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

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Abstract **— The goal of our project is to design a fingerless glove with solar cell technology that will be able to check heart rate, pulse oxygenation, skin temperature. We strive for the user to have full transparency of their health and allow them to share data collected with any healthcare professionals of their choice to track medical trends. Components include a microcontroller to communicate between the sensors and our database where the mobile application will read from and display results to the user. We aim to build an ergonomic and accurate device to ensure a positive, user-friendly experience.**

Index Terms **— Blood oxygen, heart rate, microcontroller, photoplethysmography, photovoltaic systems, sensors, solar panels, temperature sensors, Wi-Fi.**

I. INTRODUCTION

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, the 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.

Project N.I.H.M.S 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. Our device is a non-invasive wearable tech device that measures medical vitals such as heart rate, blood oxygen levels, and skin temperature of the user and transmits them to a mobile application via Wi-Fi. Our design is lightweight and made to fit the average hand.

II. HARDWARE OVERVIEW

The hardware components for Project N.I.H.M.S include a heart rate and blood oxygen photoplethysmography (PPG) sensor, infrared (IR) thermometer, Wi-Fi antenna, microcontroller unit (MCU), and solar panel. The MCU is responsible for transmitting the data recorded from the sensors to the database using Wi-Fi capability.

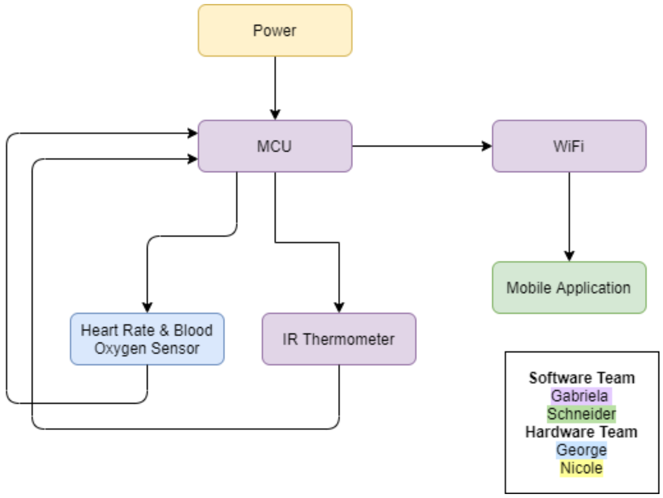


Fig. 1. Project N.I.H.M.S Hardware Block Diagram, showing the main components that make up our overall project.

A. Microcontroller

While researching for a microcontroller, we made a list of desirable aspects that we wanted for our microcontroller to have. To list a few, we wanted for it to be small to not take up as much space on the printed circuit board (PCB), able to work on low power to not consume as much energy from our power source, be able to connect to Wi-Fi easily for smooth data transmission, and to have I2C input pins to be able to create a bus to connect the sensors and transmit their data at the same time. When coming down to the decision, we went with the ESP8266EX microcontroller as it was easy to learn how to program, and it satisfied all of the other qualities mentioned previously. The ESP8266EX also has 16MB of storage, 128KB of memory, and an operating speed of 16MHz. The ESP8266EX microcontroller is programmable as it is on the NodeMCU development board.

B. PPG Sensor

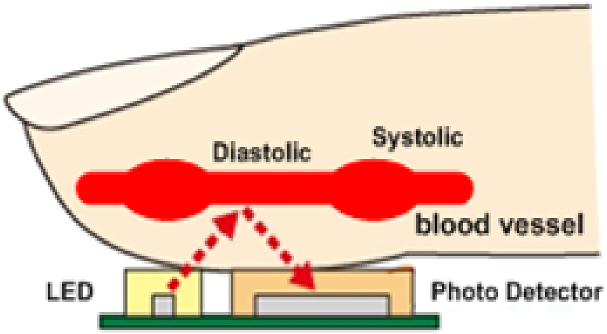


Fig. 2. Representation of how the module works and what is being measured [1].

