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Sleep Apnea Monitoring System

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Final Project Report

Sleep Apnea Monitoring System

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Project Customer:

Dr. Syed Islam

Date:

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Executive Summary

Sleep Apnea is a disorder that causes one to experience shortness of breath or even short periods where breathing ceases entirely. It can occur in people of all ages, but it is particularly dangerous for infants, as their underdeveloped respiration systems often lead to erratic breathing patterns. According to Dr. Mark S. Gaylord, the Director of Neonatology at the University of Tennessee Medical Center, up to 80% of infants weighing under two kilograms will experience sleep apnea events (defined as a period of 15 or more seconds without breathing), and many will experience between five and ten events per hour. The Sleep Apnea Monitoring System project aims to protect infants in the Neonatal Intensive Care Unit (NICU) from the health risks of sleep apnea. And not only is the project intended to detect sleep apnea events, it is also intended to autonomously respond to those events by waking the child, and it is meant to do so more accurately and in a less obtrusive manner than other similar detection systems.

Dr. Gaylord stipulated that the system that we designed should be a wireless system in order to avoid adding more wires/cords to the medical beds in the Neonatal Intensive Care Unit (NICU). The increase in wires would present a hazard to the children, who could easily become entangled. The wireless system requirement also meant that we had to avoid using external power supplies, instead relying on battery power. He also preferred that the mechanism we use to autonomously wake the child be a vibration motor located in a sock on the child’s foot. He thought that this kind of stimulation would easily wake premature infants.

The project development has primarily split between hardware and software tasks. With regards to the hardware development, we were originally given a circuit that could read charge signals from the cannula sensor and output a digital signal which represented whether or not the child was experiencing a sleep apnea event. This circuit operated at 5V, which was inconvenient, because most very small batteries do not output voltages at this level. We decided to redesign the circuit such that the operating voltage would be 2.7V instead, and instead of computing whether or not the child was experiencing apnea in this circuit, we decided to offload that operation to software on a microcontroller.

With regards to software development tasks, we first concentrated primarily on developing a proof of concept design that would demonstrate the entire system flow and verify the effectiveness of our design choices. We first acquired two Raspberry Pi Zero Ws, and we set them both up for bluetooth communication. We used Python 2 and some Bluetooth communication modules to set up a transmitter and receiver to imitate the operation of a

Bluetooth-enabled microcontroller. We also needed to consider the software that we would eventually need on a the microcontroller to determine how to classify sleep apnea events.

Requirements

1. Overall System Requirements

- 1.1. System must be able to interface with a hospital environment.
- 1.2. System must be powered with batteries.
- 1.3. System must be powered with power supplies which are already available in the hospital environment.

2. System Hardware Requirements

- 2.1. Sensor must be used to measure respiration patterns.
  - 2.1.1. Pyroelectric transducer will be used to convert changes in temperature near the nasal cavity to charge accumulation.
- 2.2. Charge Amplifier must be used to attain a usable voltage level.
  - 2.2.1. This component will amplify accumulated charge to a usable voltage level.
  - 2.2.2. The output of the charge amplifier must be an analog signal.
- 2.3. ADC (Analog to Digital Converter) must be used so that data can be transmitted digitally.
  - 2.3.1. The analog voltage signals will be converted to digital signals for easy data transmission.
- 2.4. Signal Transmission must take place to get data from the acquisition stage to the signal processing stage of the system.
  - 2.4.1. The system must use a wireless transmission method (likely bluetooth) to transmit the digital voltage signals to a data processor.
  - 2.4.2. The digital signal must be scaled such that the data can transmitted easily.
- 2.5. Signal Processing must be used to interpret the data.
  - 2.5.1. The received signals must be interpreted (likely with an algorithm on an FPGA, for speed) so that breathing patterns can be analyzed.
- 2.6. System Response must occur to alert affected persons.
  - 2.6.1. The system must respond to the interpreted data
    - 2.6.1.1. The system must wake up the affected person
    - 2.6.1.2. The system must sound an alarm of some kind to alert nurses in a NICU setting.
  - 2.6.2. The system response time must be negligibly immediate when compared to the 15-second sleep apnea classification criterion.

