engineering student include the design and implementation of photonics and optical components. The primary photonics component of the non-invasive health monitoring system is the photoplethysmography (PPG) module. The production of the PPG module begins by researching the science behind the components to find the most effective and costly parts. The components must also be tested to make sure they are working properly and as predicted, most importantly, the infrared (IR) light emitting diode (LED) and the photodiode. For example, the LED must be tested to make sure it is emitting at the correct wavelength at the proper intensity. Solar power is another important optical aspect of the project. I did extensive research on the physics that makes each element work (i.e. the infrared thermometer, photoplethysmography sensor, and photovoltaic technologies). I worked with George to implement and test the hardware specific components. As with all members, I intended to help with the software development including the image processing of the information received by the photodiode. Unfortunately, the initial photodiode was not used due to poor communication and therefore did not need my help to be programmed. I attempted to locate and compile all of the citations used.

Schnieder Maxime

For project N.I.M.H.S., we stated that we were all happy to help each other wherever someone may need help and to learn something new in all our departments. Primarily my role for our project was to focus on the coding of the mobile and web application. Responsibilities within the mobile and web application included making a viable frontend that was user friendly. Additionally, making sure the data pulled off the device was updated and displayed accurately from the database system and backend to the frontend for the user. As mentioned, I have also assisted with the other departments included in our project. I have attempted to assist and learn with the design of the PCB board and integrating the needed parts on the board. Furthermore, I have attempted to assist with some of the new technology we are using such as the PPG and solar cell technology. Lastly, for project N.I.M.H.S., I will be completing my part of the divided work to complete the documentation and citations for our paper.

Saturn PCB Design, Inc.

Saturn PCB joined as a sponsor towards the end of the project, offering consultation services to aid in ensuring that the PCB has full functionality. Working side by side with them helped with understanding the principles of how to implement some of the components chosen for the project. Located in DeBary, Florida, their proximity helped with allowing us to visit for any questions and concerns we had with the PCB, both in design and layout. Some of their consulting services included testing the electrical characteristics of the various PCB components, the addition of components deemed necessary for functionality, and explanation of principles related to how various components chosen work and interact with one another.

3. Research Related to Project Description

This section contains all of the information and details found to help decide which elements to implement in the project. This includes analyzing existing products to see what can be done similarly on the product to help prevent us from "reinventing the wheel". New technologies and methods that are useful to the project are researched and explained so that the user can know the details on how our product works with retrieving the data that we are aiming to get. Using the previously stated requirement specifications and standards explained in section 4 as a baseline, the pros and cons of each product are weighed to determine if it is a viable option to implement.

3.1 Existing Similar Projects and Products

There is a wide variety of continuous noninvasive arterial blood pressure monitoring (CNAP) devices that the project would benefit from by analyzing and researching from the larger CNAP devices seen in hospitals that doctors use to the smaller CNAP devices at home that parents may use to check their child's temperature. These products utilize different techniques for obtaining its target information. In the creation and research of our device, we made sure to research thoroughly existing similar projects and products that would help bolster our device. In the below sections are some of the most notable existing similar projects and products that we research and that stood out to us.

3.1.1 Heart Rate Monitor

Figure 3.1-1 shows a heart rate monitor which is the first existing similar product that we are familiar with. Heart rate monitors are frequently used at hospitals to measure and display a person's heart rate in real time or record the heart rate for later study [1]. When heart rate monitors are used medically in hospitals, they are usually wired and usually have multiple sensors being used and can be very invasive since they wire it to be connected to the user. These devices read electrical signals from your heart and will collect data that will help interpret the lifestyle choices that may benefit the user to choose if they are having any sort of heart issues [2]. Heart rate monitors are known to be as accurate as electrocardiograms or EKGs, as they use electrode sensors to read the heartbeat. The data is typically displayed to be the number of beats per minute. A main use of a heart rate monitor is also to determine whether the user is in the heart rate zone that they desire to be, especially while doing any sort of workout or intense exercise routine. There are alerts that will let the user know whether or not they are under or above that target zone, which allows for the user to change their pace or speeds depending on what they are currently doing to maintain a good range. In contrast to the heart rate monitor, Project N.I.H.M.S. is considered to be a continuous noninvasive arterial pressure (CNAP) medical device. This entails some similarities such as being able to measure and display a person's heart rate in real time for later study. Similar to the heart monitor, our project has technology that tracks the heart rate.

Fig. 3.1-1. Heart Rate Monitor [3]

3.1.2 Omron HeartGuide

Fig. 3.1-2 shows an Omron Heart Guide smart watch. This watch allows the user to obtain a wearable blood pressure monitor that makes tracking and managing your blood easier [4]. Omron Heart Guide tech involves an inflating bladder on the inside that you can feel pressurizing over your wrist. To start a pressure reading, the user presses the top button and then lifts the watch to heart level. It then will buzz when the elevation is correct and start to take measurements which takes about 30 seconds. The watch stores up to 100 readings at a time, and the watch will last for about 30,000 uses.

Fig. 3.1-2. Omron Heart Guide smart watch [4]

3.1.3 Blood Pressure Monitor

Fig. 3.1-3 shows a blood pressure monitor. Blood pressure monitors are used to measure how much force is being exerted on the walls of your blood vessels (artery) as blood is flowing through them [5]. There are two numbers that are reported through blood pressure monitors systolic and diastolic. Systolic is the top number that gets reported, it is responsible for the pressure as your heart contracts to pump blood to the body. Diastolic is the bottom number that gets reported and is responsible for the pressure between beats, when your heart relaxes.

Figure 3.1-3: Blood Pressure Monitor [6]

3.1.4 Fitbit

Fig. 3.1-4 shows a Fitbit. Fitbits are activity tracking devices that are usually worn on the wrist [7]. These devices have several similar features we want to implement on our device, such as continuous heart rate monitoring, GPS tracking, and wireless syncing to compatible devices. They have many other extra features: caller ID, text notifications, music control, digital paying. Fitbits are paired with an application that helps track and maintain the features mentioned. Overall, the fitbit is the one of the most popular fitness tracking devices today with 23.2 million users. The wrist technology that is used in its design is one that we were interested in using for our project, as we aimed to make our product unique due to its fingerless design.

Fig. 3.1-4. Fitbit [7]

3.2 Relevant Technologies

In this section of the document we discuss the relevant technology to our device. The technology that is used in our device is photoplethysmography. We thoroughly researched this technology to incorporate the best of what the technology has to offer to our Project N.I.H.M.S. device. Below we bring forth the highlights of this technology.

3.2.1 Photoplethysmogram

Photoplethysmography (PPG) is an optical measurement technique that detects change in blood volume in the microvascular bed of tissue [8]. The main components required of the PPG are a light source and a photodetector; the light source, such as a light-emitting diode (LED) is required to illuminate tissue and the photodetector measures the reflected or transmitted light from the light source as shown in Figure 3.2-1. There are two main photoplethysmograph designs for the component placements, transmission mode and reflection mode [9]. Transmission mode has the components facing each other on opposite sides of the skin which can be utilized on thin areas such as the earlobe or finger. This design has the photodiode measuring the transmitted light from the light source. Reflection mode, the design observed in Figure 3.2-1 as well as the design that is utilized in project N.I.H.M.S, places the components side by side. This design has the photodiode measure the reflected light from the light source. The electronic circuitry should ideally have a frequency range between 0.01 and 15 Hertz.

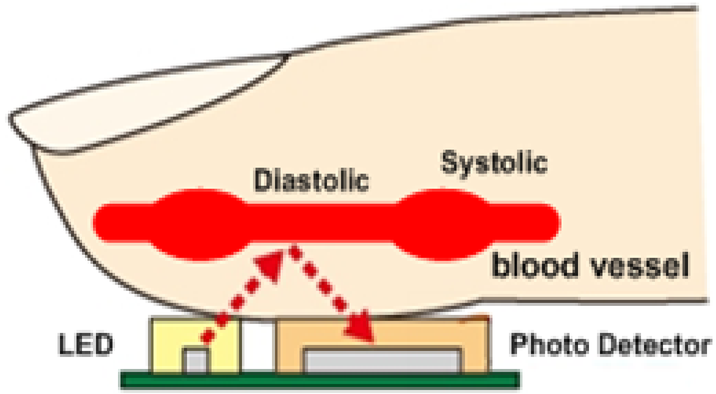


Figure 3.2-1. Representation of how the module works and what is being measured [10].

The PPG recognizes the change in blood volume as a waveform [8]. This waveform consists of two main superimposed components, oscillating (AC) and steady-state (DC), which can be separated through electronic filtering and amplification for proper analysis. The AC component, or pulsatile component, has a fundamental frequency of approximately one Hertz. The DC component is proportional to the average blood volume and slowly varies due to natural biological functions dependent on the tissue location; these functions include respiration, vasomotor activity, vasoconstrictor waves, Traube Hering Mayer waves, and thermoregulation [8, 9]. The heart rate can be determined from the signal as the waveform's periodicity corresponds to cardiac rhythm [11].

PPG is a desirable way to detect blood volume changes as it is non-invasive and can be employed at a variety of places on the human body; the fingertip, ear, and wrist are the most common placement [8, 11]. The technique satisfies most criteria for an ideal blood flow measurement technique, thus enhancing its desirability [9]. Although PPG is mainly used to detect blood volume changes, information about capillary nutritional blood flow and the thermoregulatory blood flow through arterio-venous anastomosis shunt vessels can be obtained.

The desirability of the technique is blunted due to several drawbacks: interference from ambient light and the need for persistent and stable skin contact (Allen; [10]). Light emitted from fluorescent and energy-saving lamps alters the AC component of the waveform due to the frequency [10]. Although ambient light poses a problem, the primary issue is the PPG's requirement for persistent and stable skin contact because moving the probe could disturb the data [8]. There are several techniques used to counteract the interference from motion artifacts: independent component analysis, adaptive noise cancelation, spectrum subtraction, electronic processing methodology, time-frequency analysis, and empirical mode decomposition [11]. Although there are several techniques to account for movement, there are not many to account for the large amount of movement done for intense physical activities.

Early designs included design problems with the light source that would heat the local tissue and mix up various signals relating to blood flow [8]. Tungsten filament bulbs produced the needed infrared light but output a large amount of heat thus causing the local tissue temperature increase [9]. Heating of the skin can cause burns as well as vasodilators that interrupt the desired signal. This issue has since been remedied as appropriate light sources can now be used.

3.2.2 Photovoltaics

Solar radiation is converted into electrical energy by means of photovoltaic (PV) technologies; this conversion is caused by light-induced chemical reactions that produce electrical currents [12]. Any technology designed to convert light energy into electrical energy must fulfill two requirements [13]. First, the technology must be able to absorb photons and generate electron-hole pairs in the conduction and valence bands. Second, the electrons and holes must be sent to their selective contact. Due to these requirements, PV technology consists of three layers: a hole-selective layer, a light absorbing layer, and an electron-selective layer, as shown in Figure 3.2-2.

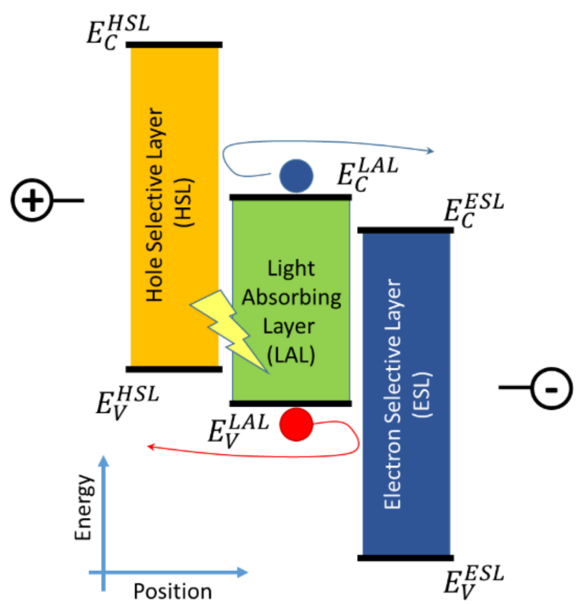


Fig. 3.2-2. Schematic diagram of key elements for solar cells. E_C and E_V represent the conduction and valence bands of the layers [13]

Within photovoltaic technology, incident photons react in several ways [13]. Photons of energy lower than the energy gap are transparent to the material and do not get absorbed. Photons of energy equal to or higher than the energy gap are absorbed by the light absorbing layer and generate excited electron-hole pairs which are then diffused. However, extra energy generated by high energy photons is lost to thermalization. Diffused electrons reaching the interface between the light absorbing layer and electron selective layer are transferred into their selective layer and can reach the electrode. If the electron reaches the hole-selective layer, it is reflected back.

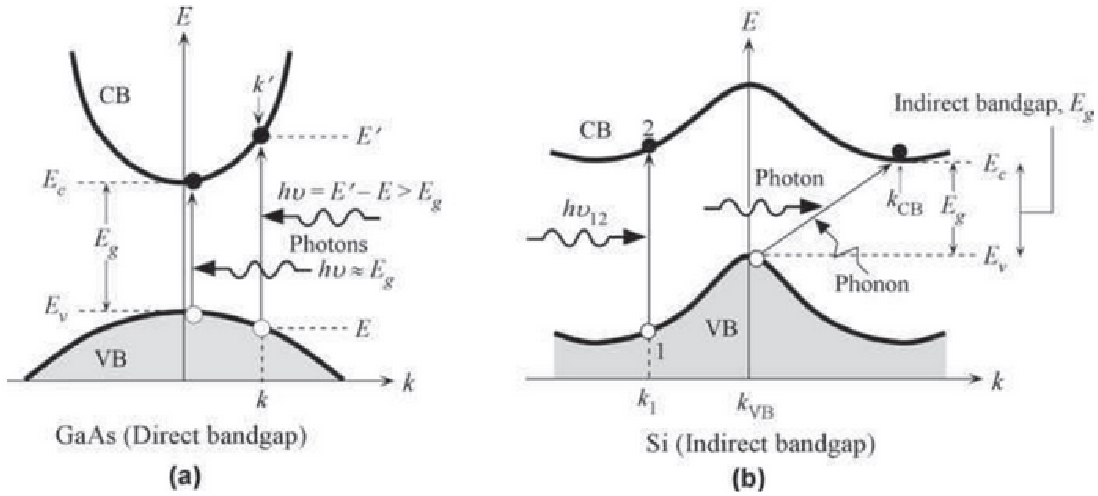


Fig. 3.2-3 Photon absorption in different band gap materials:(a) direct bandgap semiconductor and (b) indirect bandgap (VB, valence band; CB, conduction band). [14]

The absorption of photons heavily depends on the semiconductor material [14]. Materials with a direct bandgap are more desirable than material with an indirect bandgap; to absorb a photon, materials with an indirect bandgap require absorption and emission of lattice vibrations, or phonons, as shown in Fig. 3.2-2. Because there are different light absorbing materials, there are different PV technologies which are generally named after their primary material; the two primary categories are wafer-based cells and thin-film cells [15]. Wafer-based cells are built on semiconducting wafers, such as gallium arsenide or silicon, and do not require additional substrates [13]. Thin-film cells layer semiconducting films with a substrate such as glass, plastic, or metal.

The specific type of PV technology researched for use in Project N.I.H.M.S is a thin-film PV made into solar cell cloth; the cloth is intended to be manufactured into a fingerless glove. The solar cell cloth is embedded with PV cells that are layered around fibers that allows the cloth to be flexible film on the fabric [16]. Due to high demand and low availability, solar cell cloth was not an option for Project N.I.H.M.S and had to be substituted with a different photovoltaic product as a source of power.

3.2.3 Thermopile

Thermopile sensors have a similar function to photovoltaic technology where it converts light, specifically infrared radiation, into electrical signals [17]. Thermopiles are based on thermocouples which are made of two different metals connected in series. One of these metals is blackened to absorb the radiation thus retaining heat. The temperature rise with respect to the other non-irradiated junction generates a voltage. The material used has a high thermoelectric coefficient, a measure of the magnitude of the induced voltage in response to the temperature difference, such as bismuth and antimony. A thermopile consists of approximately 20 to 120 thermocouple junctions in series usually in a ring. The typical operation of a thermopile sensor is shown in Fig. 3.2-4. Although thermopile sensors are incredibly sensitive to infrared radiation, the heating and cooling process decreases the response time.

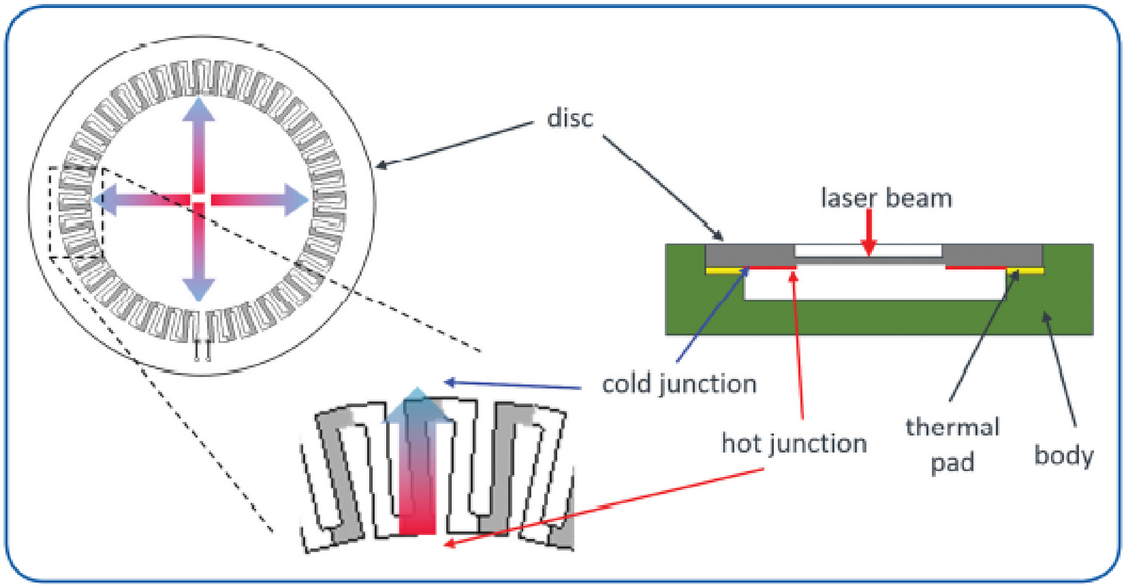


Fig. 3.2-4. Typical operation of a thermopile sensor [17].

3.2.4 Methods of Measuring Blood Flow

A variety of methods are used to measure skin blood flow [9]. A specific set of criteria should be met when using methods of blood flow measurement; the technique must be safe, sensitive, reliable, reproducible, easy to use, and inexpensive. Common methods used include skin thermometry, thermal clearance, laser Doppler plethysmography, radioactive isotope clearance, electrical impedance methods, and photoplethysmography.

Skin thermometry measures blood flow by analyzing the skin's surface temperature [9]. Thermal clearance is similar to skin thermometry as it is sensitive to the temperature, but thermal clearance analyzes the temperature's rate of change at the center of a heated area by the skin's nutrient blood flow in the dermis. The laser Doppler technique utilizes red coherent laser light to analyze blood flow through the Doppler shift of laser light backscattered from the moving red blood cells. The radioactive isotope clearance measures blood flow by intradermally injecting radiopharmaceuticals, most often xenon, and measuring its clearance rate.

3.3 Strategic Components and Part Selections

In this section of the document we discuss research done for our strategic components and part selections made for Project N.I.H.M.S. We show the part selections we chose to bring our device to life and compare it to other options that may be available in the market but are not beneficial for our device's unique required specifications.

3.3.1 IR Thermometer

An infrared thermometer is a sensor that picks up on infrared energy, which then converts the energy to an electrical signal which can display the temperature [18]. A typical setup is shown in Fig. 3.3-1. The infrared thermal detector collects the infrared radiation from a surface through a lens onto a thermopile [18, 19]. The electrical signals generated are amplified and sent to a multiplexer. Infrared thermometers are useful to measure temperature at a distance without any physical contact with the object.

In our device the IR thermometer helps with obtaining accurate readings from oxygen levels to heart rate monitoring. The IR thermometer combined with our CNAP device became a non-contact IR thermometer. This approach measures temperature and displays readings quickly. It also allows the ability to retake oxygen levels to heart rate monitoring in quick successions.

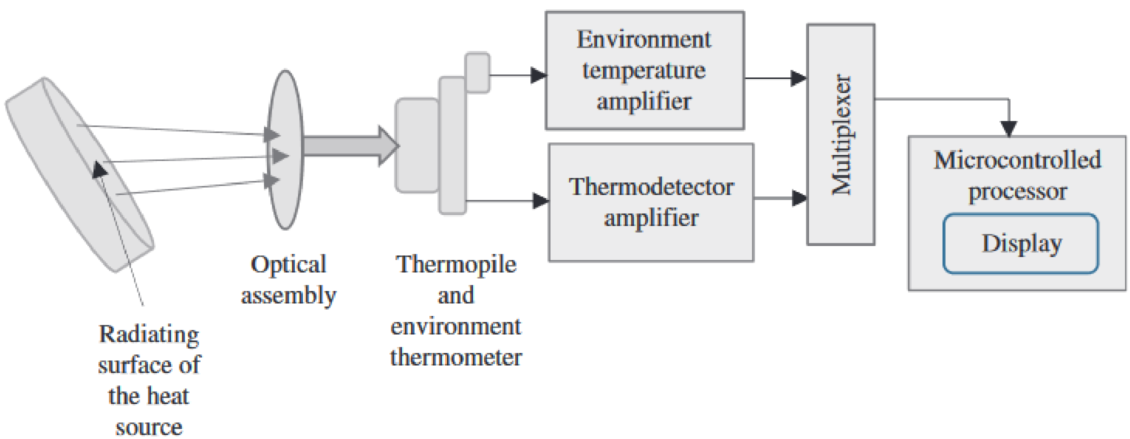


Fig. 3.3-1. Typical setup of an infrared thermometer [19].

An important factor when considering IR thermometers is the accuracy of the sensor and the range for which the component will operate. Typical normal body temperature comes in a wide range from 97°F (36.1°C) to 99°F (37.2°C) [20]. For our application, we needed to only focus on the generalized temperature that skin tends to stay at around 33ºC. When it comes to body temperature, a measured result that is more than 2 degrees off can cause a misdiagnosis to occur, and so we wanted our device to have an accuracy of ±1 ºC with respect to the actual temperature of the skin. This reflects a temperature difference of ±1.8 ºF. The final design constraints we had for this component are the size and cost, as we wanted a smaller component to not create a bulky design for the user and a lower cost for the component since this is aimed to be readily available to users. We wanted to minimize the cost as much as we could while not sacrificing the other parameters that were important to our overall goal for the project, namely the accuracy and operating temperature for the thermometer. With those parameters understood, a few components were considered for our device.

Figure 3.3-2 IR Thermometer [21]

GY-MLX90614

One of the first choices we found was the MLX90614 by Melexis Technologies NV, which consists of an IR sensitive thermopile detector chip and the signal conditioning ASSP (application-specific standard product) both integrated into a TO-39 can, an industry standard [22]. This already was a plus, as it was not only the thermopile but also the signal conditioning ASSP which is specially designed to receive and process the output of the IR sensor. It achieves a high level of accuracy and resolution due to the low noise amplifier, 17-bit ADC, and a powerful DSP (Digital Signal Processing) unit on board. The device uses an I2C communication protocol in order to transmit the measurements taken.

The MLX90614 is factory calibrated for an ambient temperature measurement range of -40 to 125ºC for ambient temperature, and -70 to 380ºC for object temperature [22]. This is a very large range which includes the necessary range we desire of roughly 33ºC. The component also is calibrated to measure objects with an emissivity of 1. Emissivity is the ratio concerning how much radiation an object will emit or absorb at a certain temperature as compared to a perfectly emissive object at the same temperature. Objects with higher emissivity will approach an emissivity value of 1, whereas objects that do not share similar properties to a perfectly emissive object will approach an emissivity value of zero. The MLX90614 is calibrated to measure objects with an emissivity of 1 but can be adjusted by the consumer to fit whichever emissivity is needed without needing to recalibrate with a blackbody. Human skin has an accepted emissivity of 0.98, and so should this component be used, the factory standard is acceptable to use for our measurement purposes. Another important feature is that the component comes in two supply voltage options, 5V compatible and 3V compatible. For the purposes of our device a 3V compatible device would be preferable. The MLX90614 also comes with an optical filter to help remove the effects of sunlight and ambient light from interfering with measurements taken.

All of these features coincide with our device specifications, if not overcompensating for them as well, such as with the measurable range of temperatures for ambient and object measurements. The component comes with a cost of $12.59, and is fairly easy to integrate with an arduino microcontroller, making it the best choice for our project.

Fig. 3.3-3. GY - MLX90614 [23]

MLX90615SSG-DAG-000-TU

The next component we considered was the MLX90615, the successor to the previously discussed MLX90614. Similar to the MLX90614, this component also has a DSP unit housed within, as well as the low noise amplifier which enables better accuracy and resolution [24]. The MLX90615, however, has a 16-bit ADC instead of the 17-bit ADC of the MLX90614, but this slight decrease in efficiency is more than worth it when considering the size difference. Due to the smaller size of the device, the MLX90615 only weighs 0.010582 oz, and so fulfills the requirement of maintaining a lightweight device for the user to continuously wear. This component also has greater accuracy within our desired range of 30 to 40ºC, having an accuracy of ±0.2ºC. The price for this piece of equipment is also considerably lower than the previous incarnation, coming in at the low price point of $15.89, decreasing to values as low as $9.60 with bulk orders of 1,000 or more. Seeing as to how this was meant to be marketed to the average consumer, having a drop of more than 6 dollars per piece is very appealing when considering mass production. These two points aid in making our device easier on the consumer in terms of cost and size. An optical filter (5.5 μm to 14 μm long-wave pass) is used to make the sensor insensitive to visible light, thus furthering the minimization of noise within the system and ensuring greater accuracy of measurement. The following figure, Fig. 3.3-4, is a block diagram of the component in question.

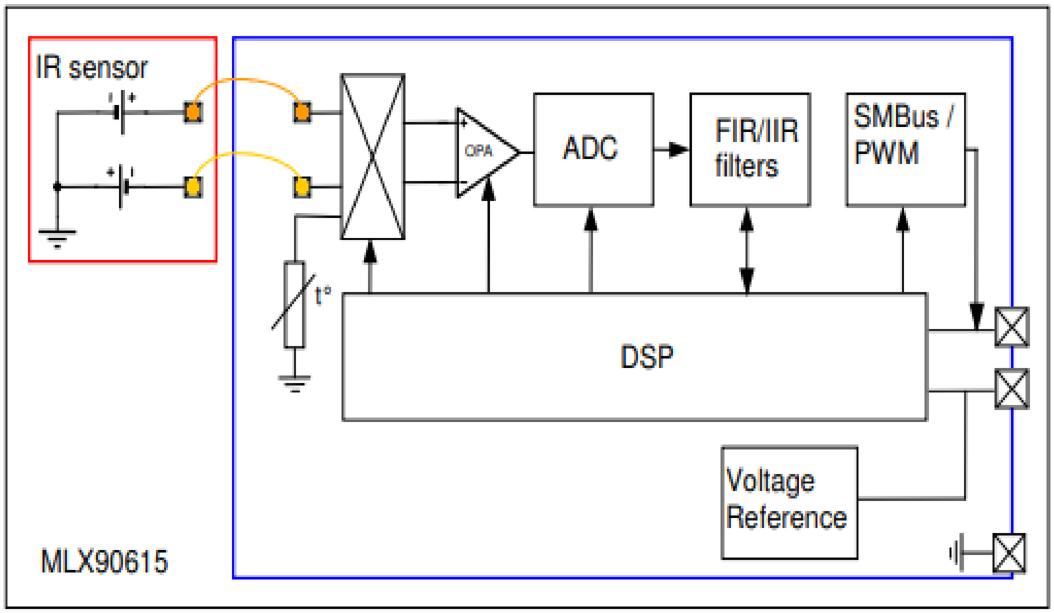


Figure 3.3-4 Diagram of the MLX90615 [25]

The DSP (Digital Signal Processor) in the MLX90615 helps to control the measurements taken, as well as handling the calculations of temperatures based on the measured readings [25]. The amplifier shown in the diagram is a low noise, low offset amplifier with a programmable gain which is used to amplify the IR sensor voltage. The output from the amplifier is then fed to the ADC (Analog-to-digital converter) before moving on to the FIR (Finite Impulse Response) and IIR (Infinite Impulse Response) filters. The output from these LPFs (Low Pass Filters) reflect the measured values of the ambient temperature and object temperature, both of which have a resolution of 0.02ºC.

The MLX90615 comes in two variations, the MLX90615SSG-DAG-000-TU and the MLX90615SSG-DAA-000-TU. The difference between these two components is the field of view that each provides (the DAG has a FOV of 80º while the DAA has a FOV of 100º). Field of View is typically associated with distance measurements, as a smaller FOV coincides with a greater distance to spot ratio. This is due to a wider field of view necessitating closer proximity to the object requiring measurements in order to reduce interference from other objects in the vicinity. The FOV of the device should always encompass only the object being measured, as is shown in Fig. 3.3-5.

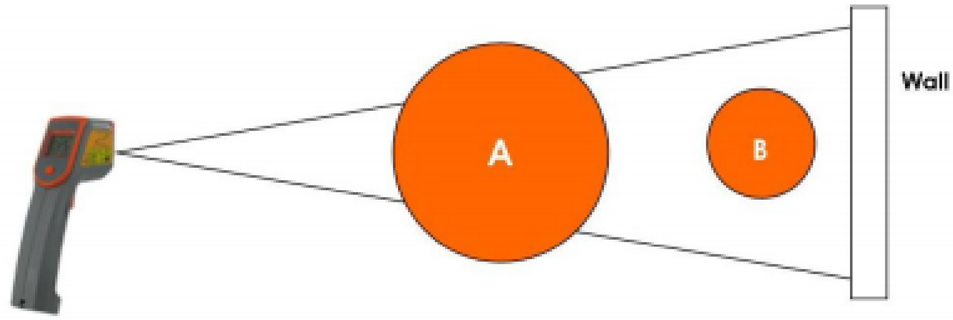


Figure 3.3-5 Field of View Diagram [26]

This was a main factor when considering object measurements with varying sizes, but for our application the device is close to the skin, negating any need to focus on how far the measurement device is from the object being measured. For this reason, the FOV of the two variations for the MLX90615 were negligible, and other factors could be considered to choose which version suits our project best. Cost was considered next, but both components cost exactly the same, and so finally the lighter component was chosen between the two for analysis. The MLX90615SSG-DAA-000-TU weighs in at 0.044159 oz, while the MLX90615SSG-DAG-000-TU weighs 0.010582 oz. The DAG is more than 25% heavier than the DAA. Without any loss of performance, the DAG was the more suitable choice of the two for our design.

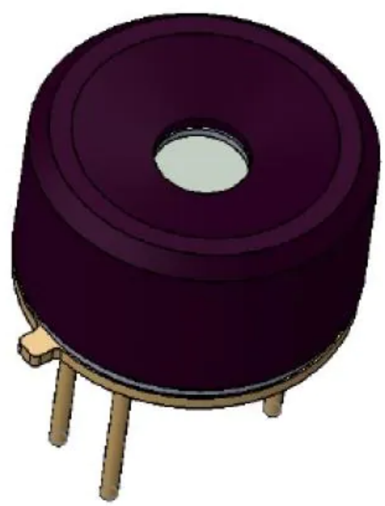


Fig. 3.3-6 MLX90615SSG-DAG-000-TU [27]

MAX6627MTA+T

Though Melexis is a leader in the field of semiconductor sensors, we thought it prudent to include a component from another company in order to provide variation to our analysis of which sensor would suit our needs best. For this reason, we decided to look into Maxim Integrated, another leader in the field, striving to create new technologies that are smaller and more energy efficient with every improvement made. The part we considered was the MAX6627, a precise digital temperature sensor that utilizes a remote sensor in order to receive the measurement data. This remote sensor is a diode-connected transistor, usually a low-cost, easily mounted 2N3904 NPN type transistor that is used to replace conventional thermistors or thermocouples [28]. The MAX6627 comes in two main types, an 8-pin SOT23 (Small Outline Transistor) or TDFN (Thin Dual Flat No Leads) Packages. Since the TDFN package is more compact than the SOT23, that variation was used for consideration. One of the most notable features of this component is the price, coming in at $5.46 for one piece moving down to $3.05 for a bulk order of 1,000 or more. This is considerably cheaper than the alternatives we considered.

The MAX6627 was chosen over the other version, the MAX6628, because of its conversion rate for measurements taken. The 6627 converts data every 0.5s versus the 6628 with a conversion rate of 8s [28]. The drawback is that the 6627 uses a typical value of 200 μA while the 6628 uses only 30 μA, but both are low enough to be acceptable for our purposes. The component operates with a supply voltage between 3 and 5.5V, with a temperature measurement range of -55 to 125ºC. When operating between 0 and 125ºC, the accuracy of measurements is ±1ºC. Although this does exactly meet our desired accuracy level, the range is very large and most of that range would never be reached for our applications. The MAX6627 has a 12 bit resolution with a resolution of 0.0625ºC, which compared to the measurement resolutions of the other components under consideration has a considerably larger step size. One other pro when considering using this component is that it only weighs 0.000705 oz, the lightest found so far. Based on these parameters, however, the MAX6627 seems to be suited more for industrial applications rather than focused on medical applications.

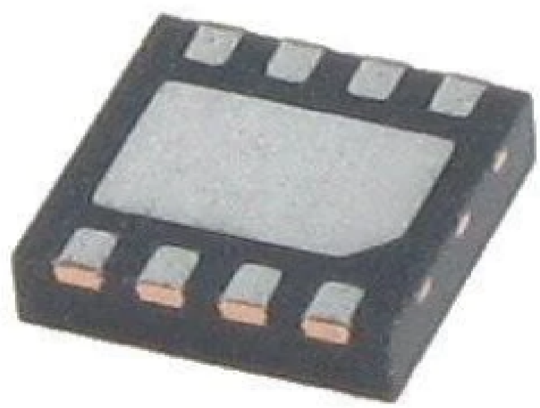


Figure 3.3-7 MAX6627MTA+T [29]

MLX90632SLD-DCB-000-SP

Another entry from Melexis is the MLX90632 FIR (Far-Infrared) sensor, a more advanced non-contact IR temperature sensor. Immediately one important thing to note is that unlike the previous models from Melexis, this component is housed in a small SMD SFN (Surface Mounted Diode and Single line of contacts, Flat, No leads) package [30]. Generally speaking, SMD packaging yields a smaller design than through hole components, so this component seemed better for our purposes. The MLX90632 comes in two variations, a standard version and a medical accuracy version. The standard version has an accuracy of ±1ºC for an object temperature range of -20 to 200ºC while the medical version is calibrated to have an accuracy of ±0.2ºC within the temperature range of 35 to 42ºC with an object temperature range of -20 to 100ºC. For this reason, the medical version suits our needs far better than the standard version. This sensor utilizes I^2C communication in fast mode plus (FM+) to send the data to the microcontroller, where the data is then processed to calculate the object temperature found. The RAM of the device holds the measurement data for the microcontroller to access, and the EEPROM houses the trimming values, calibration constants, and device/measurement settings. Both of these sets of information are used by the microcontroller to calculate the object temperature. Two versions of the sensor are available, operating at either 3.3V or 1.8V I^2C reference voltage. The supply voltage needed for the MLX90632 is 3.3V.

Just as the previous entries had, the MLX90632 also comes with an optical filter to cut off the visible and near infra-red radiant flux which provides noise immunity from ambient light. This optical filter has a wavelength pass band from 2 μm to 14 μm, a slightly lower starting point compared to the MLX90615 with the pass band from 5.5 μm to 14 μm. It has a measurement resolution of 0.02ºC, comparable with the previous models from Melexis. This component comes with a standard 50º FOV for all variations, though as was stated before the FOV is not as important for consideration with our project since the sensor will be close to the skin. The cost for this component is $15.27 for one part, decreasing to roughly $11.75 for orders greater than 100. This price is slightly lower for single components, and possibly comparable prices for bulk orders as the previous incarnations have a lower price but for bulk loads much larger than 100. The weight of the component is 0.068711 oz, which is comparably larger than the MLX90615 at a weight of 0.010582 oz but the height difference makes up for this discrepancy.

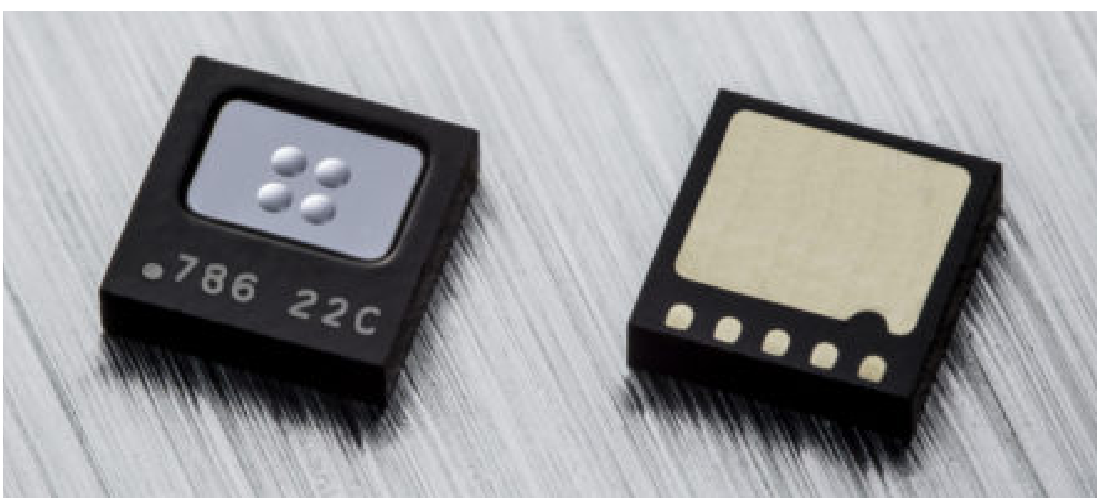


Figure 3.3-8 MLX90632SLD-DCB-000-SP [30]

It is worth noting that the MLX90632 won the Elektra Award, considered to be one of the most prestigious awards a company in the global electronics industry can receive, in the category of “World’s smallest medical grade FIR sensor” in 2019. In addition to this, it also won the 2019 Innovative Product of the Year Award in the category of temperature. Having a component in our device that is a recent innovation helps to “future-proof” our device so as not to need hardware updates in the near future. When discussing the notoriety of this piece, and the given cost efficient price point, within our team, we have decided that the MLX90632 would have been an excellent choice to use for our project, but the price of the MLX90614 was simply better for similar results. Figure 3.3-8 shows an image of the MLX9032 FIR sensor.

Table 3.3-1 IR Thermometer Comparison Table

Specification	MLX90614	MLX90615	MAX6627	MLX90632
Temperature Range	-70ºC - 380ºC	-40ºC - 115ºC	-55ºC - 125ºC	-20ºC - 100ºC
Accuracy	±0.2℃	±0.2℃	±1℃	±0.2℃
Mounting Style	Through Hole	Through Hole	Surface Mount	Surface Mount
Package	TO-39-4	TO-46-4	TDFN-EP-8	SFN-5
Price	$12.59	$15.89	$5.46	$15.27
Interface Type	I2C	PWM, MBus	SPI	I2C
Measurement Resolution	16-bit	10-bit	12-bit	16-bit
Supply Voltage	2.6V - 3.6V	2.6V - 3.4V	3V - 5.5V	3V - 3.6V
Manufacturer	Melexis	Melexis	Maxim Integrated	Melexis
Operating Supply Current	1.3 mA	1.3 mA	1 mA	1 mA

After comparing the 4 different choices for an IR thermometer using Table 3.3-1, the GY-MLX90614 was chosen to be used in our project design. The table compares a variety of criteria that could possibly affect the quality and efficiency of the project’s design: temperature range, accuracy, mounting style, package, price, interface type, measurement resolution, supply voltage, manufacturer, and operating supply current. The GY-MLX90614 was chosen based on these criteria deeming it to be the overall best. Although it is deemed the overall best, this does not mean that it is the absolute ideal IR thermometer. Accuracy of measurements is one of the most important factors that was considered in the decision making process. The GY-MLX90614 had the accuracy of the measurements taken as one of the best of the 4 components. However, this cannot be the only deciding factor as several other possible IR thermometer candidates had similar accuracy readings; three of the four IR thermometers considered had the same accuracy readings while only one of them was significantly worse, the MAX6627 model [22, 28]. Another major deciding factor is the price of the device. The cost is important not only for building the overall project but for deciding the cost for the consumer. Finally, the diminutive size also factors into why this component was chosen over the other available options. The size is important for user comfort as well as weight. Although the temperature range of the chosen IR thermometer was the smallest of the four considered, the range is well over the required range to measure the limits of the human body; the highest fever's temperature ever recorded was approximately 47°C to 53°C lower than the maximum range reading–and the lowest body temperature ever recorded was approximately 12°C to 32°C higher than the minimum range reading. These body temperatures are also the most extreme cases ever recorded; hypothermia is a body temperature below 35°C and hyperthermia is a body temperature over 39°C.

3.3.2 Solar Cell Cloth

For our design, we wanted our glove to include a fabric that was capable of handling our components and it's necessary functions as well as being comfortable for the user to wear. While looking for a particular fabric, we ran across the idea of using Solar Cell fabric, which is a new technology in itself [31]. The fabric still includes the same functions as regular solar cell panels do. This fabric could do things such as track any fitness levels, which we found useful as we can work with that on our design [32]. It is stated that this fabric is also able to be machine washed so that is another bonus for our product as it will be able to be a long lasting product that can be reused rather than having to dispose of it after a certain period of time that the product wears off [31, 32].

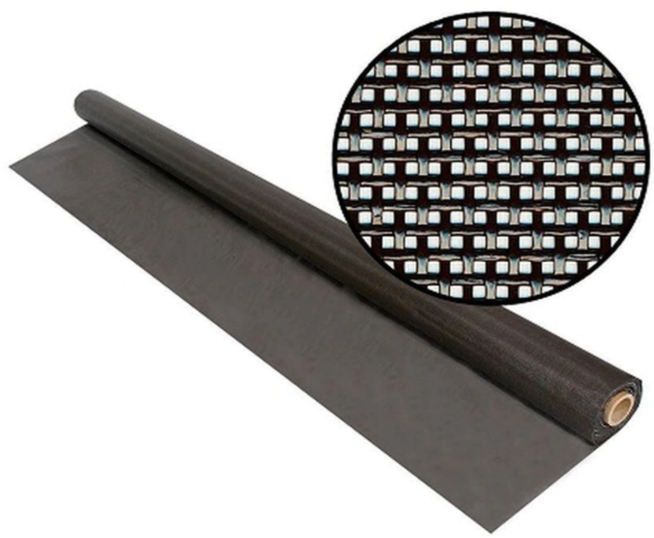


Figure 3.3-9 Solar Cell Fabric [33]

The different types of solar cell cloth we have researched to see which to use are able to see how much power is being generated, the amount of carbon emissions offsets and the income that is being generated, all by being connected to the internet and using Smart Meter Technology. All three Solar cell cloths are a flexible thin-film solar panel made out of a copper indium gallium selenide (CIGS) semiconductor material. This material is one of the most common thin-film photovoltaic technologies that convert sunlight into electric power. They have a solar energy transformation efficiency performance of up to 14% which is higher than other thin-film solar panels made of other material. They are also flexible enough to be able to roll up completely 360 degrees into a circle. Another feature they all have in common is that they are waterproof, so the solar cell technologies will still be able to work in case of any spill or other water related incident a user may come across. Lastly, all three cloths are packaged with a special Ethylene tetrafluoroethylene (ETFE) film which is durable and is known to have high light transmittance. Listed below is a table that states all of the differences between each of the solar cloths all the while including these other features that were just mentioned.