Photoplethysmography (PPG) is an optical measurement technique that detects change in blood volume in the microvascular bed of tissue [2]. 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. The PPG sensor utilized for Project N.I.H.M.S uses a reflection mode design which places these components side by side; the photodiode measures the reflected light from the light source as shown in Fig. 2 [3].

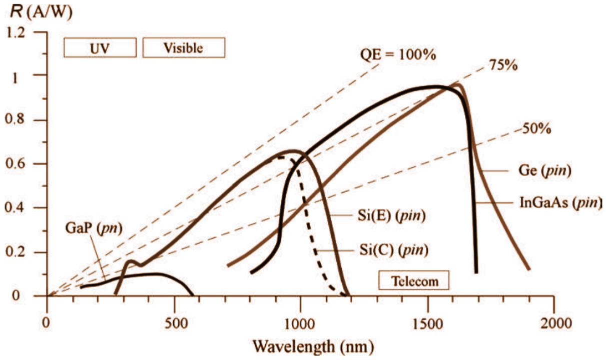


Fig. 3. Responsivity (R) versus wavelength comparison of an ideal photodiode and typical photodiodes [4].

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 placements [2, 7]. The technique satisfies most criteria for an ideal blood flow measurement technique, thus enhancing its desirability [3].

A photodetector converts incident radiation, light, into electrical signals [4]. This conversion into electrical signals is achieved through the absorption of photons which creates electrons. A photodiode's performance of photocurrent generated is given by its responsivity. This can be calculated by the following equation, (1):

$$R = \frac{Photocurrent\ (A)}{Incident\ optical\ power\ (W)} = \frac{I_{PH}}{P_O} \quad (1)$$

where I_{PH} is the photocurrent and P_O is the incident optical power. Responsivity heavily relies on wavelength and material composition, which is depicted as a graph in Fig. 3. An ideal quantum efficiency (QE) 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.

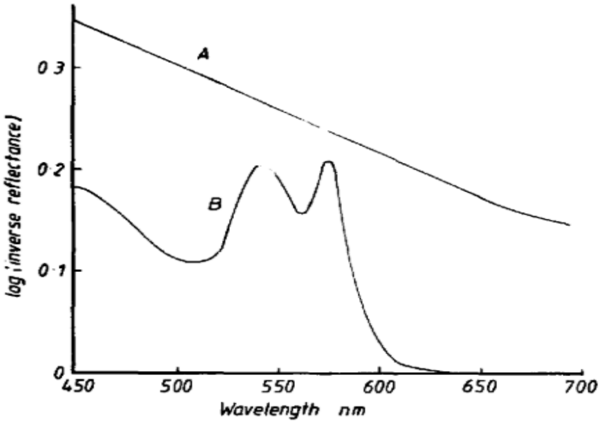


Fig. 4. Graph of light absorption curves for (A) melanin and (B) whole blood in vitro [3].

The wavelength of the light source is affected by the "optical water window", "isosbestic wavelength", and the "tissue penetration depth" [2]. The "optical water window" refers to how light in the ultraviolet and longer infrared regions is strongly absorbed by water. As water is a main component of living tissue, they have similar properties. 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 shown by Fig. 4 where the logarithmic function of inverse reflectance is a function of wavelength. There is a portion of the absorption spectra that includes visible red light and near infrared light that 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 which is found to be around 805 nm [5]. The operating wavelength dictates the depth of light penetration in the tissue [2].

The sensor utilized in Project N.I.H.M.S. is the MAX30100 by Maxim Integrated. It utilizes two different LEDs; one emits red light with a peak wavelength of 660 nm and the other emits infrared light with a peak wavelength of 880 nm [6]. The two LEDs account for the difference in oxyhemoglobin and reduced hemoglobin's light absorptions which are useful for calculating the blood oxygen level and heart rate of whoever's finger is on the sensor.