3. System Software Requirements

3.1. Networking Design
  3.1.1. The cannula design must be able to wirelessly connect to a data processor.
  3.1.2. A central authority must receive signals from each patient's cannula.
  3.1.3. A central authority must be capable of wirelessly sending signals to devices on the patients' beds.
  3.1.4. The device on the patient's bed must receive wireless signals from a central authority.

3.2. Patient Security and Confidentiality
  3.2.1. All networking must be over secure connections.
  3.2.2. Encryption must meet industry standards (ISO/IEC standards)
    3.2.2.1. Encryption techniques must ensure pertinent patient data is not being leaked (data confidentiality).
    3.2.2.2. Encryption must ensure received data is not modified (data integrity).

3.3. Data Processing
  3.3.1. The design must include a processor capable of interpreting the signal from the cannula.
  3.3.2. The processor must require an algorithm to detect if a sleep apnea event is occurring.
    3.3.2.1. The algorithm must be extremely lightweight to fit on low-power processors.
    3.3.2.2. The algorithm detection time must be negligibly immediate when compared to the 15-second sleep apnea classification criterion.

3.4. Interface Design
  3.4.1. An interface is required for the central authority.
    3.4.1.1. The interface must be easy to interpret.
    3.4.1.2. The interface must be easy for the medical staff to use.
    3.4.1.3. The interface must be accessible to nursing staff.
    3.4.1.4. The interface must provide access to view individual patient
    3.4.1.5. Error detection must be immediate.
    3.4.1.6. Error warning must alert medical staff so adjustments and corrections can be made.

Change Log

1. (10/3/2017) Change to requirement 1.1. “System is no longer required to interface directly with the hospital environment.” Instead the system is only required to make the collected respiration data accessible so that interface with external systems is possible.

2. (10/18/2017) Change to requirement 3.1.1. “The cannula shall connect directly to an external housing, which shall wirelessly communicate with the stage of the system that reacts when an event is detected.” The rationale behind this change is that it removes the “central authority” and thus dramatically simplifies the overall signal path. Also, it reduces the amount of hardware required to implement the system.

3. (10/18/2017) Change to requirement 3.1.2. “The reaction stage of the system must receive wirelessly transmitted data from the housing surrounding the cannula.” This requirement moves the “central authority” within another stage of the system.

4. (10/18/2017) Removal of requirement 3.1.3. The system no longer has a central authority, so there is no need for guaranteeing wireless transmission between the central authority and other stages of the system.

5. (10/19/2017) Change to requirement 3.1.4. “The reactionary mechanism located on the baby’s body somewhere must wirelessly receive signals from the housing surrounding the cannula.” This requirement change is also to move the “central authority” within the reactionary stage, as well as to correct the signal path detailed by the previous set of requirements.

6. (10/21/2017) Change to requirement 3.3.1. “The design must include a processor capable of interpreting the signal from the cannula housing.” This change simply reflects that the data signal will no longer be coming from the cannula itself, but rather from the cannula housing.

Design Process

To decompose the initial research required, all requirements were separated into two categories, software requirements and hardware requirements. The group was then split into two separate subgroups, one specializing in hardware and the other in software. Subgroups were assigned based on interest and academic major. Each subgroup was then responsible for decomposing requirements into achievable goals through research.

During the research stage of the design process, each individual or subgroup strictly adhered to standards derived from our customer's demands, hospital codes, and safety necessities. This ensured that each requirement included measures to prevent a violation of any health and safety regulations. A few medical standards were explicitly stated in a meeting with Dr. Gaylord, such as certain components of the design being disposable every few hours for cleanliness. However, the majority of medical standards were design choices that were left at the team's discretion. Even though our group did not know the full details of legal rules in regards to technology in the NICU, it was believed that minimizing risks such as large power components and hazardous wires would allow for a system that could easily meet unfulfilled legal requirements with a minimal fix. Each member was advised additionally to present any potential violation they may have come across during research or felt could be an issue to the rest of the group. This made the majority of issues easy to quickly address and solve in order to prevent problems from arising further in the design when a solution may result in larger design changes.