Table 3.3-2 Solar Cell Cloth Comparisons

Specification	1.25 W CIGS Cloth	2.5 W CIGS Cloth	5W CIGS Cloth
Dimensions (mm)	205 × 90 × 1(±0.2)	200 × 160 × 1(±0.2)	355 × 160 × 1(±0.2)
Open Circuit Voltage	1.7 V	3.1 V	6.7 V
Voltage	1.3 V	2.6 V	5.3 V
Current	950 mA	950 mA	950 mA
Power	1.25 W	2.5 W	5 W
Weight	22 g	40 g	66 g

3.3.3 PCB

In order to design our PCB layout, we first had to decide on what software to use for the implementation of our project design. The design software we decided to go with is Eagle Autodesk, a free design application that designs the projects through scripting. Eagle has a schematic editor with various libraries containing many electronic components. In the event that the component you want to use is not contained within the libraries of eagle, the symbol and footprint for the component can be downloaded and added as a new library for your project, thus enabling a far more modular design of the device. In the case of our project, many of the components needed to be loaded into the software in order to add them to the schematic and board layout. In order to import the symbols and footprints for many of the parts, we used a program called Library Loader. This program is able to import the files for the footprints and symbols into a single library that is auto loaded into EAGLE. Through the use of Eagle, the BOM (Bill of Materials) can also be generated quite easily.

3.3.4 Wi-fi/Bluetooth Device

Wi-fi is a technology that allows devices to access the internet and exchange information from one device to another [34]. This is done by connecting to a wireless router that allows your Wi-Fi compatible device to gain access to the internet. This implementation comes from the IEEE 802.11 standard for wireless local area network communication which defines the protocols that allows communication between Wi-Fi compatible devices. Wi-Fi operates on two operating frequencies which come with different standards for each such as 802.11a, 802.11b, 802.11g and 802.11n. Each standard operates on different frequencies, able to deliver different bandwidth, and offer a number of different channels. Similar to Wi-Fi being able to exchange information from one device to another there is also Bluetooth. Bluetooth is used to exchange data between devices in a short amount of distance [35]. This distance can reach a maximum of about 30 feet and this distance can be reduced if there are obstacles in the way. For this device we intend to use Bluetooth 3.0. With Bluetooth 3.0 it improves data speeds with help from the 802.11 standard.

Adafruit Flora BlueFruit 802.15.1

This component uses Bluetooth 3.0 to connect with other devices in order to send data wirelessly [36]. It can easily connect to any smartphone, tablet or other mobile device and also use low power energy throughout to not overload any power consumption to the device it is paired to. To transmit any data, this component uses UART at a 9600 Baud rate. The main highlight of having this component on our device, is that it is small, not bulky and weighs 34 grams, making it very lightweight. This device is also known to be for wearable devices and is sewable if needed to be.

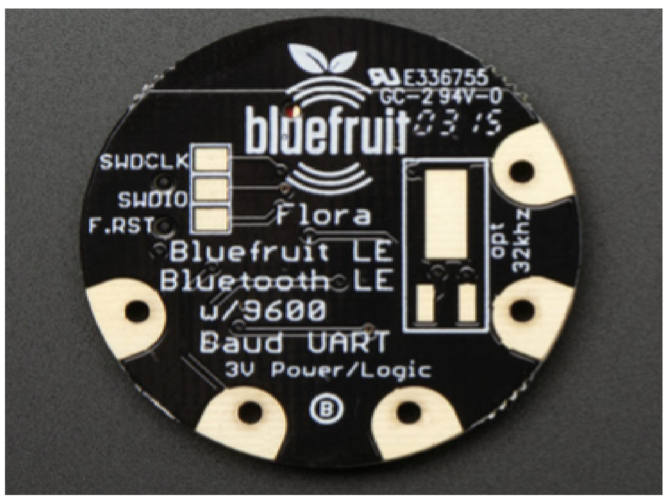


Figure 3.3-10 Adafruit 2847 802.15.1 [37]

Silicon Labs BLE112-A-V1

The BLE112-A-V1 is another low power consumption bluetooth module [38]. This module is preferred to be using the UART interface as that is the fastest rate for any data transfer at up to a 2Mbps Baud rate. However, it can also use SPI and I2C. This is also another lightweight component, weighing at 2.2 grams. Although this component is used for medical applications like our project, it does not state if it is usually used on any wearable devices.

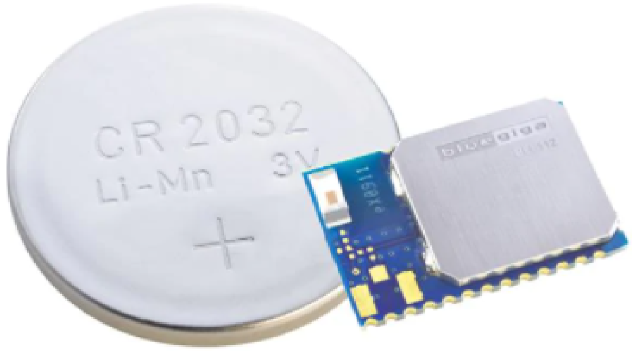


Figure 3.3-11 BLE112-A-V1 [38]

Laird Connectivity 453-00006

The last Bluetooth low power module we have researched on is the Laird Connectivity 453-000066. This is the lightest component in weight that we have looked into, coming in at less than 1 gram [39]. Like the other two modules, this module is able to connect via UART, and is also able to connect via Serial connection, I2C and SPI. It is also able to transfer data at a 2Mbps speed. This module uses Bluetooth 5.0, a more advanced Bluetooth than what we were thinking about using. There is no listing of this device being utilized on any wearable device, but we will see if we will be able to implement it if chosen for our project. This is the most cost friendly component out of the three, so it has that as an advantage between the other two.

Figure 3.3-12 Laird Connectivity 453-00006 [39]

Quectel YC0011AA

This component uses an embedded antenna to connect with other devices in order to send data wirelessly [40]. The Quectel is placed on our PCB by being surface mounted. It helps connect our PCB to our mobile application and is able to connect to any smartphone, tablet or other mobile device as needed. To transmit any data, this component uses I2C at a 9600 Baud rate and 2.4 GHz. The highlight of having this component on our device, is that it was the component used on our microcontroller, the

ESP8266. It is lightweight, low on cost and easily able to work with what is needed for our device.

Figure 3.3-13 Quectel YC0011AA [40]

Below is a table that compares all of the three bluetooth modules in which we considered using for our project.

Table 3.3-3 Bluetooth Comparison Table

Specifications	Quectel YC0011AA	Adafruit Flora	BLE112-A-V1	Laird Connectivity 453-00006
Bluetooth Connection	BLE - 802.15.1	BLE - 802.15.1	BLE - 802.15.1	BLE - 802.15.1
Memory	–	256 KB Flash	256 KB Flash	192KB
Interface Type(s)	I2C	UART	UART, SPI, I2C	Serial, UART, SPI, I2C
Price	$0.75	$18	$13	$8

3.3.5 Microcontroller

The microcontroller is a small computer on a semiconducting integrated chip. When looking into features of what we want our microcontroller to have, we needed it to be able to interact with the PPG/ECG sensors to read any data coming in. We also ensured that it is a low power microcontroller to preserve battery life. The microcontroller was also ensured to be bluetooth and WiFi detectable in order to connect to any mobile devices and send off data from the device to our mobile application. Listed below are a few microcontrollers that we believe best fit our standards for our project, where we later compare them via a table.

MAX32666

Maxim Integrated's MAX32666 is a low power dual Arm Cortex-M4 MCU that has Bluetooth Low Energy integrated into the chip [41]. It can preserve battery life by having the combination of robust memory, security, communications, power management and processing functions that are typically done by several microcontrollers, but are rather able to be done all in one board. This MCU is known to save board space as it is very small with only a 3.8 mm by 4.2 mm footprint. The reliability of this microcontroller is also an advantage on this MCU as it is robust by having integrated error correction codes on the Flash, SRAM and Cache memories. There are several interfaces that are also supported on this MCU, such as three SPI master/slave, three 4-wire UART, and three I^2C master/slave interfaces. There are also six 32-bit timers and two high-speed timers that are utilized for the clock sequences used throughout the microcontroller being powered on.

The downside of this device is the cost. As we know, in engineering we always have to deal with trade offs and this is another example of that. Even though it does mainly everything we want it to do in a microcontroller, and it saves a lot of space on our design, the price of $175 as listed on digikey is just way too overpriced for our range in budget [42]. We then move on to our next microcontroller option to discover our options even further.

Figure 3.3-14 MAX32666 Microcontroller and EV Kit [42]

STM32WB55

The STM32WB55 microcontroller made by STMicroelectronic is a multiprotocol wireless 3-bit MCU with an Arm Cortex-M4 CPU with FPU [43]. This MCU offers Bluetooth 5.2 as well as an IEEE 802.15.4 PHY and MAC radio solution that supports Thread and Zigbee 3.0 as other options for low power IPv6 mesh wireless networking protocols. This divide includes several system peripherals like the other microcontrollers listed in this document. There are 2 SPI 32 Mbit/s lines, as well as 2 I^2C buses, and 1 low power UART line and as well as 2 DMA controllers that support ADC, SPI, I^2C, UART and the timers from the clock. There is a cyclic redundancy check calculation unit on this unit as well that helps with error detection which classifies this to be a reliable MCU.

As far as timers go, there are two 16 bit two channel timers, one 32 bit four channel timer, two 16 bit ultra low power timers, and two watchdog timers–one window and one independent. The internal speed of this ranges from 100 kHz to 48 MHz oscillator. The memory components of the MCU are up to 1MB of Flash memory with sector protection against read and write operations, as well as 256KB of SRAM that has 64 KB used for hardware parity checks. Another great feature of this product is that it has a touch sensing controller for up to 18 sensors, which can be useful for the PPG/ECG sensors to collect data from the user's fingers.

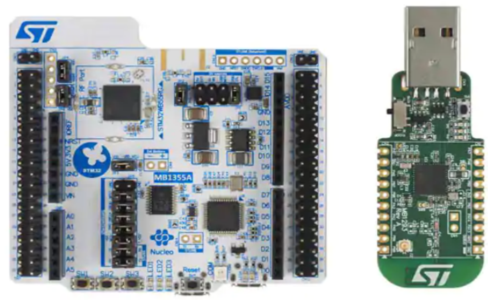


Figure 3.3-15. P-NUCLEO-WB55 Development Kit for SM32 MCUs [43]

QN9090T

The microcontroller desired for our project needed to be a low power MCU with a bluetooth component to be able to read off the data the sensors are collecting. The one microcontroller we had in mind to use when we first had our original plan laid out was the QN9090T with bluetooth by NXP semiconductors. This microcontroller has a 48MHz Arm Cortex-M4, as well as 640KB of flash memory and 152KB of SRAM [44]. The flash memory is utilized for code and data storage and is listed to have data retention for up to 10 years. The SRAM is typically divided when using it within the other ports on the MCU as that allows for simultaneous access for reading and writing data on it. It integrates a high performance 2.4 GHz transceiver with low current consumption, high sensitivity and high transmit power. This microcontroller has a carrier board that includes a debugger, NFC tag and a generic expansion board that contains buttons, LEDs, USB to UART and several other components [45].

There are several clocks on this device as well that help with the functionality of this MCU [44]. Low power wake timers are driven by a low frequency clock of 32KHz, one which is internal and the other that is an internal device connected to external pins and is the most accurate between the two options for low power timers. Main digital systems are driven with a high frequency clock which is used for the processor and system buses. Similar to the low power wake timers, the high frequency clocks also are found in two configurations, one completely internal and the other internal connected to external pins of the board. The internal clock can go from frequencies of 12MHz, 24MHz, or 48MHz; whereas the internal connected to external pins can be selected to be 16MHz or 32MHz.

The NFC reader chip that is found on the MCU can be utilized to pair your smartphone or other smart device to setup and connect via Bluetooth [45]. The Bluetooth module on this device can hold up to 8 connections properly. This MCU also has several digital/analog interfaces such as ADC, UART, I2C, and SPI. The last great feature that we thought would work best for our design was that it includes an IR modulator as one of its digital interfaces. This IR modulator can help configure any of the IR usage that is a part of our design for helping the receiver distinguish the desired signals from other infrared noise sources.

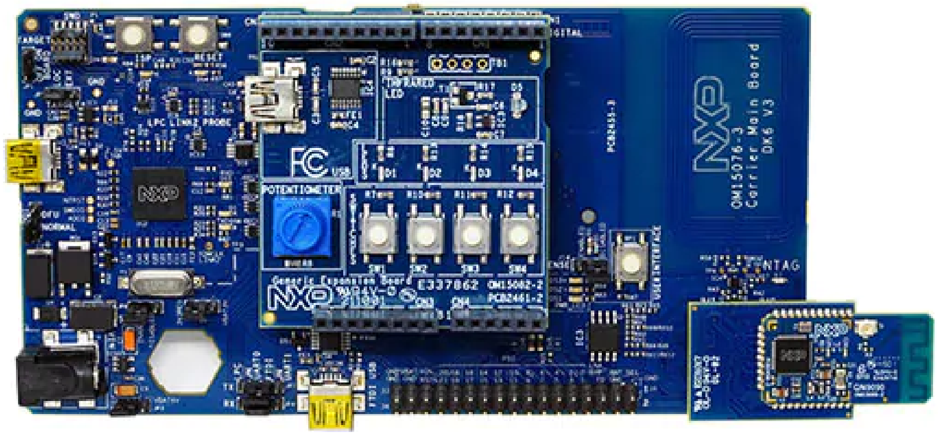


Figure 3.3-16 QN9090T Microcontroller [46]

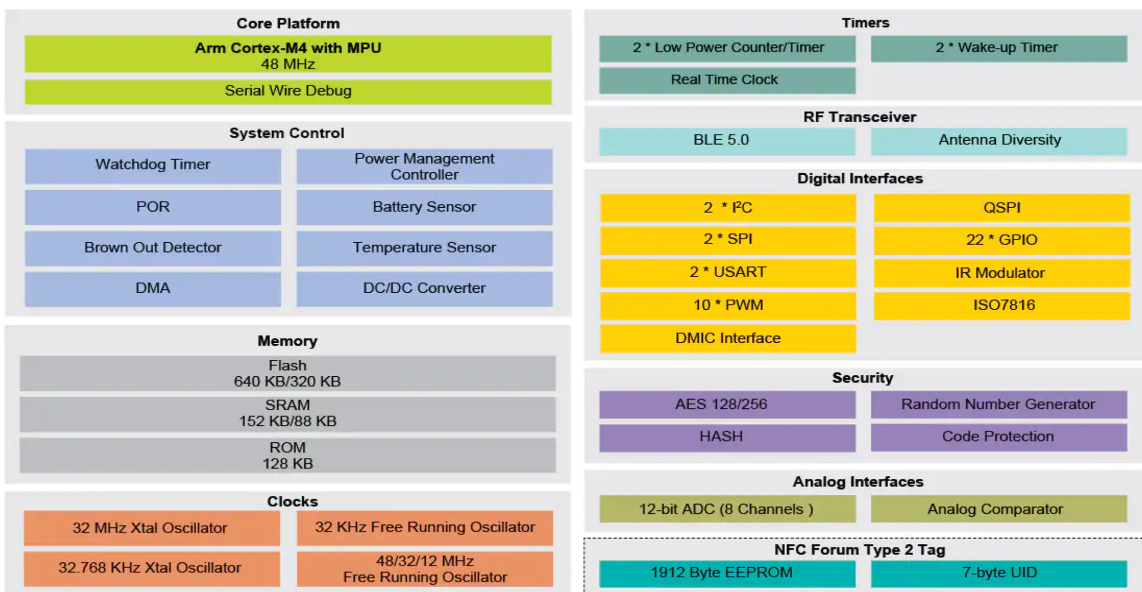


Figure 3.3-17 QN9090 Microcontroller Block Diagram [47]

ESP8266EX

For our project, we used the ESP8266EX that is a part of the ESP8266 NodeMCU [48]. The ESP8266EX is integrated with a Tensilica 32 bit CPU that is able to be used for low power mode and can reach max clock speeds of 160 MHz. It is also a microcontroller that is fairly commonly known to be used for connecting to WiFi, which is a part of something that we are attempting to accomplish with our project as well. This chip has two SPIs, one I2C, one I2S, and 2 UART data interfaces to be able to be used to communicate between any peripherals and the MCU itself [49]. A couple of more major highlights of choosing this device as being the one to use for the new project plan was that it was very well documented, easy to learn how to program it, and it is also significantly cheap.

3.3-18 ESP8266 NodeMCU [48]

3.3-19 ESP8266EX Microcontroller Chip [50]

There are several similarities as well as differences between the three microcontrollers that we have discovered to best fit the functionality purposes of our project. To help make our final decision on which MCU to go with, we laid out this table that helped us view all of the advantages and disadvantages of each one of the devices. Ultimately, the ESP8266 was decided as the best option for the project. It has the best storage capabilities and the fastest speed. The only drawback is that its flash memory is the weakest of the considered microcontrollers; although weaker, the memory is still adequate for the project's purposes.

Table 3.3-4 for Comparison between microcontrollers.

Specifications	MAX32666	STM32WB55	QN9090T	ESP8266EX
Storage	1MB	256 KB	152KB	16MB
Memory	560KB Flash	1MB Flash	640KB Flash	128 KB Flash
Speed	Up to 96 MHz	Up to 48MHz	Up to 48MHz	160 MHz
Data Bus	32 bit	32 bit	16 bit	32 bit
Cost	$176 (Digikey)	$56 (Digikey)	$40 (Mouser)	$9 (Amazon)

3.3.6 Fingerless Glove

This entails the look of what we wanted our design to be. We believe that having a fingerless glove helps the user be able to still do things with their hands such as using a smartphone, all the while collecting their medical data while having them on. We originally wanted to create this glove ourselves using the solar cell fabric. Since that was drastically set on backorder, we were not able to do so. The design of fingerless gloves is also useful to be able to reach sensors better so that waveforms of the blood pulse and heartbeat are accurately pictured. This especially provides support for the photoplethysmograph (PPG) so that it can maintain the necessary skin contact whether the sensor is placed on the wrist or finger. Though this constant skin contact is necessary for the PPG, the fingerless glove ensures that it will not compromise the user's comfort.

Figure 3.3-20 Fingerless Glove

Fig. 3.3-20 is a picture of the fingerless glove that we purchased on Amazon [51]. We decided to go with an extra large flexible glove that has expandable wrist options to make the glove customizable in size based on the person who is wearing the glove. This glove is also listed to be very flexible, which is a feature that we wanted to ensure our user that they would be able to still move their hand around if they felt uncomfortable or just wanted to use their hands for something.

Due to the amount of parts needed for our design, we also decided to customize an arm sleeve to hold the remaining parts that would not fit on the glove. This includes the printed circuit board, the solar charger, and the battery. The sleeve before customization is shown in Fig. 3.3-21. The sleeve was customized by reducing the length of the sleeve to only cover the forearm and adding pockets sewn on to the top and bottom to hold the components.

Fig. 3.3-21. Arm sleeve [52]

3.3.7 Photodiode

A photodetector converts incident radiation, light, into electrical signals [14]. This conversion into electrical signals is achieved through the absorption of photons which creates electrons. The two primary forms of photodetectors are photoconductors and photodiodes. An example of a common epoxy cased photodiode is depicted by Figure 3.3-22. There are two modes that a photodiode can operate on: photovoltaic and photoconductive [14, 53]. A photovoltaic photodiode does not have an external battery. A photoconductive mode is achieved by applying an external reverse bias [53]. The photoconductive mode of operation is the common mode for light detection which is why it is often referred to as the "photodiode mode of operation" [14]. A photodiode's performance of photocurrent generated is given by its responsivity which can be calculated by the following equation 3.3-1:

$$R = \frac{Photocurrent\ (A)}{Incident\ optical\ power\ (W)} = \frac{I_{PH}}{P_0} \qquad \text{Eq. 3.3-1}$$

Responsivity heavily relies on wavelength, which is depicted in figure 3.3-23. An ideal quantum efficiency of 100% would make the responsivity increase as the wavelength approaches the bandgap wavelength. However, this is never the case in practice. The response curve depends on factors such as device structure, semiconductor absorption coefficient, and quantum efficiency.

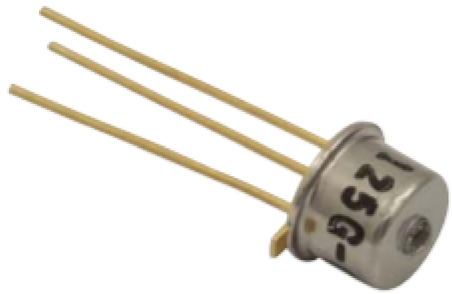


Fig. 3.3-22 Photodiode [54]

The photodiode is utilized as a part of the photoplethysmograph segment. The photodetector's main function is to measure the reflected light from the tissue which results in the waveform formed from the alternating diastolic and systolic pressure. The amount of light received by the photodetector is affected by blood volume, blood vessel wall movement, and the orientation of red blood cells [8]. An increased blood volume correlates to a lower light intensity throughout the tissue creating a weaker signal read by the photodiode.

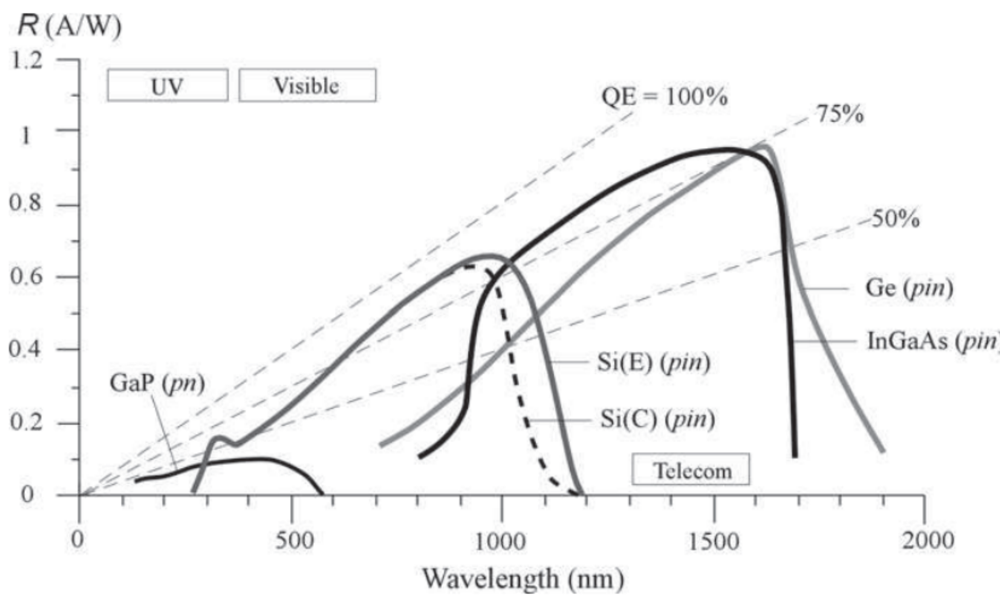


Fig. 3.3-23 Responsivity (R) vs wavelength comparison of an ideal photodiode and a typical silicon photodiode [14]

Table 3.3-5 compares the feasible photodiodes provided by Thorlabs. The table compares possible criteria that could influence the design of the project including peak wavelength,

wavelength range, active area, and price. The chosen photodiode is item FDS025. This particular photodiode had a moderate advantage in all categories. The wavelength range and peak wavelength criteria is most desirable around 600 nm to 800 nm due to the blood's ability to absorb light in this range. A shorter wavelength range is more desirable as it would be less likely to pick up ambient light. In that respect, the chosen photodiode has the most advantage of the seven. The peak wavelength has an advantage as it is close to the isosbestic wavelength of blood. The active area can contribute to user comfort; a larger device can make the device bulkier and more difficult to wear but a smaller device may make it difficult to get an accurate reading. In this respect, the chosen photodiode is small and light giving it a moderate advantage. One of the most important criteria is the price. The FDS025 is more expensive than some of the other photodiodes but has the advantage in several other categories.

Table 3.3-5 Comparison of possible photodiodes provided by Thorlabs [55]

Item #	λ Range* (nm)	Peak λ* (nm)	Active Area (mm^2)	Price (USD)
FDS010	200 - 1100	730	0.8	48.15
FD11A	320 - 1100	960	1.21	14.58
FDS100	350 - 1100	980	13	14.94
FDS1010	350 - 1100	970	100	55.73
FDS015	400 - 1100	740	0.018	53.05
FDS02	400 - 1100	750	0.049	83.59
FDS025	400 - 1100	750	0.049	34.36

*Where λ represents wavelength

3.3.8 LED

In the non-invasive health monitoring system, a light emitting diode (LED) is utilized as a part of the photoplethysmograph segment. The light interacting with the tissue results in the light scattering, absorbing, transmitting, and fluorescing [8]. It is important that the wavelength of the light source is within the appropriate absorption spectra window. Light emitted by the typical LED has a single bandwidth of approximately 50 nm.

The wavelength of the light source is affected by "the optical water window", "isosbestic wavelength", and the "tissue penetration depth" [8]. "The optical water window" refers to how light in the ultraviolet and longer infrared regions is strongly absorbed by water. Water is a main component of living tissue giving it similar properties whereas light with short wavelengths is strongly absorbed by melanin. Melanin's strong absorption of ultraviolet light, as well as strong absorption of visible light, is easily shown by Figure

3.3-24. There is a portion of the absorption spectra that includes visible red light and near infrared light is able to pass more easily allowing for better blood flow and volume measurements. Oxyhemoglobin and reduced hemoglobin have drastically different light absorptions but have similar isosbestic wavelengths. This is the wavelength where their total absorbance will not change during a physical or chemical change [56]. The signal remains unaffected when measurements are taken near 805 nm [9, 56]. The operating wavelength dictates the depth of light penetration in the tissue [8].

The required LED must emit a wavelength in the near infrared region making an infrared LED the optimal light source for photoplethysmography [8]. The main component affecting the absorption and overall effectiveness of PPG is hemoglobin as it changes with time [9]. The near red region of the light spectrum, 600-700 nm, has been shown to be the most effective. Other components affecting light absorption fall to a minima including oxyhemoglobin, hemoglobin, and bilirubin. Although melanin's light absorption is not at a minimum in the near red range, it is a significant improvement from shorter wavelengths as explained previously. Also explained previously is that oxyhemoglobin and reduced hemoglobin have an isosbestic wavelength at 805 nm; the AC waveform component is found to be independent of the wavelength past 660nm and before 805 nm.

The LED appeals to the consumer as it is compact, relatively low-cost, and has a long operating life lasting over one-hundred thousand hours [8]. From an engineering standpoint, they are mechanically robust, reliable, and operate over a wide temperature range. As opposed to earlier models of PPG light sources—such as a battery powered torch bulb—an LED has a low enough intensity to not overheat local tissue and reduces the risk of a non-ionizing radiation hazard.

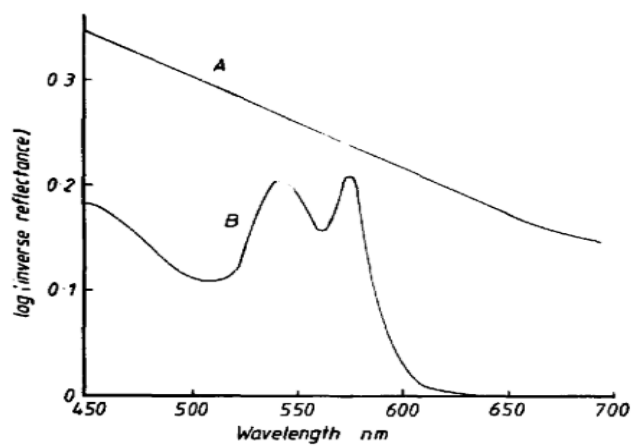


Figure 3.3-24 Graph of light absorption curves for (A) melanin and (B) whole blood in vitro [9]

Using the data and information gathered in this section, the most appropriate wavelengths for LEDs to be used for photoplethysmography are 600 nm to 800 nm. Table 3.3-6 provides a comparison of the feasible LED's provided by Thorlabs including factors that can influence how well the LED works in the project.

Table 3.3-6 Comparison of possible single-color LED's provided by Thorlabs [57]

Item #	λ* (nm)	Optical Power† (mW)	Operating Current (mA)	Spectral FWHM (nm)	Viewing Half Angle	Max DC Forward Current (mA)	Price (USD)
LED600L	600	3	50	12	15°	75	12.44
LED610L	610	8	50	12	25°	75	12.44
LED625L	625	12	50	14	24°	75	12.44
LED630L	630	16	50	14	22°	75	12.44
LED630E	630	7.2	20	17	17°	50	14.72
LED631E	635	4	20	10	20°	50	7.63
LED635L	635	170	350	15	7°	500	61.68
LED645L	645	16	50	16	20°	75	12.34
LED660L	660	13	50	14	18°	75	12.11
LED670L	670	12	50	22	22°	75	12.11
LED680L	680	8	50	16	20°	75	12.11
LED750L	750	18	50	23	11°	75	9.66
LED760L	760	24	50	24	12°	75	9.66
LED770L	770	22	50	28	12°	75	9.66
LED780E	780	18	50	30	10°	100	28.95
LED780L	780	22	50	25	12°	75	9.66
LED800L	800	20	50	30	12°	75	9.66

*Where λ represents wavelength
†Optical power at operating current

3.3.9 Solar Cell Charger

To maintain the solar cloth solar energy, our device intended to have a solar cell charger to supply that energy to the battery. Instead, the solar cell charger was implemented to supply energy to the battery from a standard solar panel. This helps the device become more portable and accessible without having to wait until certain times of the day for the sun to fully come out and charge the solar cell cloth.

Solar cell chargers charge lead acid or Ni-Cd batteries up to 48 V and up to 4000 ampere hours capacity [58]. As mentioned, instead of waiting for peak hours for the sun the solar cell charger can be connected to the solar cell device and be connected to a battery to store energy for when the sun is not fully out. Our solar cell device is compatible with Li-on batteries. This type of solar technology prices are dropping down in the market where it is affordable to see in everyday life such as at the beach, outdoor location or a fingerless glove. Thanks to this, it would help maintain a low cost for manufacturing and users purchasing our device. When deciding on a solar charger, it was important to note that solar chargers need to be compatible with the type of battery that was being charged, and so the solar chargers we considered were based on the batteries that we considered as well, so as to make sure that whatever choice we went with would be compatible with our battery choice after comparisons were made.

Bq24074

Since our battery choices were primarily from Adafruit, it stands to reason that our solar charger would also be from Adafruit so as to ensure compatibility with the battery we ended up choosing. The bq24074 in particular was a great piece for consideration because of the many ways it can be used to charge the lithium ion battery [59]. In addition to the components needed to charge via solar power, the bq24074 also comes with a USB type C port in order to charge via USB, and it comes with the capability of charging with 5-10V DC and provides faster charging than any prior solar charger by Adafruit, where they used a standard USB-A port. An immediate question that comes to mind is, can the charger be plugged into multiple forms of charge at the same time, as this could be cause for concern of overcharging the battery to the point of becoming a safety hazard. Thankfully, this has already been addressed; if the charger is plugged into multiple forms of charge, only the higher voltage source will be used to charge the battery. It does also come with the customizability of soldering in a 10K NTC thermistor in order to monitor the temperature of the device, but this is negligible in terms of our project as the device should not be subjected to intense heat or cold for prolonged periods of time.

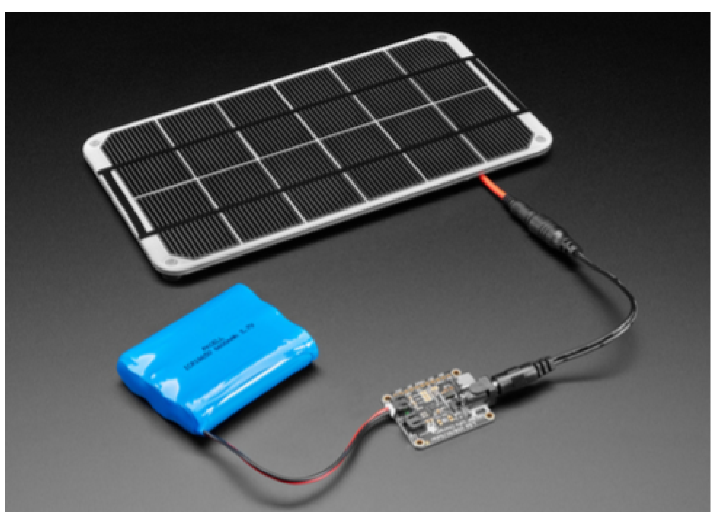


Figure 3.3-25. Bq24074 Solar Cell Charger attached to battery [59]

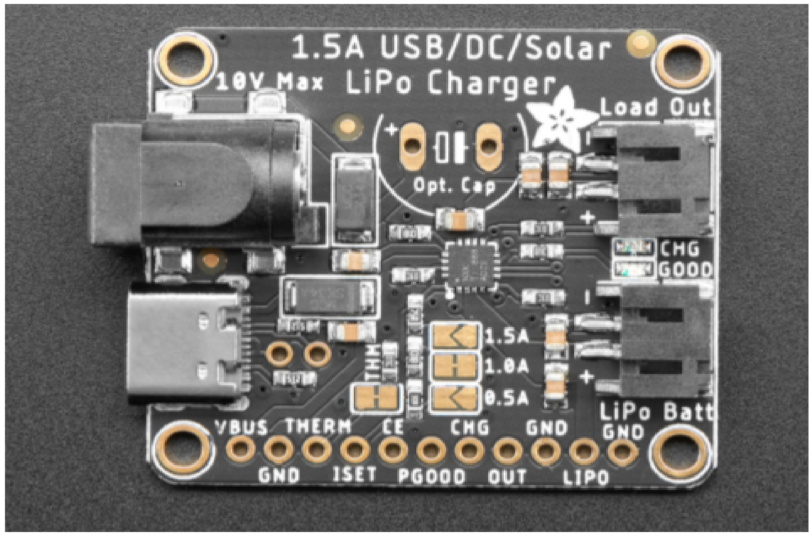


Figure 3.3-26. Bq24074 Solar Cell Charger [59]

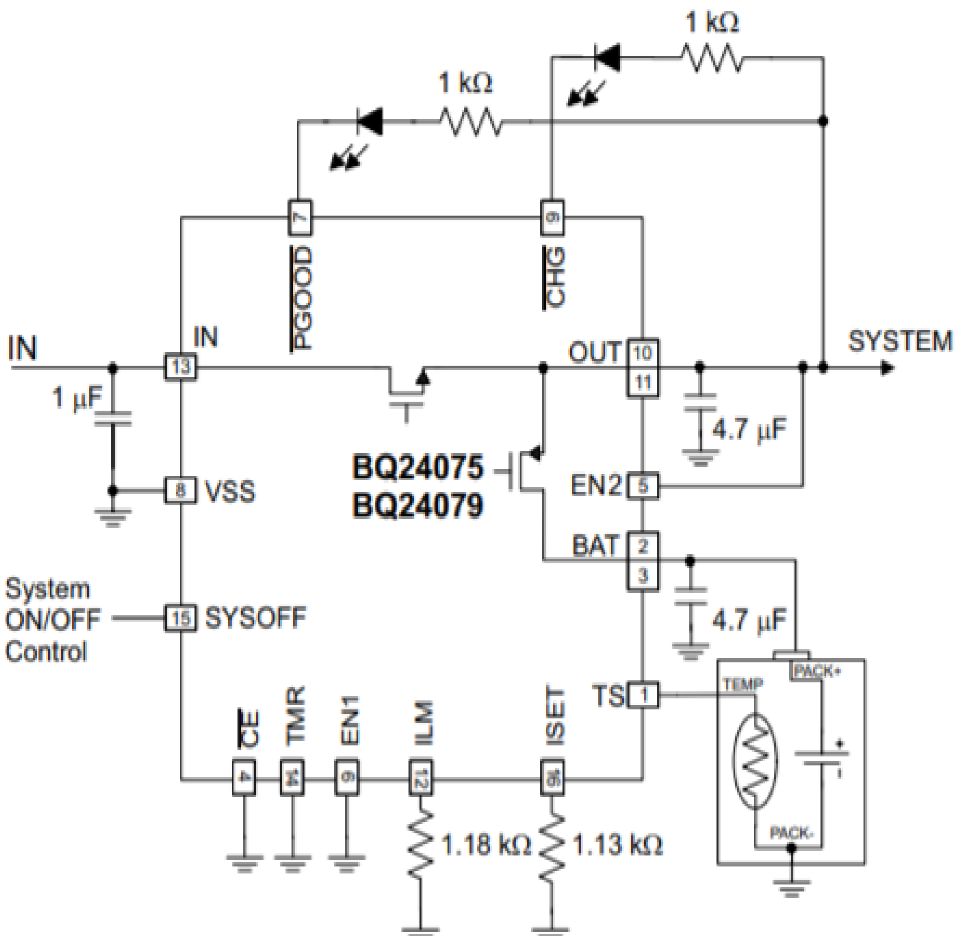


Figure 3.3-27. Bq24074 Solar Cell Charger Application Circuit [60]

MCP73871

Since we were limited to the different types of solar cell chargers we were able to use with this specific Adafruit battery we have chosen, the only other option that we are able to use is the MCP73871. This is a USB / DC / Solar Lithium Ion/Polymer charger - v2 that is also used in solar cell projects, but it is outdated compared to the bq24074 solar cell charger [61]. The MCP73871 is a 3.7V/4.2 V Lithium Ion or Lithium Polymer battery charger that charges with a 5-6V DC, USB or 6V solar panel. This solar cell charger is designed to always draw the most current up from a solar cell which would allow it to charge up to the maximum charge rate. This solar charger requires an electrolytic capacitor (provided by Adafruit) to be soldered on as a stabilization capacitor. There are also LEDs on the board that have three different colors to let the user know if it is doing any of the following three uses: whether the charger is powered on, when it is currently charging, and when the charging is complete. It was uncertain if it would work properly with any other solar panel that is not from Adafruit, which is why we decided to try out the easier, newer and cheaper solar charger, as it has not been stated that it is not unable to be used with different solar panels aside from Adafruit's.

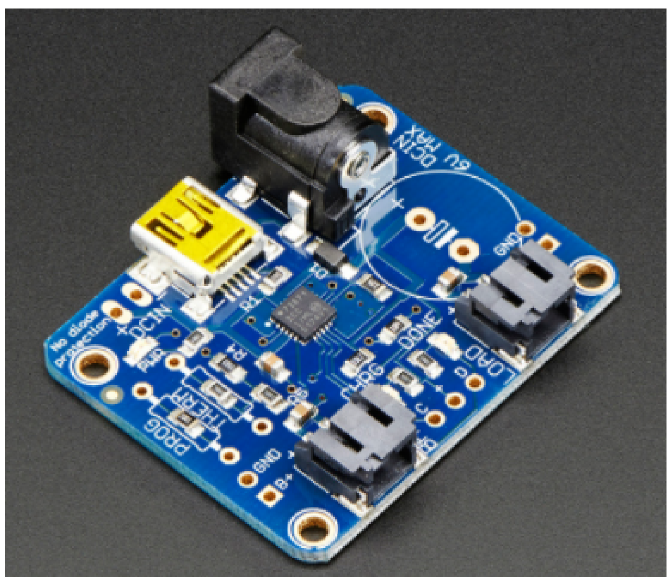


Figure 3.3-28. MCP73871 Solar Cell Charger [61]

Listed in the table below are the comparisons between both of the solar cell chargers to see the detailed differences between both options. Even though one is the predecessor of the other solar cell charger, you can see the upgrades to the specifications that Adafruit have done on this piece of technology. With the improved specifications found on the BQ24074, it is a good enough reason to choose that solar cell charger over the other as it does better in performance, is more cost efficient, and still is capable of charging the same type of battery. After rigorous testing was conducted with the BQ24074, however, the solar charger experienced a malfunction and was deemed inoperable, and so the design was continued with the MCP73871.

Table 3.3-6 Solar Cell Charger Comparison Table

Specifications	BQ24074	MCP73871
Solar Cell Input Voltage	10 V	6 V
Type of Charger	Lithium Ion/Polymer	Lithium Ion/Polymer
Max Charge Rate	1.5 A	500 mA
Price	$10	$18

3.3.10 Battery

Along with the solar panel and the solar cell charger comes with the solar battery. Batteries for solar devices are able to reserve solar energy to be used for later use [62]. These batteries are used when the solar panel is not able to consume energy from the sun during sundown hours. To choose the correct battery for our device we had to check two factors in our device: amount of electricity a solar panel can produce and how much electricity the device can output at a moment's notice. If we have a battery with a high capacity but low power, it can power many devices for a long time. If we flip the scenario and have a battery with low capacity but with high power, this would enable our device to be powered for a short amount of time. There are many types of batteries that are used, the most popular in society currently being used are lithium ion and lead acid. For our device we used a lithium ion battery. Lithium ion batteries are popular because of their longest lifespan and lightweight which means it is key to use on wearable devices. Using a lithium ion battery can cause expenses to increase compared with other types of batteries, but for our project it was the best type to consider, and so only lithium ion batteries were considered for the project.

J.Flex

One of the first batteries we considered is the J.Flex from Jenax Inc., unveiled at CES 2020 [63]. According to Jenax, the J.Flex is an "innovative flexible, solid-state, fast charging, rechargeable lithium-ion battery." This is a huge step forward in removing design limitations from the creative process of designing the look and feel of a product such as a wearable piece of technology. By being able to fold and flex the battery, we can more easily fit it into the appropriate housing on our device, ensuring a smaller, smoother and more polished design. Greater flexibility of design is paramount when taking into consideration the needs and desires of the user. One such factor that is of great importance for us is the ability of the J.Flex to be folded and moved about while still maintaining the same level of power output. This means that the battery would not lose efficiency as the user moves around with the device. The graph below shows the performance of the J.Flex for the cases of the battery charging and discharging.

The cases where the J.Flex was being bent dynamically have almost no variation from the cases where the battery was not bent, showing how efficient this new design is. The operating voltage for the J.Flex is between 3 and 4.25 volts, depending on the size of the battery used. Battery capacity varies between 10 mAh to 5 Ah, maintaining roughly 90 percent efficacy after 1,000 charge-discharge cycles. Charging time typically takes an hour.