C. IR Thermometer

An infrared thermometer is a sensor lens that picks up on infrared energy, which then converts the energy to an electrical signal which can display the temperature. Infrared thermometers are useful to measure temperature at a distance without any physical contact with the object. An important factor when considering IR thermometers is the accuracy of the sensor and the range for which the component will operate. For our application, we need only focus on the generalized temperature that skin tends to stay at, namely around 33 ºC. When it comes to body temperature, a measured result that is more than 2 degrees off can cause a misdiagnosis to occur.

The IR thermometer of our choice for this project is the GY-MLX90614 as it is a reliable, affordable, and well documented part that is known to work well with several Arduino microcontrollers. It has a temperature range of -70ºC-380ºC with a ±0.2℃ accuracy. This sensor uses I2C to communicate and send the data collected to the microcontroller. It can operate on either 3 or 5 volts of power as well. This sensor will be mainly responsible for collecting the skin temperature of the person using our device.

D. Wi-Fi Antenna

The NodeMCU board features its own Wi-Fi antenna module that is cost effective and surface mountable. The Wi-Fi antenna operates at a frequency range of 2.4 - 2.484 GHz in the IEEE 802.11 b/g/n standard, with support of the Transmission Control Protocol (TCP)/Internet Protocol (IP) communication and Wi-Fi security. We added the same Wi-Fi antenna to our device PCB for its ability to work with firmware to provide Wi-Fi connectivity to external hosts like the Arduino MCU. The Wi-Fi antenna is capable of processing the onboard data processing and helps integrate the IR thermometer and PPG sensor with our application through the general-purpose input/output (GPIO).

E. Power Source

Due to the nature of our device, it was reasoned that a battery would be the best method of providing power, as the portable aspect of Project N.I.H.M.S. is of great importance. The battery we chose is the LP785060 from Adafruit, a 3.7 V, 2500 mAh lithium-ion polymer battery with a 2 pin JST-PH connector attached already. This battery already has protection circuitry included which prevents the battery voltage from going too high or too low, in this case the battery will cut out when completely dead at roughly 2.8 V. This protection circuitry also helps protect the battery from output shorts, but in order to properly utilize the lithium-ion polymer battery, it is suggested that a lithium-ion polymer constant-voltage or constant-current charger be used to charge the battery. These chargers, also from Adafruit, ensure that the charging rate does not exceed 1200 mA.

The charger we settled on is the BQ24074, a universal USB/DC/Solar charger. Using this charger allows for many options with respect to the method of charging the lithium-ion polymer battery. The ability to charge via solar cell allows for an environmentally conscious option, minimizing the impact while maintaining a good charging capability. The solar option supports up to 10 V, and so is compatible with most compact solar cells. The USB type C port allows for charging the device and battery when not being charged via solar energy. If neither option is available, the charger can continue to provide power to the device through the lithium-ion polymer battery that was connected while charging with one of the two prior methods mentioned. When connected to multiple forms of charging, the solar charger chooses to utilize the method that provides the highest voltage. This means that the battery can be connected and charging without worry of the charge dissipating from the solar charger attempting to use the battery as its main source. The charger is capable of regulating the output sent to the device, ensuring that the output voltage never exceeds 4.4 V. This means that it is safe to use with the voltage regulators on our device.

F. Solar Panel

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 [8]. When light containing photons of energy that is higher or equal to the bandgap energy of the semiconductor illuminates the cell, photons can be reabsorbed and cause an excited electron-hole pair to be formed [9]. Afterwards, an electron current flows as the charge carriers travel to their designated contact in the cell as shown in Fig. 5. When light containing photons of lower energy illuminates the cell, the material is transparent to the radiation.

Important metrics considered 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% [10]. The solar cell efficiency measures how effective the cells are at converting light into electrical current. The chosen solar panel, the IXOLAR High Efficiency SolarMD, has a typical fill factor rating of 70% and a typical solar cell efficiency rating of 25% [10].