In the initial stages of research, our group started by discussing the most pressing open questions regarding our design and implementation. These questions were then ordered by priority and used as the starting point for our research. The first question and the one that dominated the most of our research time was by what means would we wirelessly transmit our sensor data to the other components of the design. This question prompted our research into Bluetooth, wifi, and RFID communications to see which was the most practical in our design. Additionally, an important aspect our group had to decide upon was where each component would be in the design. Consequently, our research was prioritized into finding components that satisfied our minimum size, power, and functionality requirements and seemed logical to use in one of our three solutions. Furthermore, various other questions that presented themselves during research were strategically handled by formulating multiple strategies to solve the said issue. This was critical further along our research when multiple solutions to the overall design were created.

Once the requirements were segmented, project requirements were discussed and analyzed. For each requirement, the team proposed several solutions that would meet that specific requirement. Through discussion and feasibility assessments, the team narrowed each requirement to between one and three possible solutions. Each of these solutions were then analyzed for compatibility with one another, as not all the solutions could feasibly work with one another. Furthermore, as the design was iteratively improved, the requirements were re-evaluated at each iteration to ensure all requirements and standards were met. This often involved redesigning certain design elements as well as eliminating certain potential components, as cost and ease of producibility became important factors.

When picking components for the final design, certain factors, such as cost and standards, were taken into account. The entirety of the design involved commercial, off-the-shelf components (COTS components). This was to ensure the reliability of manufactured electrical components, as any medical device involving electronics must be held to extreme standards. Medical facilities often require, or at least advise, the use of commercial, off-the-shelf components, as it eliminates certain concerns that arise when designing custom circuits that can cause device failure, causing issues in medical hardware. In order to adhere to these standards, the group investigated COTS components, largely selecting individual parts from commercial retailers, such as Adafruit, Mouser, and DigiKey. This forced the group to consider compatibility issues and methods of integration, as not all parts can easily interface with each other. This also presented further limitations in the final design, as we attempted to limit our component selection to vendors who thoroughly test all hardware before it is sold.

One of the most important questions that we had to research was a way to make the cannula (with apnea detection hardware inside it) as small as possible. Since premature babies are small, you cannot have large devices dangling off of their noses. Along with this, our customer emphasized the need for the nasal cannula to wirelessly communicate with any other components. During our research we had to find the most efficient ways to reduce the overhead on the nasal cannula while not compromising its efficiency. Additionally, another open question we answered was how our devices could communicate between each other. As previously stated, we looked into methods involving RFID and wireless communications, but we ended up deciding Bluetooth satisfied our security and wireless needs most efficiently. In order to utilize Bluetooth, however, we needed to incorporate Bluetooth components into the cannula design as well as the reactionary mechanism. When dealing with the majority of our other components, we had to answer a couple of questions regarding the specifications in order to make sure we understood the power requirements, size, and precision of each part. Questions such as “Will the chip fit in the cannula?”, “Will it require a large power supply?”, and “Can it work swiftly and accurately?” needed to be answered for each component in our design. Ultimately, the open questions we faced helped guide our research to the parts that we decided to use in our final design.

Before we settled on our current solution, we considered many different alternatives. One alternative was the use of Near Field Communications (NFC) to link the devices rather than Bluetooth. One major upside to NFC is power consumption. This made it ideal for our purposes because we are trying to minimize the power used by our design, both to protect the safety of the baby and to extend the battery life as much as possible. Another benefit of NFC is the instantaneous pairing process. To pair two Bluetooth devices you must manually set up a connection. However, for NFC all it requires is a small gap between the devices to establish a connection. While NFC seemed like a good alternative, it only has an effective range of about 10 cm which makes it good for things such as mobile payment systems but not ideal for connecting two devices which can be separated by approximately four times that range. Another considered alternative was the use of custom hardware. By using a custom chip we could essentially free ourselves from size constraints, as we could make hardware that only had the necessary logic for our application, instead of having a lot of unused multipurpose hardware in our product. Using multipurpose hardware would require redundant logic on the chip which would add greatly to the size. However, making custom chips is expensive and if the chip needs to be disposable, we would need a way to cheaply mass produce these chips. By using commercially available parts we do not have to worry about custom making each chip and thus will be able to more easily mass produce the nasal cannula devices. Also, since our customer told us that it is best to use commercially available parts, any custom integrated circuit that we were to design and fabricate would have to be extensively tested before it could be used in the hospital environment. Even then it could face serious liability concerns.