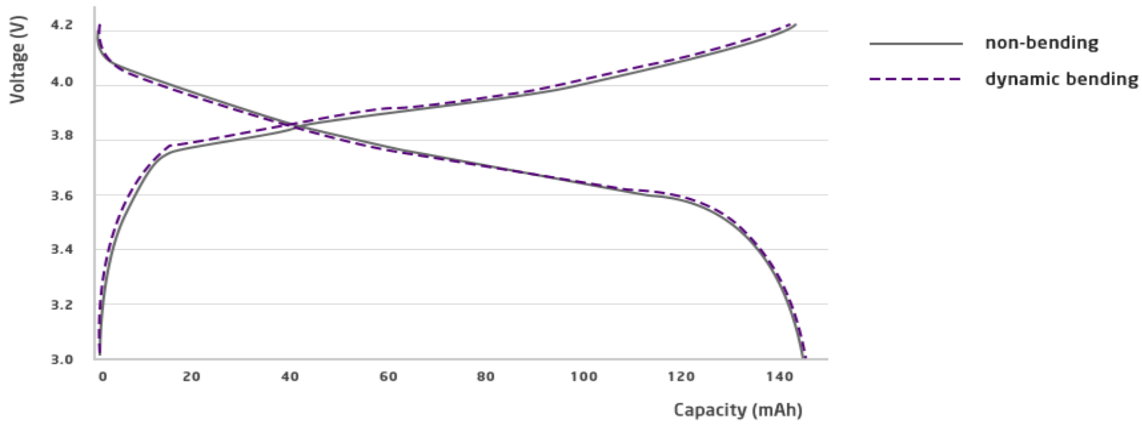


Figure 3.3-29. J Flex performance for charging and discharging [63]

A safety concern that many batteries have is that they can explode when their electrolytes, usually organic fluids that aid in quick ion movement but are flammable, leak out [64]. Another cause for safety hazards is when the cathode and anode come close together, an issue that has occurred with flexible batteries when they are overbent. Jenax has overcome this issue by developing a semi-solid electrolyte, essentially making it non-flammable. This further increases the flexibility of the battery, as the issues inherent with flexible batteries have been removed in the J.Flex. Since this is a piece of technology only recently developed, production for the J.Flex is not fully underway, with no price shown for the product. We would love to utilize this product for our project, but until the J.Flex is readily available to consumers, we were not able to consider it for our design. As our project is one that can be improved upon through time, the J.Flex is a major contender for replacing our choice of battery when it is available to do so.

Figure 3.3-30. JFlex [63]

ICR18650 2200mAh 3.7V

Another battery for consideration is adafruit's lithium ion cylindrical battery, the ICR18650. This battery comes with a protection circuit that helps prevent over-voltage, under-voltage, and over-current damage from occurring [65]. This is a plus for our design, as having a constantly charging platform such as solar cells can cause batteries to become damaged from charging too much without regulation. This, however, does not completely eliminate the problem, and so it is imperative that if this battery were to be chosen, a compatible lithium ion or lithium ion polymer constant-voltage/ constant-current charger would need to also be used to recharge the battery at a rate of 1 Amp or less. This is because the battery does not have a thermistor built in, and so temperature management becomes an important factor when recharging the battery. Unlike the previous battery considered, this battery is inflexible and so there are inherent design constraints when using this battery. This battery in particular could pose a challenge for our design as it is a fairly large cylinder and so the housing for the device would need to compensate for this size.

The ICR18650 has a nominal capacity of 2200 mAh, ±2%, with a nominal cell voltage of 3.7-3.9V. The charge cut-off voltage is 4.2V, ensuring that overcharging does not occur within the battery. It also has a discharge cut-off voltage of 2.75V, as lithium ion batteries generally should not be fully emptied before charging again. This battery also has very low impedance, equating to less than 35 mΩ. The charge time for the ICR18650 is approximately 4 hours, which is within acceptable parameters for our design. Another important factor when considering this battery is the price, coming in at $9.95 per battery, discounting to $8.96 with a bulk order of 10 or more. Overall the ICR18650 is a tentatively acceptable choice for our product, but the size of the battery could impair the final design of the device, and so another battery choice may be more suitable for use.

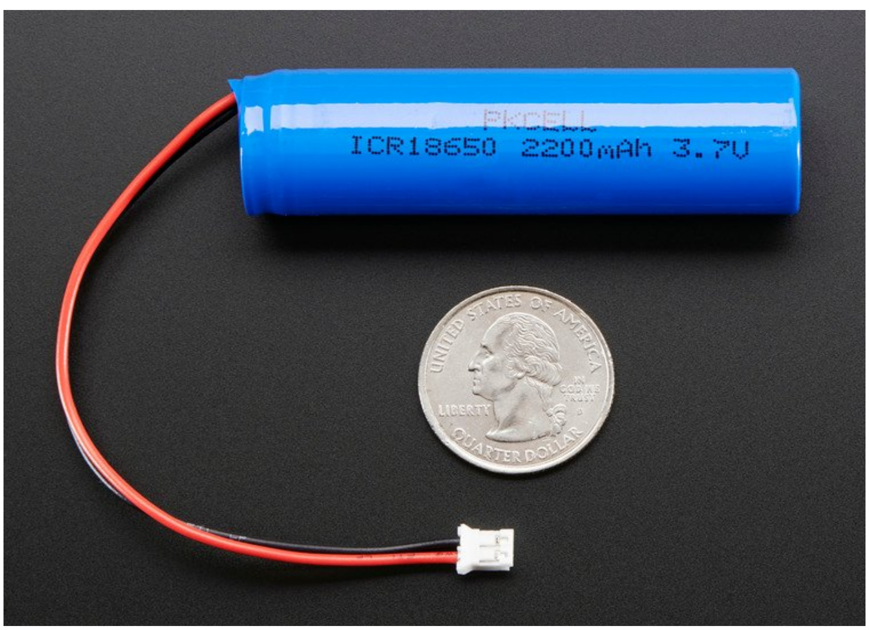


Figure 3.3-31. ICR18650 2200mAh 3.7V [65]

LIPO785060 2500 mAh 3.7V

The LIPO785060 is a thin, light and powerful battery that also has the included protection circuitry from the last battery analyzed [66]. This helps in deciding which battery to use, as that is now a negligible factor since both contending batteries have the circuitry built in. This battery has an output range from 3.7V to 4.2V when fully charged, cutting out when the battery is roughly 2.8V. The capacity for the LIPO785060 is 2500 mAh, yielding a total of about 10 Wh. This would ensure that the device could continuously monitor your vitals overnight without worry of long periods of unmeasured time. Similar to the ICR18650, this battery should be charged with a lithium ion/lithium ion polymer constant-current/constant-voltage charger to ensure a safe experience with the battery. This is also not a flexible battery, and so care must be taken when designing the housing for the battery in the total project design. The LIPO785060 also has a charging time of approximately 4 hours, and many of the comparisons between this battery and the ICR18650 are the same across the board. Comparing prices, however, shows that this battery costs $14.95 for one, decreasing to $13.46 for bulk orders of 10 or more. The price difference is the tradeoff for having a larger capacity for holding charge. The main factor in choosing between them then becomes the dimensions of each one, and whether the project would benefit from a cylindrical shape or a flat rectangular shape. In our case, the shape of the LIPO785060 is more suitable for a less bulky build of the device as compared to the ICR18650.

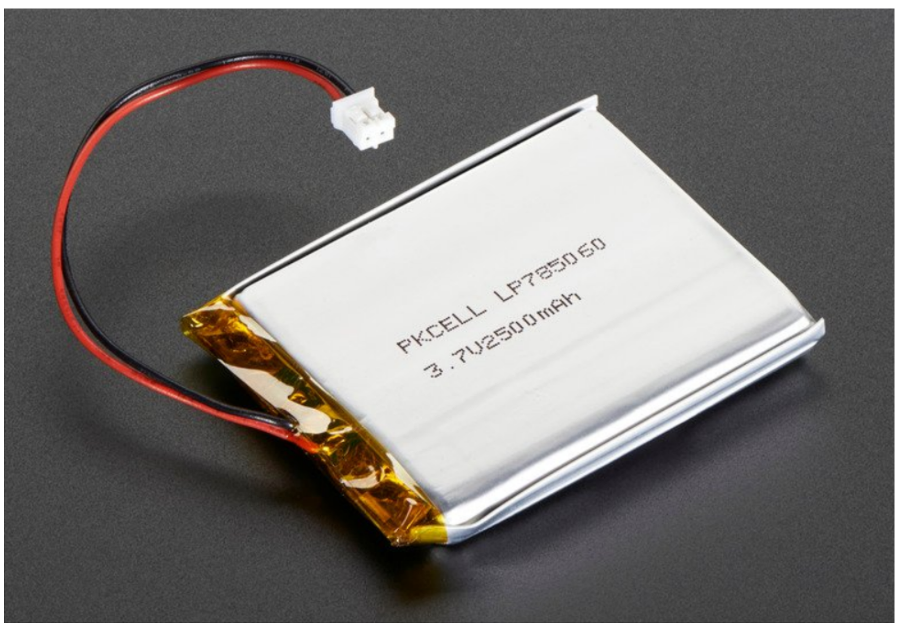


Figure 3.3-32. LIPO785060 2500 mAh 3.7V [66]

Going through the comparisons, we reasoned that the J.Flex is future technology that is currently unavailable at the time this documentation was written, but it would be the battery of choice should it be made readily available in the future. Given this fact, the comparison then became between the ICR18650 and the LIPO785060, which are shown to have similar properties. Although the LIPO785060 is more expensive, with a ½ increase in cost when compared to the ICR18650, the additional capacity and the shape of the battery prove to be more beneficial for the purposes of our project. With a flat design, the wearable can be less bulky and thus more ergonomic for a greater user experience, especially since our project is designed to be continuously worn throughout the day. Should the J.Flex reach production and manufacturing stages soon, it is suggested to change to the J.Flex in order to facilitate a design that focuses even more on ergonomics, to the benefit of the user.

Table 3.3-7 Battery Comparison Table

Specifications	J.Flex	ICR18650	LIPO785060
Nominal Voltage	3.8 V	3.7 V	3.7 V
Capacity	10 mAh - 5Ah	2200 mAh	2500 mAh
Charging time	~1 hour	~4 hours	~4 hours
Price	N/A	$9.95	$14.95

3.3.11 ECG/PPG Sensor

This is an integrated sensor that includes two measurement techniques. The first is an electrocardiogram (ECG) and the other one is a photoplethysmogram (PPG). The electrocardiogram helps read the electrical pulse from your heart beat by the use of electrodes. The PPG uses LED light that penetrates the skin and measures the reflection from internal veins in a finger, this helps measure the heart beat. The measurements from the PPG and electrocardiogram can also help measure blood pressure. The sensor has a bluetooth module which can be read off of any low power MCU with bluetooth capacity on it. Data off of the device would then be able to be transferred to our mobile application. We were hopeful to be able to retrieve the ECG and PPG waveforms that would then lead to retrieving heart rate and blood pressure estimated measurements. Unfortunately, we decided to remove the ECG portion of the project and only continue with the PPG portion. In order to get any proper results made by this sensor, it is crucial that the user is holding their hand steady enough to make the proper waveforms.

Fig. 3.3-33 depicts how the PPG reads the signal. The user's instantaneous heart rate is calculated by measuring the time between consecutive systolic peaks; this corresponds to the AC signal's period in a singular, generally red, LED. If the time between peaks is short then it is considered to be high blood pressure. Similarly, if the time is longer, then it indicates low blood pressure. The measurements that this sensor provides can also help with a requirement we have listed, which is to inform the user to speak to their physician or emergency authority if there may be any potential danger that is currently occuring with the user. If there are many changes in the blood pressure or heart rate, that can signify potential heart issues such as a heart attack.

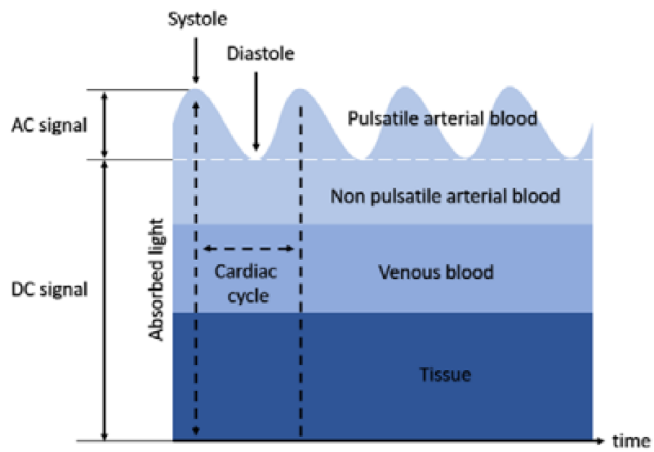


Fig. 3.3-33. DC and AC components of a PPG signal.

If the device uses multiple LEDs, the oxygen saturation, or SpO_2, can be calculated. The SpO_2 measures the ratio of oxyhemoglobin, which absorbs infrared light, to reduced hemoglobin, which absorbs red light. The ratio is calculated using the following equation:

$$R = \frac{AC_{red} / DC_{red}}{AC_{IR} / DC_{IR}}. \qquad \text{Eq. 3.3-1}$$

Once R is determined, a linear approximation derived from a best-fit straight-line approximation is calculated. Because the photodiode in the PPG cannot differentiate between wavelengths, Channel Slot Timing is used to measure the difference in power between red and infrared light; each LED takes turns emitting light over the course of microseconds.

RT1025

On the RT1025, one sensor consists of 3 electrodes that are specifically tied to the ECG. Two of them are used to measure the differential signals from your body, and the third one is to remove body noise to further help with measuring the small ECG signals we are trying to read from the other two electrodes. The ECG signals are typically in the unit of microvolts. The other sensor on the RT1025 consists of two LEDs, a red one and an IR one, and a photodiode. The LEDs are used to determine the difference in blood circulation and can also check blood oxygen levels.

Another important component on the RT1025 is the accelerometer which is useful for helping make the measurements precise if the user were to be in constant motion while wearing the glove. These provide offsets to help get precise results from the sensors.

To provide power to the RT1025, it can be done by using a low dropout regulator. The way conservation of battery life is done is by using high efficiency converters for the high current applications of the RT1025. We wanted our sensors to portray efficient and precise data when it’s not even in use, as that helps balance it out for when the sensors are actually detecting data when fingers are being placed on them. When the sensors are not currently operating and collecting data, they are still using low current to ensure efficient reads for future usage.

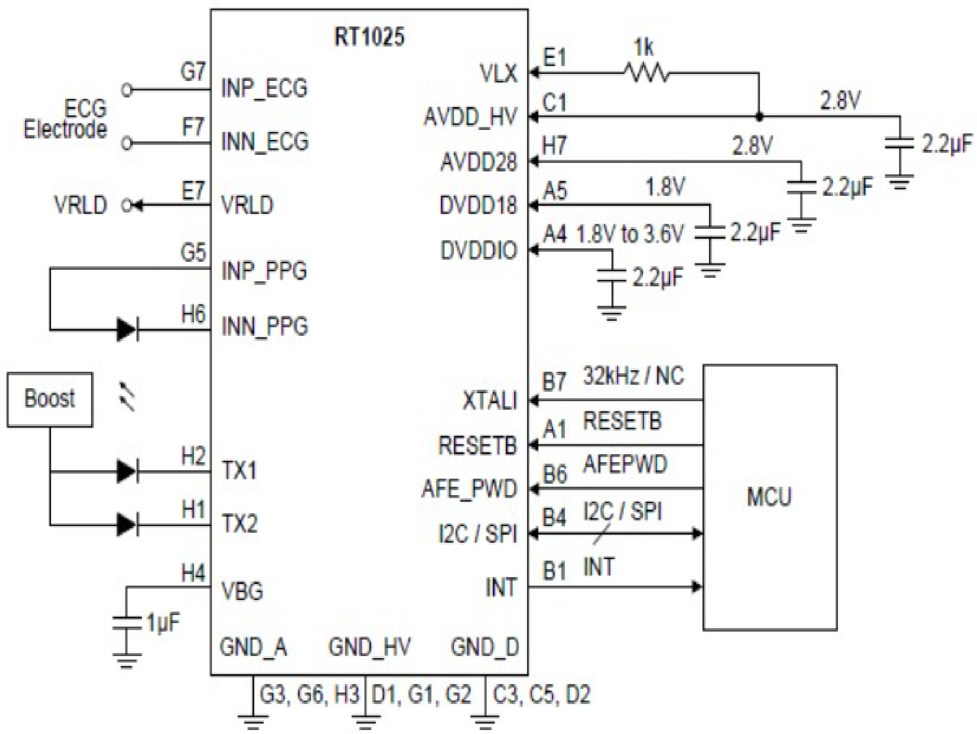


Figure 3.3-34. RT1025 Layout

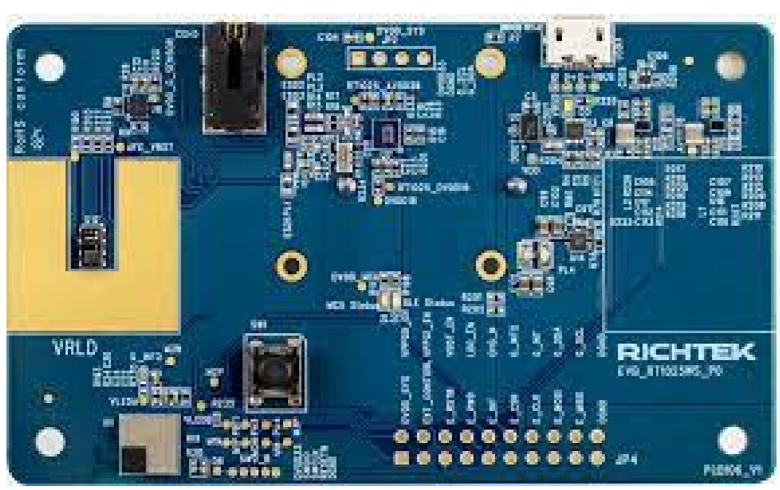


Figure 3.3-35. RT1025 PPG/ECG

MAX86150 PPG and ECG

The MAX86150 is an integrated electrocardiogram, pulse oximeter, and heart rate monitor sensor module. It allows for a simultaneous and synchronous collection of PPG and ECG signals. The MAX86150 maintains a very small total solution size without sacrificing performance. Minimal external hardware components are necessary for integration into a mobile device. It is also known to be useful for medical wearable devices. The MAX86150 operates on a 1.8V supply voltage with a separate power supply for the internal LEDs. In order to communicate to and from the module, a standard I2C-compatible interface is used.

Figure 3.3-36. ProtoCentral MAX86150 PPG and ECG

MAX30100

Maxim Integrated's MAX30100 sensor is utilized for reading heart rate and blood oxygen levels. To do so, the design has two LEDs, one that emits red light and the other that emits infrared light. It also has a photodetector, optimized optics, and low-noise analog signal processing to detect pulse and heart-rate signals. Highlights for choosing this as the sensor for our current project for heart rate and blood oxygen detection are because it is known to be a part that consumes less power, has fast speeds for data being output, and it uses I2C as the communication protocol, same as the one the ir thermometer is planning to use as well. It combines two LEDs, a photodetector, optimized optics, and low-noise analog signal processing to detect pulse oximetry and heart-rate signals.

After working with the MAX30100 and the MAX30102, this sensor had many issues. There are inherent design flaws in the development board. To use the board, adjustments had to be made. One adjustment was to remove the three 4.7 kΩ resistors from the board and connect different 4.7 kΩ resistors externally. An alternative adjustment was to connect a solder bridge from the 3.3 V regulator to the outermost 4.7 kΩ pullup resistor and then break the connection between that same pullup resistor and the other voltage regulator.

Figure 3.3-37. MAX30100 Heart Rate and SPO2 Sensor

TIDA-01580

Texas Instrument’s TIDA-01580 is a wireless ECG, SpO2, PTT and heart rate monitor reference design for medical and consumer wearables. It is flexible with ultra-low-power modes and integrated FIFO can keep the MCU in sleep mode to increase the battery’s lifespan. It is capable of transferring data wirelessly via Bluetooth 4.2 or 5.0. A downfall of this device is that it uses a CD2032 battery to operate which would only last for a 30 day battery life. This device is known to be weable, which applies to our project. However, this device is currently only available for testing and performance purposes, and not available for sale, so we are not able to use it for our project.

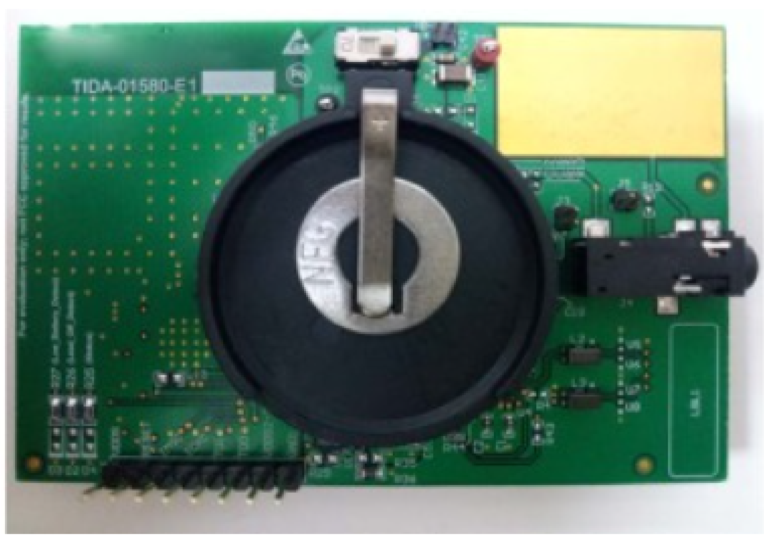


Figure 3.3-38. TIDA-01580

Listed in Table 3.3-8 is the PPG/ECG sensor comparison table that lists the differences between the four sensors that we have looked into using for our project. This helped us determine the pros and cons of each sensor which led us to choose the MAX30100 as the sensor to go with for our design.

Table 3.3-8 PPG and ECG Sensor Comparison Table

Specifications	RT1025	MAX86150	TIDA-01580	MAX30100
Interface Used	I2C	I2C	SPI	I2C
Voltage Supply	1.62 V - 3.3 V	1.7 V - 2 V	1.8 V - 3 V	1.8V - 3.3V
Price	$15	$44	N/A	$11

3.3.12 Solar Panels

Due to the high demand and low availability of solar cell fabric, the function has been replaced with an ordinary fingerless or partially fingerless glove with a detachable solar panel.

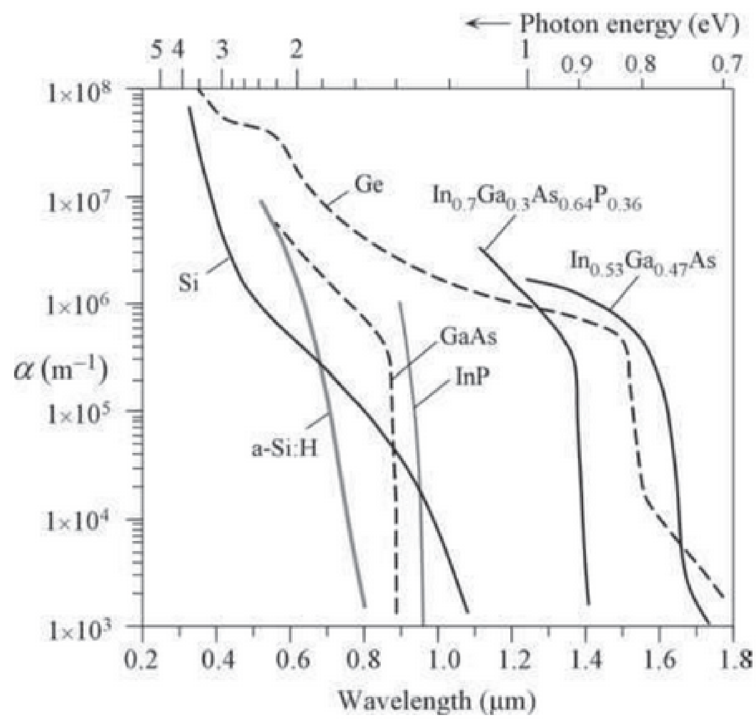


Fig. 3.3-39. Absorption coefficient (α) versus wavelength and photon energy for various semiconductors [14]

The quality of the solar panel depends heavily on the base material used to absorb photons [14]. The absorption coefficient of various semiconductors is shown in Fig. 3.3-39. Although ninety-percent of solar cells are made using silicon, its indirect bandgap limits light absorption [13] Its popularity is due to the low manufacturing cost and wide wavelength absorption. Gallium Arsenide has a direct bandgap with a strong absorption coefficient. However, GaAs solar cells are difficult for high-volume manufacturing and have a high material-cost.

Important metrics to consider when researching solar panels are the solar cell efficiency and the fill factor. The fill factor is a measure of how close the solar cell's I-V characteristics are to the ideal properties; solar cell efficiencies are generally 70-85% [14]. The solar cell efficiency measures how effective the cells are at converting light into electrical current; solar cell efficiency is defined as the maximum output power from the device per unit incident radiation power. Silicon-based solar cell efficiencies are generally 18% to 25%. Gallium Arsenide based solar cell efficiencies are the highest of any material system with a maximum efficiency of 29.3% [13].

Since the majority of the solar panels considered had the same fill factor and solar cell efficiency, other considerations include the maximum peak power. Ideally, the solar panel should be able to power the project with little to no problems. Taking into consideration the functionality of the product and the comfort of the user, the height of the panel should be as small as possible and, most importantly, the panel should not exceed the space on the back of the user's hand. Table 3.3-9 shows the primary solar panel candidates.

Table 3.3-9 Solar panel comparison table

Product	Length (mm)	Width (mm)	Height (mm)	Maximum Peak Power (mW)	Fill Factor (%)	Solar cell efficiency (%)	Price (USD)
SM850K12L	38.5	33	2	221	70	25	7.73
SM850K12TF	38.5	33	1.5	220.5	70	25	8.49
SM730K12L	33	32	1.8	189	70	25	6.60
SM730K12TF	33	32	1.5	188.6	70	25	7.23
SM710K12L	32.5	33	2	184	70	25	6.60
AM-5412CAR	33	50	1.8	87.6	60	8	8.01
P121	52	52	2.9	330	74	22	5.50

IXOLAR

The SM850K12L, SM850K12TF, SM730K12L, SM730K12TF, and SM710K12L solar panels are part of ANYSOLAR's IXOLAR series. The solar panels in this series are made up of monocrystalline silicon solar cells. Due to this, they have a wide spectral range from about 300 nm to 1100 nm and a solar cell efficiency from 15% to 25%. Although the series is made from silicon, it is suitable for Project N.I.H.M.S.

Amorton

The AM-5412CAR solar panel is part of Panasonic's Amorton series. It is created using amorphous silicon solar cells which are covered with a glass substrate. Similar to the IXOLAR series, the Amorton series works with a wide spectral range but nearly as vast. Unfortunately, amorphous cells have a solar cell efficiency of about 5% to 8% and are subject to efficiency degradation. Amorphous cells are typically found in low powered technologies such as electronic calculators due to the low solar cell efficiency. This low conversion rate makes it unsuitable for Project N.I.H.M.S.

Voltaic Systems Solar Cells

The P121, also known as the SunPower Maxeon Gen III Je3A, is a monocrystalline solar cell produced by Voltaic Systems. It is subject to the same benefits and drawbacks as the IXOLAR series; it has a wide spectral range and relatively good solar cell efficiency of about 22%. However, the P121 was deemed too large for Project N.I.H.M.S. and does not produce enough voltage at its peak maximum power.

3.4 Possible Architecture and Related Diagrams

In Senior Design 1 our initial architecture was to have a fingerless glove or partially fingerless glove made out of solar cell cloth that would be integrated with a PCB primarily to take into consideration user comfort and user friendliness as most of the components need to be in the wrist or finger area for accurate readings. The PCB hosted our parts talked about in section 3.3 including the IR thermometer, MCU, and PPG sensor. We hoped to use the solar cell cloth as a primary source to power the glove but instead used a standard monocrystalline solar panel. We also incorporated a solar cell charger with a battery that powers the device if need be. Besides being a non-invasive device that can monitor heart rate/telemetry, pulse oxygenation, skin temperature we intended to add additional features.

Some possible features we hoped to add was a random reminder that tells the user to breathe. This feature would've been important for our device to help promote mental health and wellness. Another feature would be an alert to the user local authorities if the user readings are at a critical level. With this feature it would have our device act as a life alert device if needed. Last feature would grant the user the capability of sending reports of up to a year to a recipient of their choice. The recipient can be a doctor that can view the user monitored levels and they would be able to gauge how the user has been managing their health within the last year.

3.5 Parts Selection Summary

In deciding which components would best suit our needs for this project, the components were separated into each type and multiple parts were compared and considered. These parts all varied by cost, efficiency, size, and other factors which allowed us to make a broader comparison between different types and variations of components. The main deciding factor for each component type is shown in the following groupings based on what each component is able to provide, as well as different parts that fulfill some but not all requirements, until the part was narrowed down to the one chosen in the table at the end of this section. It is important to understand that this is not an exhaustive list of every possible component, but rather a comparison between a few standout choices for each part needed before deciding amongst those parts which ones would best fit the goals and specifications of our project design.

3.5.1 Plan A Summary

Table 3.5-1 belows shows a summary of the part selection originally chosen for our project. These parts and their prices were estimated as depending on availability since they could have changed over the course of the project. These prices are also including shipping costs as well. Throughout the course of building our project, we kept an eye out for any cost efficient parts that we could add instead of the ones listed so that we could stay within our cost limit. In addition to this, the advent of new technology always poses the question of whether or not it is in our best interest to upgrade to a newer, better part. This parts selection table summarizes our ideal and current choices for parts, some parts were changed. For more information about each item please see section 3.3.

Table 3.5-1: Part Selection Summary

Item	Part Number	Manufacturer	Cost
IR Thermometer	MLX90632SLD-DCB-000-SP	Melexis	$20
Solar Cell Cloth	114990058	Seeed	$30
PCB	N/A	Advanced Assembly	$50
WiFi/Bluetooth	2487	Adafruit	$30
Microcontroller	QN9090THN	NXP Semiconductors	$15
Photodiode	FDS025	Thorlabs	$35
LED	LED750L	Thorlabs	$10
Solar Cell Charger	BQ24074	Adafruit	$10
Battery	LP785060	PKCELL	$15

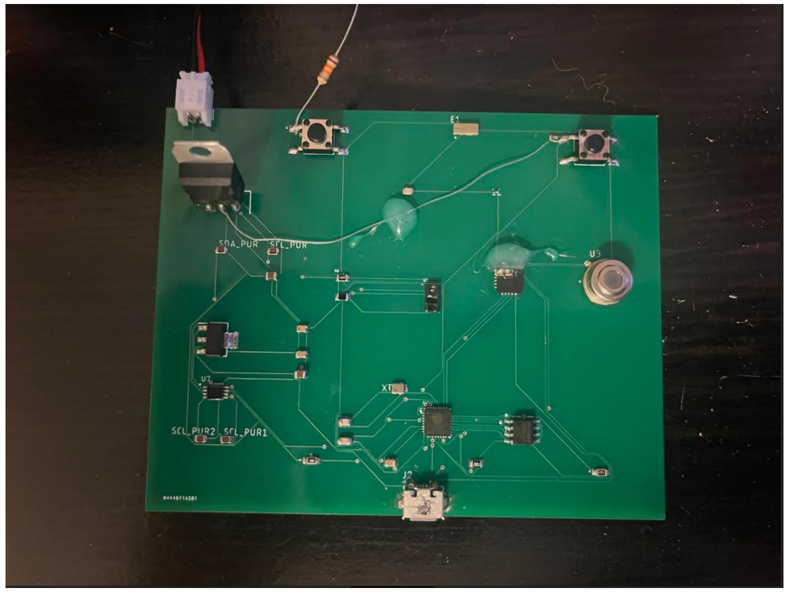


Fig 3.5.1. Plan A PCB

3.5.2 Plan B Summary

Table 3.5-2 belows shows an updated summary of the part selection chosen for our project during Senior Design Two. These parts and their prices are accurate to what we ordered during the semester. Throughout the course of building our project we made sure to keep an eye out for any cost efficient parts that we could add instead of the ones listed. Without a sponsor, this became an important aspect for our group. In addition to this, some of the parts changed due to limited resources on said parts. Some vendors were also changed due to finding different vendors that would ship that parts faster or the pricing of the part was found at a lower cost. With the approval of Dr. Wei, we were able to build a PCB that simulated what we had working on our breadboard throughout the entirety of the time in Senior Design 2 with parts that were “snap-on”. For more information about each item please see section 3.3.

Table 3.5-2: Part Selection Summary

Item	Part Number	Manufacturer	Cost
IR Thermometer	MLX90614	Melexis	$12
Solar Panel	SM850k12TF	Anysolar	$13.19
PCB	N/A	PCBWay	$11
Wifi Antenna	277-YC0011AA	Quectel	$0.75
Microcontroller	ESP8266	ExpressIF	$16.50

PPG sensor	MAX30100	Maxim Integrated	$11.89
Solar Cell Charger	BQ24074	Adafruit	$10
Battery	LP785060	PKCELL	$15

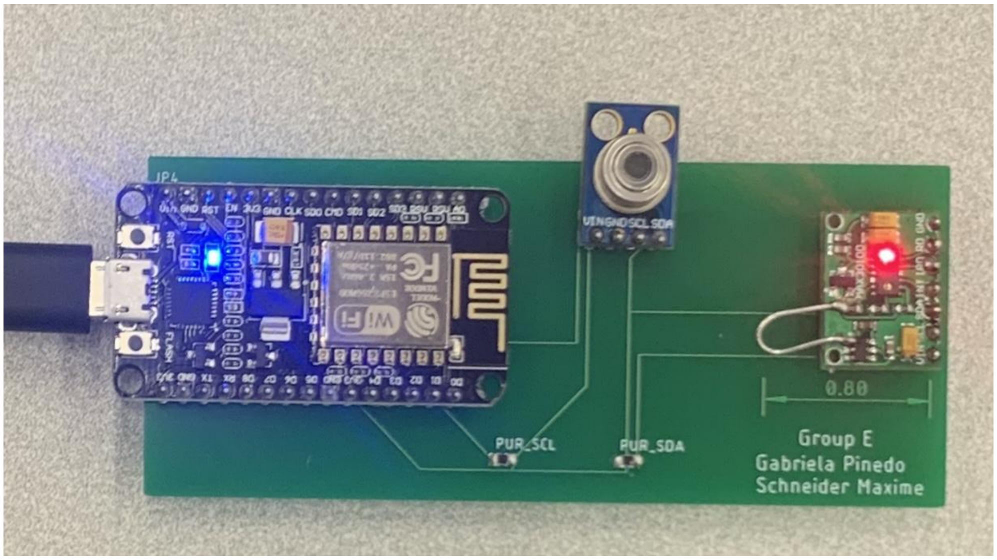


Fig. 3.5.2. Picture of Plan B PCB

3.5.3 Plan C Summary

Many of the parts had inherent design flaws leading to the purchasing of different elements. Table 3.5-3 gives a part selection summary of the final attempt reviving Project N.I.H.M.S.

Table 3.5-3: Part Selection Summary

Item	Part Number	Manufacturer	Cost
IR Thermometer	MLX90614	Melexis	$12
Solar Panel	SM850k12TF	Anysolar	$13.19
Double Sided PCB Kit	CA-EL-CP-021	Elegoo	$12.84
NodeMCU	ESP8266EX	NXP Semiconductors	$16.50
PPG sensor	MAX30102	Maxim Integrated	$7.20
Solar Cell Charger	MCP73871	Adafruit	$44

Battery	LP785060	PKCELL	$15

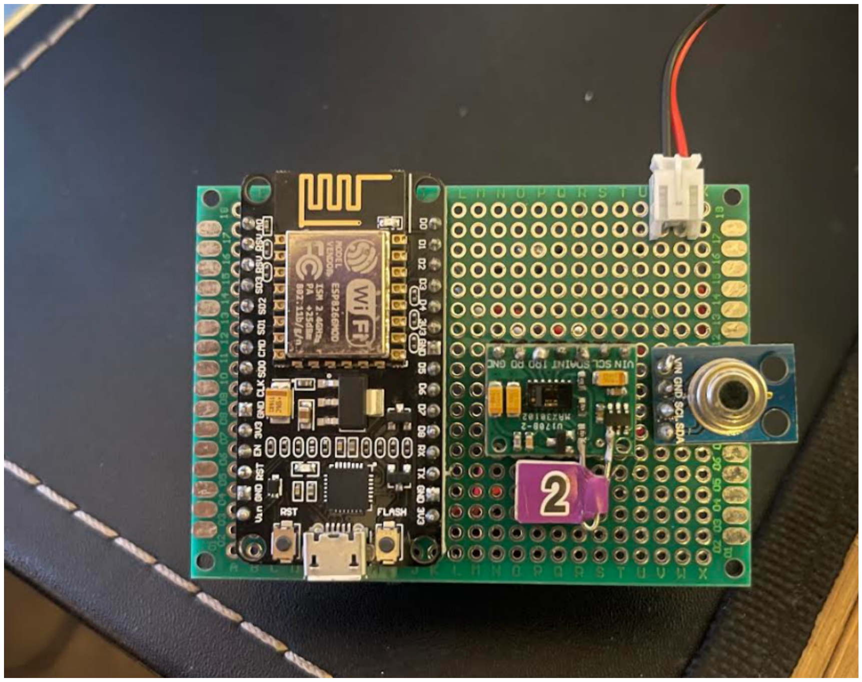


Fig 3.5.3. Plan C PCB

3.6 Related Medical Research

In order to understand the scope and magnitude of our project, it is imperative to understand the various measurements our device takes, as well as the significance of those findings. Project N.I.H.M.S. measures 3 major indicators of health (Heart rate/Telemetry, Pulse Oxygenation, Skin Temperature). Each of these correspond to various functions of the body and are the result of many biological processes occurring concurrently. Originally, Project N.I.H.M.S. was designed to measure more vitals, such as blood pressure and ECG readings but were cut to ensure an accurate design. The following research encompasses data regarding some of these features, but was left in this document for future iterations to include these features.

3.6.1 Heart Rate Explanations

<u>Heart:</u>

The heart is the center of the cardiovascular (CV) system, allowing for the pumping of blood filled with oxygen throughout the body. For this to happen, however, the heart muscle (known as the myocardium) itself requires a steady supply of oxygen. The myocardium is about the size of a fist and is located in the mediastinum between the lungs, pumping roughly 60mL of blood with every beat. This can equate to about 5L/min, which can further double under duress, as the body may have increased oxygenation needs during these moments of strenuous physical activity. The physiology of the heart is broken up into 4 parts, an upper chamber and lower chamber pair for the left and right side, which are separated by the septum. The upper chambers are referred to as the atriums, while the lower chambers are the ventricles of the myocardium. It is important to understand the processes by which the myocardium receives blood and pumps it throughout the body, starting with the right atrium. The right atrium receives the deoxygenated venous blood (the process for which is referred to as venous return), flowing through the superior and inferior venae cavae. The myocardium also provides blood to the right atrium through the coronary sinus. The majority of this venous return flows passively from the right atrium through the tricuspid valve and to the right ventricle during the act of filling with blood, known as ventricular diastole. The rest of the venous return is pushed from the right atrium into the right ventricle during atrial systole, the contraction phase of pumping. This section of the heart, the right ventricle, is located behind the sternum and is responsible for the development of the pressure needed to close the tricuspid valve, open the pulmonic valve, and push the blood into the pulmonary artery and to the lungs.

After the lungs have reoxygenated the blood, it moves from the four pulmonary veins into the left atrium. During ventricular diastole, the mitral valve is opened to allow most of the blood to flow into the left ventricle, the remainder being pushed into the left ventricle when the left atrium contracts. With systolic contraction, the left ventricle has enough pressure to close the mitral valve and open the aortic valve. Once in the aorta, the blood is circulated through the arteries and throughout the body in order to deliver oxygen to all the cells before returning through the superior and inferior venae cavae to repeat the process. The flow by which this all occurs is shown in the diagram below.

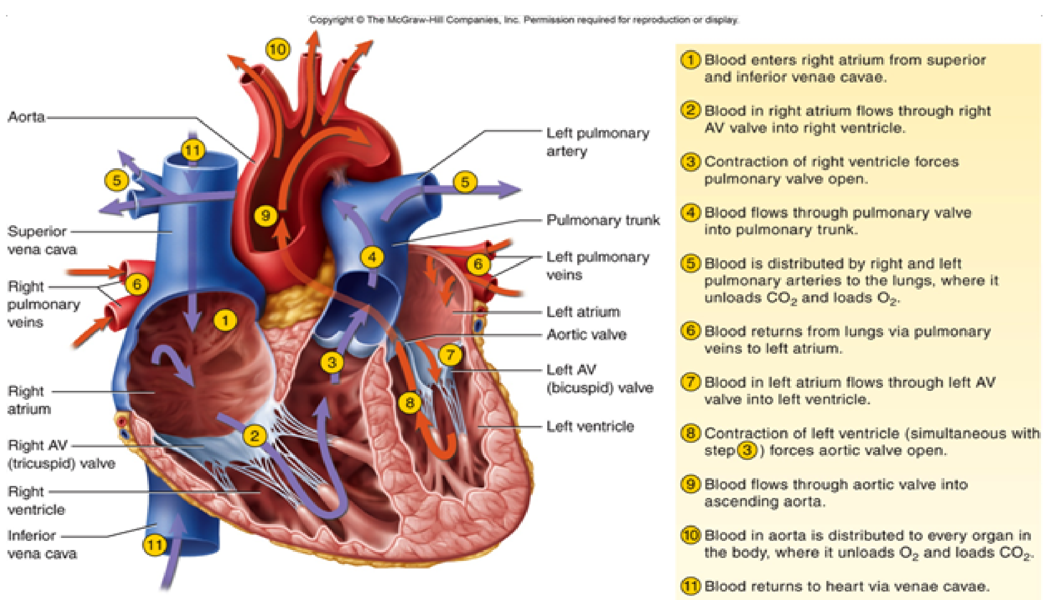


Figure 3.6-1: Blood flow

To keep this constant flow of blood pumping throughout the body, mean arterial pressure (MAP) must be at least 60 mm Hg, with pressure between 60 and 70 mm Hg required to maintain perfusion of major body organs, such as the kidney and brain. Mean arterial pressure will be further elaborated on within the blood pressure section of this document.

Heart Rate:

The cardiac conduction system is responsible for generating and transmitting electrical impulses which stimulate the contractions of the heart. The conduction system instigates contraction of the atria first and then the ventricles, thereby enabling the complete filling of the ventricles before ventricular ejection occurs. Cardiac output is maximized through this inherent methodology. In order to have this level of synchronization, two types of specialized electrical cells (nodal cells and the Purkinje cells) have three physiological characteristics.

- Automaticity: The ability to initiate an electrical impulse.
- Excitability: The ability to respond to an electrical impulse.
- Conductivity: The ability to transmit an electrical impulse from one cell to another.

Nodal cells are what the atrioventricular (AV) and sinoatrial (SA) nodes are composed of, and both of them reside in the right atrium. Heart rate is described as the number of times the ventricles contract each minute, with the SA node being the primary pacemaker for this process. The generalized standard for a normal resting heart rate for an adult is between 60 and 100 beats per minute, with an increasing heart rate resulting in an increase in myocardial oxygen demand. Once the electrical impulse passes from the SA node to AV node, a slight delay is made to allow the ventricles to fill before relaying the impulse to the ventricles. If something were to occur to cause the SA node to malfunction, the role of pacemaker functionality would move over to the AV node, with a standard rate of 40 to 60 impulses per minute. Should both the SA and AV nodes fail, the final failsafe of the cardiac conduction system is a pacemaker site in the ventricle which will pulse at its inherent bradycardic rate of 30 to 40 impulses per minute. A diagram representing the cardiac conduction system is shown below.