The solar panel used in Project N.I.H.M.S is composed of monocrystalline cells [10-11]. It has a spectral sensitivity range from 300 nm to 1100 nm; the side spectrum allows for indoor and outdoor use. Although monocrystalline materials generally have a higher cost than polycrystalline materials, it lacks impurities giving it a higher power conversion efficiency and lacks degradation over operating time.

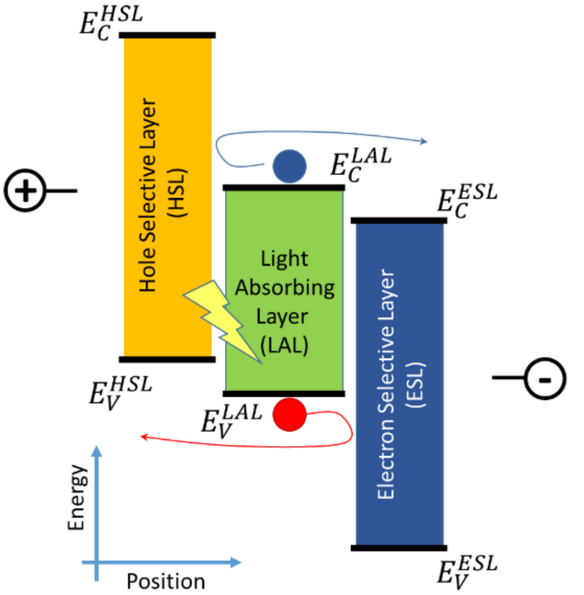


Fig. 5. Schematic diagram of key elements for solar cells. E_C and E_V represent the conduction and valence bands of the layers [9].

III. SOFTWARE OVERVIEW

The software portions of our project include the embedded programming of the microcontroller, the database setup, and the mobile application where results would be displayed. The C++ programming of the microcontroller was done via using the Arduino IDE and the mobile application as well as the setup for the database was configured using the Android Studio IDE and written with a Flutter SDK .

A. Embedded Systems Programming

The MCU's programming consists of collecting the data from the two sensors and sending the real time data to the database to store it in. The two sensors are connected on an I2C bus which are run by the serial clock (SCL) and serial data (SDA) lines that are located on GPIO pins D1 and D2 respectively on the microcontroller. These two lines each also have 10 kΩ pull up resistors that help with keeping the signal high when no other device is maintaining it low.

The microcontroller is only able to read data from the sensors and send it off to the database if the internet connection via Wi-Fi is working, therefore that is the first thing that is setup and checked on the program.

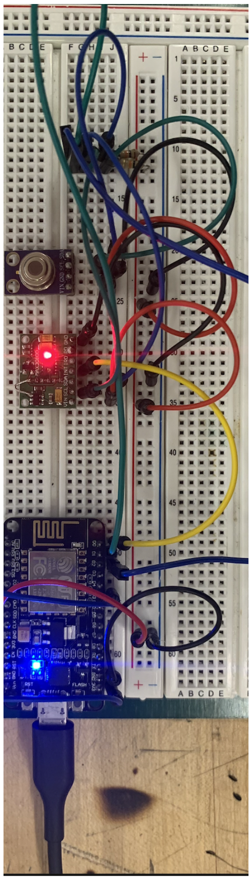


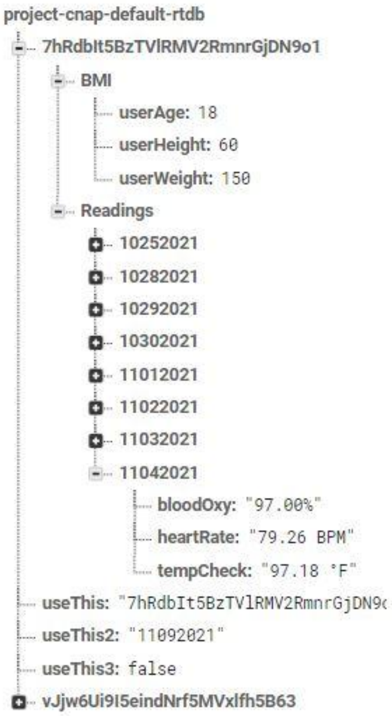
Fig. 6. Overall circuit connecting sensors to MCU via an I2C shared bus.

B. Database Setup

Google's Firebase is an application development software that enables developers to develop iOS, Android and Web applications. We chose to run on Firebase's real time database for our project as we wanted live results to be transmitted and updated while using the device. The structure of our database is simple, first starting off with a user ID to identify which account is currently logged in and using the device.

Under each user, there are two subcategories, one that records the user's height, weight, and age upon signing up with their account to our app. The other subcategory being the monitored readings that are being tracked each day, which are organized by date and displays the user's skin temperature, blood oxygen level, and heart rate.

Lastly, we have 3 other categories that allow us to send the data from the microcontroller to the appropriate slot in the database. Usethis contains the current user ID that is logged in to the mobile app, and changes whenever a different user logs in. Usethis2 displays the current date of when the mobile app is being utilized. This is needed to send the data to the appropriate date that the vitals are being recorded. Lastly, Usethis3 displays true if the Wi-Fi connection is on and working, and false if Wi-Fi is not connected. The user will only be able to get their current vitals if internet connection is on.



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      10282021
      10292021
      10302021
      11012021
      11022021
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        tempCheck: "97.18 °F"
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  useThis2: "11092021"
  useThis3: false
  vJjw6Ui9I5eindNrf5MVxlfh5B63
```

Fig. 7. Screenshot of Project N.I.H.M.S' real-time database on Google's Firebase.

C. Mobile Application

Main function of our mobile application is to access monitored readings from the fingerless glove. After a new user signs up or a returning user logs in, they will be able to make new readings by retrieving their current vitals from the device or access older readings from up to a year of the current date. After retrieving their readings, they will be able to generate a PDF document that they can download on their personal mobile device to be able to share the PDF with medical professionals or whomover they choose. Our mobile application was coded using Flutter, which is a Google Software development kit. Utilizing Flutter made it simple to connect to the database and deploy the application on Android mobile devices.

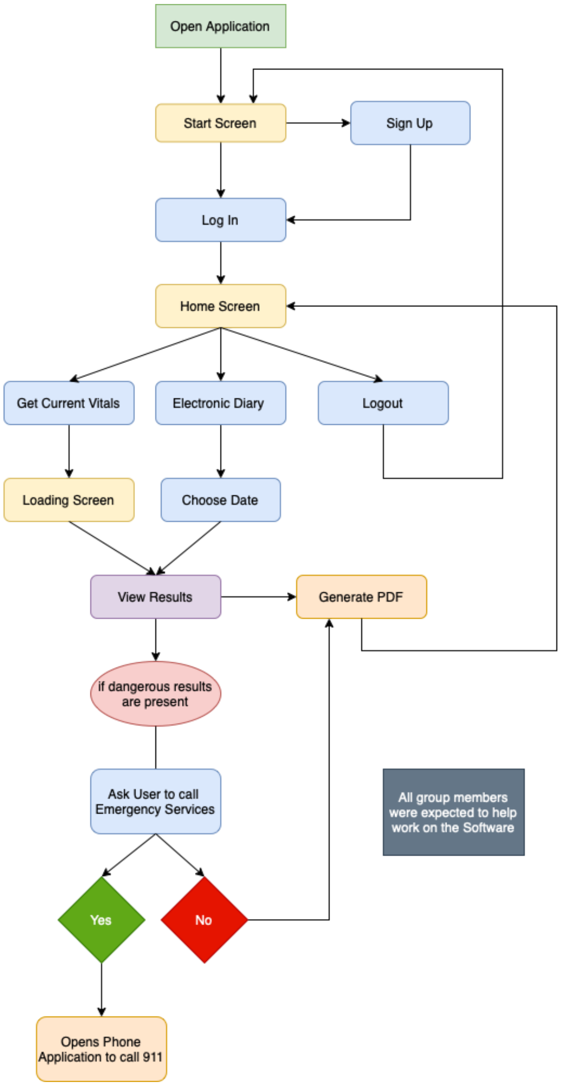

Fig. 8. Software flowchart depicting the layout of our mobile application.

IV. PROJECT DESIGN

A. PCB

A PCB incorporating the microcontroller, sensors, Wi-Fi module, and buck converters was designed, utilizing a 2 layer configuration in order to minimize cost while maintaining performance. Most of the components were chosen to be SMD instead of through hole, unless it was not possible to utilize the part without using through hole. This decision was made in order to minimize the thickness of the total PCB, as it is meant to be worn whenever measurements would like to be taken.

The PCB design software of choice for us was EAGLE, as we had practice using it before from Junior Design. Many of the parts were not featured on EAGLE libraries though, so we had to manually download a number of the footprints and symbols from various sources, such as Ultra Librarian and Component Search Engine. One of the resources we utilized the most was Library Loader, a program that automatically imported the downloaded files from Component Search Engine directly to a newly created library in EAGLE, ensuring that all the parts' symbols and footprints were readily available and easily accessed. With footprints and symbols for many parts being available online, we were able to avoid having to manually create the symbols and footprints ourselves, which saved us considerable time. Once the components necessary for functionality were all accounted for, board layout for the PCB was easily facilitated thanks to the user-friendly environment created by EAGLE.

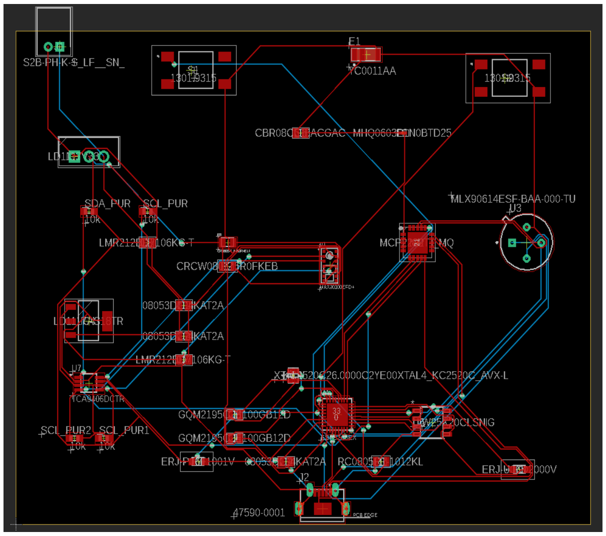

Fig. 9. Screen capture depicting out PCB layout

For the production of our PCB, we went with a split method, having the actual board created at one location, and then having all the parts soldered on at another one. We used PCBWay as our board creation option, as they came highly recommended to us when talking to PCB assemblers. Utilizing a first time user discount, we were able to procure 5 PCB boards for $20, helping us maintain lower costs for our overall budget. Since they are located in China, shipping took a little bit longer than if we had gone with a local PCB manufacturer, but with a lower price point that does not reflect a trade off in quality, we reasoned that this was a beneficial decision.

Our PCB includes certain niche parts, such as a JST-PH connector and an IR temperature sensor, and so including these parts necessitated ordering from multiple online vendors rather than a single one. The majority of parts were ordered from Mouser, with the microcontroller coming from Digikey and the JST-PH connector coming from Newark.

While waiting for the shipments of components and boards to arrive, we looked into various assemblers in the area to find which one suited our needs the best, and arrived at the decision to go with Quality Manufacturing Services, Inc. Being relatively close to campus with respect to other locations, they often do work with senior design groups on a more personal basis. We found this approach to be beneficial for us to gain a better understanding of how to go about the process of completing the production of a PCB.

B. Glove

For our glove, we wanted to have a fingerless option as that would help for more accurate results as it allows for the user to reach the sensors better. This is especially needed for the PPG sensor as it requires skin contact to receive the proper waveforms to do the calculations for the blood oxygen and heart rate measurements. Our PCB would be fully incorporated inside of the glove, where we will align the sensors to be properly placed where it can retrieve data from the user's hand. We strive to make this glove lightweight as it should not weigh more than 2 pounds. Also, we would cut open some portions of the glove and adding extra padding material needed to provide better comfort for the user while wearing the glove.

V. CONCLUSION

Project N.I.H.M.S is a device that would be beneficial and used in the medical field. 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. Project N.I.H.M.S consists of two sensors, IR thermometer and PPG sensor, that will be able to check heart rate/telemetry, pulse oxygenation, and skin temperature. These monitored readings are then sent to the microcontroller unit, the ESP8266EX. The MCU has a surface mounted Wi-Fi antenna that then receives the data from the two sensors and sends it to our Google firebase database. The data sent via the Wi-Fi antenna to the Google firebase will now be able to be retrieved and displayed onto our mobile application.

The software component of our device consists of two components: the embedded software of the MCU and the mobile application. The embedded software on the MCU was written with the Arduino IDE and coded to send the data from the sensors to the backend, Google firebase database. After the mobile application retrieves the data it can now be displayed for the user and is able to be generated into a PDF file that can be shared. If the data received is outside of normal vitals, it will trigger the emergency alert system.

VI. Biographical Sketches

The contributors to the non-invasive health monitoring system (Project N.I.H.M.S) are Gabriela Pinedo, Nicole Fossenier, Schnieder Maxime, and George Ruiz.

A. Gabriela Pinedo - Computer Engineering

Fig. 10. Photograph of Gabriela Pinedo.

Gabriela Pinedo is a first-generation undergraduate Computer Engineering student at the University of Central Florida. She is a member of various UCF STEM organizations such as Alpha Sigma Kappa - Women in Technical Studies, IEEE, and SWE. Gabriela was in charge of programming the microcontroller as well as working on programming and organizing the backend side of the mobile application. After UCF, Gabriela will start off her engineering career working at Texas Instruments in Dallas, Texas as a Product Engineer.

B. Nicole Fossenier

Fig. 11. Photograph of Nicole Fossenier.

Nicole Fossenier is pursuing her Bachelor of Science in Photonic Science and Engineering at the University of Central Florida after transferring from Eastern Florida State College with her Associate of Arts degree. Initially intending on pursuing a degree in electrical engineering, she decided to pursue this particular branch of engineering after the undergraduate adviser of the College of Optics and Photonics, Mike McKee, gave a presentation about the degree at her community college.

C. Schnieder Maxime

Fig. 12. Photograph of Schnieder Maxime.

Schnieder Maxime is a first-generation undergraduate Computer Engineering student at the University of Central Florida. He is a transfer student from his hometown community college, Florida South Western State college. He is a member and served a term as a Vice President of an engineering club, National Society of Black Engineers (NSBE). In this project, Schnieder was responsible for creating the mobile application for the user interface as well as helping integrate the hardware and software together. After UCF, Schnieder will be heading to Pittsburgh, Pennsylvania to start off his career in the Technology Development Program at PNC Bank.

D. George Ruiz - Electrical Engineering

Fig. 13. Photograph of George Ruiz.

George Ruiz is a second-generation undergraduate Electrical Engineering student at the University of Central Florida, having transferred with his Associate's Degree from Valencia College. He is a member of IEEE, within which he is a part of the Engineering in Medicine and Biology, Robotics and Automation, and Control Systems Societies. He also is on the Therapeutic Systems and Technologies Technical Committee, as well as the Wearable Biomedical Sensors and Systems Technical Committee. For this project, George was responsible for the design and creation of the PCB, as well as assisting with the testing of the power source for the project. After graduation, George will be heading to Washington, D.C. to pursue a career in prosthetics R&D with the FDA.

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