To design a secure, reliable, autonomous sleep apnea detection system, we included a disposable cannula sensing unit and a reactionary vibration mechanism on the child's leg. These two devices would wirelessly communicate, allowing the sensing unit to activate the reactionary mechanism, waking the baby if a sleep apnea event occurred. This would require the disposable cannula equipment to be directly and wirelessly paired with the reactionary mechanism. Another system we considered involved an intermediary microcontroller mounted on the side of the bed, requiring the intermediary unit to be paired to both the disposable cannula and the reactionary mechanism. This would allow us to minimize the computational equipment on the cannula, allowing us to dispose of less equipment every time the cannula is replaced. Moreover, this design scheme would allow us to pull data out of the intermediary microcontroller, potentially analyzing breathing patterns, looking for key indicators that a sleep apnea event might occur. In researching each of these potential solutions, we began to create a new design that utilized the positive aspects of both former designs. This new design was eventually refined into the final system. In this new system, we split the cannula design into two distinct pieces in order to minimize the quantity of resources in the disposable unit. However, in this case, we decided to keep the second portion of the cannula attached to the cannula sensor, housing it in a detachable shell. This would allow us to detach and reattach this portion of the cannula, preventing the need to dispose of it every time the cannula must be replaced due to mucus build up. Furthermore, this would reduce the steps required to pair the wireless communication devices, as the removable cannula piece could be consistently paired with one reactionary mechanism, and could plug directly into the cannula sensor. Ideally, this would reduce the effort required from nurses to set up these autonomous systems on a child's bed. We decided to pursue this new system from here, as it seems to be an ideal compromise between the two step and three step systems.

We decided that it was a little too ambitious to try and implement our entire design in one semester, so we decided to break it up into manageable pieces and work on them individually. The first step was to implement a proof-of concept design that would ensure that the overall system design worked properly. We decided to use two Raspberry Pi Zero Ws to mimic the functionality of Bluetooth-enabled microcontrollers in the final design, because they are generally easy to use. We set up a system that took an analog input voltage signal and recognized apnea events as periods when the input signal fell below a certain threshold for more than 15 seconds. We then connected both of the Pis via their Bluetooth modules and controlled and monitored the connections in Python scripts. When an apnea event was classified, the Pi connected to the input signal would transmit a trigger signal to the receiving Pi, which mimicked the operation of the reactionary mechanism. It would interpret the transmitted signal and activate a vibration motor. When the analog input signal moved back above the threshold, the vibration would cease, as the infant will have begun breathing again.

Along with the proof-of-concept design, we also decided to redesign the front-end circuitry that directly interfaces with the sensor. Since one of the customer's requirements was that the system be battery powered, we began to research different kinds of batteries that could be used for the system. Since the battery will be powering the nasal cannula and surrounding hardware, which is small, the battery must also be small. We therefore decided that it was preferable to use a button battery, as the only way to get a battery that is smaller would be to get it custom-made. However, we also realized that the coin cell and button batteries that are commonly available have maximum output voltage ratings of 3V. This was a problem, because the current front-end circuitry had an operating voltage of 5V. Our redesign of the circuit brought the operating voltage down to 2.7V, which could be sustained by a 3V battery. We found a voltage regulator that would output 2.7V when given a higher voltage (i.e. 3V), and we had to order new charge and voltage amplifiers that worked at the 2.7V operating voltage. We decided not to include circuitry to classify apnea events, as we thought this operation could easily be offloaded to a Bluetooth-enabled microcontroller.