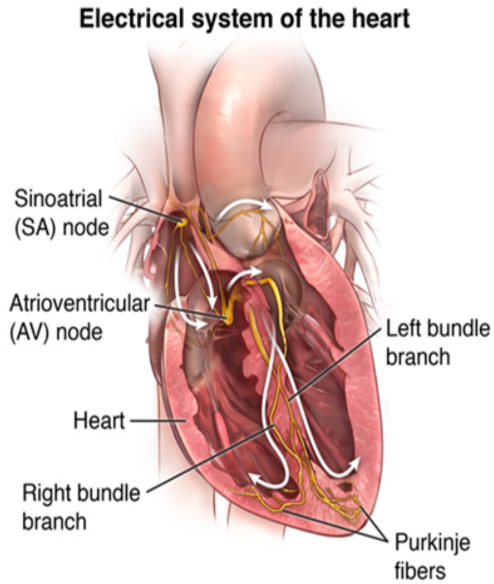


Figure 3.6-2 Electrical System of the Heart

When discussing the cardiac conduction system, it is important to note the concept of cardiac action potential. Cardiac myocytes (the working cells) are stimulated through the impulses generated by the nodal and Purkinje cells. These simulations are due to the exchanging of ions, most notably sodium, potassium, and calcium, as they enter and exit the cell. During rest, the primary extracellular ion is sodium, and the primary intracellular ion is potassium. Due to these different charges, the inside of the cell has a negative charge while the outside of the cell has a positive charge. When the cell is stimulated, however, sodium or calcium will cross into the cell and force potassium ions to leave the cell, thereby reversing the polarity to represent a positive charge within the cell and a negative charge outside of the cell. This period of reversed polarity is noted as the depolarization phase, and when it is completed the ions revert to their original charge, referred to as the repolarization period. This cycle of constant depolarization and repolarization is called the cardiac action potential and is represented with the figure below.

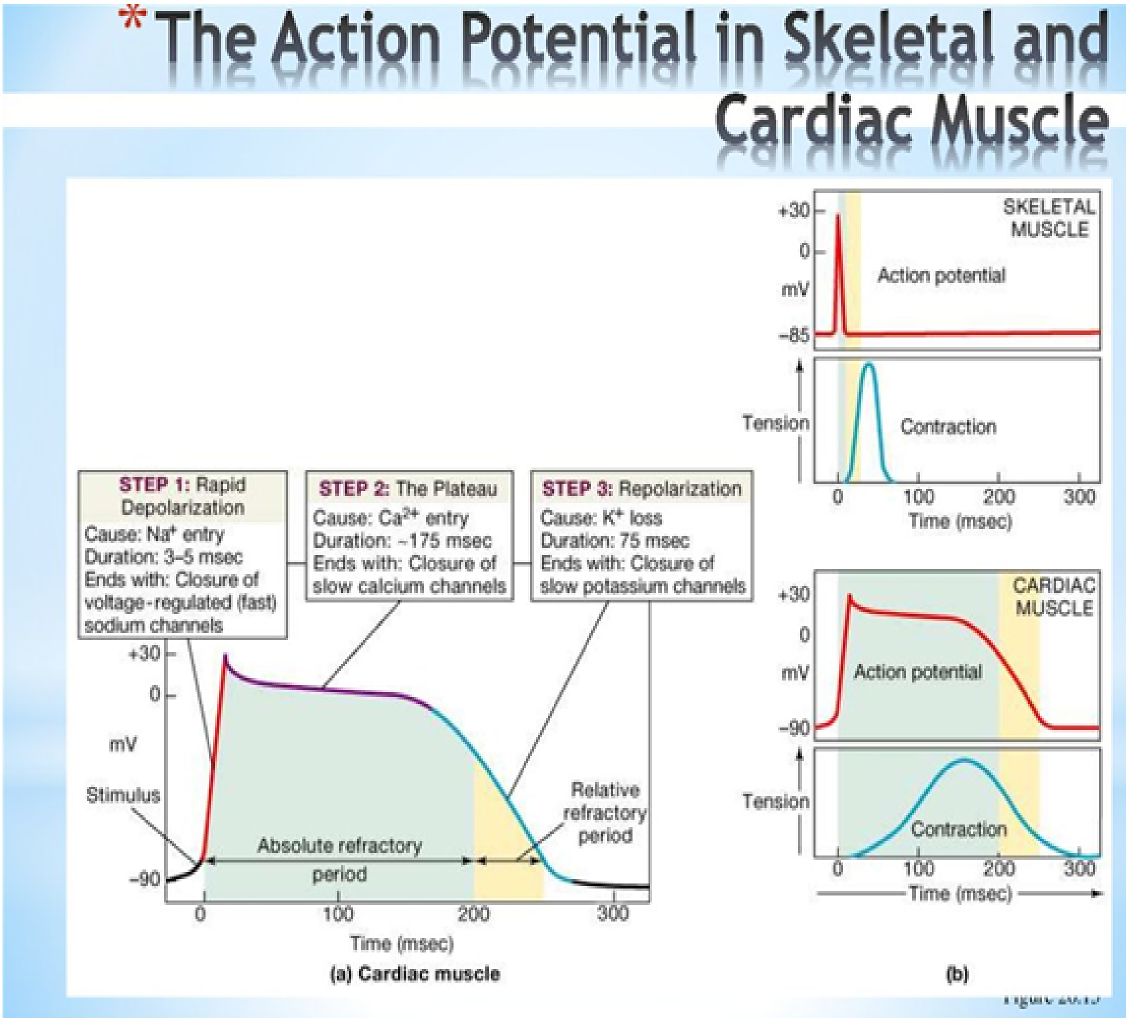


Figure 3.6-3 Action Potential in Skeletal and Cardiac Muscle

As is shown in the figure, the myocardial cells have two different refractory periods during the repolarization period, the absolute refractory period and the relative refractory period. During the absolute refractory period, the cell is unable to respond to any electrical stimuli, meaning that it is incapable of initiating any early depolarizations. The relative refractory period, however, may depolarize prematurely, which can cause premature contractions. If this were to occur, there would be an increased risk of potentially life-threatening dysrhythmias, such as:

Atrial Fibrillation: An uncoordinated atrial electrical activation that causes a rapid, disorganized, and uncoordinated twitching of atrial muscles. Atrial fibrillation can start and stop suddenly for a short amount of time (paroxysmal dysrhythmia) or it may be persistent, necessitating treatment to terminate the rhythm or to control the ventricular rate. Typically, atrial fibrillation occurs in those of advanced age with structural heart disease, or in people with diabetes, obesity, hyperthyroidism, pulmonary hypertension, and acute moderate to heavy alcohol intake. Atrial fibrillation has been linked to an increased risk of stroke and premature death. In some instances, atrial fibrillation occurs with no underlying pathophysiology (called lone atrial fibrillation). The following characteristics are indicative of atrial fibrillation.

- Ventricular and atrial rate: Atrial rate is typically 300 to 600; ventricular rate is typically 120 to 200 if left untreated.
- Ventricular and atrial rhythm: Highly irregular.
- Quasi Random Signal (QRS) shape and duration: Usually normal but may be abnormal.
- P wave: No discernible P waves; irregular undulating waves that vary in amplitude and shape are seen and are referred to as fibrillatory or f waves.
- PR interval: Is not measurable.
- P:QRS ratio: Many:1

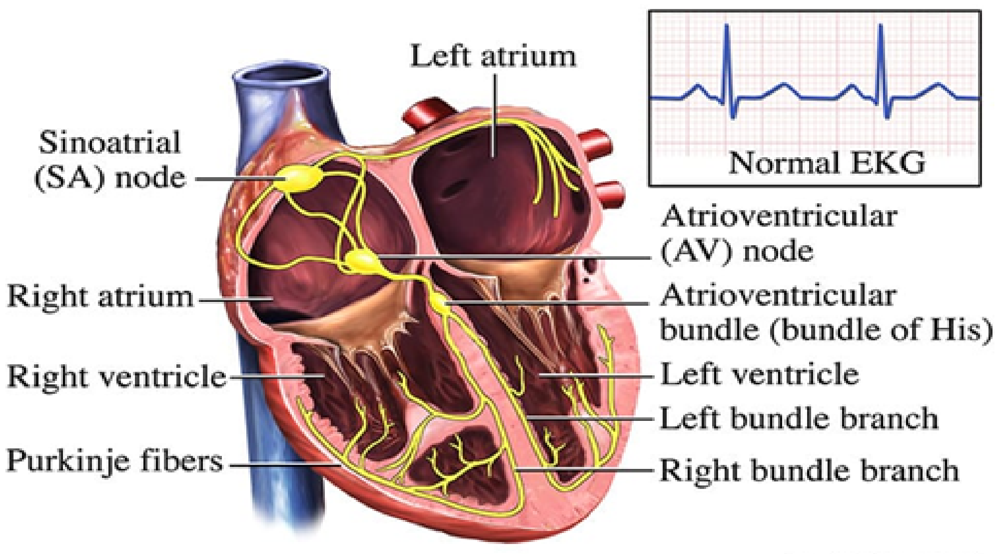


Figure 3.6-4 Normal EKG Demonstration

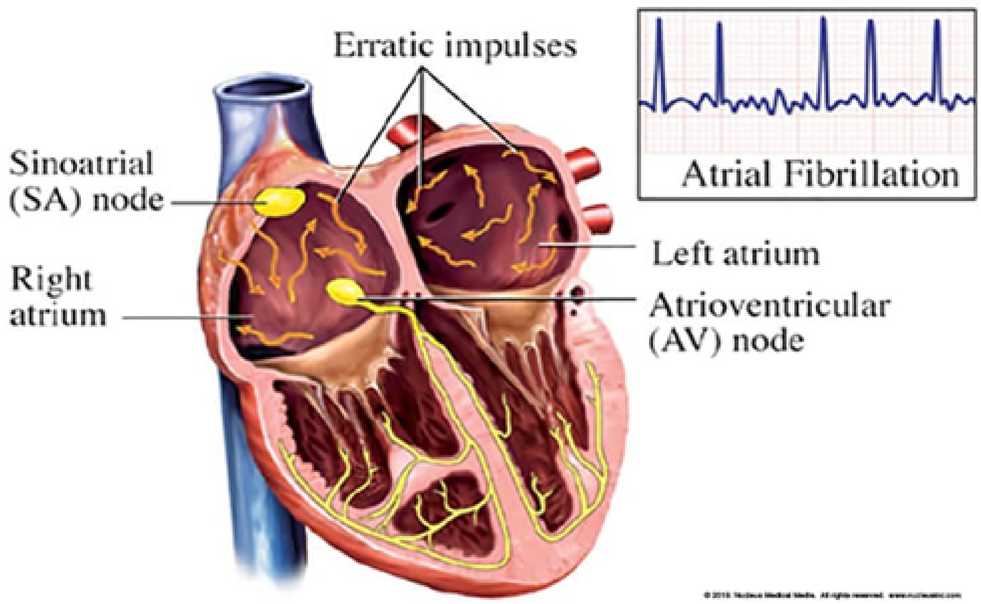


Figure 3.6-5 Atrial Fibrillation Demonstration

Those with atrial fibrillation may be asymptomatic or have significant hemodynamic collapse, with symptoms such as hypotension, chest pain, pulmonary edema, and altered level of consciousness. This is especially if they also have hypertension, mitral stenosis, hypertrophic cardiomyopathy, or some form of restrictive heart failure.

<u>Ventricular Tachycardia</u>: Ventricular Tachycardia is defined as three or more PVCs (premature ventricular complex) in a row, occurring at a rate exceeding 100 bpm. Those with larger Mis (myocardial infarction) and lower ejection fractions are at higher risk of lethal ventricular tachycardia. Typically, those with ventricular tachycardia are unresponsive and pulseless, and so are an emergency case. Ventricular tachycardia usually has the following characteristics.

- Ventricular and atrial rate: Ventricular rate is 100 to 200 bpm; atrial rate depends on the underlying rhythm (i.e., sinus rhythm).
- Ventricular and atrial rhythm: Usually regular, with atrial rhythm possibly being regular as well.
- QRS shape and duration: Duration is 0.12 seconds or more; bizarre, abnormal shape.
- P wave: Very difficult to detect, so atrial rate and rhythm may be indeterminable.
- PR interval: Very irregular, if P waves are seen.
- P:QRS ratio: Difficult to determine, but if P waves are apparent, there are usually more QRS complexes than P waves.

If presenting without a pulse and unconscious, defibrillation is the action of choice. For long-term management, those with an ejection fraction less than 35% should be considered for an implantable cardioverter defibrillator.

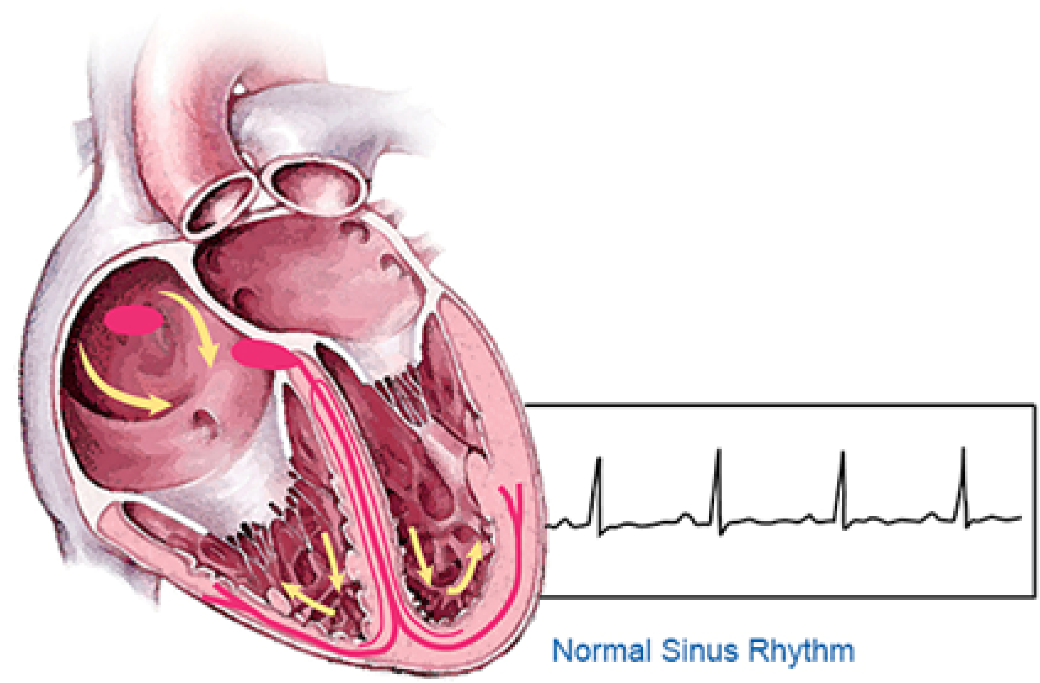


Figure 3.6-6 Normal Sinus Rhythm

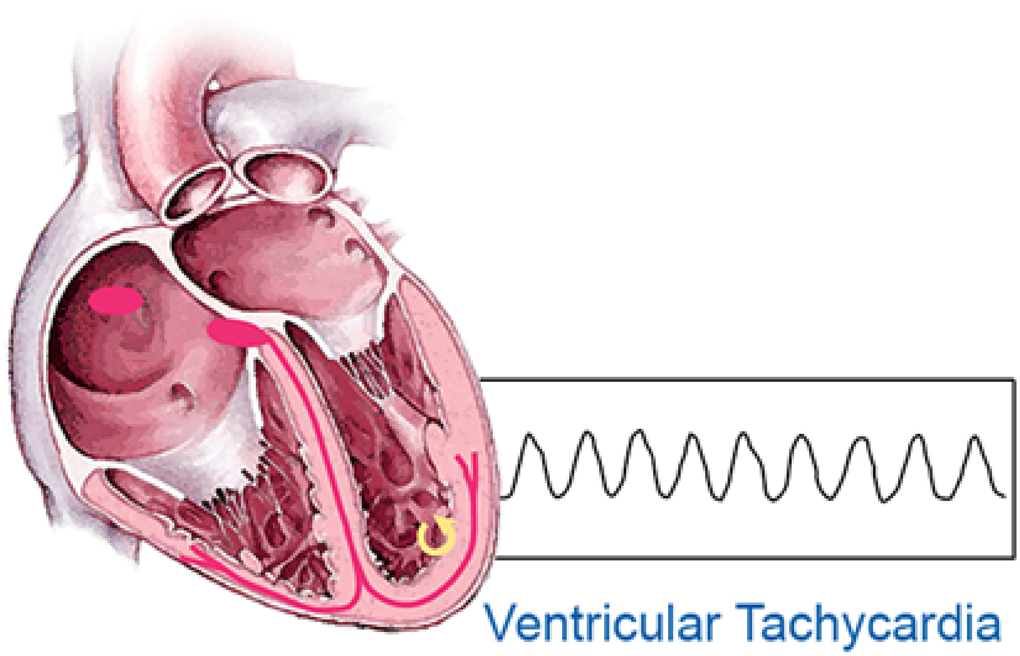


Figure 3.6-7 Ventricular Tachycardia

Ventricular Fibrillation: A rapid, disorganized ventricular rhythm, ventricular fibrillation is the most common dysrhythmia in patients with cardiac arrest. This rhythm causes ineffective quivering of the ventricles. No atrial activity is seen on the ECG. Ventricular fibrillation is most commonly caused by coronary artery disease and resulting acute myocardial infarction. Other causes include but are not limited to untreated or unsuccessfully treated ventricular tachycardia, cardiomyopathy, valvular heart disease, and electrical shock. Ventricular fibrillation typically has the following characteristics.

- Ventricular rate: Greater than 300 per minute.
- Ventricular rhythm: Extremely irregular, without a specific pattern.
- QRS shape and duration: Irregular, undulating waves without recognizable QRS complexes.

Ventricular fibrillation is always characterized by the absence of an audible heartbeat, a palpable pulse, and respirations. If the dysrhythmia is not corrected, cardiac arrest and death are imminent. Early defibrillation is critical to survival, with administration of immediate bystander cardiopulmonary resuscitation (CPR) until defibrillation is available. The chance of survival decreases by 7-10% per minute in delay of defibrillation.

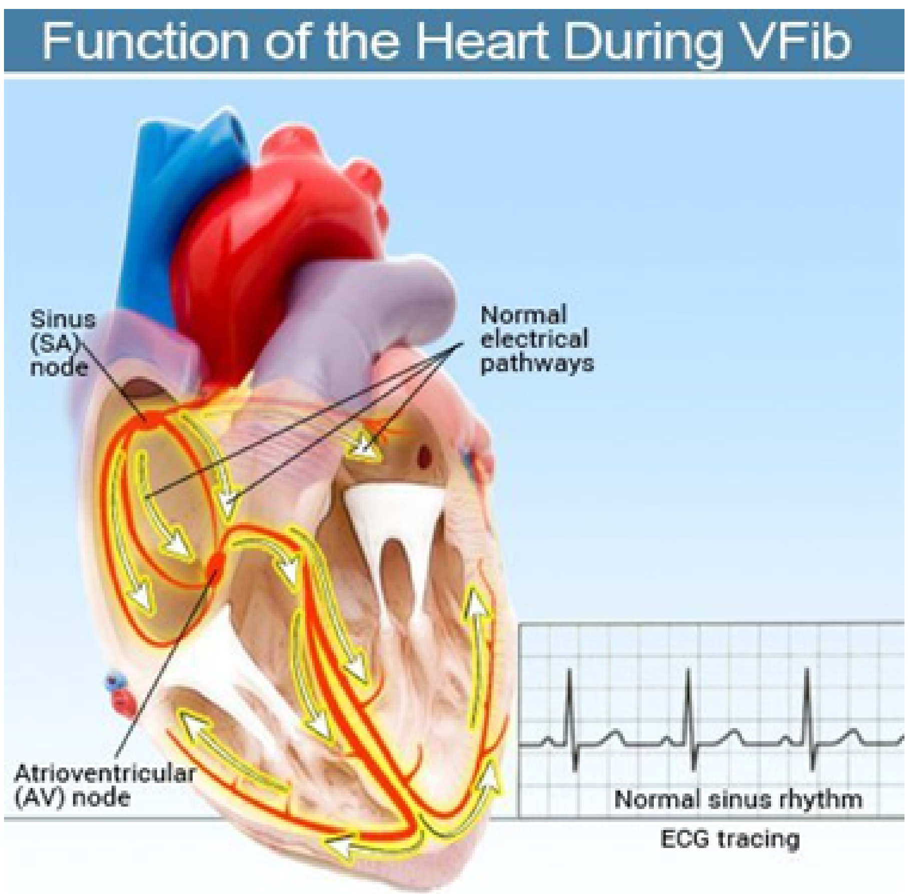


Figure 3.6-8 Function of the Heart during VFib

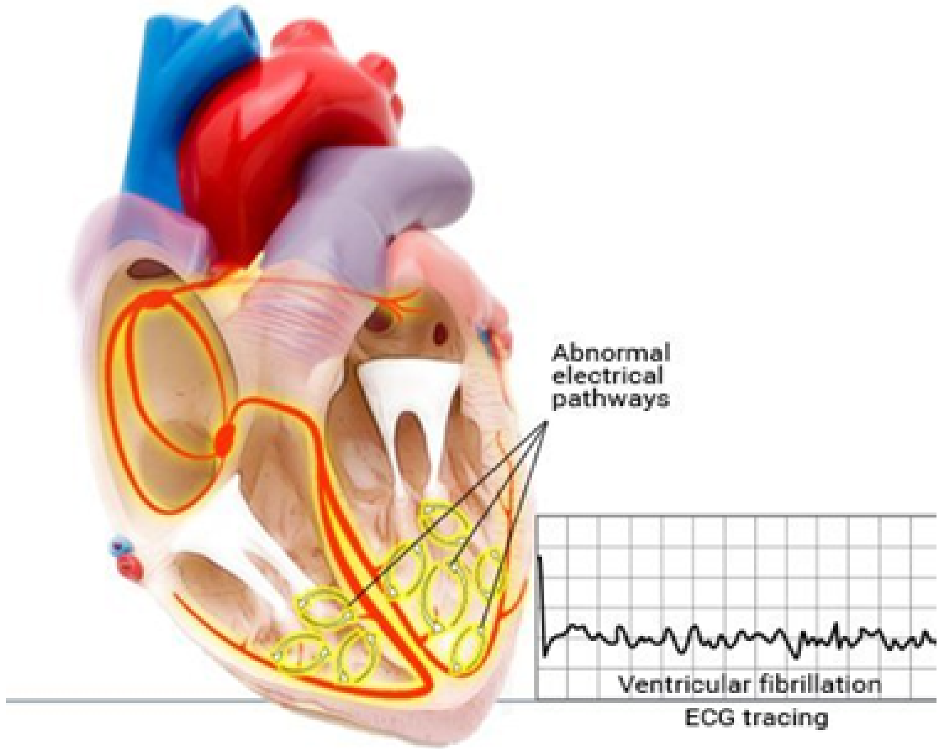


Figure 3.6-9 Function of the Heart during VFib

Electrocardiography:

The electrocardiogram (ECG) is a graphical representation of the electrical currents of the heart. Continuous ECG monitoring is typically used for those who are at high risk for dysrhythmias, such as the ones discussed in the previous section. This process typically uses two to twelve leads placed on various locations of the body in order to measure the electrical current flowing between them. The two standards for continuous ECG monitoring are hardwire cardiac monitoring and telemetry, and they both share similar characteristics.

- Simultaneous monitoring of multiple leads.
- Monitoring ST segments (ST-segment depression is a marker of myocardial ischemia; ST-segment elevation is indicative of an evolving MI).
- Provides visual and audible alarms.
- Trend data over time.
- The ability to print a strip of rhythms measured.

Typically speaking, hardwire cardiac monitoring is reserved for a hospital or emergency room setting, whereas telemetry is used in outpatient cardiac rehabilitation programs, and is also used in many personal wearable devices. Telemetry refers to the transmission of radio waves from a battery-operated transmitter to a central hub of monitors. The components of a normal ECG are shown in the next diagram, and each will be explained separately.

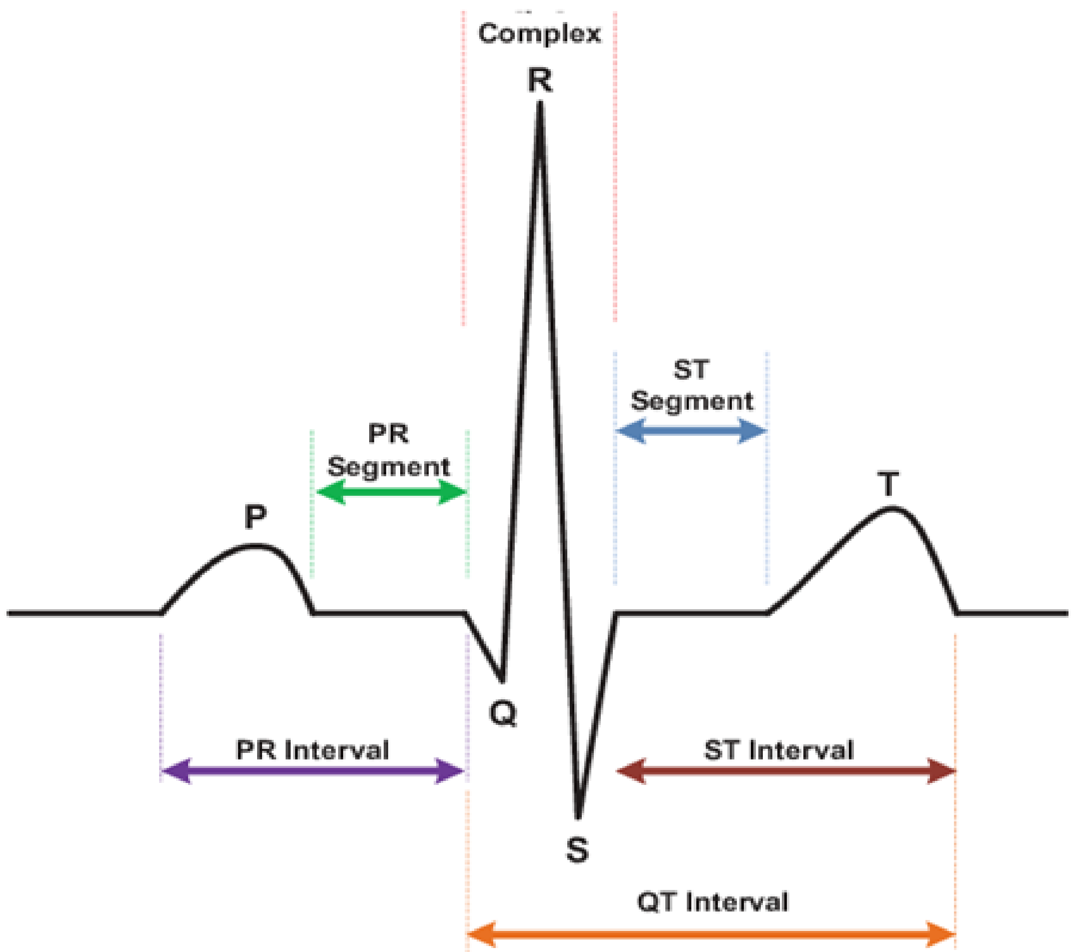


Figure 3.6-10 Normal ECG Components

- <u>P Wave</u>: The P wave is a deflection that represents atrial depolarization. The shape of the P wave may be a positive, negative, or biphasic (both positive and negative) deflection, depending on the choice of lead used. When the impulse measured is consistently generated from the sinoatrial (SA) node, the P waves have a standard shape with respect to the lead chosen. If an impulse were to be generated from a different location, such as the atrioventricular (AV) node, the shape of the P wave would change, indicating that an ectopic focus has fired.
- <u>PR Segment</u>: The PR segment is the isoelectric line from the end of the P wave to the beginning of the QRS complex, occurring when the impulse travels through the AV node. It is then delayed before continuing through the ventricular conduction system to the Purkinje fibers.

- PR Interval: The PR interval is taken from the beginning of the P wave to the end of the PR segment. In addition to the atrial depolarization time, the PR interval also takes into account the impulse delay in the AV node and the travel time to the Purkinje fibers. This typically measures from 0.12 to 0.20 seconds.
- QRS Complex: The QRS complex represents the ventricular depolarization phase. The lead chosen determines the shape of the QRS complex. The Q wave is not always present, but if it is included it represents the initial ventricular septal depolarization. When the Q wave is abnormally present in a lead, it represents myocardial necrosis, otherwise known as cell death. The R wave may be small, large, or absent, depending on the lead chosen. The S wave is a negative deflection following the R wave and is not always present in every lead.
- QRS Duration: The QRS duration represents the time required for the depolarization of both ventricles. It is taken from the beginning of the QRS complex to the beginning of the ST segment, and typically measures from 0.04 to 0.10 seconds.
- ST Segment: The ST segment is normally an isoelectric line and represents early ventricular repolarization. Various factors can affect the length of the ST segment, such as electrolyte disturbances or the administration of medications. ST elevation or depression can be caused by myocardial injury, ischemia, or infarction, conduction abnormalities, or the administration of medications.
- T Wave: The T wave represents the ventricular repolarization, usually being positive, rounded, and slightly asymmetric. If an ectopic stimulus excites the ventricles during this time, it may cause ventricular irritability, lethal dysrhythmias, and possible cardiac arrest. T waves may become tall and peaked, inverted, or flat due to myocardial ischemia, potassium or calcium imbalances, medications, or autonomic nervous system effects.
- ST Interval: The ST interval represents both the ST segment and the T wave, accounting for the total ventricular repolarization, including any early repolarization effects.
- QT Interval: The QT interval represents the total time needed for ventricular depolarization and repolarization. This interval varies with age, gender, and will change with the heart rate, lengthening with slower heart rates and shortening with faster rates. Electrolyte disturbances, certain medications, Prinzmetal's angina, or subarachnoid hemorrhages can all prolong this interval. A prolonged QT interval could lead to a unique type of ventricular tachycardia called torsades de pointes.

Looking at the ECG results, the heart rate can be estimated by counting the number of QRS complexes within 6 seconds and multiplying that number by 10 in order to calculate for a full minute. This is referred to as the 6-second strip method and is a quick way to determine the mean or average heart rate. Although this method is the least accurate, it is the method of choice for irregular rhythms. For a more accurate reading, the big block method is used as long as the QRS complexes are regular or evenly spaced.

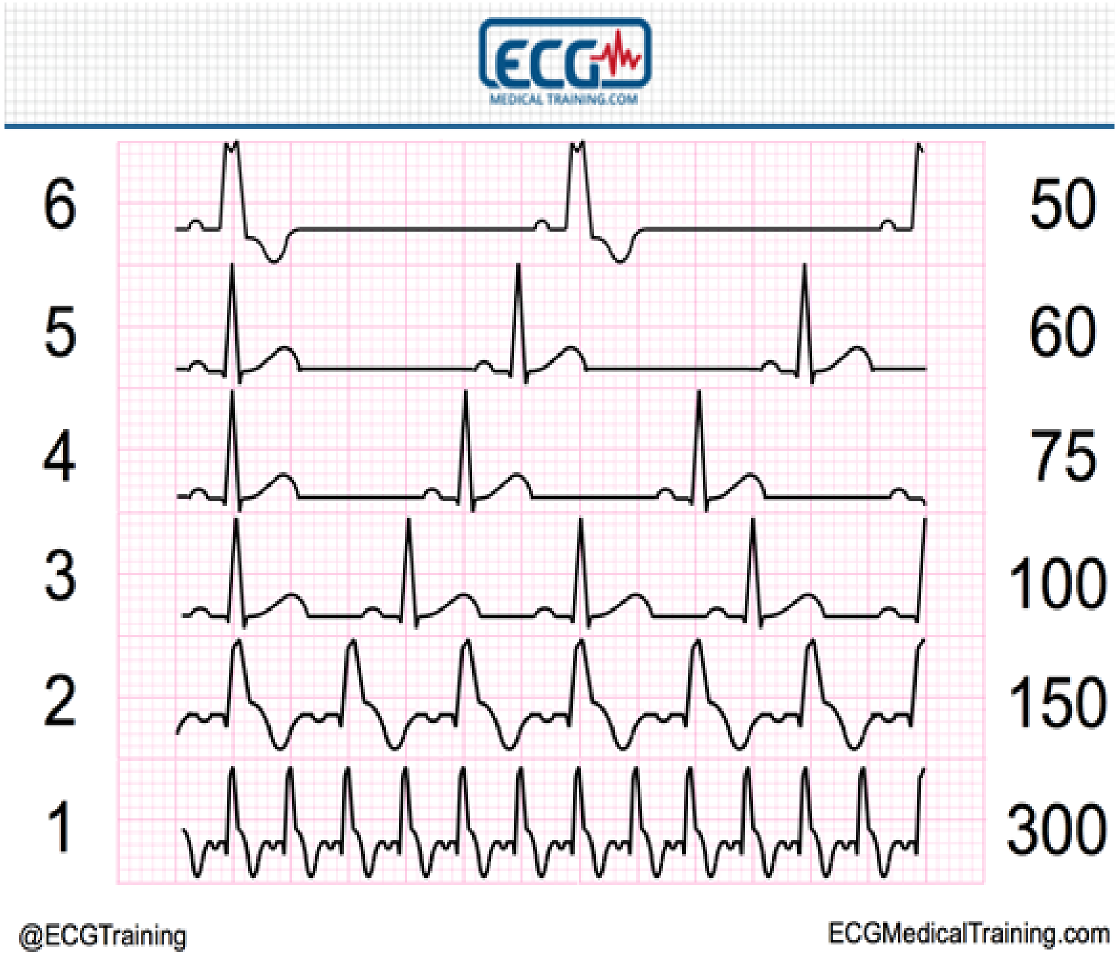


Figure 3.6-11 ECG chart

Pictured above is a graphical representation of the big block method. The way to utilize it is to count the number of large blocks between the same point in any two successive QRS complexes (usually this means going from R wave to R wave) and dividing that number into 300. There are 300 big blocks within a minute. For example, the top ECG output has 6 large blocks between each R peak, so 300/6 = 50.

3.6.2 Blood Oxygen Explanations

<u>Blood Oxygen</u>:

Blood oxygen refers to the amount of oxygen your red blood cells are carrying as they flow through your body. This level of oxygenation is typically regulated closely by your body, ensuring that an appropriate level is maintained throughout your day. Most of the time, blood oxygen levels are not monitored often unless there is an underlying reason to, such as someone with shortness of breath or chest pain. Typically speaking, there are two main methods of measuring blood oxygen levels, Arterial blood gas or a pulse oximeter.

<u>Arterial Blood Gas</u>:

Arterial blood gas refers to a blood test that is used to measure the level of oxygen in your blood, as well as the level of other gases within. In addition to this, it can also measure the pH level of your blood, all of which are relevant to understanding your baseline vitals and maintaining an understanding of how healthy you are. Although arterial blood gas is very accurate, its main drawback is that it is an invasive procedure. Blood is drawn from an artery rather than a vein, hence the name for the test, because the blood drawn from an artery will be oxygenated. Blood that is flowing through the veins is deoxygenated, and so does not provide an accurate result.

Typically speaking, the gases that are measured are oxygen and carbon dioxide. These help to evaluate lung function and help to detect any acid-base imbalances. The human body is careful when it comes to self regulation of pH levels, usually maintaining a pH level between 7.35-7.45. If blood becomes too acidic (acidosis) or too alkaline/basic (alkalosis), this could be an indication of respiratory, metabolic, or kidney disorders. The means by which the body regulates acids and bases has two main components: the elimination of carbon dioxide through exhalation of the lungs, and the process of metabolism. Carbon dioxide is an acid when dissolved in blood, and so the elimination of it through breathing helps to maintain a better alkaline level. For metabolism, the cellular process of changing one substance to another in order to produce energy creates acid that the kidneys are then responsible for eliminating.

When undergoing blood gas analysis, the following components are generally included:

- pH: a measure of the balance of acids and bases within the blood, which is affected by factors such as bicarbonate (HCO_{3-}) being prevalent in the blood, which can cause an increase in the alkaline levels of the blood.
- Partial Pressure of O_2(PaO_2): Measures the amount of oxygen gas in the blood. This value should be between 80-100 millimeters of mercury (mm Hg) in a healthy individual.
- Partial Pressure of CO_2($PaCO_2$): Measures the amount of carbon dioxide gas in the blood.
- O_2saturation (O_2Sat or S_aO_2): The percentage of hemoglobin that is carrying oxygen. Hemoglobin is the protein in red blood cells that carries oxygen through blood vessels to tissues throughout the body.
- O_2content (O_2CT or C_aO_2): The amount of oxygen per 100 mL of blood.
- Bicarbonate (HCO_{3-}): The main form of CO_2in the body. It is a means of measuring the metabolic component of the acid-base balance within the blood.
- Base excess/Base Deficit- a calculated number that represents the total of the metabolic buffering agents (anions) in the blood. These anions include hemoglobin, proteins, phosphates, and bicarbonates.

The blood sample is usually taken from the radial artery in the wrist, situated below the thumb on the inside of the wrist, where the pulse can be felt. In order to test the viability of this placement, a circulation test called an Allen test is performed. This test involves compressing both the radial and the ulnar wrist arteries, then releasing each to watch for the pinking of the skin as the blood returns to the hand. If this is not seen in one hand, the test is performed again on the other wrist. If either wrist seems to be unsuitable, the brachial artery in the elbow or the femoral artery in the groin can be used, though these locations require special training in order to properly access them. After blood is drawn from the artery, pressure must be placed on the sample site for approximately 5 minutes to ensure that the blood pumping out of the puncture site has completely stopped. As can be expected, this is an incredibly invasive and stressing procedure, not conducive for our project as its entire nature is to be as easy on the user as possible. For this reason, the second method of blood oxygen detection, pulse oximetry, is used for our project.

Pulse Oximetry:

A pulse oximeter is a noninvasive device that estimates the amount of oxygen in your blood. To achieve this task, infrared lights are sent into capillaries in your finger, toe, or earlobe. The reflection is then measured to see how much light was reflected from the gases in the blood. Blood oxygen saturation is measured through this method, known as the SPO_2 level. The drawback is that this method is not as accurate as the arterial blood gas method, as this has a 2 percent error window. However, this testing method is infinitely easier to perform than the arterial blood gas test. Outside factors can affect the efficacy of pulse oximeters though, such as dark nail polish or the extremities being cold. In February 2021, the Food and Drug Administration (FDA) issued an alert stating that poor circulation, dark skin pigmentation, thick skin, users who currently use tobacco, or unclean fingers can affect the efficiency and accuracy of the pulse oximeter. One way to improve the accuracy of the results is to have a warm, relaxed hand being held below the level of the heart.

Figure 3.6-12 Pulse Oximeter

The SPO_2 measurements taken are then compared to the standardized norm to see how healthy the individual would appear to be. Typical oxygen saturation levels for a healthy adult are 95 percent or higher, those with a level around 92 percent have potential hypoxemia, or deficiency in oxygen reaching tissues in the body. The following diagram shows the typical ranges when measuring oxygen saturation levels.

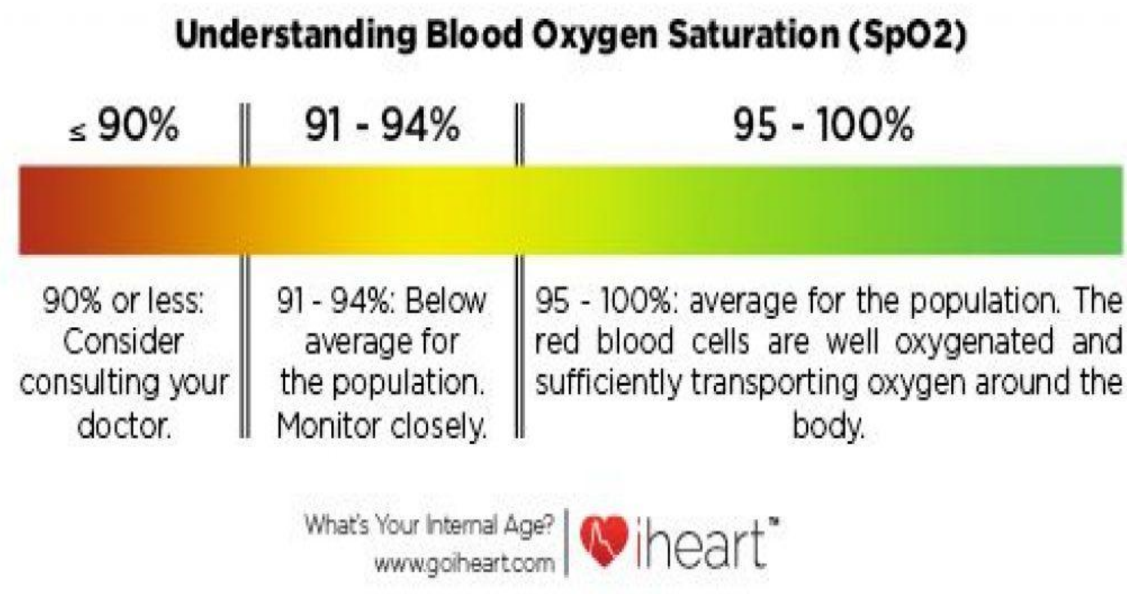


Figure 3.6-13 Blood Oxygen Saturation Chart

It is worth noting that if the user has chronic obstructive pulmonary disease (COPD) or other lung diseases, these ranges may not apply. Those with severe COPD can show pulse oxygen levels between 88 to 92 percent and be considered in the normal range. When blood oxygen is too low, regardless of which method is used, symptoms may begin to pop up such as:

- Shortness of breath
- Chest pain
- Confusion
- Headache
- Rapid heartbeat

A further lack of appropriate oxygenation can lead to cyanosis, or a bluish cast to the skin and mucous membranes. Peripheral cyanosis is when this discoloration is displayed in the hands and feet. The reason for this blue tint is because red blood cells that are rich in oxygen are bright red in color, whereas when the red blood cells have a lower level of oxygen contained within, they become a darker red which reflects more blue light, thus making the skin appear to be blue in coloration.

Figure 3.6-14 Irregular Coloration of Skin

One reason for this tint of skin color could be cold extremities, and so the skin must be warmed. If after warming the skin, the coloration persists, then this coloration is indicative of a life-threatening emergency, and should the following symptoms accompany the discoloration, EMT services should immediately be called.

- Gasping for breath
- Fever
- Headache
- Shortness of breath or difficulty breathing
- Chest pain
- Sweating profusely
- Pain or numbness in the arms, legs, hands, fingers, or toes
- Pallor or blanching of the arms, legs, hands, fingers, or toes
- Dizziness or fainting

When blood oxygen levels are low, especially if they maintain a low level for long periods of time, it can be indicative of many healthcare issues, such as:

- COPD, including chronic bronchitis and emphysema
- Acute respiratory distress syndrome
- Asthma
- A collapsed lung
- Anemia
- Congenital heart defects

- Heart disease
- Pulmonary embolism

These disorders typically involve a decrease in the exchange of oxygen and carbon dioxide, or affect the efficacy of the red blood cells in carrying and transporting oxygen throughout the body to all the tissues.

3.6.3 Pulse Explanations

As was discussed in the heart section of this documentation, the pulse rate is synonymous with the heart rate, or the number of times the heart beats in one minute. Pulse rates are never static, as they vary from person to person. For this reason, there is a standardized range of resting pulse values for adults that is fairly wide, ranging from 60-100 beats per minute while resting. Resting heart rate refers to the pulse rate at which the heart is pumping the lowest amount of blood necessary to function properly, typically due to a lack of motion of the body. Most of the time, you will be at your resting heart rate if you are sitting or lying down and you are calm, without any excitation. The level of exercise for an individual can also affect the pulse rate of an individual, with some athletes reaching a resting pulse rate of roughly 40 beats per minute due to the efficiency of their heart's functionality through better cardiovascular exercises. Other factors that could lead to a decreased normal pulse rate would be:

- Air temperature: As temperature and humidity increases, the heart needs to pump more blood to maintain the equilibrium of blood oxygenation within the system, and so the pulse rate may increase. This increase typically is no more than 5 or 10 beats a minute.
- Body position: While resting, sitting or standing, your pulse stays around the same level, but for the first couple of seconds after standing your pulse can increase for a couple of minutes, until the body has adjusted to the new position.
- Emotions: Varying emotions can affect pulse rate, in particularly feelings of stress and anxiety can raise your pulse. This is due to the "fight or flight" mechanic built into us that increases the flow of blood so as to make a quicker decision and be prepared for it.
- Body size: Size does not usually change pulse very much, but individuals who are very obese may see an increase in resting pulse values compared to those of average weight and size.
- Medication use: Drugs that block adrenaline (such as beta blockers) tend to slow your pulse, while an excess of thyroid medications will raise it.

As the individual becomes older, however, the regularity of their heart rate can change, as well as instabilities created from a heart condition that may arise. An average of sorts has been tabulated for your convenience below to show that as the individual in question ages, the minimum, maximum, and normal heart rates will change.

Age	Min	Normal	Max
1 to 12 months	75 / 50	90 / 60	100 / 75
1 to 5 years	80 / 55	95 / 65	110 / 79
6 to 13 years	90 / 60	105 / 70	115 / 80
14 to 19 years	105 / 73	117 / 77	120 / 81
20 to 24 years	108 / 75	120 / 79	132 / 83
25 to 29 years	109 / 76	121 / 80	133 / 84
30 to 34 years	110 / 77	122 / 81	134 / 85
35 to 39 years	111 / 78	123 / 82	135 / 86
40 to 44 years	112 / 79	125 / 83	137 / 87
45 to 49 years	115 / 80	127 / 84	139 / 88
50 to 54 years	116 / 81	129 / 85	142 / 89
55 to 59 years	118 / 82	131 / 86	144 / 90
60 to 64 years	121 / 83	134 / 87	147 / 91

Figure 3.6-15 Pulses in different ages

If, while resting, the heart rate is consistently above 100 beats per minute, the person may be experiencing tachycardia. A prolonged state of a resting heart rate below 60 signifies bradycardia. These are indicative of an underlying health concern, and having continuous measurements to see the trends in pulse rate can aid in early diagnosis. Now, it's important to go over two main categories of pulse rates, the maximum and target pulse rates. The maximum pulse rate is the number of beats per minute that your heart can achieve under maximal stress. The target heart rate is a percentage of the maximum heart rate, and is generally speaking the range where exercising yields its maximum benefits. The means of which to calculate these two values has been combined in the next diagram.

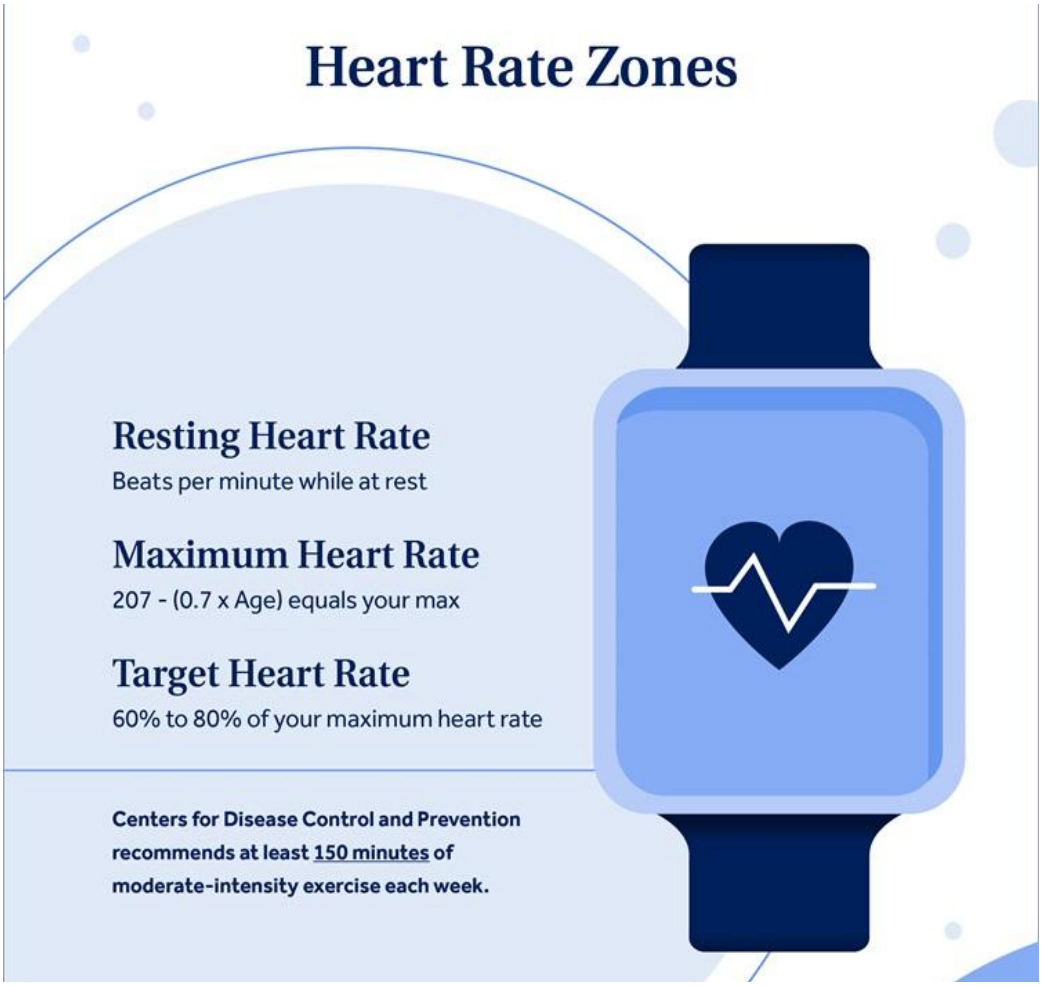


Figure 3.6-16 Types of Heart Rate Zones

Keep in mind, however, that this calculation for your maximum heart rate is a rough estimate, and that if you wish to find out a more accurate measurement of your maximum heart rate, a maximal exercise test performed under the supervision of a doctor or exercise physiologist can be done. Prolonged duration of maintaining your maximum pulse rate can lead to symptoms such as:

- Severe shortness of breath
- Chest pain
- Dizziness
- Excessive Sweating
- Severe heart palpitations

These are signs that your body needs to slow down, and it is for this reason that the target heart rate is the most beneficial range to be in when exercising. According to the American Heart Association, during a moderate intensity workout your target heart rate should be about 50 to 70 percent of your maximum heart rate, while doing an intense workout session should yield a target heart rate of 70 to 85 percent of your maximum pulse rate. The level of conditioning for exercise should also be taken into account, as a beginner should not start with a max intensity workout and expect to not have any repercussions. To increase the threshold of advisable pulse rates, a beginner might consider walking every day, slowly working up the length of the walking workout to build a tolerance for a higher target heart rate workout session. To better understand the level for which an individual should work out, the next chart illustrates the various target ranges for your heart rate.

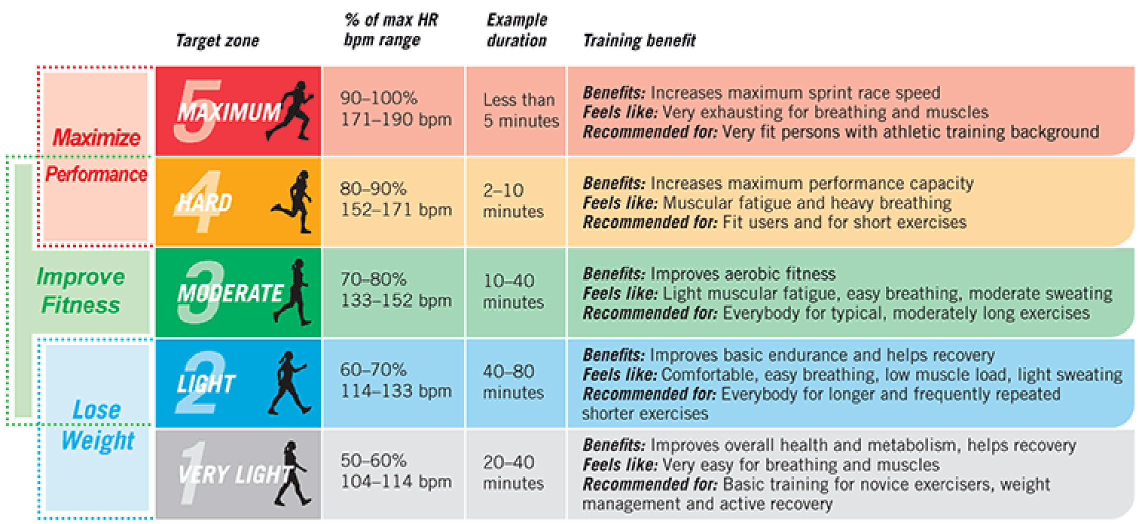


Figure 3.6-17 Heart Rate Ranges, Zones, and Benefits

These categories show that a lower target heart rate corresponds to a workout geared more towards the beginner, whereas increasing your target heart rate as a percentage of maximum heart rate requires a greater discipline in fitness and exercising behaviors. It also helpfully shows the benefits for maintaining each level of performance, and how you should be feeling while in that particular zone. This is a great way to ensure that you are in the zone accurately for your level of expertise, as being very exhausted for breathing while at a 50-60% target heart rate would indicate that a less rigorous workout regimen would need to be implemented before increasing further up the zones.

Measuring heart rate typically has two methods, manually checking your pulse or using a machine such as a fitness tracker. There are 4 main locations to check your pulse, shown in descending order:

- Radial Pulse: This is done by measuring the pulse from your radial artery by placing your pointer and middle fingers on the inside of your wrist below the thumb.
- Carotid Pulse: This method uses the carotid artery to measure pulse by placing your pointer and middle fingers on the side of your windpipe just below the jawbone.

- Pedal Pulse: This method is used less often than the previous two, but is still a viable method for measuring pulse. It involves placing your index and middle fingers above the highest point of the bone that runs along the top of your foot.
- Brachial Pulse: Most commonly used in young children, this method checks your brachial artery for your pulse. You must first turn your arm so it's slightly bent and your inner arm is facing up toward the ceiling. Then, place your index and middle fingers along the side of your arm between the crook of your elbow on the top and the pointy part of your elbow bone on the bottom. After this, move your fingers about an inch up your arm, and press firmly to feel the pulse.

Regardless of which manual method you choose, once the pulse can be felt, count out how many beats occur in 15 seconds, and then multiply by 4. This will yield your pulse rate, or your beats per minute. The other methodology involves using an electronic device to measure your pulse rate. These sorts of devices typically utilize ECG measurements or PPG sensors to detect your pulse rate. Our project will also be utilizing this technology. Both of these types of measurements can be found in greater detail within this document. The image below shows a chart of all known fitness watches that determine the zone of heart rate that a user is in and categorizes them in color to see which cases are extreme and which are in a good zone. This is a similar idea to what we want for our glove to contain.

POLAR		MYZONE		fitiv fitness | unlocked	
% Heart Rate Max	Color or other Indicator	% Heart Rate Max	Color or other Indicator	% Heart Rate Max	Color or other indicator
50-60	Gray	50-60	Gray	27-59	Warm Up
61-70	Blue	61-70	Blue	60-69	Fitness
71-80	Green	71-80	Green	70-79	Endurance
81-90	Yellow	81-90	Yellow	80-89	Hardcore
91-100	Red	91-100	Red	90-100	Red Line

Orangetheory FITNESS		WATCH		fitbit	
% Heart Rate Max	Color or other Indicator	% Heart Rate Max	Color or other Indicator	% Heart Rate Max	Color or other Indicator
50-60	Gray	0-60%	Warm Up	**Below 50**	Out of Range
61-70	Blue	60-75%	**Fat Burn**	**50-69**	**Fat Burn Zone**
71-83	Green	75-85%	**Cardio**	**70-84**	**Cardio Zone**
84-91	**Orange**	85-100%	**Peak**	**85+**	**Peak Zone**
92-100	Red				

Figure 3.6-18 Heart Rate Comparisons between several Heart monitoring devices

3.6.4 Blood Pressure Explanations

<u>Blood Pressure</u>:

The National Cancer Institute at the National Institutes of Health defines blood pressure as "the force of circulating blood on the walls of the arteries." For the human body to function, oxygen needs to be brought to the tissues and organs via the red blood cells. This is done by the pumping of the heart, which creates pressure that pushes the blood cells through the various arteries, veins, and capillaries of the body. Two main forces govern blood pressure: Systolic Pressure is generated as blood pumps out of the heart and into the arteries to circulate through the system. Diastolic Pressure is created during the period between beats, when the heart is at rest. The generalized format for blood pressure is shown with the systolic pressure first, followed by diastolic, i.e. 120/80 mm Hg.

The main danger inherent with blood pressure is high blood pressure, otherwise known as hypertension. This is when the force pressing against the walls of your blood vessels is consistently too high. The chart below shows 5 stages of blood pressure from nominal values to a hypertensive crisis.

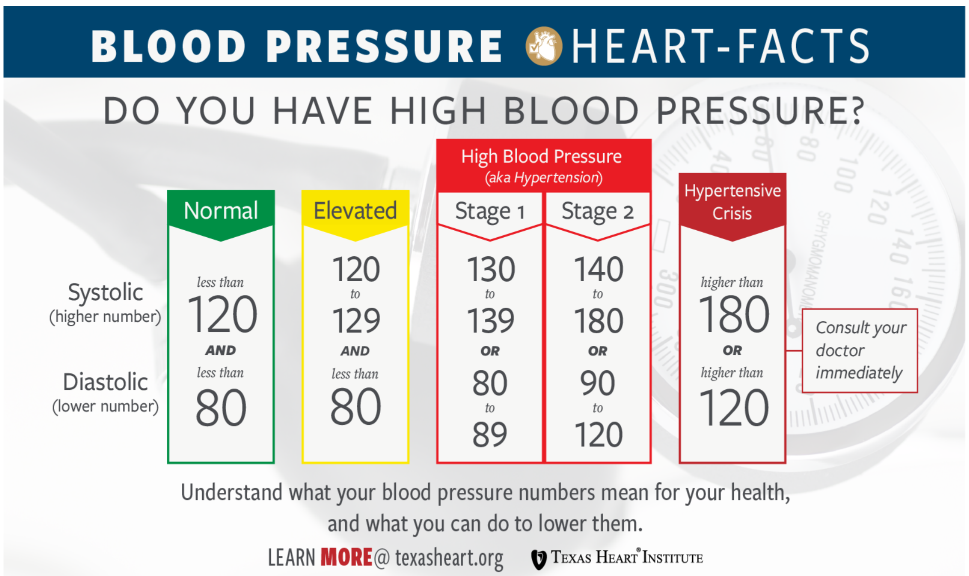


Figure 3.6-19 Blood Pressure Chart

The 5 stages listed above are as follows:

- Normal: Blood pressure readings in the green zone, with systolic less than 120 and diastolic less than 80. Heart healthy habits such as a balanced diet and maintaining regular exercise are key to staying within this zone.
- Elevated: Blood pressure readings in the yellow zone correspond with readings that are consistently between 120-129 for systolic and less than 80 for diastolic. Although there is not any immediate danger while in this zone, it is imperative to improve your heart health as this stage can lead into hypertension.
- Hypertension Stage 1: This is when systolic pressure is consistently between 130 and 139, while diastolic pressure is between 80 to 89. When consistently within this zone, doctors are more likely to prescribe a lifestyle change, and may consider

prescribing blood pressure medication based on the probability of you developing atherosclerotic cardiovascular disease (ASCVD), such as heart attack or stroke.

- Hypertension Stage 2: This is the stage when blood pressure is consistently at 140/90 mm Hg or higher. While in this stage, doctors are likely to prescribe a combination of blood pressure medications and lifestyle changes.
- Hypertensive crisis: This stage immediately requires medical attention. If your blood pressure readings exceed 180/120 mm Hg, wait five minutes and then test again. If the readings are still unusually high, contact your doctor immediately. If your blood pressure is higher than 180/120 mm Hg and you are experiencing symptoms such as chest pain, shortness of breath, back pain, numbness/weakness, change in vision or difficulty speaking, you should call 911 and receive medical attention.

A helpful chart to understand the effects of high blood pressure on the body is shown below.

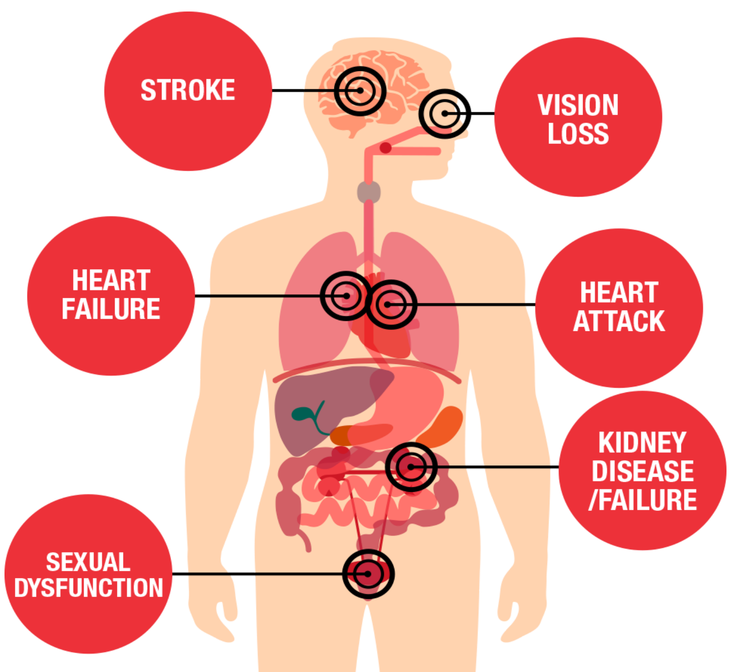


Figure 3.6-20 High Blood Pressure Effects

3.6.5 Body Temperature Explanations

Body temperature is a measure of how well your body can make and get rid of heat. The body should be able to stay within a safe temperature range even without the effects of weather alerting it. Blood vessels in the skin change whenever the body is too hot or too cold than what it needs to be. Those blood vessels widen in the skin to carry excess heat to the surface of the skin. This may cause sweating to occur, which further helps cool down the body. When blood vessels narrow, the body is too cold. This reduces the flow of blood that goes to the skin to help save the body some heat. This can cause a person to experience chills, which helps the body make more heat.

A couple of reasons as to why we measure body temperature are:

- Fever Check
- See if medicine for fever is working on the user
- Determine plan for pregnancy by determining ovulation

A study was conducted at The Royal Melbourne Hospital on patients, some of which had chronic kidney disease, to see how wrist temperature measurements could be used as an index of infection. These patients wore a fully charged wearable device on the wrist at all times to continuously measure their skin temperature. 104 recording sessions were performed from 91 different individuals. The results of this study showed that skin temperature does indeed have the potential to alert people to the possibility of infection. In this way, by having our device measure skin temperature, the user can be better equipped to get an early warning of infection, thus enabling for earlier diagnosis and treatment. A chart has been drafted to show the general zones of skin temperature with relation to fever, changing color with each zone for ease of understanding. Below you can see a body temperature chart that displays the normal temperatures for several ages and the conversion between celsius and in fahrenheit.

BODY TEMPERATURE CHART

Age	Normal	°C to °F Temperature Conversion Chart
Body Temperature for a Baby	A normal temperature in babies and children is about **36.4C (97.5F)**, but this can vary slightly. A **fever** is usually considered to be a temperature of **38C (100.4F) or above**.	36.4 °C = 97.6 °F **36.5 °C = 97.7 °F** **37.0 °C = 98.6 °F** **37.4 °C = 99.4 °F**
Body Temperature for Children	The average normal body temperature for children is about **37°C (98.6°F).**	**37.6 °C = 99.6 °F** **38.1 °C = 100.6 °F** **39.0 °C = 102.2 °F**
Body Temperature for Adults	Normal body Temperature under the arm (**axillary**) is about **36.5°C (97.7°F)**	**40.0 °C = 104.0 °F** **41.0 °C = 105.8 °F**

Figure 3.6-21 Body Temperature Chart

4. Related Standards and Realistic Design Constraints

This section includes all information on standards that relate to our project throughout the time of us planning out what we are to do in our project to the time where we will focus on building and testing our final prototype. We needed to be considerate of all constraints of what our design may hold, as many different constraints and liability may arise. Fortunately, these constraints and standards were discovered during the research portion of our design. Meeting these standards did not hinder our project, but were interwoven with us meeting our own engineering specification requirements and also the requirements of the user.

4.1 Standards

Standards are known to be the terms and conditions that need to be fulfilled in order to successfully state that a product is ready and completed. Identifying and following standards are a part of good practice in engineering. When thinking of standards that we would have to follow for our project, we had to think of standards that need to be understood at the user level, implementation level, and development level.

At the user level, we know that the intricate details of technology terms and engineering keywords are not needed. These standards should be simple for anyone reading up on our project to understand what the design of the product is supposed to entail. It is not until the implementation level, where the details of the standards are to be laid out and are the standards that directly go hand in hand with the design and requirements of the product. At the development level, the standards are updated and modified from the list of implementation level standards since at this point we should've been able to test things out and see if our standards were even possible to implement on our design. If we were able to meet better standards than the ones that we expected to have, then we updated those and explained how we got to the better standards.

Our team was also required to follow all of UCF's guidelines and standards through the process of planning, researching, building, and testing our product. We started off our process by first choosing an idea for our project, then researching the details of the idea as well as components that would help bring it to life, all in the meantime being able to ask any questions and have group video chat sessions with our advisor to help tell us if we are heading in the right direction. Throughout this part is where we had to also start our documentation while we did our research, which stated all details of our project and was the major part of what we did in our Senior Design 1 class.

In Senior Design 2, we mainly focused on our building and testing stages of the project. Throughout each breakthrough we made with the design of our product, we frequently tested all possible test cases several times and so that we could guarantee that the requirements and standards we listed were met. We also tested our components prior to interconnecting them to see if they all functioned properly. This was the biggest time constraint that we faced, as we had little time to build and ensure that all parts of the project were working before the end of the Fall 2021 semester.

While testing, we followed all safety standards that were placed inside special labs at UCF and ones that we read when going through the manual of each component that we worked with. While coding up our application, we asked for constant checks on our standards that we had on our application and saw if they were being met, or if we needed to further adjust any part of the application to work better. The software part of the project was considered to be a combination of building and testing happening simultaneously. We wanted to test each part of our project separately as well as how it was working on the overall system several times before we moved on to another part of our project. We had a whole month of just testing and debugging as a time period before we needed to make any final presentation videos.

4.1.1 Design impact of relevant standards

For our project, we looked into several different possibilities to implement our design. We took into consideration what constraints we would face depending on what design we went with. The fingerless glove aspect of our design is the central part of our design and we had to configure where we would be placing our parts to limit any difficulties with using the product and having little to no safety standards being affected in a negative way. This section of our document describes the several standards that our design impacts. We wanted to have constraints that were reasonable to have and possible to implement so that our system could be able to come to life. We focused on the following standards: economic, time, environmental, social, political, ethical, health, safety, manufacturability, and sustainable constraints.

4.1.2 Programming Languages - Dart Standard

In Project N.I.H.M.S. We used Flutter for our mobile and web application. Flutter uses Dart language which is a user interface that wraps the C++ code in Dart classes and libraries. Dart follows the Ecma-408 (European Computer Manufacturers Association). Ecma International is a non profit standards organization for information and communication systems. Ecma-408 standards encompass many different levels that are directly related to the software details of our project.

Just like other languages, Dart comes with object-oriented, class-based, garbage-collected language combined with C-style syntax. Similar to C language, Dart needs to have a main() function predefined method to act as an entry point for the code to run. To be able to execute the program it may be done in one of three ways. One way would be to use an online compiler that supports Dart, like Dart Pad. Another way, which is how we plan to use it for Project N.I.H.M.S., is an IDE that supports Dart. Some commonly known IDEs are IntelliJ, Eclipse, and Visual Studios. Last way to execute the program would be compiling it through the terminal by executing the code file name through the terminal as "dart file_name.dart". Within the Dart standard it describes the scope of the Dart language such as variables, functions, classes, interfaces, mixins, extensions, enumerations, expressions, statements, libraries and scripts, and lastly type annotations.

4.1.3 Design Impact of Programming Languages - Dart Standard

The Ecma-408 standard had many different impacts on our software design of the Project N.I.H.M.S. As our group wrote the code, we followed the standards and documentation that followed the Dart language to gain access to its full capabilities. This was so we could enhance the reliability of our device. Without the help of the standards and documentation we would not be able to deliver a software design of substance or quality. This was achieved by making sure the Project N.I.H.M.S code works fluidly in the mobile app allowing the user to move around from the home screen to different routers and navigations. Since our device is to be used in a medical and sometimes time sensitive manner, it was important we used correct and efficient code. Rounding errors, format errors or out of bound exceptions must be close to non-existent when it comes to our device.

4.1.4 W3C Standards

W3C is that standard that defines the open web platform of project N.I.H.M.S. phone application development. With the joint of five leading global organizations in 2012, the mission of W3C is “to lead the World Wide Web to its full potential by developing protocols and guidelines that ensure the long-term growth of the Web”. They hope to bring their vision to life which is One web. In our project, we followed the W3C standard for building which included HTML and CSS to create our mobile web application. HTML and CSS are used to build the web pages for our project. HTML is used more for structure and CSS is used for styling and layout. W3C also includes information on how our phone application can be made for accessibility to people with disabilities. This standard helps promote web access anywhere from any device. W3C offers these standards at no cost and is easily downloadable.

4.2 Realistic Design Constraints

In our project we looked closely at realistic design constraints that can or may impact our design. One that stood out the most for us which led to our motivation and idea for our project was COVID-19. The current state of the world in this pandemic has brought a lot of distress when it comes to medical issues. We felt that a project like ours would help bring some solution and peace to those who especially have underlying medical conditions. Below we will go over additional constraints we kept in mind when designing, coding and implementing our device.

4.2.1 Economic and Time Constraints

From the beginning of our project, we decided that we wanted to find a sponsor that will help our group financially and/or with any advice with our design and technology choices. Although we had many attempts with reaching out to several different companies and asking to see if they were interested in being involved with our project, we either did not get anyone willing to participate or ended up just not receiving any response back. Due to this, our group has now switched to the back up idea to self fund this project.

We researched a few components and parts that we wanted to include on our design which were not as expensive as we thought they would be, which we expected would still work well with our design. We were hopeful that going with the cheapest parts would not ruin the overall performance of the entire system. If by any chance we had ordered any parts that were malfunctional or did not fit overall with our design, we would have to spend more money than previously expected. When designing every part of our project, it was crucial for us to try to get it correct on the first try, as if we had not done so, it would cause us to lose both money and time which were very limited to us already. Our group had researched our parts throughout the first few weeks of our semester and have discussed what we want to purchase.

One of the ways that our main economic constraint, not having a sponsor for our project, impacted our overall design was the lack of funding for a flex or rigid flex PCB. Originally we felt that using a flexible PCB would be beneficial to the user for the ease of mobility that it would bring. Being able to bend and flex with the natural motions of the body would ensure that the components were comfortable to wear while also being effective in taking in measurements. Unfortunately, this kind of design requires much more funding to realize, and was ultimately deemed too expensive for us to pursue.

As far as time constraints go, we were working against the clock when it came to completing every aspect of our project, documentation and the actual prototype included. We began working on our research and documentation in our Senior Design 1 class in the Spring of 2021 with the intention of building and finishing our project in Senior Design 2 in the Fall of 2021. Due to most of us not being available in the Summer due to internships and other opportunities, we had decided to push back development until the Fall. We worked on creating schedules throughout the Summer and the Fall to keep in touch and make further progress on any breakthrough development ideas for our design. Even with pushing back development in the Fall, we only had that semester to fully have a working prototype with most, and hopefully all, of our requirements that we have listed earlier in this document. However, if we had run into any trouble with the development process, we decided it would be ok to cut off a few of the functions we wanted to add on our product. We planned on setting several goals we wanted to meet throughout our building and testing period, which helped us organize ourselves and see where we were at in the process. We planned to hold each other accountable to finish set tasks that would lead to us achieving our goals.

Although not only due to timing constraints, certain features had to be cut from the overall design in order to ensure the rest of the features functioned properly. These features include the capability of measuring blood pressure and ECG measurements; without proper time and understanding of the components that allow for safe measurements of these parameters we chose not to include them rather than have them included at a level that would be deemed unsatisfactory for our overall goal.

4.2.2 Environmental, Social, and Political Constraints

With the increasing effect caused by global warming, it is our job as habitats of Earth to do our best to not accelerate the process. Using the sun as a source of power helps generate clean and sustainable electricity that does not come with the toxic pollution or global emission that may come when generating electricity or energy. In our device we primarily used photovoltaic (PV) solar cells. PV solar cells on a large scale can potentially harm the environment when it comes to land use and habitat loss, water use, and use of materials that may be hazardous in manufacturing. We used PV in our device at a small range, which would not impact the environment on such a large scale. Our device would contain thin-film PV cells which unfortunately contain toxic materials. If not properly handled and disposed appropriately the materials would cause major environmental and public health issues. Because of this, PV cells are often recycled rather than disposed of at landfills. Next we had to check the impacts LED has on the environment. The concept of LED has actually helped energy efficient technology. Overall, the environmental constraints listed had little impact on our project, as we originally designed our project to focus on ensuring that these constraints were accounted for. We felt that including the desire to have minimal impact on the environment into the beginning conception of our project was important to our own core values.

Some corporations have taken up the social responsibility of showing care for the environment and following safe green procedures when it comes to PV solar cells, LED and other harmful materials. Without corporations and manufacturers taking up this responsibility, this would have caused a constraint on making this medical device. A social constraint we could have encountered would be users driving and using our device or app while behind the wheel. To combat this we added a warning notice to users on the app and also with the device how-to-use directions. This device also was not designed to be worn in an active fitness regimen, and so this impacted the overall appeal of the device. Future iterations of this device may make changes to reflect this desire, but at this point it was not seen as an important aspect to design around.

Politically, some constraints can arise as far as following standards and regulations in making the device. Since the device is a medical noninvasive device with features that can check oxygen levels to heart rate monitoring, we would have to get it FDA approved. Another political constraint is how our device would do in the marketplace. There are many similar wearable devices such as Fitbit and Apple watches as well as similar CNAP devices such as heart rate monitors. To make sure we have enough success to join the market we would have to make sure it can combine that best of the wearable devices with the CNAP devices while meeting FDA standards and regulations.

As a group, it was decided that this project would not be something to create with the intention of making a business out of, and so we were able to avoid the requirements of FDA approval. Our work lays the foundation for further work to be done on this device, which could at that time be brought up to a level deemed worthy of mass production. At that time, it would be necessary to ensure that the device meets all requirements necessary for FDA approval.

4.2.3 Ethical, Health, and Safety Constraints

At the time of this writing, we were still in the state of a pandemic where it had affected all of our school work to be mainly remote. However, our university had plans to start reverting back to the norms of in person classes in the fall, but still were advising everyone on campus to take precautions. We were unsure if this meant that we would need to work around a set schedule to get into our design lab on campus or if we would be able to access it at any time we needed to, like how it was meant to be prior to the pandemic. We also kept constant communication with one another to let each other know if we were exposed to COVID-19 or were feeling any symptoms, in case we were planning to meet as a group in person.

As an alternative, we were comfortable with doing most of our meetings via video conference calls online. However, when it was time to physically build our project we needed to meet face to face. This pandemic affected our project in a negative way, such as shipments of our parts being delayed, causing us to have less time to build our product. There were several shortages of items that we were also considering, which made it more difficult to get our hands on specific components and forced us to choose a different option if the part was unavailable. In addition to parts needing to be changed out with variations in availability, the actual production of the PCB board was also affected by COVID-19. Our boards came from China, and so they took an extended amount of time waiting in customs before continuing to ship to us.

The ethical constraints that we faced were the same ones that we believe all engineers must follow as stated in our ABET lectures. We needed to develop our own original work and ideas throughout the whole process of our research and design time. We needed to communicate with each other as to how we came up with the ideas that we wanted to implement and give proper credit to where it was due accordingly. As we researched and saw the designs that have been created in the past, we knew that we had to design something with similar features yet make it completely our own. There was enough that was different about our project to not be considered as plagiarism with respect to another device, and so the ethical constraints of ensuring not to encroach on another person’s work was avoided with little impact on our design. It is also worth mentioning that this device is in no way meant to replace the need for proper medical care, and should be treated as a means of aiding in the process of taking care of yourself. It would be ethically irresponsible to present this device as a replacement to normal healthcare procedures.

Since our design was targeted to help users with medical records and obtaining medical data, it tied into health and safety pretty much automatically. We did not want our device to cause any extra pain or negative side effects when using it. This was a very critical constraint that we shared a high priority for. If it were to put anyone at risk of any danger or harm when using the device, it would be a catastrophic turnout for our group. We worked hard on researching parts that can help our design be functional and yet comfortable and easy for the user as well, so we looked forward to our device being safe as well. We planned on making a fingerless glove, in hopes of having that allow for our device to not overheat with the components that were integrated in the glove itself.

We planned on designing a layout of the components to be placed in a way that would not interfere with the comfort of the user. Research on parts that are able to be waterproof was also essential, as we wanted the user to be able to machine wash our product in case they were to get anything on it. It was also important to not have any of our components be able to get any shorts or shocks as if that were to occur while the user was wearing our glove, that can risk the safety of our customer. We planned on this glove to also be able to fit any average size hand, so it would be a bit bigger than the hand, yet not too big as that can affect the way the product can read the data inefficiently or incorrectly. None of the components should be able to move around or fall off of the device as well, as that is a potential risk of injury therefore possibly harming the user.

4.2.4 Manufacturability and Sustainability Constraints

There are many constraints that we wanted to have in our design that we felt were a high priority as it would overall provide a positive experience with our product if we would be successful in implementing those constraints, or negatively if we could not finish them. A huge constraint of ours was the weight aspect. We wanted our product to be light so that the user would be able to move around with it and not experience any sort of discomfort if the user needs to be active while using it. Ways that we could provide comfort are by protecting all components that can stick out by covering it with the solar fabric. We would need to do this without possibly breaking any equipment for this constraint to be addressed.

Accuracy was another main constraint we were aiming to accomplish. The overall product needed to be able to read the user’s vitals correctly in order to determine if there were any major medical issues that would then be presented to a medical professional. There may be some times where the user was required to be in a steady position in order to collect the proper measurements. We also needed to find a way to accommodate several hand sizes by making sure that the sensors are placed in a position that can read every different user's fingers. We tested our product with different hand sizes as well to state that this constraint had been met.

We also made sure that the hardware components that we placed in this glove were secure while a user uses our product, as if those components were to move out of place or fall off it could ruin the functionality of our design completely. If we were to place the components of our design on the outer parts of the glove, things such as bumping the components against a hard surface, or water damage could play into possible risks that would affect the part, causing it to stop working partially or all together. If we were to place the components on the inside of the glove, it is important that the user is aware of all movements that they are allowed to make as those would potentially alter any measurements being made.

To make sure that our product would be sustainable, we made our design completely off of parts that are already pre-built that are found on electronic sites, such as Mouser, Digikey and so on. We wanted our system to be able to be reproduced if it were to be successful, and also be upgradeable if anyone were to be willing to do so. If we were to create our own parts such as the PPG sensor, it would take up alot of time and cost and it could've possibly caused us to not be able to finish our project.

5. Project Hardware and Software Design Details

In this section of the document we will go over Project N.I.H.M.S. hardware and software design details. The hardware details will be covering our different subsystems used. This includes describing several electrical components that are essential in each of the subsystems in our overall system. This will be useful if any developer in the future wants to implement their own version of our product, and can see if there are any other devices that are more feasible or cost efficient. Software details will discuss the software we decided to use for our design.

5.1 Initial Design Architectures and Related Diagrams

Initially at the beginning of Project N.I.H.M.S. our first task as a group was to complete the bootcamp document called the Divide and Conquer. The bootcamp and document was to help us as a group start thinking of possible ideas for our project and also a form of team bonding. With the Divide and Conquer came the initial design for our project. Although the final design in Senior Design 2 did not completely match our initial design in Senior Design 1, the bootcamp and Divide and Conquer played a key role in planting a seed of how our project can grow. It also helped in assigning each group member responsibility for the project, although this fluctuated as well. To not have had the bootcamp and the document would have been a challenge for us as a group of where to even start or how we would like the project to be designed.

5.2 First Subsystem

Figure 5.2-1 shows an operational amplifier, also known as an op amp, which is an integrated circuit that helps amplify weak electrical signals. It has two input pins and one output pin. They are useful in our case, within the PPG part of the sensor as it could help get better results of the user's finger in case the person using the glove did not apply much pressure on the sensor in order for it to read it. It can further be improved by putting the amplified signal into the microcontroller.

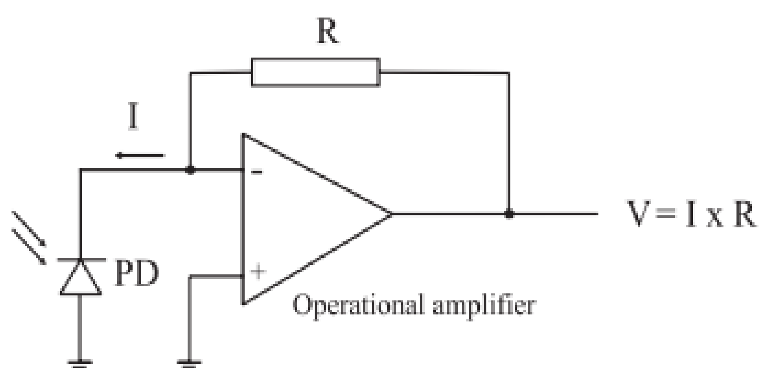


Figure 5.2-1:Operational Amplifier

The op amp, as shown in Figure 5.2-1, is also able to eliminate noise from an input signal. This occurs by extracting the signal with the target frequency that is wanting to be found. In this case, it would focus on determining the pulses and electric signals coming from the user's veins, and would block out any other potential distraction such as movements or different respiration activity to help focus on making the correct waveforms.

The PPG also includes a low pass filter in the subsystem. The low pass filter passes signals that have a lower frequency than the desired cutoff frequencies.. Low pass filters are typically used to filter out noise from a circuit, meaning that any frequencies higher than cutoff would go to ground.The amplitude of all high frequency signals are greatly reduced. The cut off frequency on a PPG for the low pass filter is 30Hz. Figure 5.2-2 shows an image of an RC low pass filter.

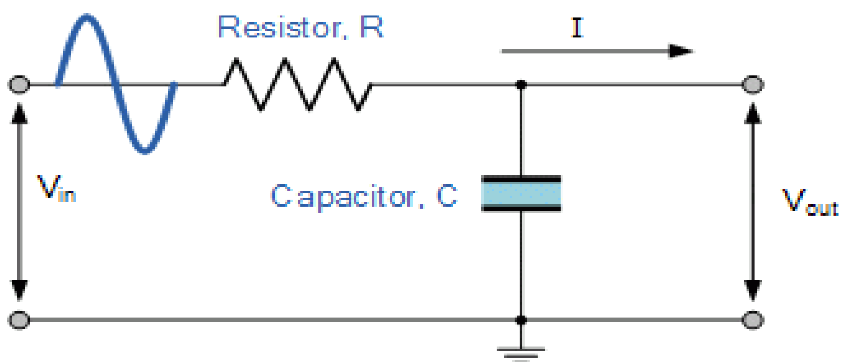


Figure 5.2-2 RC Low Pass Filter

Another part of the PPG subsystem is the high pass filter. The high pass filter is only utilized if it passes the low pass filter and further needs to amplify the signal and then invert it to make it to the final interface. The high pass filter allows for the DC component of the PPG to filter out the average blood volume before it gets to the chip. Any frequencies lower than cutoff will impede and go to ground. The cut off frequency on a PPG for the low pass filter is 0.5 Hz. Figure 5.2-3 shows an image of an RC high pass filter.

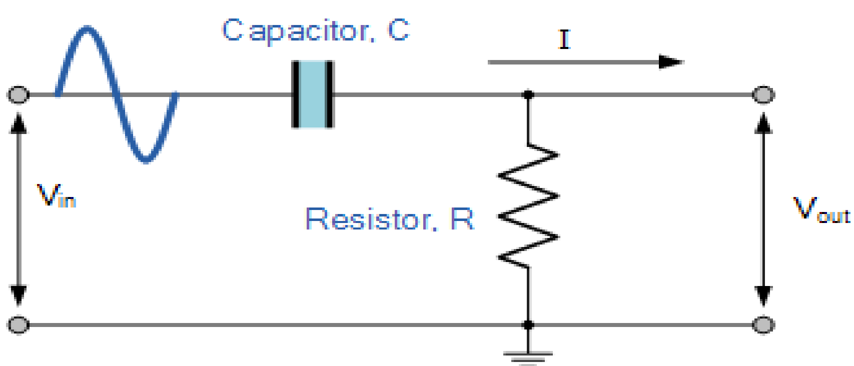


Figure 5.2-3:RC High Pass Filter

The PPG subsystem shown below has a transimpedance amplifier stage that converts light intensity at the photodiode to an amplifier output voltage. The signal conditioning stages surrounding the transimpedance amplifier include low pass filtering, high pass filtering and further amplification, inversion and signal interfaces. The AC component and a measure of the DC component are available for pulse wave analysis. A constant current driver stage for the PPG LED is also shown.

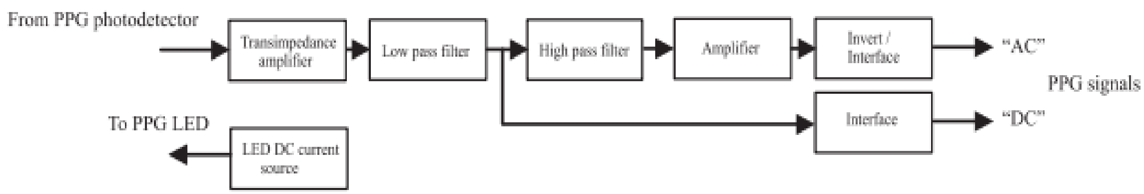


Figure 5.2-4 PPG Subsystem

5.3 Second Subsystem

The ECG subsystem includes both analog and digital components. This channel supports two different modes: 2E and RLD, that acts like buffers between human and circuit. They include a programmable gain amplifier (PGA), analog to digital converter (ADC), and a right leg drive (RLD) that help sense and digitize the ECG signal. The channel outputs 24 bits of data per channel in binary twos complement format, MSB first, where the 23rd bit is the sign bit. Below is the equation used to calculate the ECG signal in millivolts.

$$ECG(mV) = \frac{ECG\ ADC\ Output\ Code * LSB * 1000}{ECG\ Gain} = \frac{ECG\ ADC\ Output\ Code * \frac{4V}{2^{23}} * 1000}{ECG\ Gain} \quad \text{Eq. 5.3-1}$$

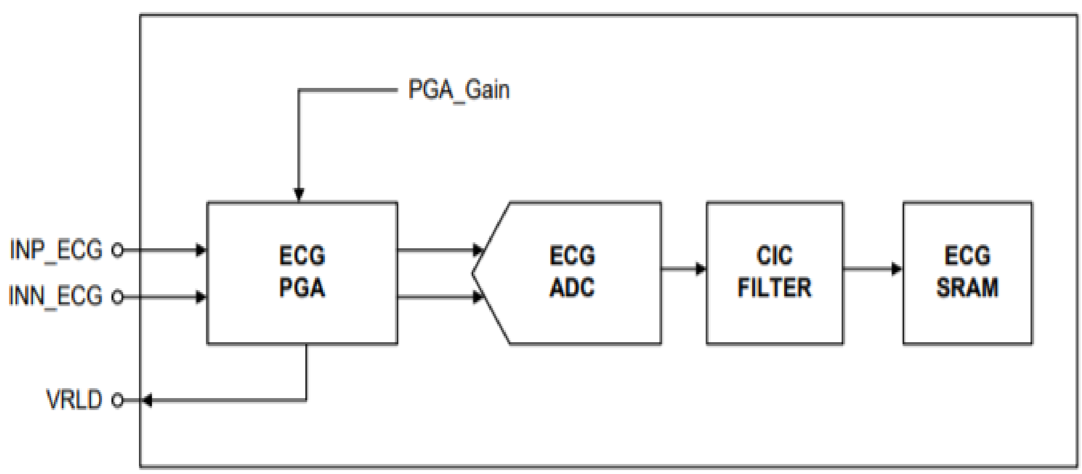
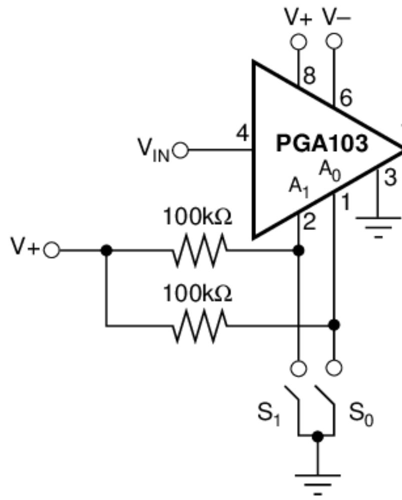


Figure 5.3-1 ECG Subsystem

The PGA is an electronic amplifier (typically based on an operational amplifier) whose gain can be controlled by external digital or analog signals. It's function is to condition the signals as they pass through the amplifier.