In parallel with these projects, we also designed the same system on a PCB. The ultimate goal would be to shrink the circuitry interfacing with the cannula down to a very small size. This would be most easily accomplished if we first proved that we could construct it on a PCB. Once the system has been proven to work on a PCB, additional measures could be taken to shrink the design to a manageable size. Fig. 1 and Fig. 2 show the full schematic of the PCB design and its layout as well.

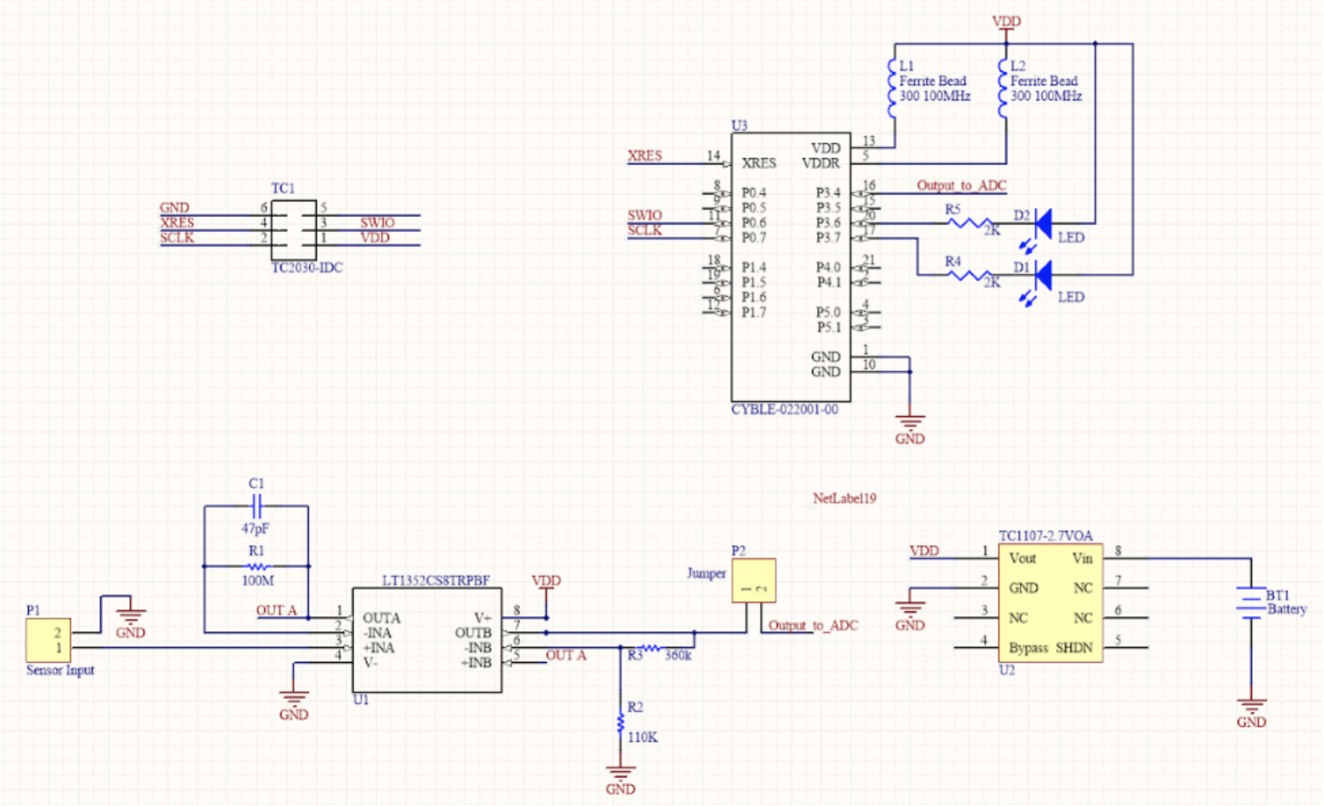

Figure 1. The schematic of the PCB design.

The components chosen for the design displayed in Fig. 1 include:

- MS414GE: MS Lithium Coin Cell Rechargeable Battery (BT1)
- LT1352CS8TRPBF: Dual 250µA, 3MHz, 200V/µs Operational Amplifiers (U1)
- TC1107: 300mA CMOS LDO with Shutdown and VREF Bypass (U2)
- CYBLE-022001-00: Fully certified and qualified module supporting Bluetooth® Low Energy (BLE) wireless communication (U3)
- TC2030-IDC: "Legged" 6-pin Plug-of-Nailstm Cable fitted with a 6-pin 0.1" pitch ribbon connector (TC1)
- 742792641: Ferrite Bead 300 Ohm 0603 1LN (L1 and L2)

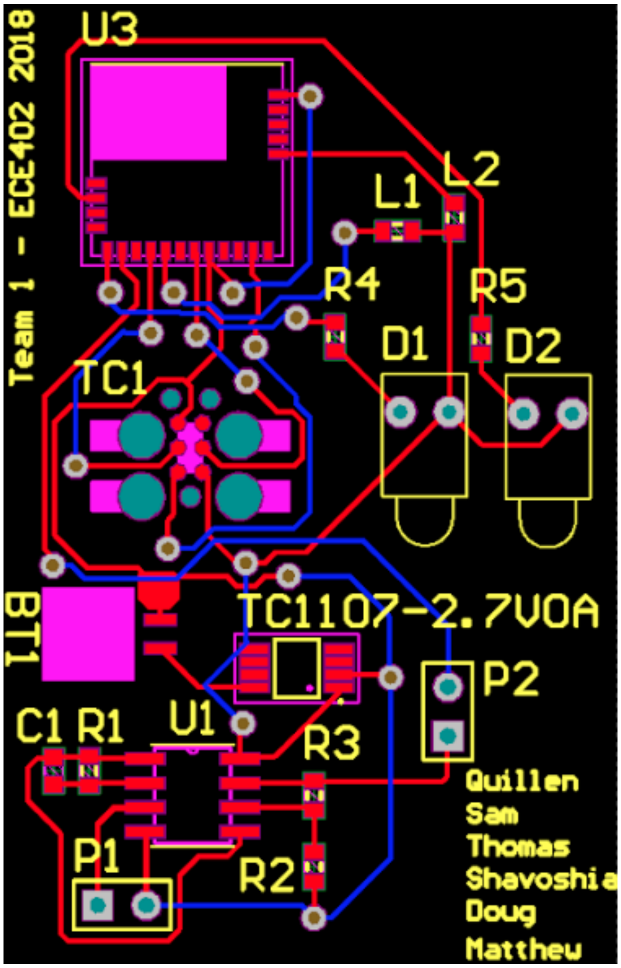

Figure 2. The layout of the PCB design.

The PCB Layout consist of two layers: the top and bottom layer. Its dimensions were required to be smaller than the amplifier circuit setup provided by Samira used to demonstrate proof of concept at the beginning of our project of 8 cm by 13 cm. The PCB layout design pictured in Fig. 2 has a layout of 3 cm by 5.1 cm. With these dimensions, the area of the circuit was reduced to 14.7% of the previous setup which did not have any wireless communication circuitry.

The requirements that we originally determined for our project have been modified significantly along with our design of the product. However, we have directly compared all of the foreseeable outcomes of our current implementation against the requirements given to us by Dr. Gaylord, and we have determined that the current design meets nearly all of the requirements that he gave, and minimally compromises on the others.

Lessons Learned

The design process was overall a great learning experience. We learned how to effectively communicate with our customers to determine the specific requirements of the project, and we worked together to brainstorm different design ideas that meet those requirements. One of the problems we ran into during this brainstorming process was making sure that everyone on the team understood the different proposed design ideas and understood the benefits and drawbacks of each one. There were a few times one of the team members mentioned an idea, but it was not given the consideration it deserved simply because the rest of the team did not understand the advantages of that particular design choice. To try and combat this kind of misunderstanding, we had to work on our communication skills. We had to learn how to better explain our ideas in a way that our colleagues could understand. This practice would hopefully prepare us to eventually present our ideas to those who are less familiar with our project area as well.