GAIN	S_1	S_0
1	Closed	Closed
10	Closed	Open
100	Open	Closed
Not Valid	Open	Open

Figure 5.3-2 Programmable Gain Amplifier

Figure 5.3-3 shows an analog to digital converter which is a component that is utilized in the ECG subsystem. Its main function is to convert analog signals into digital signals. This would be useful as the ADC averages the QRS complex recordings internally to filter out random noise, so late potentials become visible in the ECG image. This is done by an advanced signal acquisition and processing technique using high-resolution sigma-delta that the ADC is capable of doing.

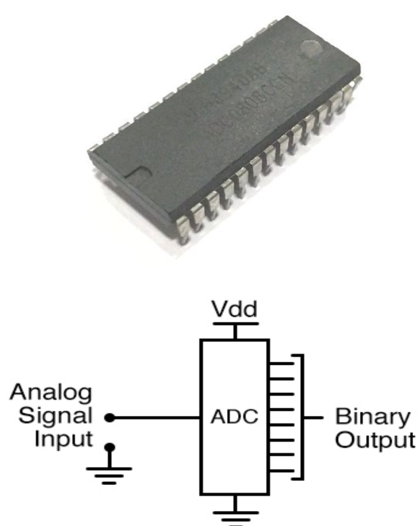


Figure 5.3-3 Analog to Digital Converter (ADC)

5.4 Bill of Materials

Below is a list of materials that were used to build our project. We have disregarded adding basic minor electronic components such as resistors, transistors, capacitors, and other consumable items, which have been omitted from the list. After researching and discussing it as a team on which components we thought were best fitting to our project in performance and cost efficiency, we came down to these items to use for our project. Our project was fully funded by the four members within our group and the cost was split evenly. Below is the cost to build one single glove.

Table 5.4-1 Bills of Materials

Quantity	Manufacturer	Manuf. Code	Availability	Price	Description
3	Melexis	MLX90614	112	$16	MLX9014 IR Thermometer
1	Adafruit	2847	43	$30	2847 Wi-Fi / Bluetooth Device
6	Maxim Integrated	MAX30100	1275	$11.89	RT1025WS PPG Sensor
3	Espressif	ESP8266	10	$6.65	ESP8266 Microcontroller
1	Adafruit	SM850K12TF	3	$13.19	SM850K12TF Solar Cell
1	PKCELL	LP785060	765	$15	LP785060 Battery

5.5 Software Design

The initial thought for our software design for our device was implemented using a stack program called FERN, which is: firebase, express, react and node. Firebase is used for the database backend and is built on Google's infrastructure. Express is used to help work flexibly with Node.js and connects to the backend. React helps with user friendly interfaces and helps build single page applications. Similar to react, we used Node.js that works together in our frontend and backend of our webapp using JavaScript. After further research and looking at all the functionality we would like to incorporate with our device, we decided to use flutter app development instead. Flutter is a Google software development kit that is used to develop mobile applications such as Android, iOS, Linux, Mac, Windows, and the web all from one single code. Flutter is still a fairly new UI framework but widely popular using Dart as its programming language. Flutter was picked over our initial software design, FERN, and other stacks or other UI frameworks like React Native. This is because Flutter grants less development cost, it allows us to write one single codebase that will compile on many different platforms which minimizes cost of maintenance of the software. Thus reusing the single codebase allows us extra time without the need to rewrite code over again to allow the app to run on different platforms.

Main function of the code will be to access data from the fingerless glove to be able to be seen on any phone application (Android, iOS, etc) and any web application (Mac, Windows, Linux, etc). The user will be able to read the data from the device and have a unique feature to be able to send data to their doctor or a recipient of choice through email. The microcontroller was also coded to make sure accurate readings are able to be pulled off the device. The microcontroller also helps the data be transferred correctly from the device to our online web and phone applications. The WiFi antenna helps with the transfer of the data to ensure the data is accessible and uploaded in a timely manner.

5.5.1 Microcontroller Software Design

The software design for our microcontroller is quite simple for our device. After the user straps on the glove, and starts up the connection between the glove and phone application, the user can then start getting their current vitals by the click of a button. The phone application will then start the monitored readings of the heart rate/telemetry, pulse oxygenation, skin temperature. The user will wait for the phone application to let them know when it will finalize their results. The time to access the application and connect with the device to then display the monitored readings on the phone application should take a max of 45 sec, given the user has a stable WiFi connection. To achieve these monitored readings we correctly routed the microcontroller I2C pins to our IR thermometer and heart rate and blood oxygen PPG sensor I2C pins to form an overall I2C bus. We as well also connected as resistors and power sources that are the things that give us the readings. Using Arduino IDE, I was able to directly program the ESP8266EX module to do all data collection and data transmission to the Google Firebase, with this single software program. Using C++ and .h libraries for each component of the hardware, I was able to program a single .ino file which is known as the file for arduino code, to get our project do what we wish for it to do all at once. Below is a screenshot of what the Arduino IDE environment looks like.

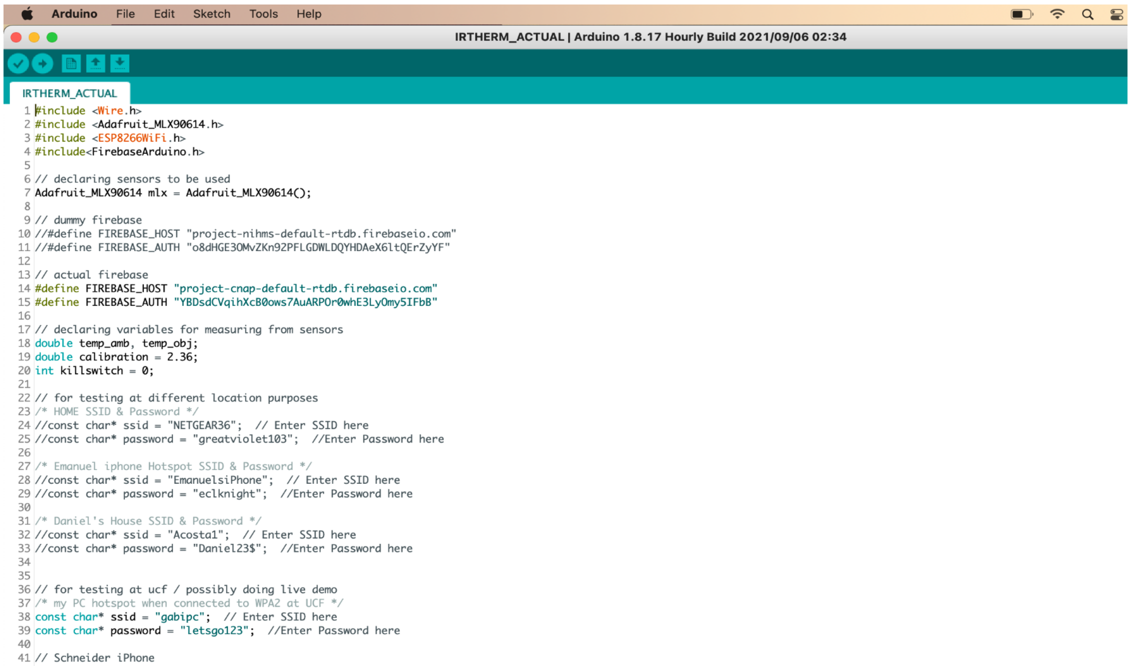


Figure 5.5-1 Snippet of the Arduino IDE environment

5.5.2 Frontend

This section will explain how the User Interface (UI) and other frontend details will work in our project. This will help the user understand the way that the mobile application is meant to work, along with what functions are available on each screen that is available on the mobile application.

5.5.2.1: Start/Login Screen

As we have stated before, our mobile application will be working hand in hand with our physical device. We as a group have all agreed on having our user interface be easy and simple to teach to use so that any person can handle the device themselves with little to none amount of technical support. Our user interface will prompt the user to make choices which have been displayed on our software flowchart found in section 3 of this document. At the start of launching our mobile application, it will require the user to login to their account that shall be stored on our database. If a user does not have an account, they can do so by clicking the sign up link that is on the bottom of the screen to begin getting any of their results from their device and further use all of the features that the mobile application has to offer. Another part of this start screen is the question mark button that is assigned for the help screen to pop up. This help screen will mainly describe what the application is going to be used for, along with what they need in order to start using the application.

A couple of user errors and test cases we will be looking for when developing this screen are:

- Incorrect Username or Password
- Attempt of use of Username of Password that does not exist
- Clicking on the help button or sign up link and not getting the proper screen

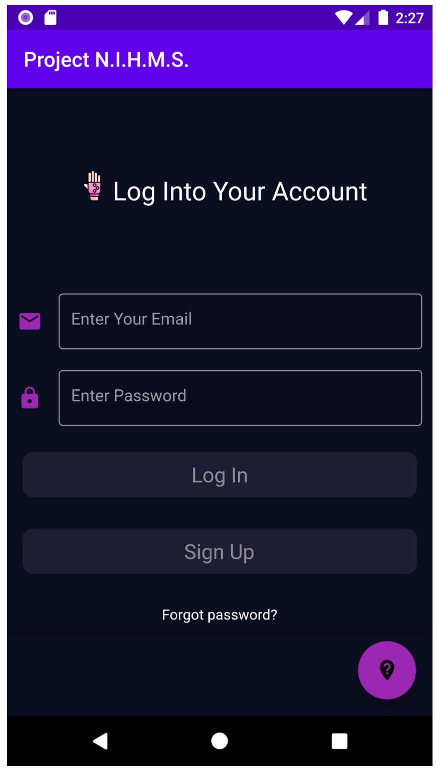


Figure 5.5-2 Start Screen for mobile application

5.5.2.2: Sign Up Screen

If a user does not have an account and device registered to our mobile application, they can sign up by providing the following information:

- Username
- Password
- Verify Password by Reentering Password
- Body mass indicator (height, weight and age)

The user will only be allowed to move on to the next screen by hitting the next button, only if they have filled out all of the information properly and have not left anything blank. In clicking the next button, an error message will appear if any of the following errors have occurred:

- Password and reentry of password do not match
- Username has already been taken by another account
- Missing entry on one of the required boxes
- Password not meeting the required character amount

If the user has no issues with the sign up process, they will go back to the login screen to login and take them to the decision screen that is described in detail in section 5.5.2.3.

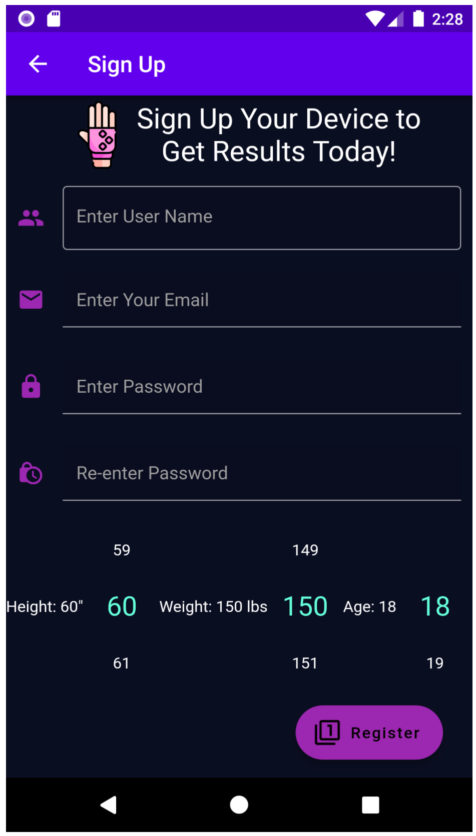


Figure 5.5-3 Sign up Screen for mobile application

5.5.2.3: Home / Welcome Screen

After logging in, the user will be prompted to the home screen where they will be able to choose what they want to do next. On the top of the screen it will display the username that is currently logged in so that they are able to know which account they are going to add their data to or which data they are able to see in the electronic diary. If the user wants to use the physical device and get their current vitals, they may press on the button to do so that will first take them to check connection to the device, as shown on section 5.5.2.4. If the user decides to go to their electronic diary to see any of their past results from within a year's time, then they will hit that button which is described on section 5.5.2.5. If the user decides that they are done with the application, they can choose to log off, and then they are taken back to the login screen that is the beginning screen shown upon launching the application.

Errors the user may be able to experience are:

- Incorrect username / date
- Logout button does not sign out of account
- Get current vitals button does not start process of collecting data
- Electronic Diary does not open when hitting its button

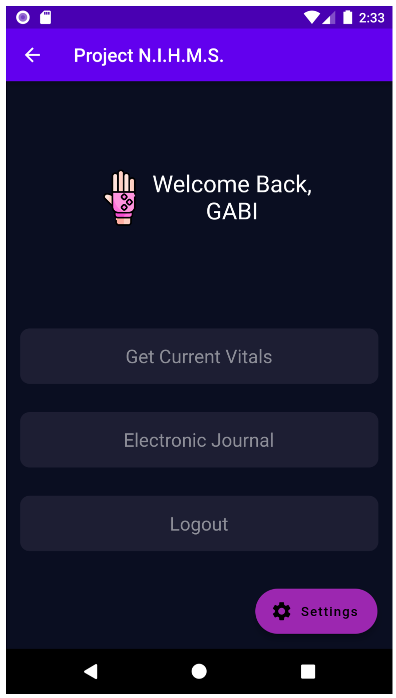


Figure 5.5-4 Home / Welcome screen for mobile application

5.5.2.4: Connection Check Screen

This screen will show the user which device is currently under check for a connection. The device should match the device number from upon registering the account in the first place. When the device is turned on, Wi-Fi connection and Bluetooth connection should also be on and connected to the device to move on to the next screen. The next button should only work when the status is displayed to be connected and both Wi-Fi and Bluetooth are in green letters to show that they are on and working properly. Otherwise, the next button should be greyed out and not able to move on to the next screen. If it is able to move forward, it will take the user to the progress screen which is described in section 5.5.2.6.

A couple of errors the user can see are:

- Incorrect device number displayed therefore device connected unknown
- Connection status is idle due to poor connection
- Next button is still able to hit when connection is unstable

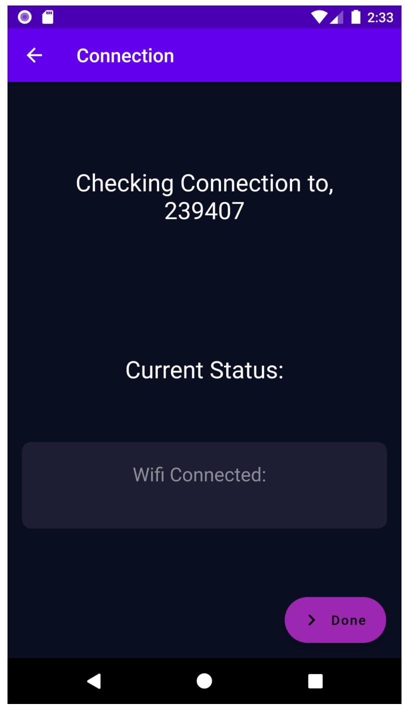


Figure 5.5-5 Connection check screen for mobile application

5.5.2.5: Electronic Diary: Choose Date Screen

This screen is what is shown as another option when at the Home screen. If a user wants to see any of their past vital results that were calculated on a certain date they can do so by choosing which date they want to go to as long as it's within a year's reach of the current date. They will also have the option of using a calendar widget to scroll through and select the date off of that. Once the date has been selected, the user can hit the next button to take them to the data that was recorded off of that date. The screen for that will be the same as if the user wanted to get the data of the current date, and is shown in a descriptive way in section 5.5.2.7.

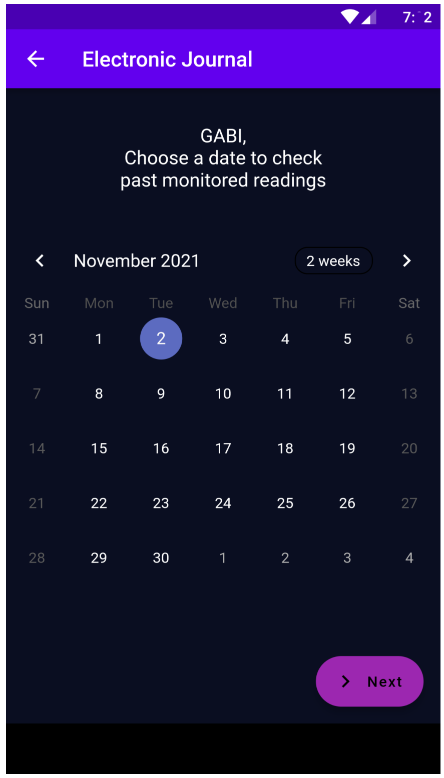


Figure 5.5-6 Electronic Diary Choose date screen for mobile application

5.5.2.6: Progress Screen

Here we are showing the user that the device that is connected is currently collecting data and in the process of generating the results on the mobile application. It instructs the user to please stay still throughout the process as that will ensure more accurate results. The device should still generate results if the user moves but they will be unreliable. Depending on connection speeds, the results can be generated quickly or a bit slower than expected. The user may also stop attempting to get their current vitals by hitting the stop button. If they do so, all collected data from up to that point will be deleted off the database and there will be no history of any vitals for that attempt. They will also be prompted back to the home screen. Once the user gets to 100%, they will be prompted to the vitals option screen which is described in section 5.5.2.7.

Some errors the user can come across are:

- Inability to stop collecting data when hitting stop button
- Progress bar not showing accurate timing and status of progress
- Delay or timeout in generating data causing for progress bar not to function

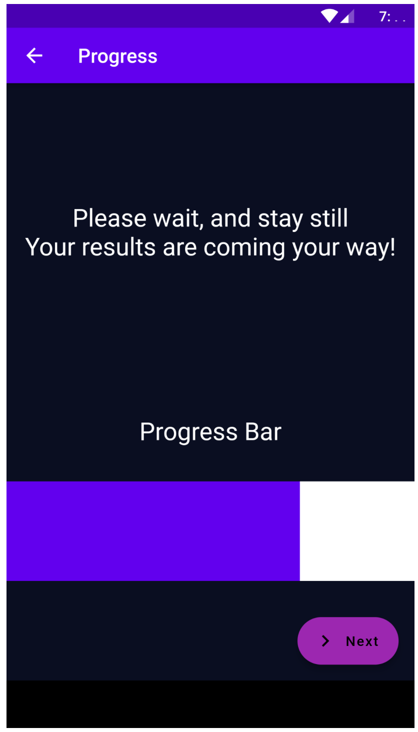


Figure 5.5-7 Progress screen for mobile application

5.5.2.7: Vitals Option Screen

This screen is where the user will be able to see the options of which results they want to look at of the date that is displayed on the top of the screen. When coming to this page from getting the current results of using the device, the device would have already taken all of the proper measurements of all of these vitals and placed the data in specific categories so that the user can just choose which one they want to see and it will be able to display all data and any level of danger if it applies to the situation. Once the user has chosen a vital, they will only be able to return back to this screen once finished reading about the vital they are looking at. From this screen, they can also choose to retry to get their vitals again in case there was any window for error throughout collecting the data. The user can also decide to return back to the home screen, in which case, the data that was collected will then be stored in the E-Diary for that date. Lastly, from here they can also generate a PDF of these results, where that will be shown in section 5.5.2.8.

Some errors a user can run into are:

- Inability to attempt to retry collecting vitals when hitting retry button
- Inability to see result when clicking on specific vital button
- Inability to attempt to generate PDF when hitting generate PDF button

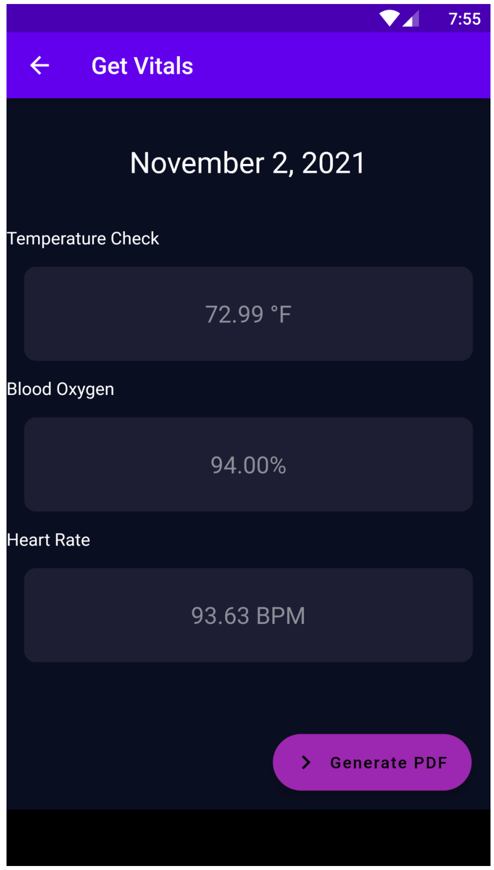


Figure 5.5-8 Vitals Options for mobile application

5.5.2.8: Generate PDF Screen

The final screen that will be in our application will be the screen where a PDF of results will be shown on the mobile app and then the user has a share button which will trigger the specific phone's share settings. From those share settings, they can choose to email with their preferred email account, and are also able to text message it to one of their contacts, and also be able to save that PDF on their phone's storage space. When the user is done with sharing the PDF, they will still be active on this screen, where they can also go back to the home page by clicking on the home icon on the top right, or they can close out the app completely to get back to the login screen to start all over again.

Some errors that the user can run across are:

- Sharing options do not open upon hitting the share button
- Blank PDF is created / saved
- Incorrect data is displayed on PDF
- Home button does not take user back to home screen
- Inability to upload PDF to email to be able to send

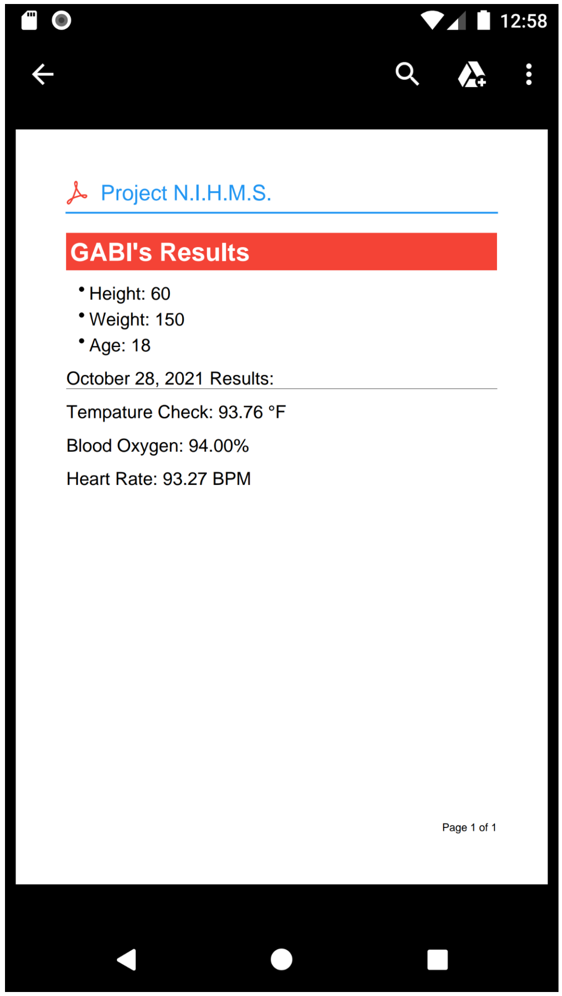


Figure 5.5-9 Generate PDF for mobile application

5.5.3 Backend

For project N.I.H.M.S., we will be using firebase for our backend. Google's Firebase goes hand in hand with our frontend UI, Flutter. Google's Firebase enables the best back-end server for small scale applications. It is able to run our mobile application code without the need of managing servers with the help of its Node.js environment. Firebase allows us as engineers to have a sense of low maintenance when it comes to managing the database. After using one command to deploy our code to the server, Firebase takes over and automatically matches the usage patterns of our app so no need to work about any server configuration, adding new servers, deleting old ones or even SSH credentials. Finally Firebase helps keep our software application logic private and secure. This helps keep the user away from the engineering functions and makes sure the user is kept private from the code, without the fear of it being reverse engineered.

Our project will be both Android and IOS. The Flutter UI makes this simple since it allows you to use one code for both OS's. Flutter will give us two different packages to configure for both OS with the Google Firebase domain. The backend for our project is responsible for updating our mobile application. The monitored readings of the heart rate/telemetry, pulse oxygenation, skin temperature will be updated through the use of the backend that is outputted through the I2C bus from the microcontroller. Google firebase backend will assist in updating the user profile to make sure each user is able to set their own dietary monitored health needs. Another feature of our Project N.I.H.M.S. that our backend will assist in alerting the authorities in critical monitored readings. The user profile will help determine each user's dietary monitored health readings. In the case where a user profile who has selected they have diabetes and her readings shows irregular or critical health readings, an alert will appear to the user that their local authorities will be alerted. They will have one minute to either dismiss the alert or the mobile application will then send the alert to local authorities. Lastly, Google's firebase backend will aid in sending data to recipients. Additionally in the user's profile, they will be able to add a recipient who will receive data from the monitored readings.

5.6 Summary of Design

Overall, the hardware design of our project was a fingerless glove that would be integrated with our PCB board that consists of an IR thermometer, WiFi antenna, microcontroller, photodiodes, LEDs, solar panel and a battery. The IR thermometer, photodiodes, and LEDs would generate one subsystem responsible for collecting the users heart rate/telemetry, pulse oxygenation, and skin temperature. WiFi antenna and microcontroller would generate another subsystem. This subsystem would be responsible for accurately pulling data from the other subsystem. After accurately obtaining the data, it would then be transferred to our mobile and web application so the user could read and/or send that data to a recipient of their choice with the help of our software design.

The overall software design consisted of a phone application and web application. The user would be able to check prior data readings dating back a year from the current date the user is viewing the data. While the user is checking their vitals, if there are any abnormalities that are alarming there would be an alert that automatically contacts the authorities for the user.

6. Project Prototype Construction and Coding

This section of the document will discuss the prototyping construction and coding to bring our device and project to life. We will be including the schematics of our project, PCB information and our plan on how we will program our application and any components we need to also code on here as well.

6.1 Integrated Schematics

This schematic shows our PCB with some of the components separated, as they are within their own PCB. The RT1025 is one such component, and so the diagram for it has been included separately as well. Displayed in our PCB layout below, are the microcontroller, IR thermometer, LED and photodiode. We included the schematics of the other components that were utilized in our project as well.

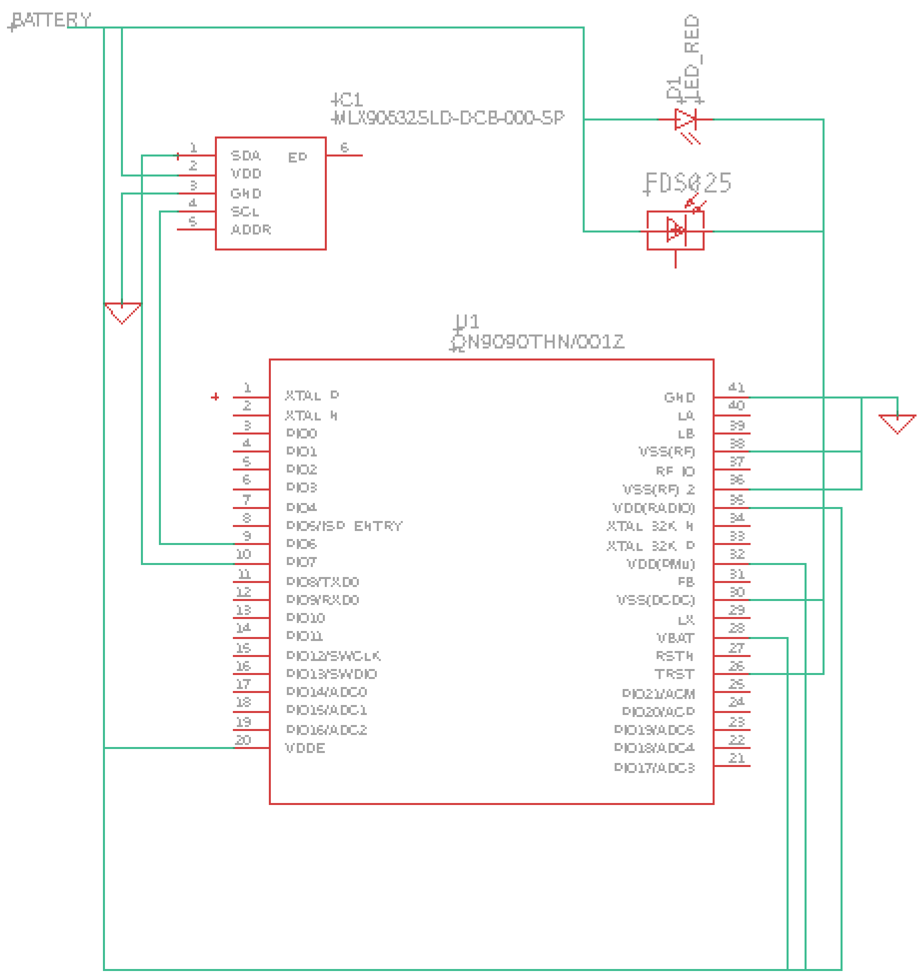


Figure 6.1-1 PCB Layout

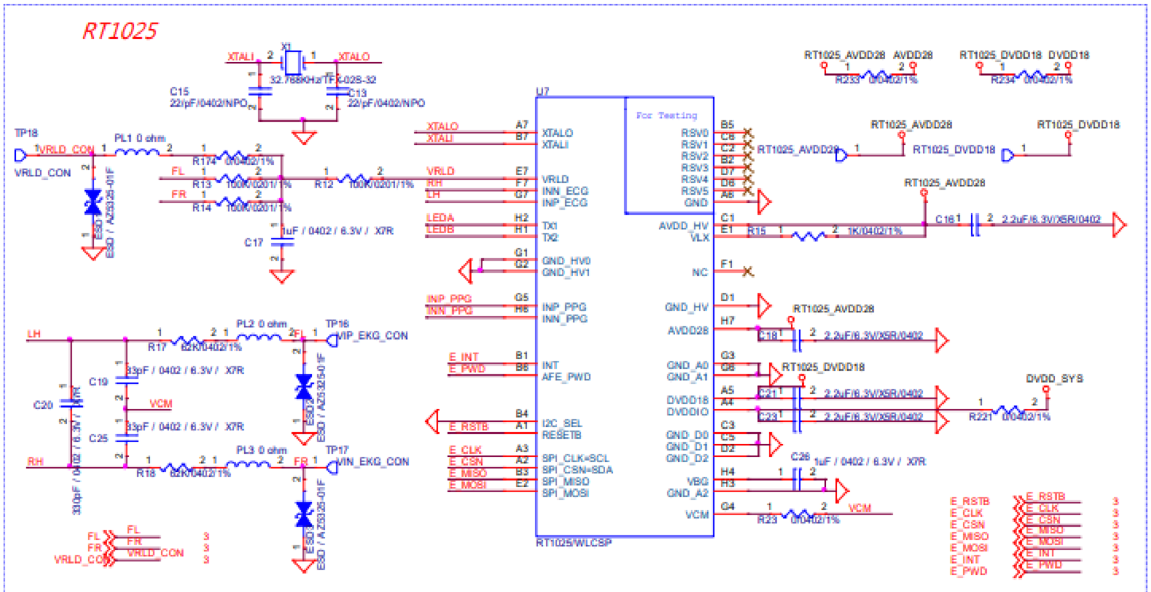


Figure 6.1-2 RT1025 Schematic

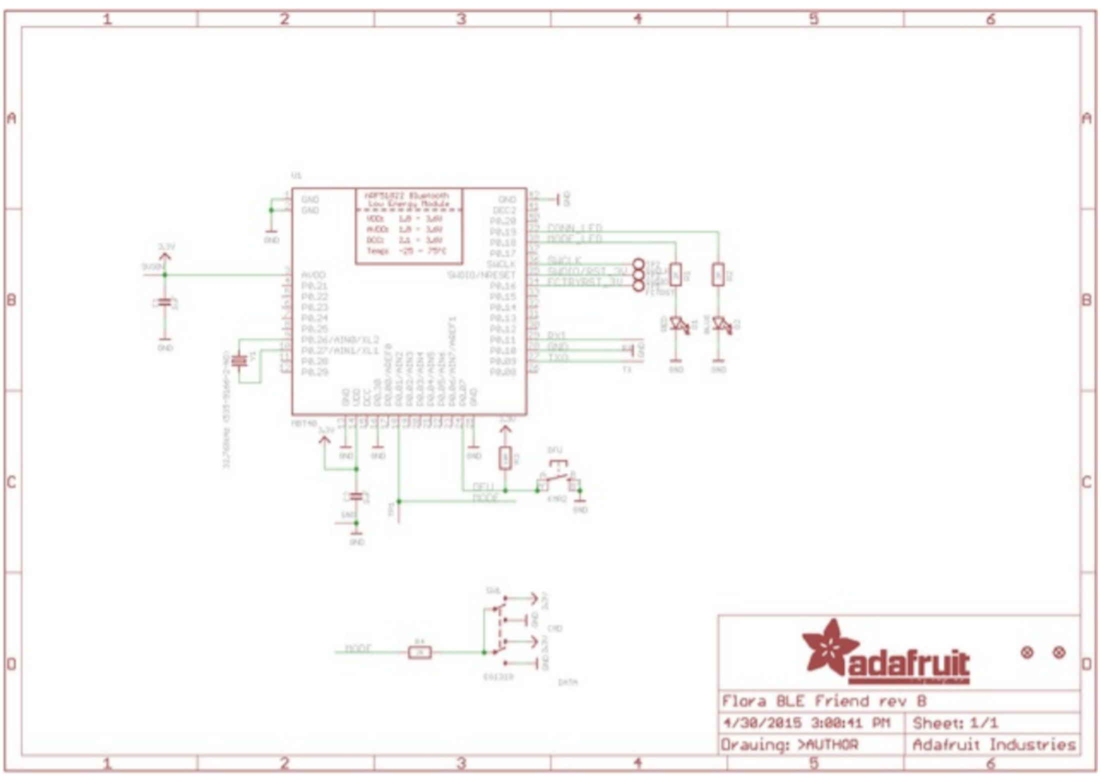
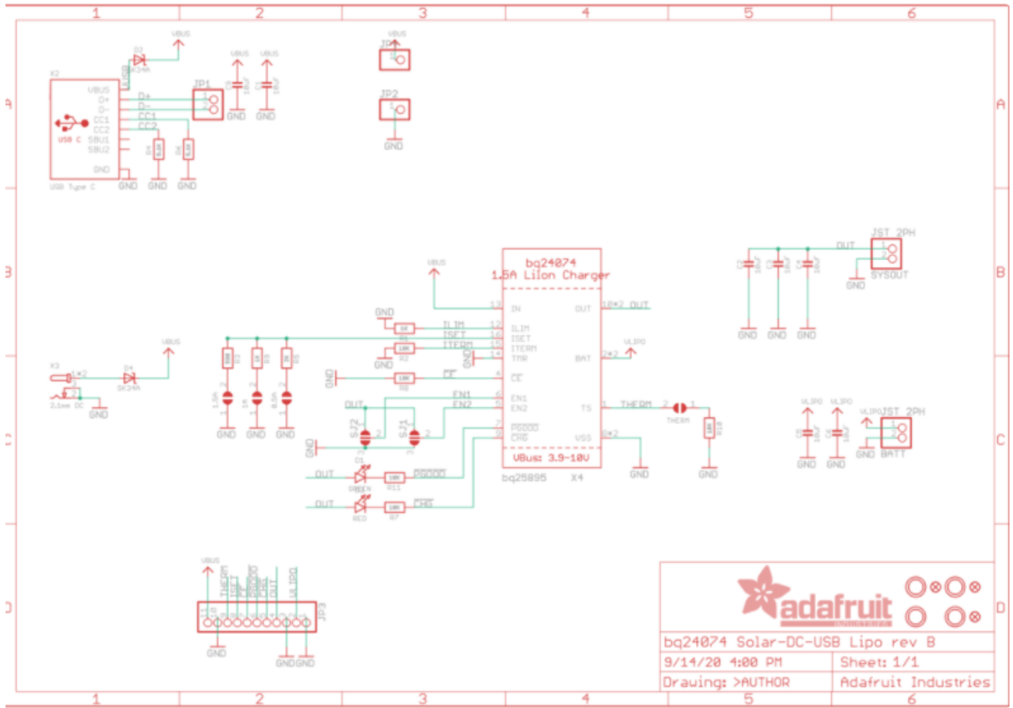


Figure 6.1-3 Adafruit Flora Schematic (Permission pending)



6.1-4 bq24074 Solar Charger Schematic (Permission pending)

After continuing to improve the prior schematic shown, the PCB schematic shown below was completed.

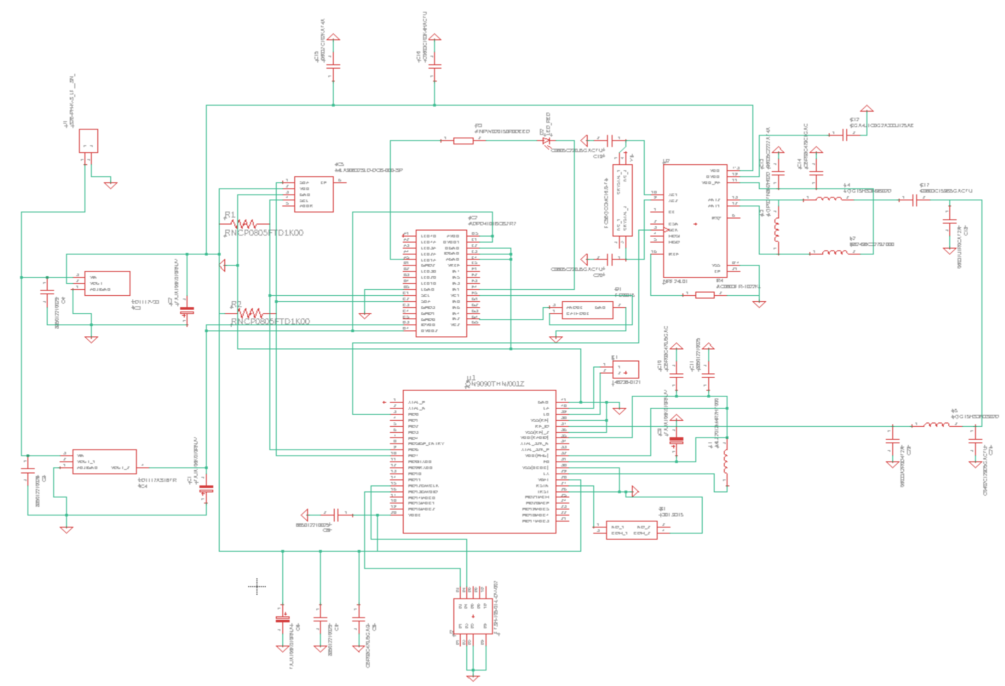


Figure 6.1-5 PCB Layout (Plan A)

This design implemented two buck converters to supply the two main voltage levels required for the various components. Some of the other changes included a 9 pin header in order to write to the microcontroller, a wifi module connected with a crystal oscillator, a reset switch, and many coupling capacitors, resistors, and inductors. This design was ultimately changed because many of these parts were unavailable for purchase at the time of design completion. Another reason for the departure from this design is because many of these components were emerging pieces of technology. This originally was deemed a positive aspect when considering parts, but became an issue with regards to troubleshooting and data available on the parts. Encountering this problem, we decided on using parts that have been around for longer, as they would have more data regarding how they work and issues that have been resolved. Implementing these different parts, the following design was decided upon.

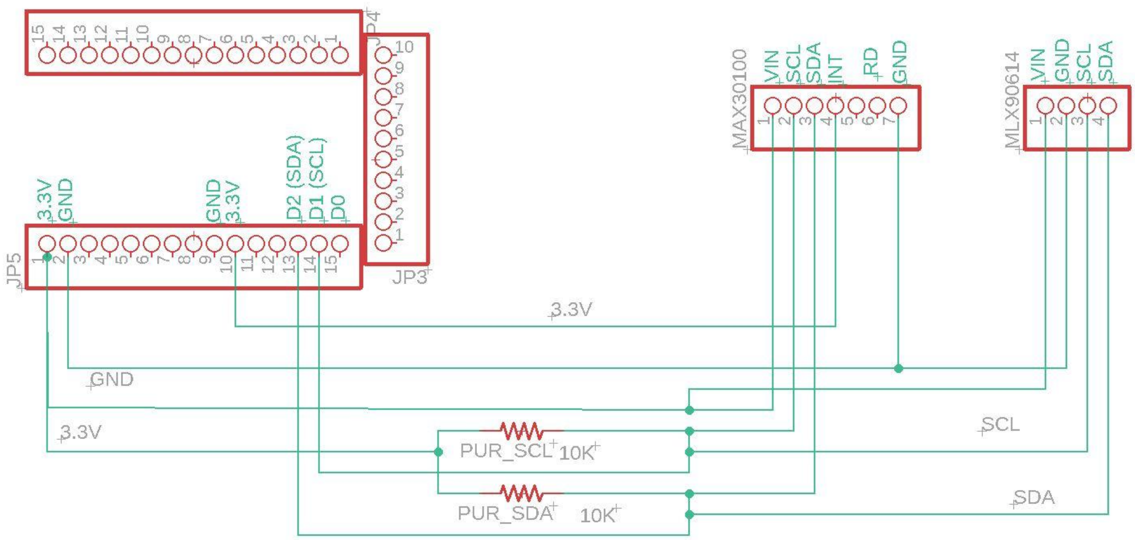


Figure 6.1-6 PCB Layout (Plan B)

This design simulates the same layout of the prototype that has been breadboard tested throughout the Fall semester. The PCB is designed for every part to be a through hole part, with the exception of the pull up resistors for the SCL and SDA lines of the I2C bus, which are both surface mount. This design was approved by Professor Wei to allow for us to showcase our requirements and specifications outlined for our project.

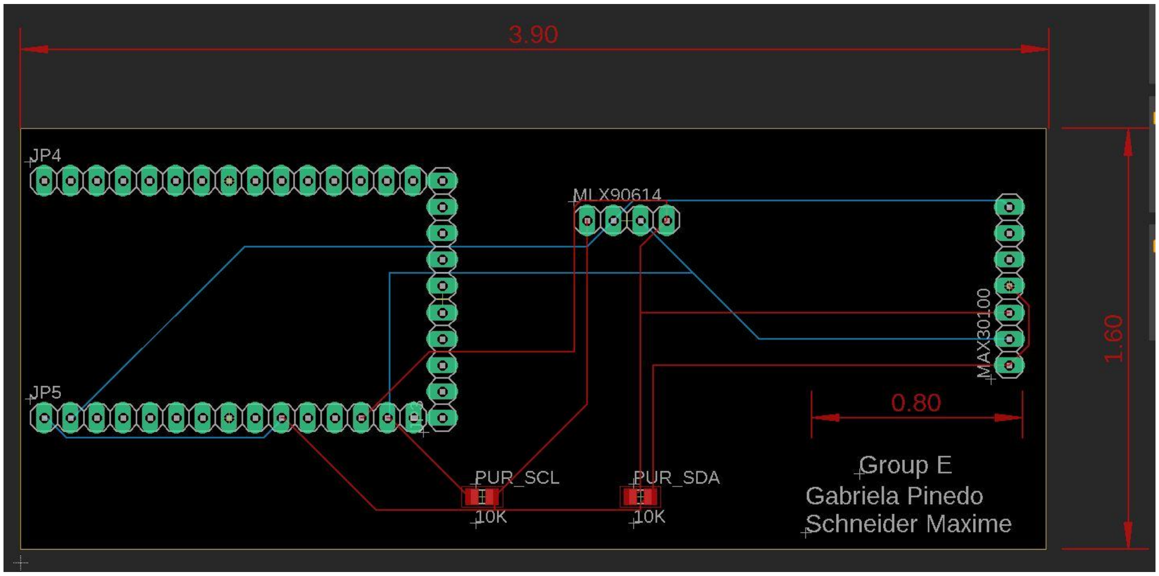


Figure 6.1-7 PCB Board Layout (Plan B)

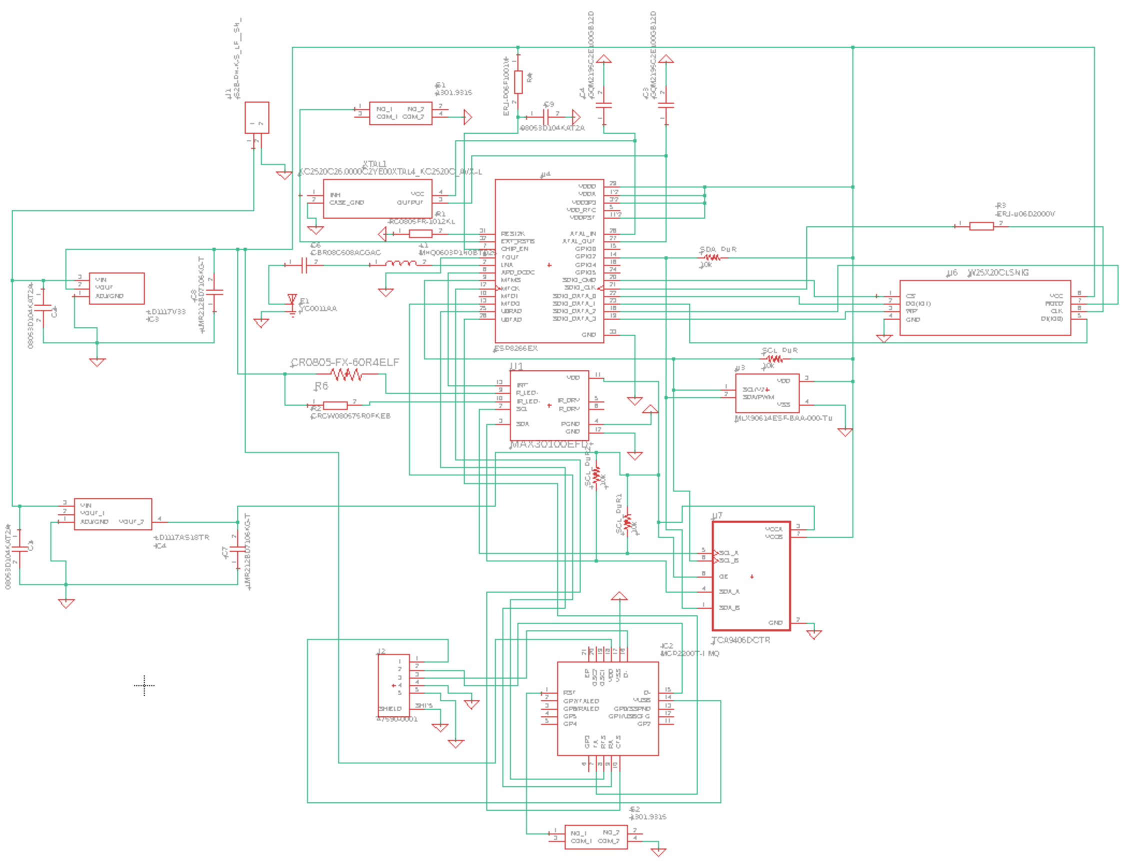


Figure 6.1-8 PCB Layout (Plan C)

The buck converters and JST connection were kept, but the vast majority of parts were changed to accommodate the new design. This included a new microcontroller, sensors, an additional reset switch, and a change to micro USB instead of pin headers for updating the microcontroller. Having settled on this new design, the board layout for it is shown below.

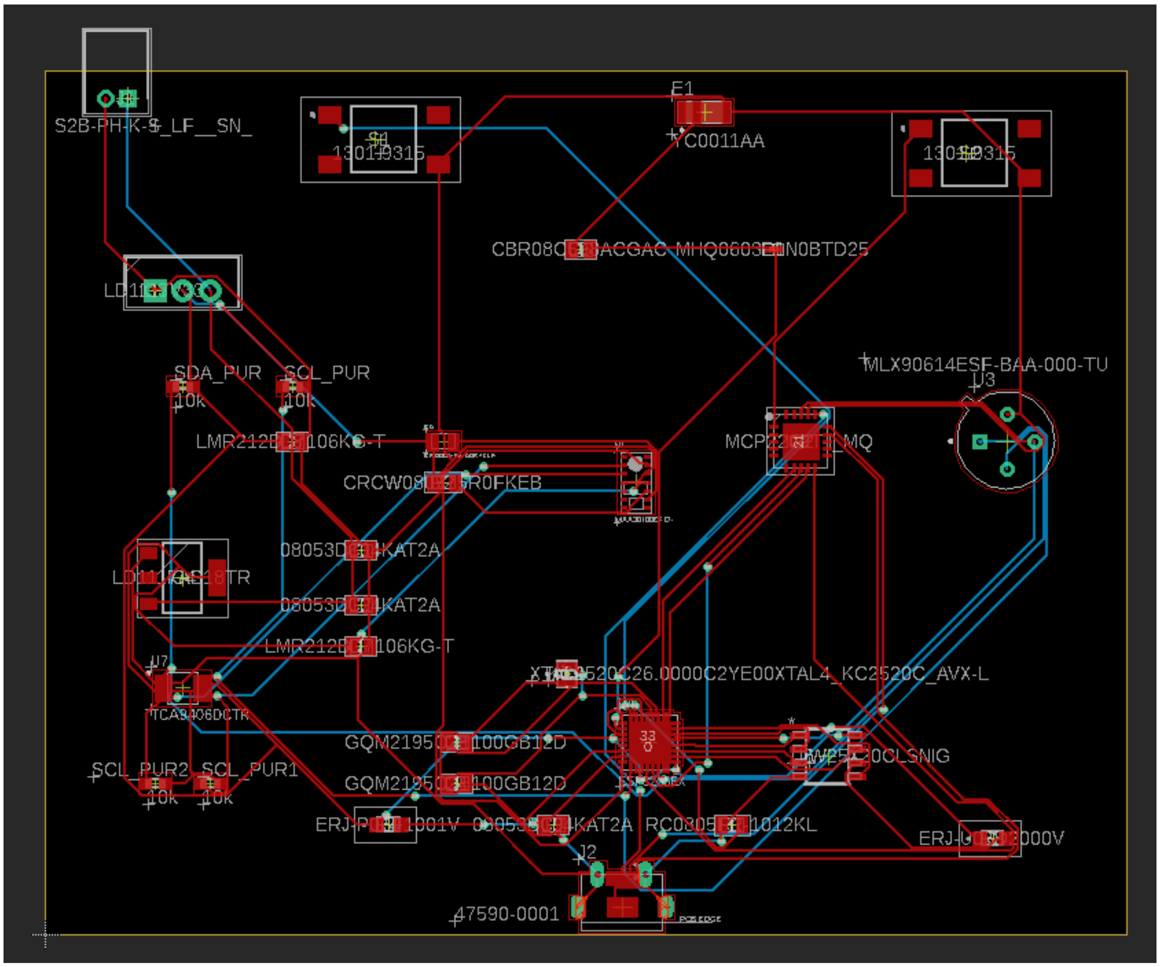


Figure 6.1-9 PCB Board Layout (Plan C)

6.2 PCB Vendor and Assembly

When considering which PCB vendor would best suit our needs, a couple of factors needed to be taken into consideration. Most notably is the type of PCB being manufactured. As our design for a wearable involved a decent amount of flexibility, we would have preferred a flex or rigid-flex PCB as opposed to a rigid only design. This will allow for greater ease in incorporating the completed PCB into our full design. Another factor of great importance is the price, as we would like to reduce costs so as to allow more users to afford the opportunity to use this device. Unfortunately, the cost of flex and rigid-flex was deemed too high for our self-funded group, and so rigid PCB designs were the only ones considered. A few different PCB vendors were taken into consideration when deciding which would suit us and our project best. Ultimately, we decided to split up the task of PCB fabrication into two parts. We had the PCB made at one location, and then the parts soldered at another. This enabled us to keep costs down while ensuring quality care was still taken into consideration.

Quality Manufacturing Services, Inc.

The first vendor we considered to assemble our PCB is Quality Manufacturing Services, Inc. located in Lake Mary, Florida. The fact that they are located a short distance from us helped with maintaining contact if any more PCBs needed to be assembled. They also have quite a reputation as a business that provides the best value for their customers, working to ensure an honest and transparent process from start to finish. Having a business close to us that has, as they say, the hallmarks of integrity, experience, and value would ensure a smooth process in refining the details of our PCB design. The fact that one of the many business types they manufacture for are medical companies bodes well and that means they have experience in working with some of the components we included in the PCB design. Overall this is a great choice for a PCB vendor, but other comparisons still need to be made in order to ensure the best choice for our project.

Rush PCB

The next vendor we considered is Rush PCB, a vendor located in San Jose, California. Due to this, one factor to immediately consider was the increase in shipping costs to send it from there to our group in Florida. This would increase the cost of production for our project, and so was seen as a detriment to this choice. However, Rush PCB does offer the benefit of having a vast portfolio of different PCB assembly options, based on whether they need to purchase the parts as well or if we purchase the parts, in addition to whether or not the PCB design requires a rigid, flex, or rigid-flex design. Although this vendor does not have a baseline price for PCB assembly, getting a quote is easy by emailing them the BOM and Gerber files. The flexibility of design with this vendor would make them a great choice to work with in order to complete our project design.

Advanced Assembly

Our final contender for the PCB assembler is Advanced Assembly, located in Aurora Colorado. Their focus is on quick turn PCB assembly, allowing for a production time of less than a few days. They also offer free DFA analysis, helping in ensuring that the completed design is error free. Advanced Assembly also focuses on flexibility, allowing different types of PCB to be produced in addition to working side by side with the consumer to ensure everything is completed in an appropriate and timely manner. Since we at first were looking into using a flex or rigid-flex design for our PCB, Advanced Assembly seemed like a good choice for our purposes. Interestingly enough, they do also offer student discounts for PCB production, and so that was a plus for considering them as our PCB vendor.

Based on our comparisons between the three vendors, the suitable choice for us seems to be Quality Manufacturing Services, Inc. They have a great rapport with working with UCF students, working with them along every step. This is beneficial for us as having a chance to work together with a company is preferable to not being able to discuss project details and changes with our vendor. Since we were able to bring the PCB board and the components to them, assembly was free of charge as well, which greatly assisted us in maintaining a lower overall cost.

PCBWay

For fabrication of the board, we went with PCBWay, a PCB prototype and Fabrication manufacturer based in China. The way to build a PCB is by uploading the proper Gerber files on their website, where they will then showcase an actual picture of what your design will look like before the order is placed. This vendor is also very affordable, coming at $20 for the 5 board minimum required for an order. This is the vendor we used to order the Plan B PCB.

6.3 Final Coding Plan

For our plan, we decided to go on a scrum basis in order to program our application and to test all of the features that need to be met. We worked on a 2 week sprint basis, and tried to list a set of goals that we wanted to reach in regards to the software aspect of the project. A few goals set in mind are listed as follows:

- Read data off PPG
- Calculate proper vitals off sensors' data
- Generate a PDF or other document to be downloadable off application with the data measured
- Be able to send that PDF straight off the mobile application
- Make sure application opens up within 10 seconds of attempting to open it on mobile device
- Be able to use mobile application on both iOS and Android Devices
- Alert the user of any abnormalities found in data collected
- Alert the user of any misuse of the glove and to attempt to retry to collect data once stable enough to do so.
- Ask user if they would like to contact the authorities if any irregular heart issues were to be detected
- Automatically call authorities if the user does not answer within 1 minutes after asking the user if they were in any danger and wanted to contact authorities.

After looking at several IDEs and coding spaces, we felt the most comfortable with using Visual Studio Code. Visual Studio code is not only a clean space to program, but it is also known to have several plug-ins for specific languages that can be useful when trying to debug and find errors quickly. Everyone who has programmed previous to this class is familiar with Visual Studio code and so it only makes sense to continue on with the well known IDE rather than learning how to use another one for the sake of time.

Another IDE we utilized for the testing process is Android Studio. This is needed as we required our mobile application to work on both iOS and Android devices. Android Studio is capable of downloading and running emulators of several android SDKs and devices. This is useful since instead of linking devices onto our computers and then needing to wait for the application to fully download only to see whether the build was successful or not, we are able to test with digital devices that still were like if we were doing it the longer way. This saves us a bunch of time and we were able to see our edits quicker and easier. This is a free IDE that is able to be downloaded on every OS: Windows, Mac and Linux. This is useful since some of our team members have Windows devices and the others have Mac devices, which are accommodating to both and are not required for either side to get a new device to be able to work on our project.

For iOS devices, we needed to download XCode. XCode is Apple's development kit. This kit includes all required things to manage and develop on any iOS device. Similar to Android Studio, we are able to download virtual iOS devices to test and debug our program before we decide to fully export it to run on a physical mobile device. Since we are using Dart as our main programming languages to develop our project, we will need to install the dart.dmg file to be readable on XCode to have it work on iOS devices.

The mobile application needed to process all of the inputs from the sensors and go through op amps and high pass and low pass filters before getting to the microcontroller. The microcontroller needed to be programmed such that it could process all of the data from the sensor inputs and then display them on the mobile application. We would most likely be using C or Java to implement this part of the program. Most if not all of us are knowledgeable in C so we used that programming language for this part.

Github was an essential platform that we used while in the development process of making our application. Github allows for several developers to add, edit and download code that is committed to our repository. In our group, two of us have used Github in the past while the other two members of our group have not. There was a little learning curve required for all of our members to get the gist of how Github works, but overall it was useful for everyone to know about it as this saved us all time on the programming parts of the project. Github allows for each developer to see any changes that have been done to the program. Developers can write comments on what changes they have done as well so that everyone can know which update has been done and on what part of the code has it been done to. Another thing that is useful about Github is the fact that every single commit is saved on the one project folder, so in the case of us getting to a point where we do not know where we went wrong on our code, we can restore our status at a certain point where we know things are working. This will help us from potentially restarting our project over again from the beginning, which would be a lot of wasted time that we do not have to spare.

In order to finalize any requirement to be listed as passed and completed, we came up with several test cases on our own to try to see if in any occasion the application no longer works how it's meant to be after doing specific tests. If we have successfully found a loophole to get around anything then it is called a bug. We worked thoroughly to fix any bugs we found and documented them on how we found them and with any solution we came up with to get rid of it. We did this without further breaking any other part of our application's program. It is important that this is done just in case any user accidentally makes any mistake with the application and needs help with handling it in the future.

7. Project Prototype Testing Plan

This section goes over the prototype testing plan used for the hardware and software design of the project. Testing was done to make sure the design is actually operational and viable. A safe and proper environment has been secured to run any tests that are or may be needed in order to try to fix any issues that may arise. The goal was to have several stages of the prototype that were constantly documented and ensure that all of the requirements were met. The next goal was to then further try to improve the design by adding more features that improve the design through user friendliness as well as efficiency. When testing the prototype, it was intended for a set group of volunteers of different ages, genders, heights, and sizes to be obtained to determine that the product is useful for a diverse consumer pool.

7.1 Hardware Test Environment

Testing the hardware environment began before we ordered products from manufacturers. The hardware environment had to be simulated using simulation applications such as Eagle and Multisim. Eagle is an easy to use application; it grants access to editing schematics for the project and is used to create the PCB ensuring all the products needed for the device can fit on the PCB board and check if they actually communicate with each other. In addition to Eagle, Multisim is also used to test the schematics for the project. Multisim saves a lot of time by being able to gather any unforeseen errors in the circuit schematics and design. This avoided any unwarranted damage to the hardware products. When testing the solar material, it had to be ensured that not only the sun is able to power the device but also that the solar cell charger and battery is efficient as well. Testing is done to make sure accurate monitored readings of the heart rate/telemetry, pulse oxygenation, skin temperature is being tracked as well.

The intended facility to test optical equipment including light emitting diodes (LED), photodetectors, and solar cells was the senior design lab in room A207 in the CREOL building on the UCF campus. The undergraduate lab in CREOL has been the actual primary testing room as the CREOL senior design lab does not have adequate instruments to test optical equipment. All equipment listed in this section except for the near infrared (NIR) LED are provided by the CREOL laboratory. The senior design room in the engineering 1 building on the UCF campus was used to test other electrical elements used in the project.

For our Plan B and C layouts, we breadboarded and tested in the senior design lab found in ENG1 456. Using all of the electrical equipment such as multimeters and oscilloscopes to measure if the correct amount of current is being passed through each component has been a crucial part of this whole process. Another thing we used and were grateful that is available to us there is the wiring and soldering equipment which was used when we needed to work on our prototype throughout the semester. This was where we spent the majority of our time, as we were aware that we needed to spend time to figure out any issues we came across when figuring out the software and hardware connections and implementing it as a single working product.

7.2 Hardware Specific Testing

To test specific pieces of hardware we relied on the devices in the engineering lab to determine if any pieces were working well before placing it onto our design. We needed to wire and solder some components and in the process of doing so, ensure that there are currents and voltages still transmitting between each component so we knew that none of our parts had shorted while interconnecting them. We tested that each part also did its required function by checking in between the hardware and software and seeing the results that were being transmitted.

7.2.1 LED Testing

Testing the near infrared light emitting diode (NIR LED) ensures that it is emitting light at the proper wavelength and at the expected intensity. It also ensures that the LED is emitting at the proper power. These characteristics are compared to the datasheet given with the LED by Thorlabs.

7.2.1.1 Determining Spectral Characteristics

The spectral characteristics of the LED include the wavelength at which the LED emits as well as the full width half max (FWHM). The FWHM gives an idea of how much light outside the peak wavelength the LED is emitting. The equipment used to test the spectral characteristics of the LED is included in Table 7.2-1.

A current-limiting resistor is utilized in the circuit to test the LED spectrum characteristics to prevent overloading the LED and keep the current running through it within the operating limits (CREOL). The circuit used is shown in Fig. 7.2.1-1. To find the appropriate resistor value, the following equation is used:

$$R = (V - V_{MAX})/I_{MAX} \qquad \text{Eq. 7.2-1}$$

Where R is the resistor value in ohms (Ω), V is the power supply voltage in volts (V), V_{MAX} is the maximum forward voltage drop across the LED in volts (V), and I_{MAX} is the corresponding current through the LED in amperes (A). The 750 nm LED from Thorlabs tested has a maximum forward voltage of 2.1 V at 50 mA. For testing purposes, it is easier to use an existing resistor and rearrange the current-limiting resistor equation to find the power supply:

$$V = (R * I_{MAX}) + V_{MAX} \qquad \text{Eq. 7.2-2}$$

Using a 150 Ω resistor and Equation 7.2-2, the appropriate power from the power supply calculated is 9.6 V.

Table 7.2-1 Component list used for analyzing LED spectral characteristics

Component	Vendor	Item #
Protoboard	Circuit Specialist	PBB-272
NIR LED	Thorlabs	LED750L
150 Ω resistor	Digi-Key	150H-ND
2 Minigrabber test clip patch cord	Pomona Electronics	3781
2 Minigrabber to stacking banana plugs	Pomona Electronics	3782
Spectrometer	Thorlabs	Blue-Wave16-VIS-25
Fiber optic patch cable	Thorlabs	M35L02
LED mount	Thorlabs	S1LEDM
Lens tube	Thorlabs	SM1L10
Fiber optic mount	Thorlabs	S120-SMA
Zero size aperture	Thorlabs	ID25Z
2 Threaded 30 mm cage plates	Thorlabs	CP02
3 Optical mounting posts	Newport	SP-3
3 Optical post holders	Newport	VPH-3

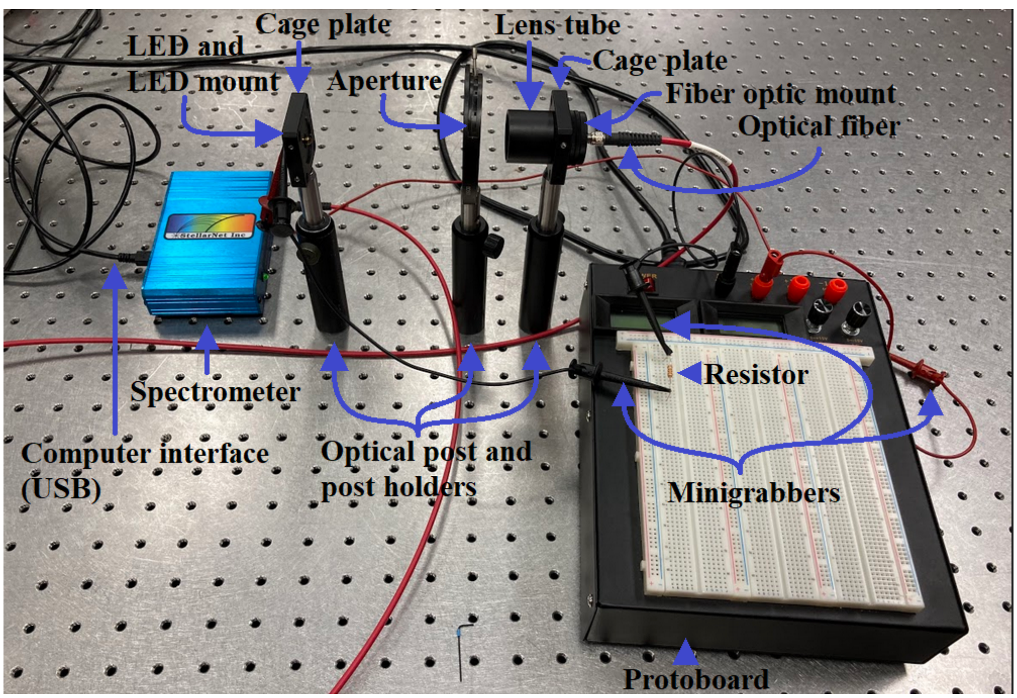


Fig. 7.2-1 Experimental setup for analyzing LED spectral characteristics

Aligned along the optical axis from left to right is the LED, aperture, lens tube, and optical fiber as shown in Figure 7.2-1. The LED is held in a cage plate using an LED mount. The fiber optic cable is held in a cage plate using a fiber optic mount. Attached to the fiber optic mount is a lens tube. The LED setup, aperture, and optical fiber setup are all held up using an optical post and optical post holder which are screwed into an optical table. The aperture is completely closed. The aperture allows the amount of light emanating from the LED to be adjusted to prevent the optical fiber from becoming oversaturated.

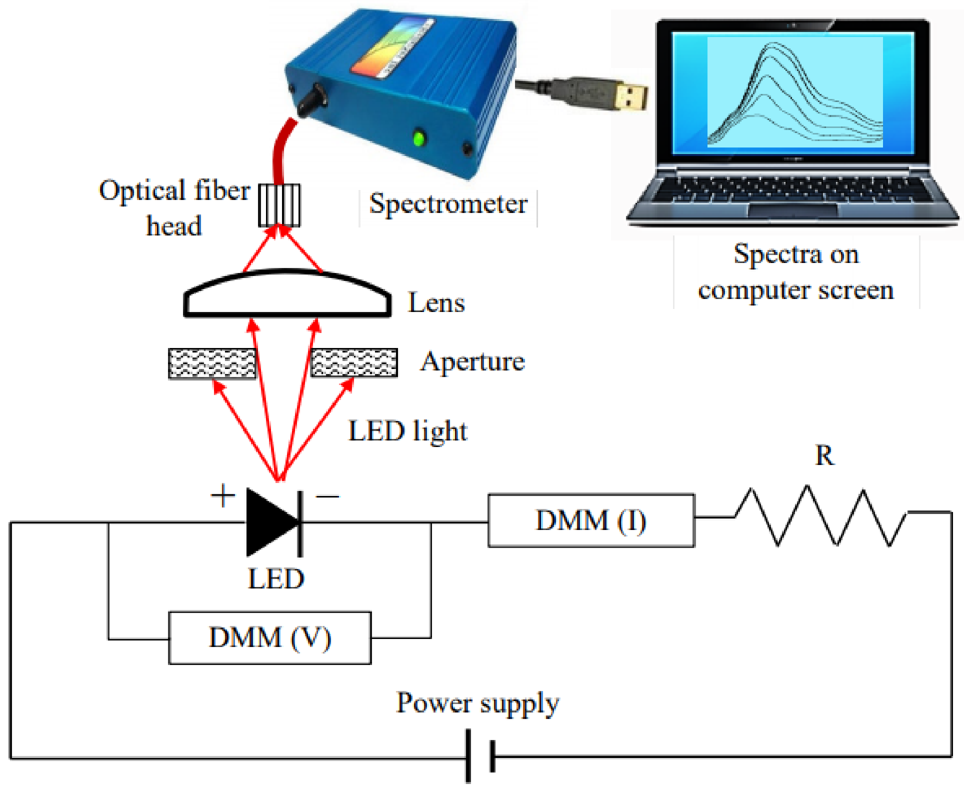


Fig. 7.2-2 Experimental circuit setup for analyzing LED spectral characteristics (CREOL)

Connected to the LED's anode and cathode are alligator clips. The other end of the anode connected alligator clip is connected to a protoboard after the system is finished being set up. The protoboard acts as the system's power supply. The other end of the cathode connected alligator clip is connected to one end of the resistor so that the LED and resistor are in series. The other end of the resistor is connected to ground. The circuit schematic is depicted by Figure 7.2-2; the physical setup omits the digital multimeters and aspheric lens. An aspheric lens allows the light to be collimated and more easily read by the optical fiber but is not necessary and therefore not used in the physical setup.

The fiber patch cable is connected to the spectrometer which is connected to a computer running "SpectraWiz" software. The final setup is depicted by Figure 7.2-1.

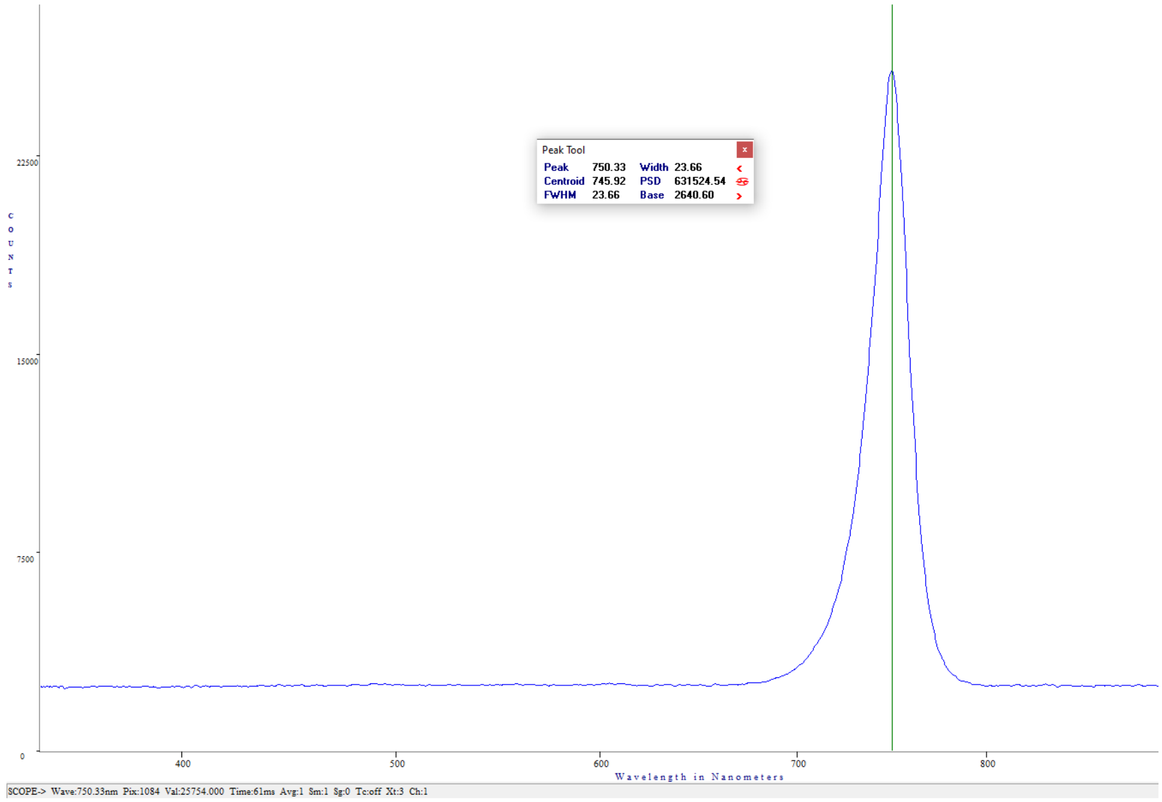


Figure 7.2-3 Wavelength spectrum plot of a 750 nm LED using SpectraWiz

After the system is set up, the power supply for the protoboard is turned on and has the positive and negative voltages set to 0 V. The anode connected alligator clip has the free end connected to the positive power strip of the protoboard. The protoboard's positive voltage is increased until the LED illuminates. The aperture is slowly opened to allow a small amount of light emitted from the LED to be read by the optical fiber head. The small amount of light prevents a high intensity light from damaging the fiber and charge coupled device (CCD) elements in the spectrometer.

The spectrum is monitored using the spectrometer and SpectraWiz software. The peak tool on SpectraWiz is used to locate the point of the spectrum's maximum count which indicates the peak wavelength as shown in Figure 7.2-3. The proper peak wavelength given by the LED datasheet is 750 nm ± 20 nm with a bandwidth of 23 nm. The measured LED is perfectly in range with a peak wavelength of 750.33 nm and a bandwidth of 23.66 nm.

7.2.1.2 Determining Optical Power

The equipment used to test the optical power of the LED is included in the following table, Table 7.2-2:

Table 7.2-2 Component list used for analyzing LED optical power

Component	Vendor	Item #
2 Alligator clip connectors	Pomona Electronics	2240
2 Auto-ranging digital multimeters (DMM)	Circuit Specialist	HH2205D
2 Cage plate assembly rods	Thorlabs	ER-P4
LED mount	Thorlabs	S1LEDM
Lens tube	Thorlabs	SM1L10
Magnetic mount	Newport	MB-2
2 Minigrabber test clip patch cord	Pomona Electronics	3781
2 Minigrabber to stacking banana plugs	Pomona Electronics	3782
NIR LED	Thorlabs	LED750L
3 Optical mounting posts	Newport	TR5
Optical post holder	Newport	VPH-3
Optical Power meter	Newport	1919R
Photodiode sensor	Newport	918D-SL-0D3R
Plano convex lens	Thorlabs	LA1422-A
Protoboard	Circuit Specialist	PBB-272
Right angle post clamp	Thorlabs	RA90
2 Threaded 30 mm cage plates	Thorlabs	CP-02
150 Ω resistor	Digi-Key	150H-ND

The resistor used is the current limiting resistor to keep the current within the LED's operating limit. The setup for determining the LED's optical power is similar to the setup for determining the LED's spectral characteristics but without the aperture and spectrometer.

Aligned along the optical axis from left to right is the LED, plano convex lens, lens tube, and power detector as shown in Figure 7.2-4. The LED is held in a cage plate using an LED mount. The lens is held in a cage plate using a lens mount superimposed with a lens tube. This lens allows the light to be collimated and more efficiently read by the power meter. Cage assembly rods hold the two cage plates together so that the system is properly aligned along the optical axis. The LED and lens system is held up using an optical post attached to the lens mounted cage plate. The optical post is screwed into a mounting base plate that is secured to an optical table. The power detector is attached to an optical post and held in place by a right angle clamp. The clamp is attached to another optical post and secured to a base plate screwed into the optical table.

Connected to the LED's anode and cathode are alligator clips. The other end of the anode connected alligator clip is connected to a protoboard after the system is finished being set up. The protoboard acts as the system's power supply. The other end of the cathode connected alligator clip is connected to the negative probe of a current measuring digital multimeter. The other probe is attached to one end of the resistor so that the LED, current measuring multimeter, and resistor are in series. The other end of the resistor is connected to ground. A voltage measuring multimeter is placed in parallel with the LED with the positive probe attached to the anode and the negative probe attached to the cathode. The circuit schematic is depicted by Figure 7.2-5.

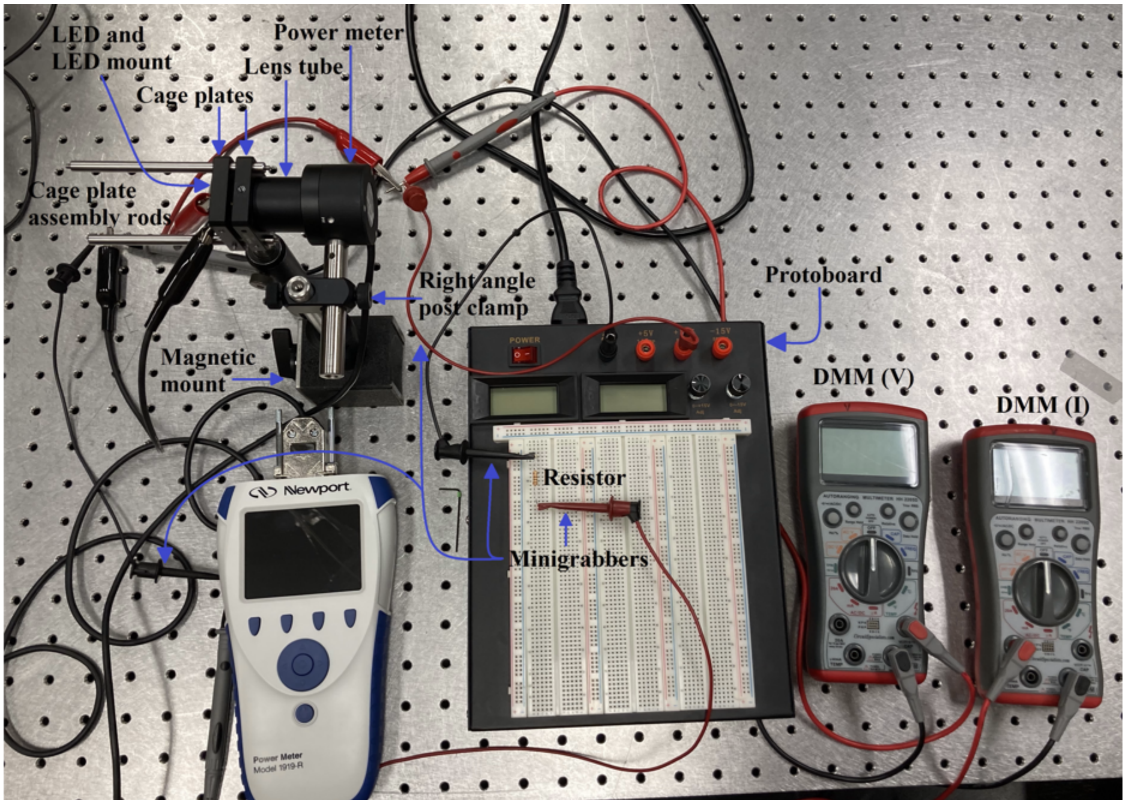


Fig. 7.2-4 Experimental setup for analyzing LED optical power

After the system is set up, the power supply for the protoboard is turned on and has the positive and negative voltages set to 0 V. At this point, the power meter should also be activated to read the power of the light output by the LED. The anode connected alligator clip has the free end connected to the positive power strip of the protoboard. While monitoring the current measuring DMM, the protoboard's positive voltage is increased until the current is near the LED operating limit, 50 mA, unless the voltage measured by the voltage measuring DMM reaches 2.1 V–the maximum forward voltage–or the supply voltage from the protoboard reaches 9.6 V as calculated earlier using Equation 7.2-2.

A properly working LED750L element should emit an optical output power of approximately 18 mW when it is at its operating current of 50 mA.

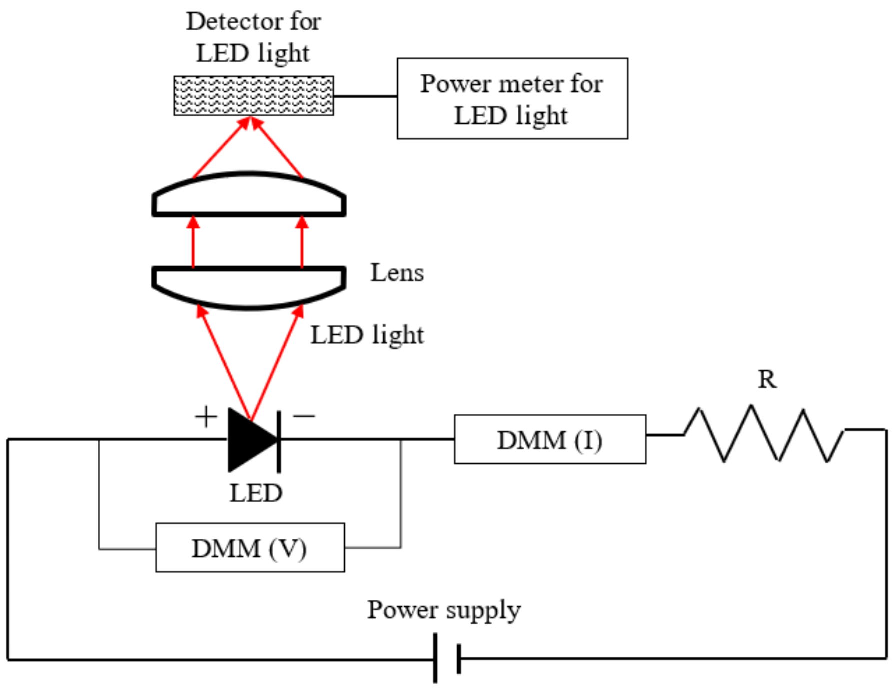


Fig. 7.2-5 Experimental circuit setup for analyzing LED optical power (CREOL)

The data collected is displayed in Fig. 7.2-6. The threshold voltage is determined using this collected data and extrapolating the slope of the I-V from the medium voltage region to the voltage axis; the intercept on the voltage axis, as shown in Fig. 7.2-7, determines the threshold voltage, which is calculated to be approximately 1.5 V.

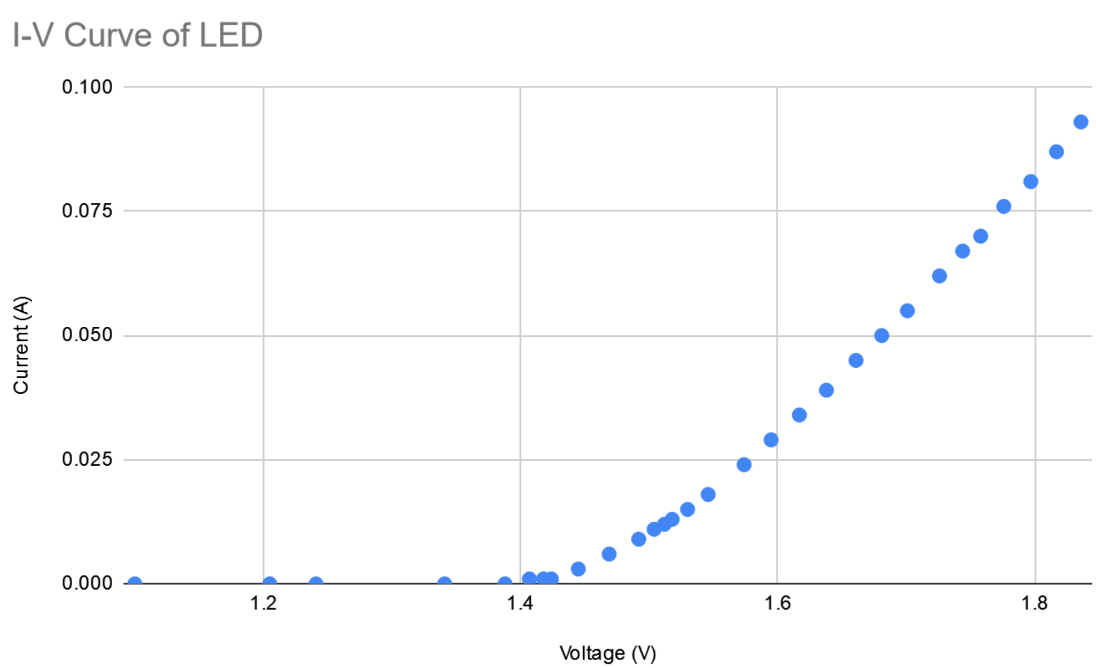


Fig. 7.2-6 I-V characteristics of the LED750L plotted

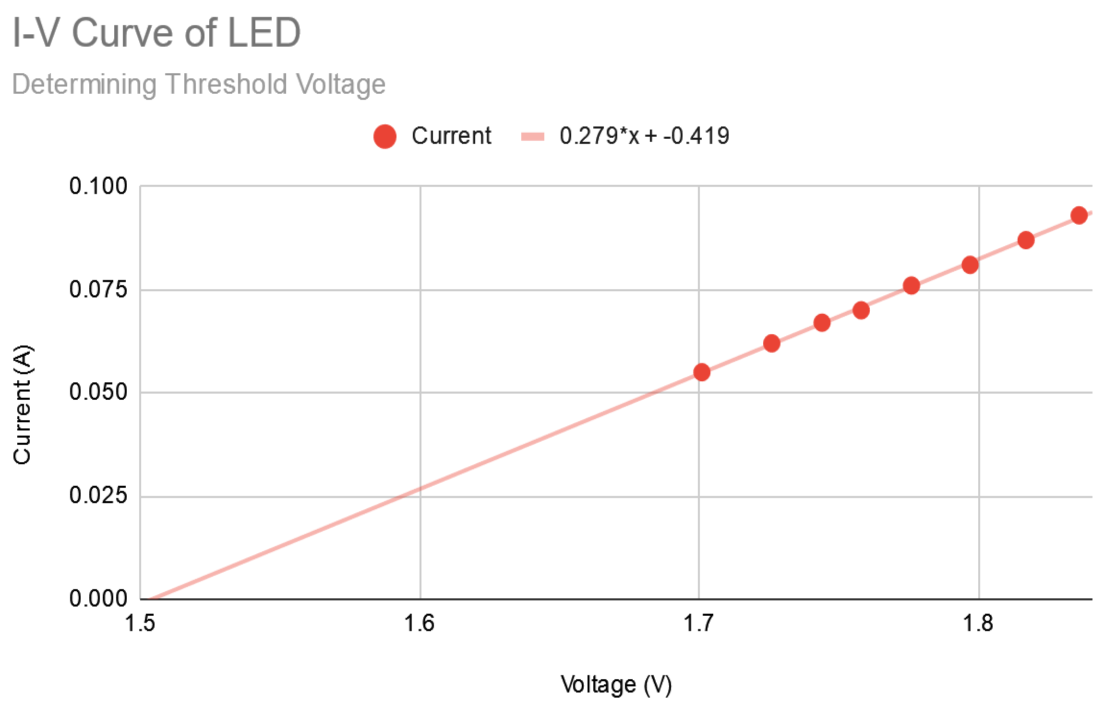


Fig. 7.2-7. I-V points of the LED750L past the medium voltage region plotted with trendline

7.2.2 Solar Cell Testing

The solar cells need testing to ensure they are outputting a sufficient amount of power as well as a sufficient conversion rate for the project. As the solar charger regulates an output of 4.4 V, the solar panel should be able to output at least amount of voltage. Determining the evaluation of a solar cell's performance primarily depends on finding the fill factor and the conversion efficiency. It can also be beneficial to determine the solar cell IV characteristics and dark current. The data collected is compared to the solar panel's datasheet, if the datasheet provides the values; the data sheet does not provide all values found during testing. All of the equipment except for the solar panel is provided by the CREOL undergraduate lab at UCF. The equipment used to test the solar cells is included Table 7.2-3.

Table 7.2-3 Component list used for analyzing solar cells

#	Component	Vendor	Catalog Number
1	Solar panel	AnySolar	SM850K12TF
1	Fiber optic cable	Dolan-Jenner Industries	2112007024
1	White light source	Dolan-Jenner Industries	4715MS-12W-B10
2	Digital Multimeter	Mastech	MS8264
2	Plano convex lens	Thorlabs	LA1422-A
2	Optical mounting post	Newport	SP-6
1	Resistor box	Elenco Electronics Inc.	RS-500
6	Right angled clamp	Thorlabs	RA90
1	Optical Power meter	Newport	1919R
1	Photodiode sensor	Newport	918D-SL-0D3R
1	Neutral density filter	Thorlabs	ND20A
5	Optical mounting post	Newport	SP-3
1	Lens mount	Thorlabs	LMR1S
1	Lens mount	Thorlabs	SMR1
1	Bar-Type Optic Holder	Edmund Industrial Optics	55-530
1	Mounting base plate	Newport	B-2
1	Screw [base plate to post]	Thorlabs	SH6MS12
2	Screw [base plate to table]	Thorlabs	SH6MS15
1	Optical table	Newport	4940-CF-132057
1	Magnetic base	OptoSigma	MB-CB-PB
1	Optical post holder	Newport	VPH-3
6	Minigrabber to banana plug	Pomona Electronics	3782
1	Optical mounting post	Newport	SP-4

Procedure

The electrical circuit for the solar cells is constructed as shown in figure 7.2-9. The solar device is placed in series with a current measuring digital multimeter by connecting the common port to the negative solar panel connection using a minigrabber. The multimeter is placed in series with the resistor box by connecting one side of the resistor box to the milliamp port of the multimeter using another minigrabber. The other end of the resistor box is connected to the positive solar panel connection using another minigrabber. A voltage measuring DMM is then placed in parallel with the resistor box with the common port and voltage port connecting to either side of the box using more minigrabbers.

Along the optical axis, as shown in Figures 7.2-8 and 7.2-9, is the LED white light source, first lens, second lens, ND filter, power meter, and solar panel. Four of the elements are connected to three-inch optical rods held by a right angled clamp: the solar panel held in place by a bar-type optic holder, the power meter with an ND filter superimposed on top, and both lenses held inside lens mounts. The optical fiber cable is held inside a right-angle clamp attached to a four-inch optical rod. Along a six-inch optical post mounted to the table by a mounting base plate is the solar panel, power meter, and lens setups respectively. Next to this setup is another optical post held in place by an optical post holder and magnetic base. The other lens and optic fiber cable setups are connected to the second six-inch post.

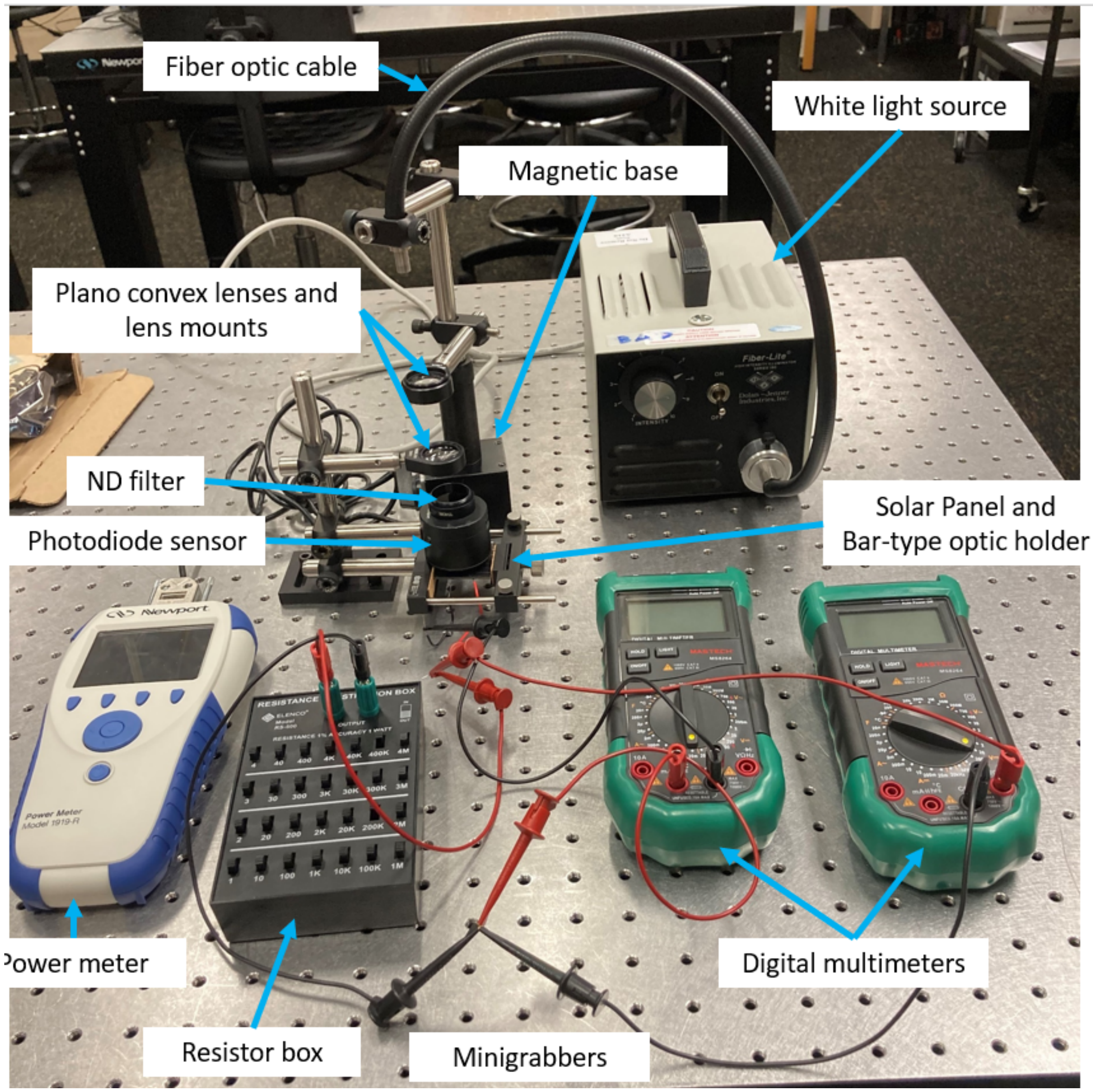


Fig. 7.2-8 Optical setup for measuring the power of incident light illuminating solar cells

The first lens is used to collimate the light from the white light source while the second lens is used to focus the light for optical power measuring. The ND filter is used to prevent oversaturation of the power meter and gain an accurate reading.

The dark current is found by having a minimal amount of light reaching the solar panel surface; the incident background light is reduced by having the white light source and room lighting turned off. The dark current (I_D) and dark voltage (V_D) are measured from the digital multimeters along with varying load resistances from the resistor box.

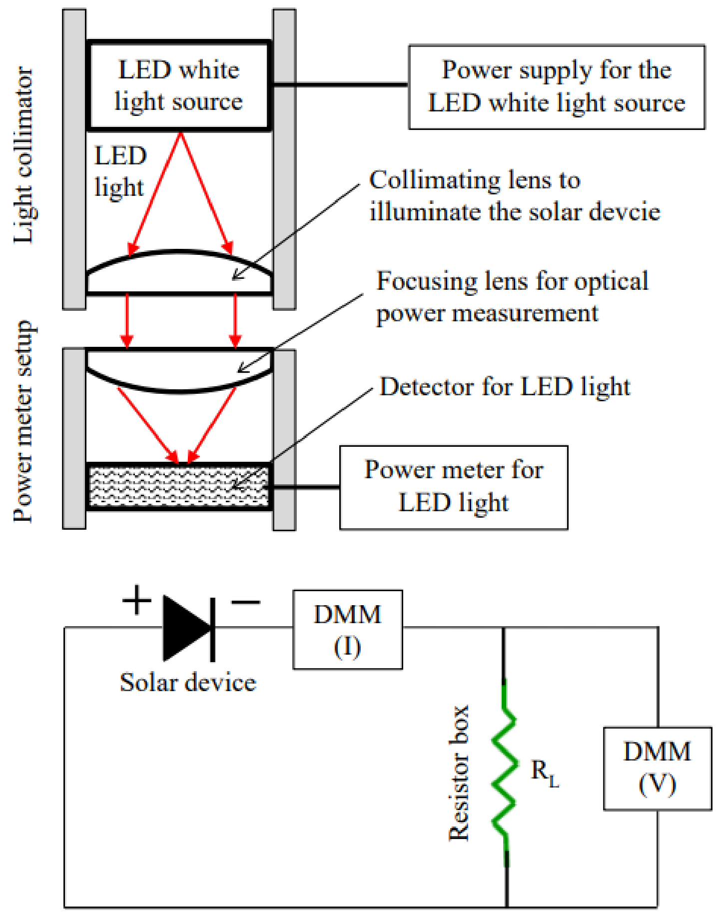


Fig. 7.2-9 Electrical circuit for measuring I-V and I-P measurements of solar cells (CREOL)

The I-V measurements for different powers of incident light are then determined. The white light source is turned on and illuminates the area of the solar panel. The power of the light is measured using the photodiode sensor through the focusing lens and ND filter. After removing the photodiode sensor and focusing lens from the light's path, the current and voltage are measured using the multimeters using the same resistances while determining the dark current and voltage. This process is repeated using three different power levels.

Data

This section includes the data measured during solar power testing.

Table 7.2-4 Power measured (P_M) from white light source

Power	P_M (mW)
P_0	0
P_1	0.77
P_2	1.2
P_3	1.88

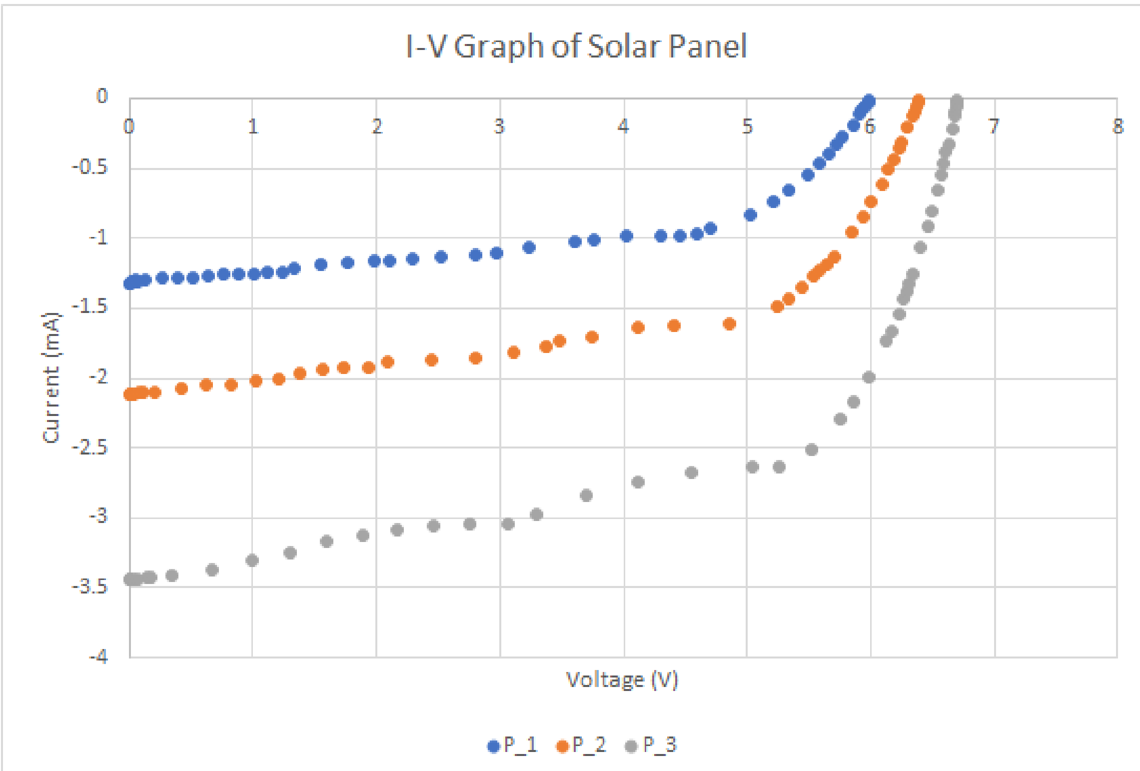


Fig. 7.2-10 I-V characteristics of solar panel SM850K12TF by AnySolar

Calculations

The power measured by the power meter (P_M) is altered by the neutral density filter to prevent oversaturation of the photodiode sensor. The actual power (P_A) of the incident light on the solar panel given in Table 7.2-5 is calculated using the measurements taken in Table 7.2-4 and modifying them based on the optical density of the filter as shown in equation 7.2-3:

$$P_A = 10^2 \times P_M \qquad \text{Eq. 7.2-3}$$

Since the dark power is measured with a minimal amount of light, the neutral density filter was not used and therefore remains the same as the measured power.

Table 7.2-5 Calculated actual power (P_A) of light source

Power	P_A (mW)
P_0	0
P_1	77
P_2	120
P_3	188

The actual solar cell current (I_A) and actual solar cell voltage (V_A) are calculated by subtracting the dark current or voltage from the measured current or voltage. The resulting data is shown in Fig. 7.2-10.

The fill factor (FF) is defined by Equation 7.2-4, where I_M is the maximum current, V_M is the maximum voltage, I_L is the photocurrent, V_{OC} is the open-circuit voltage, and I_{SC} is the short-circuit voltage:

$$FF = \frac{Area\ of\ actual\ maximum\ power\ rectangle\ (P_{AM})}{Area\ of\ ideal\ maximum\ power\ rectangle\ (P_{iM})} = \frac{I_M V_M}{I_{SC} V_{OC}} = \frac{P_{AM}}{I_L V_{OC}} \quad \text{Eq. 7.2-4}$$

The open-circuit voltage and short-circuit current are found by graphing the current versus the voltage, depicted by Fig. 7.2-10. The intercept of the V-axis yields the open-circuit voltage, V_{OC}, and the intercept of the I-axis yields the short-circuit current, I_{SC}, shown in Table 7.2-6. The product of the open-circuit voltage and short-circuit current yields the ideal maximum power, also known as the area of ideal maximum power rectangle. The ideal maximum power and actual maximum power, P_{AM}, are shown in Table 7.2-7.

Table 7.2-6. Open-circuit voltage and short-circuit voltage of the solar panel at different incident power levels

Power	V_{OC} (V)	I_{SC} (mA)
P_0	0.03	0
P_1	5.97	-1.32
P_2	6.37	-2.11
P_3	6.68	-3.44

Table 7.2-7. Ideal maximum power and actual maximum power of the solar panel at different incident power levels

Power	P_{iM} (mW)	P_{AM} (mW)
P_0	0	0
P_1	-7.88	-4.45

P_2	-13.44	-7.82
P_3	-22.98	-13.85

The fill factor can be calculated using equation 7.2-4 and the ideal maximum and actual maximum powers found in Table 7.2-7. The conversion efficiency (η) is defined using equation 7.2-5:

$$\eta = \frac{Area\ of\ actual\ maximum\ power\ rectangle\ (P_M)}{Power\ of\ the\ incident\ light\ (P_i)} = \frac{I_M V_M}{P_i}. \qquad \text{Eq. 7.2-5}$$

The power of the incident light, P_i, is equivalent to the actual power, P_A, found in Table 7.2-5. The conversion efficiency is calculated using P_A and P_{AM}. Both the fill factor and conversion efficiency are found in Table 7.2-8.

Table 7.2-8. Fill factor and conversion efficiency of solar panel based on varying powers of incident light

Power	FF (%)	η (%)
P_1	56.50	5.78
P_2	58.20	6.52
P_3	60.28	7.37

Observations

As the incident light increases, so does the fill factor and conversion efficiency. However, the data collected is vastly different from the information given in the SM850K12TF solar panel spec sheet. Using equation 7.2-5 and the conversion efficiency in Table 7.2-9, the maximum incident light power before complete saturation is 884 mW. However, the solar panel has been shown to provide more than enough power to power the project.

Table 7.2-9. Given data from SM850K12TF Solar Panel Spec Sheet

V_{OC} (V)	I_{SC} (mA)	P_{AM} (mW)	FF (%)	η (%)
8.29	35.1	221	70	25

7.2.3 MAX30100 LED Testing

Due to changes in the project, the MAX30100 replaced the LED750 LED and FDS025 photodiode. Although the spectral characteristics were able to be found, the I-V characteristics were limited in finding due to the MAX30100 being mounted to a development board.

Table 7.2-10 Component list used for analyzing the MAX30100 LED spectrum

Component	Vendor	Item #
Pulse Oximeter and Heart-Rate Sensor IC	Maxim Integrated	MAX30100
Lens tube	Thorlabs	SM1L15
Spectrometer	StellarNet	Blue-Wave 16 VIS-25
Fiber optic patch cable	Thorlabs	M35L02
Fiber optic mount	Thorlabs	S120-SMA
Triple Channel DC power supply	Keithley	2230-30-1
Power cable	Volex	E62405
Right angle post clamp	Thorlabs	RA90
Jumper wire set	Digi-Key	438-1049-ND
Cage plate	Thorlabs	CP03
Mounting base plate	Thorlabs	BA2
Screws	Thorlabs	SH6MS06
Optical posts	Newport	SP-6
Optical post holder	Newport	VPH-1.5
Minigrabbers	Pomona Electronics	501-1055-ND

Procedure

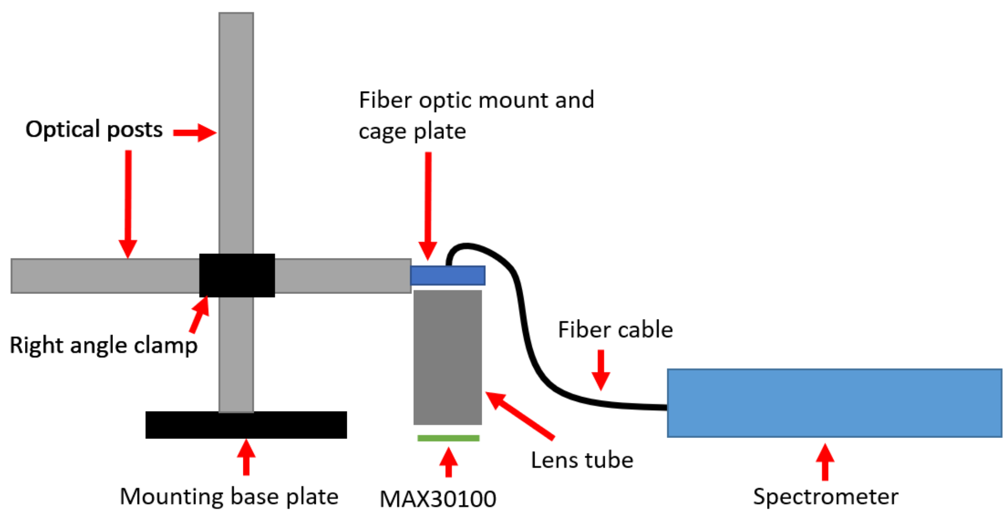


Fig. 7.2-11 Experimental setup for analyzing MAX30100 LED spectral characteristics

The pulse oximeter and heart-rate sensor (MAX30100) is connected to a RCWL-0530 breakout board as shown in Fig. 3.3-33. Due to this, the MAX30100 remained connected to a breadboard rather than being held in place with a lens mount as the LED750L was. A lens tube covered the MAX30100 to prevent outside light from being perceived by the spectrometer. A fiber optic mount was held in place by a cage plate above the lens tube to hold the fiber optic cable in place. The fiber optic cable was connected to the spectrometer which was connected to the computer. The full setup is depicted in figure 7.2-11. The software used to read the information read by the spectrometer was SpectraWiz. To turn the on the red and IR LEDs, the power supply output 3.3 V to the V_{IN} port of the breakout board. The IRD and RD ports were each connected to 150 Ω resistors which connected to ground.

Data

This section relays the data found while testing the spectral characteristics of the MAX30100.

Table 7.2-11. Data collected from SpectraWiz on the MAX30100

LED	λ_P (nm)	$\Delta\lambda$ (nm)
Red	659	18
Infrared	874	49

Due to the way the MAX30100 was programmed, there was a significant difference in power between the red LED and the IR LED. This can be seen in Fig. 7.2-11 where the count of red being observed is significantly higher than the counts of infrared. Unfortunately, this caused a skewed result of the IR full width half max as seen in Fig. 7.2-12.

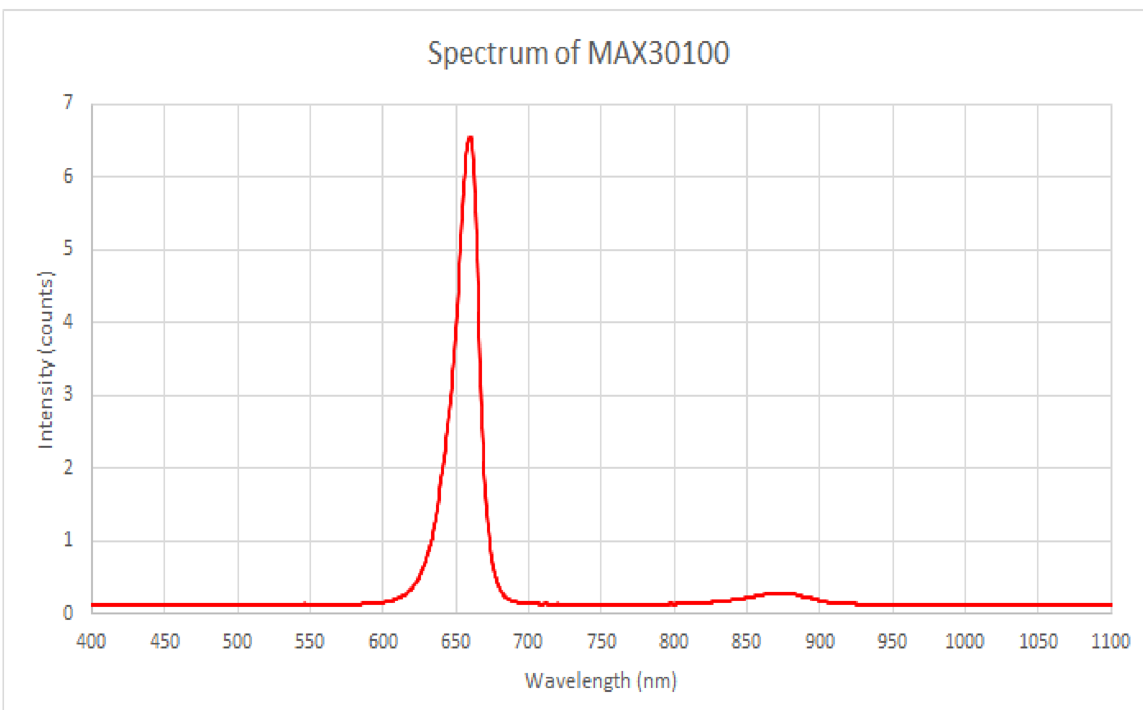


Fig. 7.2-11. Light intensity of the MAX30100 LEDs versus the wavelength in nanometers

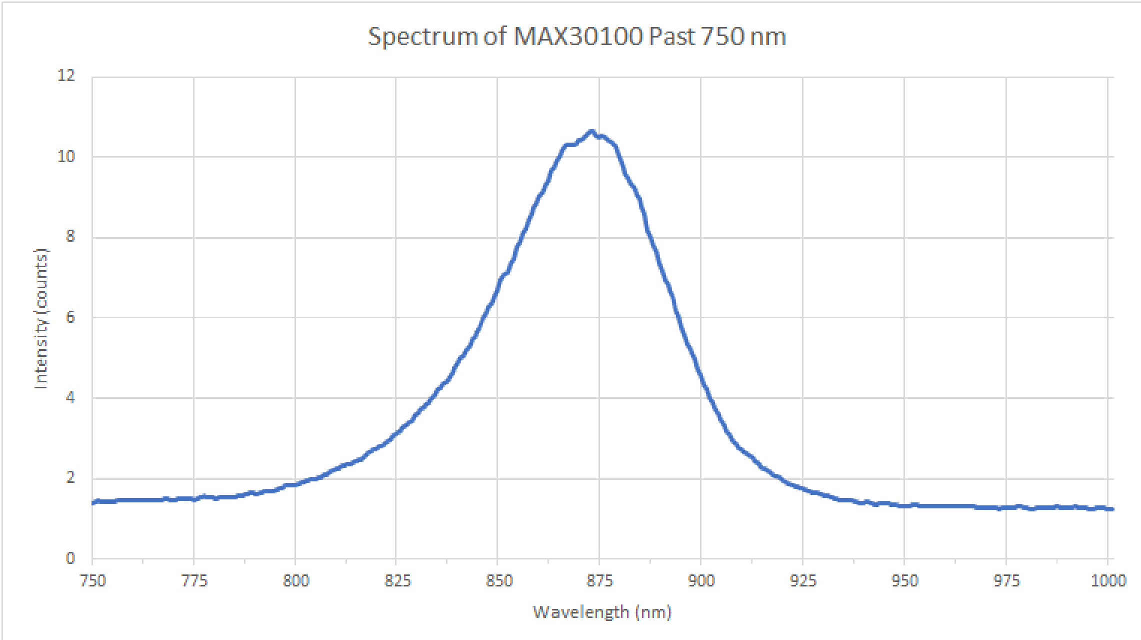


Fig. 7.2-12. Light intensity of the MAX30100 LEDs versus the wavelength in nanometers emphasizing the infrared light longer than 750 nm

<u>Observations</u>

The MAX30100 measured data gave an acceptable range compared to the expected data which can be found in Table 7.2-12.

Table 7.2-12. Given data from MAX30100 Spec Sheet

LED	λ_P (nm)	$\Delta\lambda$ (nm)
Red	660	20
Infrared	880	30

7.3 Software Test Environment

Anytime an engineer or programmer is creating any type of code or wishes to compile code, there must be tests and test cases run to make sure the code is efficient. The most proficient way to do this is usually to test your code oftenly as possible, sometimes even line by line to make sure nothing you are adding affects the code in a negative way. The test being run on the software environment is to ensure the mobile app is working 100%. Some key factors we tested on the software environment was making sure the monitored readings of the heart rate/telemetry, pulse oxygenation, skin temperature were displayed accurately from the device to the app in a timely manner. Additional testing software environment key factors included making sure all button options, routers and navigation bars are all properly usable on each use. We needed to test and make sure in case abnormalities had occurred during the monitored readings that the alert to the authorities actually pops up and gives a warning to the user that the authorities will be called and then actually contacts the authorities. Last test for the software environment was to make sure the user can actually send their health monitored readings to a recipient of their choice through email.

7.4 Software Specific Testing

Throughout the implementation of our mobile application, we needed to create a table that would list test cases of things we wanted our application to do. Once we believed we finished programming the part of our application that does a certain function, we then ran and tested with our hardware prototype to see if it did what it needed to do successfully. If we arrived at any hardships we documented what happened in the version of the program that we tested and then any potential solutions we can try to help fix them. We included all algorithms and data types that we utilized and for which part that we assessed them at.

Front-end testing for our software design was the easiest to test for our project. The frontend software design can be tested without the need of adding anything to the backend or database. However the frontend was a key part because this is what the user will be using directly to operate the device. Testing was done throughout the design as we add more to not only the software but also the hardware portion of our project. We made sure all buttons and options are not only displayed in a pleasant way for the user, but also made sure the button click events are operable to correctly move to the correct button click event destinations and pages. There are seven specific tests that we ran for our front end that we go over in the sub sections below.

Backend testing for our software design was definitely a challenge for our project. Backend testing differed from frontend testing in many ways. Frontend testing confirms the overall look and overall performance of the application, whereas backend testing confirms the application database. Within backend testing made sure information was actually being stored in the database. To do this we needed a strong database and structured query language (SQL). SQL is a query language that is designed to retrieve information from the database. More specifically it performs tasks such as updates data or retrieves data from the database. There are five specific tests that we ran for our back end that we go over in the sub sections below.

7.4.1 Unit Testing

Unit testing helps ensure the code is running efficiently on all lines of the code. A unit stands for the smallest piece of the software design that can be tested. It is the lowest of the testing levels that we will discuss. Unit testing is done by testing an individual chunk of code that runs according to the programmer and user expectations before moving on to other features of the code. This may involve input validations or calculations. This test also optimizes the code to ensure the fastest runtime achievable is met.

7.4.2 Acceptance Testing

After unit testing follows acceptance testing. Unit testing is primarily checking small pieces within functions, algorithms and the general line by line code. Acceptance testing is to guarantee that all those pieces are now able to execute all together without interrupting the last. Acceptance testing is used to ensure all features of the frontend are functioning. This can be done in many ways, but for Project N.I.H.M.S. We implemented these tests in two ways: internal acceptance testing and user acceptance testing. Internal acceptance testing, commonly referred to as alpha testing, was executed by my group partners who were not directly responsible for the actual programming of the code. User acceptance testing, or beta testing is performed by the user. In our project it was conducted by the general public who were willing to volunteer for our project testing results.

7.4.3 Visual Regression Testing

In between the unit testing and acceptance testing, we had visual regression testing. Visual Regression testing is completed by analyzing and comparing screenshots of different browsers and Os to see if any pixels have changed. Our application for our device is hosted on Android and iOS. Thus we had to make sure both phone applications, resolutions and screen sizes were tested to stray away from different or scrambled UI. For our project we used a couple different tools to run these tests. With the flutter application you are able to run both Android and iOS simulation to have a peak of how your phone application will look on both devices. Another tool we used to check for different screen sizes and resolution was Cypress.

7.4.4 Accessibility Testing

Accessibility testing is undertaken to enforce that our application is usable by people that may have any type of disabilities. People with disabilities have technology that assists them with operating software. Some of those softwares are speech software, screen reader software, screen magnification software and special keyboard software. We must ensure when creating our application that these features are included as well. This test can be done either manual or automated.

7.4.5 Performance Testing

Performance testing is conducted to promote stability and speed of our design. In addition to acceptance testing, performance testing is done to determine if the system was developed to meet the speed and responsiveness requirements of our team. Performance testing is done normally to find a term referred to as a bottleneck. Bottlenecks cause a single point that can hold back the overall performance of a code or project. This helps to illuminate exactly where our program may fail or lag. Some common performance testing performed was load testing and stress testing. Load testing is to test our applications under a specific load amount. We must test an expected number of users and profiles being used over a period of time. Another type of performance test is a stress test. Which is similar to load testing, but with stress testing we check the higher than expected number of users and profiles.

7.4.6 Integration Testing

Integration testing is done to check how the program is interacting smoothly after integrating the code. Small details such as a drop-down button list for our site might stop working after integrating pages and navigation bars together. End to end testing also consists of integration testing because this helps the testers fix any set up issues. Some specific things we tested for integration is the login page, user recipient email feature, and lastly the feature to have a year worth of data held.

7.4.7 Cross-Browser Compatibility Testing

Last type of testing we did was cross-browser compatibility testing. This enables users to have the same delivery of our phone application, regardless of whatever browser they are using. This allows for the phone application to work regardless of browser combinations, OS systems and devices. Testing cross-browser compatibility includes ensuring the design, accessibility and responsiveness of our design, regardless the device, is up to par. This test occurs during the development of our phone application and then periodically during pre release and release of our application.

7.4.8 Black-Box Testing

Black-box testing is a type of software testing where a tester with no insight of the design, structure and the code tests it. This test is also commonly referred to as specification based testing. This test is done to test that the engineering requirement specifications were met. It serves as a way to link the phone application with our intended customers. The output of the test is heavily compared to our expected output. This test helps reduce the number of errors within our coding system.

7.4.9 White-Box Testing

White-box testing is commonly known as glass box testing, testing the internal framework of our phone application. White-box testing directly tests the program logic. White-box testing is tested by a tester that does have insight of the code as opposed to black-box testing. A couple techniques used by white-box testing is statement coverage, branch coverage, and path coverage. Statement coverage keeps a bit of coding that will get compiled for errors before becoming part of the actual coding structure. Branch coverage technique checks every loop around if-then-else statements. Lastly, path coverage technique is used to make sure every single path of the application is reachable.

7.4.10 Structural Testing

Structural system testing is used to verify our project is running correctly. Structural system testing encompasses its own types of testing and each has its own focus for the backend test. First, stress testing, which is to check how much data will the backend be able to handle. Next, execution testing, which is to check the hardware and software to ensure our engineer specified requirements for accuracy and response time are being met. Then, recovery testing, which is making sure our data has some sort of backup data that is maintained to ensure we can always recover our design if we reach a point of a design failure. Followed by operation testing, which is to measure the completeness of our software design and to add any support code or mechanisms if needed. Lastly, security testing, which is enforcing our design, has data protection to keep security risk at a minimum .

7.4.11 Functional Testing

Functional testing helps check the functionality of our design. Functional testing follows the procedures of quality assurance. Quality assurance is to pay attention in every step of our design from delivery to production to certify our engineer specified requirements are followed. This test ensures the SQL user commands and SQL search commands are compiled with accuracy. Following functional testing and quality assurance requires us the developers to prioritize features of our design to to test first. Most important feature above all else will be getting accurate reading and then being able to send those readings to a recipient of choice as needed.

7.4.12 Non-Functional Testing

Non-functional testing follows different types of testing within its own. First, availability testing, which tests the device and software design will be available 24/7 without failure no matter the time of day or night. Next, compatibility testing, which tests to make sure the backend executes on the user devices no matter the OS, device or platform. Lastly we have reliability testing which tests our design life cycle ensuring it takes a short time to repair if there are any types of failure to our device.

8. Administrative Content

This section of the document will show the time management our team kept from Senior Design 1 to Senior Design 2. In order to keep up with the progress of our project, we set several milestones and deadlines for when we wanted to have those completed. It will also host the team budget and our search for a sponsor for our device. Most of our meetings within the time period of us being in Senior Design 1, were done virtually either via zoom or discord chat. We know that during the building and testing parts of Senior design 2 we would need to be meeting in person as we cannot work as a team to virtually build a physical product. These in person meetings may change due to the coronavirus, as if anyone were to be sick we would have to pause some of our meetings to ensure the safety of all of our members.

8.1 Milestone Discussion

The table below are our project milestone tables: one for our semester in Senior Design 1 and the other for our semester in Senior Design 2. They both display the timelines of what our team plans to complete in order for us to succeed with our overall project from the beginning of Senior Design 1 in the Spring of 2021, to the end of Senior Design 2 in the Fall of 2021. These dates are goals that are tentative and may be flexible to move around as some parts of our project may take a longer or possibly even shorter amount of time to complete. If we keep up a good pace of working as a group towards our goals, there is no doubt that we will be successful in both of these classes. If we were to fall behind on any goal that we are attempting to reach, we will attempt to hold “hackathon” style meetings where we stay up with one another and work to try to meet our goal.

Senior Design 1 Main Goals:

- Select Project
- Contact Potential Sponsors
- Divide responsibilities within group members
- Research and Document
- Send updated progress on documentation of project to advisor
- Order parts for project and test if working
- Have a final document that describes our project in detail.

Senior Design 2 Main Goals:

- Finish testing all components to ensure working properly
- Begin building subsystems of final project
- Begin programming mobile application
- Test throughout any progress that has been made
- Document process throughout development timeline
- Finalize all building and have working prototype
- Demo working prototype to advisors and peers

As of today, we have managed to complete these milestones. Throughout the course of the semester we ran into a couple of difficulties with our updates on our document, but we managed to work together as a team and make extra time to fix our mistakes. After putting in more time into it, we were able to complete and edit our document in time for submission.

Table 8.1-1: Project Milestones Table for Senior Design 1

Date	**Milestone to be completed**
January 22, 2021	Solidify project goals and objectives
January 22, 2021	Start Research on Project
January 22, 2021	Begin Work on first Divide and Conquer Document
January 29, 2021	Finish first Divide and Conquer Document
January 30, 2021	Begin Work on updated Divide and Conquer Document
February 12, 2021	Finish updated Divide and Conquer Document
April 2, 2021	Finish 60 page project documentation
April 16, 2021	Finish 100 page project documentation
April 27,2021	Final Documentation Due (End of Senior Design 1)
April 28, 2021	Order Parts for Design of Project
May 9, 2021	Test all Parts are functional - reorder if necessary

These next milestones are what we are looking forward to completing in our final semester of our undergraduate education. We plan on completing our senior design 2 course with a working prototype that will be able to do all of the functions expected of it.

Table 8.1-2: Project Milestones Table for Senior Design 2

Date	Milestone to be completed
August 23, 2021	Begin work on Software
August 23, 2021	Begin work on Hardware
September 10, 2021	Test every part of project separately
September 23 , 2021	Test parts when connected together
September 30, 2021	CDR File Submission
September 30 - Dec 1, 2021	Test and Debug and work on any other unresolved issues
November 1, 2021	Middle Term Demo
November 12, 2021	8 Page Conference Paper & Project Committee Form
November 23, 2021	Finalize Project
November 26,2021	Project Showcase
November 23, 2021	Final Test
December 1, 2021	Presentation of Project
December 3, 2021	Last day of School
December7, 2021	Final Documentation Due

8.2 Budget and Finance Discussion

The table below shows the components of our design that we planned to order and be used in our project. Some components were not used, or were replaced for different components as we started testing and integrating all the components within the device. We were unable to get monetary sponsorship to help us with the cost of our project, and so as a group we decided to split the cost of the project evenly between the four of us.

Table 8.2-1: Budget Table

Item	Estimated Cost: ~300
IR Thermometer	$20
PCB	$50
Wi-Fi / Bluetooth Device	$50
PPG	$30
Microcontroller	$25
Fingerless Glove	$20
Photodiode	$35
LED	$15
Solar Panel	$10
Battery	$15

9. Project Operation

This section of the paper explains the correct operation of all functions for the Non-Invasive Health Monitoring System. Results of not following the instructions properly on how to operate this prototype may cause an inaccurate read of results.

Setting Up The Device:

1. Turn on N.I.H.M.S device
2. Download N.I.H.M.S mobile application on mobile device
3. Sign up with an account on mobile application
4. Connect wirelessly via WiFi from device to mobile phone
5. Move to Handling the Device: Collecting data instructions

Handling The Device: Collecting data

1. Ensure that hands are free of any dirt, dust, or water substances.
2. Insert hand in glove and make sure that it is pulled up all of the way to proper fit
3. Turn on device if not already on from setting up device
4. Open application and login to account
5. Hit get current results button on app
6. Stay as still as possible, refrain from making quick sudden movements for accurate results
7. Ensure throughout collecting data that hand is placed with proper pressure on PPG
8. Let go once at 100% complete with collecting data process
9. Users may take off the glove at this point to further use the mobile application to read/send results.

Handling The Device: Reading/Sending data

1. Users can view results via PDF on the mobile application after data has been collected. They can choose to send/share their PDF by hitting the share button that triggers sharing options from the phone.
2. From the sharing options screen, the user can save PDFs on their mobile device or share directly via email.
3. Once complete, the user will be prompted back to the home screen where they can log off or choose to keep using the mobile application.

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Appendix B - Datasheets

Microcontrollers:

https://www.nxp.com/docs/en/nxp/data-sheets/QN9090(T)QN9030(T).pdf

https://datasheets.maximintegrated.com/en/ds/MAX32665-MAX32668.pdf

https://www.st.com/resource/en/datasheet/stm32wb55cc.pdf

IR Thermometers:

https://www.mouser.com/datasheet/2/734/MLX90615-Datasheet-Melexis-953269.pdf

https://www.mouser.com/datasheet/2/734/MLX90632_Datasheet_Melexis-1595868.pdf

https://datasheets.maximintegrated.com/en/ds/MAX6627-MAX6628.pdf

https://www.mouser.com/datasheet/2/734/MLX90614-Datasheet-Melexis-953298.pdf

Batteries:

https://cdn-shop.adafruit.com/product-files/328/LP785060+2500mAh+3.7V+20190510.pdf

https://cdn-shop.adafruit.com/product-files/1781/C2253_-_ICR18650_2200mAh_3.7V_with_PCM_20140728_APPROVED_8.18.pdf

Bluetooth Modules:

https://www.mouser.com/datasheet/2/737/adafruit_flora_bluefruit_le-1915341.pdf

https://www.mouser.com/datasheet/2/368/Bluegiga_Technologies_BLE112_Datasheet-1203259.pdf

https://www.mouser.com/datasheet/2/986/Laird_09102018_Datasheet_-_BL651_prelim_v0_01-1590643.pdf

PPG/ECG Sensors:

https://www.ti.com/lit/ug/tidudo6b/tidudo6b.pdf?ts=1619915097075&ref_url=https%253A%252F%252Fwww.google.com%252F

https://www.richtek.com/assets/product_file/RT1025/DS1025-00.pdf

https://datasheets.maximintegrated.com/en/ds/MAX86150.pdf

Appendix C - Software

Backend Testing:

https://www.professionalqa.com/backend-testing

Software:

https://www.mobindustry.net/how-to-develop-an-app-for-the-internet-of-things-iot/

FERN:

https://medium.com/code-a-la-carte/getting-real-time-with-fern-stack-96b8a6e8f8e

Flutter:

https://enlabsoftware.com/development/why-startup-choose-flutter-for-cross-platform-app-development.html

Firebase:

https://www.cypressoft.com/post/choose-firebase-over-backend-development/#:~:text=Firebase%20provides%20the%20best%20back,project%20scalability%20and%20data%20security.
https://firebase.google.com/products/functions

W3C:

https://www.w3.org/standards/

Dart:

https://www.cleverism.com/skills-and-tools/dart/#:~:text=Definition%20of%20Dart,is%20an%20open%20source%20software.
https://en.wikipedia.org/wiki/Dart_(programming_language)
https://en.wikipedia.org/wiki/Ecma_International
https://dart.dev/guides/language/spec
https://www.geeksforgeeks.org/introduction-to-dart-programming-language/

Firebase:

https://www.testim.io/blog/front-end-testing-complete-overview/