Another lesson learned was the management of project goals. Though we successfully set many project goals that helped us move forward on the project, there were often unexpected difficulties that forced us to change the direction of the project. We learned the benefit of staying in communication with our project customer and re-evaluating the direction of the project to still meet the expectations of our customer while also creating feasible goals.

We also had some difficulty with our design implementation. During the design process we had decided that we wanted to utilize a Bluetooth-enabled microcontroller to transmit a digitized signal wirelessly to a receiver. However, we did not fully understand the extent of the surrounding circuitry required to use a microcontroller, or the interfaces needed to program it directly. We learned that some Bluetooth-enabled microcontrollers have transmission antennas built into the package, whereas others do not. The chip we originally planned to use did not have a built-in antenna, and would thus have required additional external circuits and additional component cost as well. Furthermore, we underestimated the difficulty of prototyping the bluetooth chips we acquired specifically when it came to having the proper equipment such as a breakout board model for the chip, an additional bluetooth chip for communications testing, and a programmer dongle.

At one point during the project we had difficulty acquiring some of the parts we needed. One specific part that we needed, a dual operational amplifier package with a wide supply voltage range and good gain-bandwidth product specification, was particularly hard to find. We worked closely with representatives from different vendors, and after some scavenging, we discovered that the part was obsolete. We then had to determine a good equivalent part and order that one instead. This experience helped us to learn how to better engage with parts vendors, and taught us how to deal with obsolete parts by finding suitable replacements.

Another issue that dealt with over the course of the semester was simply figuring out times that we could work together on this project, since all of the team members were so busy with jobs, other classes, and extracurricular activities. We set up a meeting time once per week, but we quickly came to realize that about one or two hours of work per week was not enough to make sufficient progress on the project. We ended up working most effectively when we met in small groups of one or two team members to tackle different aspects of the project design. However, we were still not able to consistently find times to meet and work on our design. It would be easier to make consistent progress on a project like this in an actual work environment where every member's schedules line up.

For future projects, our team has found that the earlier you acquire the parts for your design as well as the useful tools to interface with the design the easier it becomes to quickly adjust to unforeseeable issues. Thus, for future projects it seems wise to quickly begin testing the design as soon as a rough draft for a logical solution is complete. Additionally, for future projects our team would utilize the budget more and take advantage of the resources available for help in implementing a solution. We used available tools at Min Kao such as the computers for altium (with licensing provided by the University) and the testing/soldering equipment in the lab to build our prototype board, but did not fully use the budget given to obtain all the useful prototyping tools and recommend that future groups lay out a budget that includes all reasonably priced parts and tools.

Some of the relevant courses that were greatly beneficial in the design of our project included specific classes in the fields of amplifier design, embedded systems, and communications. For instance, ECE 455 (Embedded Systems Design) gave relevant information on handling the IDEs for microcontrollers as well as implementing them into the design. Additionally, classes such as ECE 431 (Operational Amplifiers) taught us about many of the real-world restrictions in the design process, which was helpful during our design and implementation of a prototype. ECE 482 (Power Electronics Circuits) provided valuable experience with PCB circuit design with programs like Altium.

Team Member Contributions

Doug Aaser (Major - Computer Science):

- My contributions to this project were all in the software portion and it's writing. My main contribution was setting up the Bluetooth communications between the Raspberry Pi's that we used for testing. This process involved many different steps including: installing an operating system on the Pi's, figuring out how to make two Pi's communicate via Bluetooth, writing the actual software with which to read in a breathing pattern and convert it into a binary signal to send to the vibration device, and all troubleshooting that came along with setting up these functionalities. In regards to deliverable, I mainly helped with proofreading and making sure that documents were ready to be turned in, on top of writing sections of which I was assigned.

Quillen Blalock (Major - Electrical Engineering):

- As team lead, my primary responsibilities included management of team goals and project progress. I organized team meetings and established communication means among the team. I also assisted with overall project design, research, and was especially involved in the PCB design. Once Thomas Turner, Sam Brown, and I put together a schematic design involving the current amplifier and wireless communication systems, I used Altium to create the schematic, footprints for each device, and PCB layout to be used in future work on this project. I also managed bi-weekly team responsibilities with MBO reports and met with TAs to discuss project outlooks. During reports, I assisted with writing and organized presentation responsibilities.

Samuel Brown (Major - Electrical Engineering):

- My roles on the project team include Hardware Solutions Architect, Software Solutions Architect, Hardware Designer, Writer/Presenter, and Lead Report Writer. As Hardware Solutions Architect, I spent time coming up with specific hardware-specific solutions options and helped to organize brainstorming sessions. As Software Solutions Architect, I helped to ensure that the design that we ultimately chose to implement could be easily interfaced with future software applications. As Writer/Presenter, I helped with the team presentations and contributed to the team project reports. As Lead Report Writer, I took primary responsibility for the content of the written reports that our team turned in, and also reviewed and edited the informational content within the presentations that our team gave over the course of the semester. In addition to the above roles, I assisted with some of the team organizational aspects, reserving rooms and overseeing a couple of the meetings that our team leader could not attend. I also managed the research and acquisition of parts for the project. I oversaw the development of software for the proof-of-concept design and supervised and assisted with the construction of the soldered front-end circuit operating at 2.7V.

Matthew Carpenter (Major - Computer Science):

- My responsibilities were primarily centered around the software aspects of the design and implementation, as my experience with hardware is fairly limited. I was responsible for designing all software tests to ensure incremental progress on the software was correct and fully functional. I also worked with other members of the team to create the software needed to enable the Bluetooth pairing between microcontrollers. While my knowledge of hardware is limited, I also attempted to help the hardware design team by researching and documenting potential parts for purchase. This included researching and selecting Bluetooth transceivers to hopefully incorporate into the PCB design in the future. Finally, I was also responsible for contributing a great deal to the essays, and organized and outlined the first two essays.

Shavoshia Leslie (Major - Electrical Engineering):

- My main responsibilities included maintaining the document repository and coordinating its use. I did this by creating google documents to keep the assignments organized as well as looking over the documents before they were turned in. I also helped determine the color and themes of the poster and the powerpoint to make assure it was professional. As an Electrical Engineering major on the team I helped research in electrical component hardware that that is used in our project when developing the proof of concept prototype. I used my skills in soldering to solder the electrical components to the breadboard. In addition to the responsibilities listed I was the person responsible for the final review of the project assignments, including, papers, powerpoints and the poster.

Thomas Turner (Major - Electrical Engineering):

- My tasks included researching acceptable microcontrollers for the PCB layout that included Bluetooth capabilities, being operational with a 2.7 V power supply, and a small footprint to keep the overall board size low. In this I aided the teammate in charge of the altium design in correctly mapping signals from the sensor circuitry to the right pins on the Bluetooth chip. Additionally, I helped improve the user interface of the PCB by adding status LEDs to notify the user of a power on and when a connection is established. Another important task I had to figure out was finding an efficient and working way to program the PCB. I found a small sized 6-pin programming cable and its pcb footprint for the method of programming the bluetooth chip. Ultimately, I contributed a lot in these areas as my prior knowledge consisted mainly of this material along with my professional experience.

Signatures of Team Members

Quillen Blalock: Date: 4/24/18

Shavoshia Leslie: Date: 4/24/18

Doug Aaser: Date: 4/24/18

Sam Brown: Date: 4/24/18

Matthew Carpenter: Date: 4/24/2018

Thomas Turner: Date: 4/24/18

Customer Approval

The customer is in agreement with our project direction and is satisfied with the progress that we have made so far.

Signature:

Dr. Syed Islam

Syed K Islam

Date:

04. 24 .18

Customer Comments: