University of Illinois at Urbana-Champaign

ECE 445 Team #14

Child Development Sensor Design Document

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October 6, 2017

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1 Introduction

1.1 Objective

Human interaction at early development stages is vital to the growth of young children. It is therefore imperative that studies be conducted on the interactions between children and their parents, who are usually the most influential caregivers during early development. Modern research in child development is vast. There are countless, dynamic variables in a child's early developmental period that set children on trajectories of psychological adjustment which can be difficult to alter. Although studies are expansive, the method of current research is limited[1]. Although development is dependent on repeated real-time interactions with caregivers over large amounts of time, research observations in the lab occur in short, predetermined intervals. Development cannot accurately be assessed in isolated, static interactions. Additionally, many modern development observations occur within a controlled laboratory setting. However, growth is intimately tied to settings such as homes and classrooms. On occasions where research is conducted in natural context, assessments are brief and researchers must be present. Due to these limitations, research methodology must be advanced through innovation.

The goal of our project for Senior Design is to develop a device that allows researchers to obtain accurate data on child development. To overcome the limitations of research occurring in controlled environments, we will be developing a wireless device that can capture and transmit accurate data to a smartphone or a memory stick. This eliminates the limitation for researchers to be present during data collection. Caregivers are able to place the device on the child and conduct studies at home or classrooms, locations where multiple repeated interactions occur, as opposed to in a controlled laboratory setting. Therefore our device would enable accurate assessment of childhood behavioral and physiological development. We will be corresponding with a mechanical engineering team to design this device. The tasks have been broken up into the following: We, the electrical team, will design the sensor network, the wireless data handling/transmission, the electrical safety of our designs, and the storage of the data. The mechanical team will be tasked with designing the housing of the electronics, the form factor of the sensing device, and the physical safety precautions necessary when in contact with children such as overheating and motion. This is a joint multidisciplinary effort advised and sponsored by Professor Harley Johnson, UIUC MechSE, and Professor Nancy McElwain, UIUC HDFS.

1.2 Background

The research on Childhood Development is extensive and complex due to many influencing variables in a child's environment. To obtain valuable data to assess a child's development, physiological, psychological, and behavioral patterns must be studied. Information such as a child's heart-rate variability[2][3], body temperature and movement, quality of sleep[4], and characteristics in pitch of a caregiver's voice[5][6] are all useful information in determining a child's growth and influencing factors such as stress. The main parameters we will be obtaining in our Senior Design project will be cardiac vagal tone, through an electrocardiogram waveform, and voice analysis through a microphone.

We will be obtaining an ECG and a voice recording of the research subject. The data will be processed and wirelessly sent to a memory storage for ease of research accessibility. Ultimately the goal is to have accessible research data unobtrusively obtained in a natural environment. The ECG sensor and probes and the microphone will be characterized and optimized for the accuracy specifications determined by the researchers. The wireless communication will be designed and information will be successfully received and accessible by researchers. Power electronics will be designed to power various circuit components in our device. We plan to deliver a working prototype of the electrical components by the end of our work for Senior Design.

1.3 High-Level Requirements

1. Obtain accurate and synchronous ECG and voice data on research subjects.
2. Wirelessly transmit sensor data in accessible format to a cloud server so that users can access it from anywhere with an internet connection.
3. Develop and implement sensor hub (ECG sensor, voice recorder, Bluetooth module, battery source) and main hub (microcontroller, Bluetooth + WiFi module, power electronics) components that fit form factor constraints.

2 Design

2.1 Block Diagram

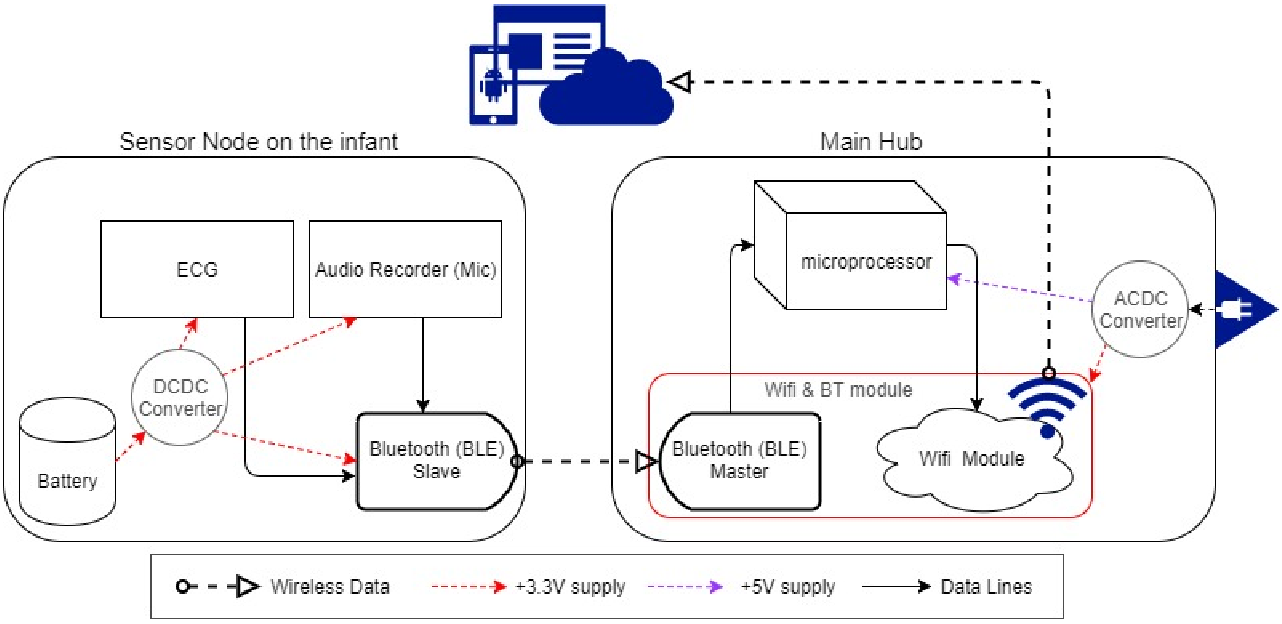

Figure 1: Full System Block Diagram

To allow an infant to move freely within a room or building while also being able to monitor their cardio signals without much obstruction, our design would need to be separated into two main parts. One part will have to be worn on the infant to monitor his/her electrocardiogram and record their voice. This part needs to be small, cool (operates with low temperature) and light. Thus, it needs to have minimal hardware, and the hardware needs to consume low power. So this part, which is the Sensor Node as shown in the diagram above, will only have the sensors, the audio recorder, and a low energy Bluetooth module powered by a battery. No data processing will be done on this sensor node; instead, it will directly send the datastream, using Bluetooth, to a main hub. The hub will be the main processing unit. It will contain a Bluetooth module to act as a master, a microprocessor to analyze, filter and sync both the ECG and voice recordings, and a WiFi module to push these data to a cloud server. Since this will consume more power, it will be powered by a wall plug. Detailed specifications of each block will be discussed further in the following sections.

2.2 Physical Design

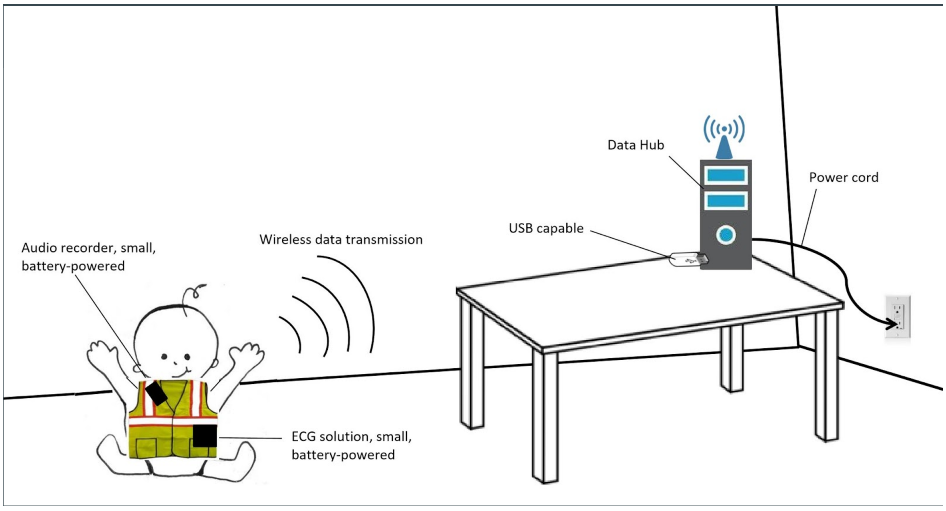

Figure 2: Use Case Scenario of Child Development Sensor System

The diagram above gives a glimpse of what the prototype of our project would look like. The sensor node will be embedded into a vest so that an infant can simply wear the vest on top of their clothing, and all the sensors will be in contact with him/her while also making it difficult for the infant to tamper with the sensors. The vest will be designed by the mechanical team. The vest will be fully battery powered to allow free movement. Since everything is embedded within a vest, it would be more convenient if even the leads of the ECG will be reusable instead of the typical one-time-use disposable electric leads. Hence, when characterizing our ECG sensors, we will also look into non-adhesive leads options.

The sensor node in the vest will send its data to a main hub, which will be stationary (shown as data hub in Figure 2). It will preferably be placed near a WiFi router so that it can push the received data into the cloud smoothly.

2.3 Block Design

Functional Overview - Sensor Node

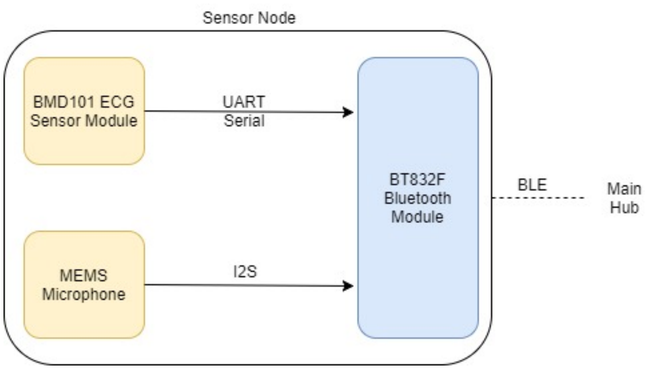

Figure 3: Sensor Node Modular Block Diagram

The Sensor Node shown in Figure 3 is the components that will be attaching to the test subject. This is the main sensing component that will be communicating wirelessly with the data hub through Bluetooth. Subcomponents contained within the sensor node include the ECG sensor, microphone, power electronics, and communication antennas. In Figure 3, we have chosen what we think are the best suitable components/modules.

Firstly, the ECG sensor will be recording a child's heartbeat as a waveform and not just beats per minutes (bpm). To accomplish the above, we have to decide how many electrodes are necessary or sufficient to graph usable waveforms. Most common ECG lab machines have 12 leads. Using 12 leads would provide high accuracy readings and can be used to diagnose heart diseases, but this would make our final package too bulky for a toddler to wear. Alternatively, we could use 3 or 5 leads. Lesser electrode contacts result in noisier waveforms and less accurate measurements. That being said, given that the use of these ECG waveforms is just for monitoring a child's heartbeat instead of diagnosing heart diseases, we will use just 3 leads.

The voice recording aspect is to supplement ECG data such that researchers would know what the infant/toddler was doing during the measurement period. The biggest challenge would be implementing a microphone module that would be sensitive for clear audio recording. Both these sensors will communicate directly through data lines or buses with the Bluetooth module. Given the selected sensor modules, BMD101 ECG module uses a UART Serial output which can then be packaged by the Bluetooth module before transmitting. For the MEMS microphone, since it is digital output, most of these microphones output through an I2S port. We will most likely use BT832F as our Bluetooth shield solely because it has these two serial I/O protocols.

To turn the sensor node on and off, we will use a simple flip switch circuit, with debounced components as shown in Figure 4.

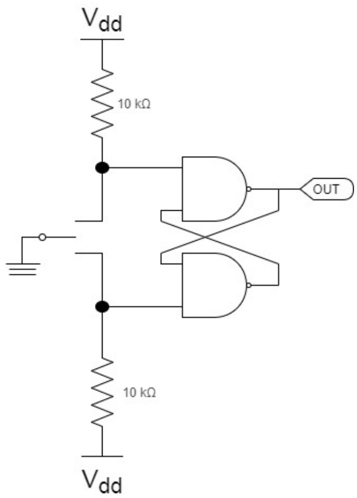

Figure 4: Simple debounced switch

Block Requirements	Verification & Validation
Overall dimensions of the final PCB with components mounted should fit the dimensions specified by the mechanical engineering team.	Final PCB will be placed into housing to make sure it conforms to specified dimensions.
Power consumption should be low enough to keep the temperature of the housing/casing to below 100 degrees Fahrenheit (37 Degrees Celsius).	Include a thermistor into the design to measure housing/casing temperature. Also, a thermometer gun will be used to monitor under all typical operations during development.
Needs to be light so that it does not affect an infants movements. Sensor node ideally around 1.5 lbs (± 0.5 lbs) excluding housing/casing.	Weigh the whole PCB with batteries and all the components soldered on using a scale.
Does not have loose parts that can easily be ingested by an infant or toddler.	Final product will be worn by child through multiple use cases to affirm no moving parts.

Sensors

Typical voltage differences throughout our body caused by our heartbeats are in the order of a few hundred microvolts to a few milivolts [17]. Thus, it would be great to have 12 leads on a subject so that all the voltage differences can be added together before amplification. However, given the limitations of our project, we will aim for just 3 leads since the accuracy we are aiming to achieve is only about 70% as requested by the research team. This posts some challenges since having lesser leads might increase the signal to noise ratio. For higher resolution, it would be ideal if we can obtain 16-bit sample at a sampling rate of 125 Hz to 500 Hz [18]. The ECG sensor that we are most interested in is the BMD101 because it comes fully fitted with built-in DSP, analog front-end, and pre-written algorithms that will give us raw 16-bit ECG signal output through UART (57600 baud rate) which can then be plotted into a waveform [7]. Also, some forms of BMD101 come with a dedicated Bluetooth submodule which we will use for wireless packet transmission to the main data hub. BMD101 claims to have a noise level of less than 10uV [7].

We are considering two forms of microphones, electret and MEMS. Electret microphones have a typical frequency range of 20Hz-20kHz which is more than sufficient for our needs as we are trying to record voices at most, but an electret microphone might not be sensitive enough such that audio recordings will be clear. On the other hand, MEMS microphones are smaller and more compact in size. Also, they offer better audio reproduction that are less prone to vibrations compared to electret microphones. Another advantage to MEMS microphones is the fact that they produce digital output instead of analog outputs which make interfacing with microcontrollers much easier. Thus, we have decided to first test out the SPH0645LM4H MEMs microphone which produces digital output through a I2S port. It has a sampling rate of 32 kHz - 64 kHz, a bit depth of 18 bits, a SNR of 65 dB-A, and a sensitivity which allows audio pitches around 50 Hz - 15 kHz [19].

Block Requirements	Verification & Validation
ECG sensors will need to be at least 70% accurate relative to the waveform obtained from a typical ECG sensor used by the research team. Or qualitatively, out of the 5 main dips and peaks observable from an ECG waveform, only the R peaks needs to be easily distinguishable from each other.	ECG waveforms obtained from our prototype will be compared with the current ECG sensors used by the research group. Then, the mean absolute percentage error can be computed, and verified to be lesser than 30%.
Voice recordings need to be sensitive and clear enough such that there is audible speech obtained from the recordings. Preferably, 16-bit mono samples at around 44.1 kHz sampling rate, and a signal to noise ratio of about 70dB-A ('A' means weighted at 1kHz signal)	Using MatLAB FFT algorithms, compare the frequency spectrum of source recording with microphone output to deduce SNR. This can also be verified by testing if a recording of someone reading a passage can be discerned when played back.
Voice recordings might invade a user's privacy, so there must be a physical button to allow users to stop the recordings at any time.	Verify that when the button is pressed, microphone is disabled and no audio data is received by main hub. This can be done by constantly reading serial output of main hub.

Wireless Transmission

For the sensor node, the only wireless component would be transmitting data to the main hub. Most off-the-shelf Bluetooth modules come with built in PCB antennas which makes it easier for our design process since it takes up less space and we would have one less component to design. Additionally, for ease of development, getting a Bluetooth module with a built in SoC and memory makes all the handshaking processes easier to deal with, and we will also be able to purchase a development board to learn how each Bluetooth module works. Since it is required that the components on the sensor node be low powered, we will only consider the low powered Bluetooth options, namely BLE. A typical BLE only draws 7mA at peak transmission using 3V supply voltage, and while in other states like idle or sleep, it draws even less than 1μA. Preferably, the Bluetooth modules can handle enough range such that an infant wearing it can freely move anywhere in a room or even within the same floors of a building. So, the BLE modules should provide about 30 meters of range. With the emergence of Bluetooth 5 on BLEs recently, it is possible to go up to 200 meters range while consuming low power.

The Bluetooth module we are interested in right now is the BT832F model. It has a built in PCB antenna, ARM processor, on chip memory and a RAM which is very favorable for our needs. It also uses Bluetooth 5 which claims to give us a range of 200-300 meters line of sight while only taking in very low power. During active mode, it uses around 7.5mA at TX +4dBm, which when added with its sensitivity of -96dBm, gives us a 100dBm power rating. From further research, with walls attenuation within buildings, it should give us about 50m of range when using an embedded 2.5GHz transceiver. This model transmits data at the speed of 8Mbps, which is plentiful for us. Therefore, since this is Bluetooth 5 technology, we will also have the option to fourfold the range at the expense of data transmission rate if needed[8].

Block Requirements	Verification & Validation
Bluetooth ranges can reach at least 10 meters so that an infant is able move freely within a room.	Verify that it works at a distance of 10 meters by having the sensor node placed exactly 10 meters from the hub measured using tape measure. Or quantitatively, the signal strength at 10 meters should at least be -80 dBm measured using spectrum analyzer.

Power Electronics

The sensor node will comprise of several components that require the correct power. For our source, we have decided to use AAA batteries, each rated for 1.5 V and 25 mA (1000 mAh). We have decided this will be suitable to our needs because this provides enough current for approximately 40 hours. There will be design tradeoffs between using two or three batteries. Using two batteries would allow us to save space on our node, giving the product a smaller form factor. Additionally we would be able to connect the two batteries in series to provide us 3 V. As we have noted in sections regarding other components, many of our components require 3.3 V. Therefore a boost converter must be designed to step the voltage up to the necessary 3.3 V from our 3 V source. The series connection does not provide us additional current however 25 mA is enough for our sensor node to function. Our two AAA battery setup would be able to provide us 75 mW input power. Using three AAA batteries would produce a larger form factor, however, we would need to step down the voltage from 4.5 V to 3.3 V for our other components. This would give us more input power at 112.5 mW. We will attempt developing this design first due to the inherent stability of a buck compared to a boost. Additionally a voltage regulator may be used in tandem with the developed buck to eliminate output voltage ripple that may occur at high frequencies due to a transient load.

We will be designing the DC-DC converters from scratch for our sensor node. Initially we plan on prototyping with the breadboard and probing the outputs to confirm that the values are the expected inputs to the node components. Our initial design will look similar to a standard buck or boost converter. See Figure 5 for typical circuit schematics.

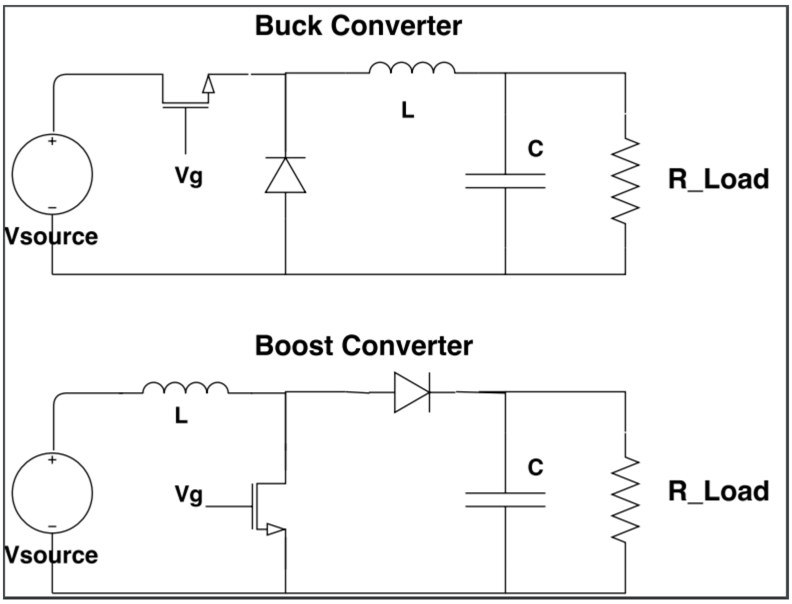

Figure 5: Buck and Boost Converters

To discuss power requirements, we must also discuss maximum load. We will be using the BT832F[8] for our sensor node bluetooth module. The maximum power drawn from this chip is $(7.4\ mA)(3.6\ V) = 26.64\ mW$. For our ECG sensor, BMD101[7], the maximum power draw is $(900\ \mu A)(3.6\ V) = 3.24\ mW$. The microphone, SPH0645LM4H-B, has a maximum draw of $(600\ \mu A)(3.6\ V) = 2.16\ mW$. See 1 for maximum load calculation.

$$\begin{aligned} P_{OUTmax} &= P_{BTmax} + P_{ECGmax} + P_{MICmax} \\ &= 26.64\ mW + 3.24\ mW + 2.16\ mW \\ &= 32.04\ mW \end{aligned} \tag{1}$$

As seen in the calculation, both the two or three battery designs discussed in this section meets the load power requirements.

Knowing the output power, the equivalent resistance of the load can be calculated as:

$$R = \frac{V^2}{P} = \frac{(3.3\ V)^2}{32.04\ mW} = 339.9\ \Omega \tag{2}$$

The current drawn from the load can then be calculated to be

$$I_{load} = \frac{3.3\ V}{339.9\ \Omega} = 9.7\ mA. \tag{3}$$

The duty cycle for the switch controller is defined as:

$$D = \frac{Vout}{Vin} = \frac{3.3}{4.5} = .733 \tag{4}$$

Using Equations 4 and 3, the current drawn from the source can be obtained as:

$$I_{source} = DI_{load} = (.733)(9.7\ mA) = 7.113\ mA \tag{5}$$

Knowing the current drawn from the source, the operation time (OT) of the batteries can be calculated to be:

$$OT = \frac{1000\ mAh}{7.113\ mA} = 140.58\ h \tag{6}$$

This definitely satisfies the original estimate of 40 hours operation time at 25 mA load. Additionally, the source must be able to supply power for four hours per use, a typical study duration. The source would be able to supply power for ideally 35 uses.

Inductance and capacitance values can be calculated according to the following formulas:

$$L = \frac{D(1-D)Vin}{f_{sw}\Delta i_l},\ C = \frac{\Delta i_l}{8 f_{sw} \Delta v_c} \tag{7}$$

where f_{sw} corresponds to the switching frequency and Δi_l and Δv_c corresponds to the ripple of inductor current and capacitor voltage.

The following figures show the simulated design of the converter discussed above using LTSpice. Values were tweaked slightly to meet specifications. Figure 6 shows the schematic and Figure 7 shows the plot of the output voltage waveform.

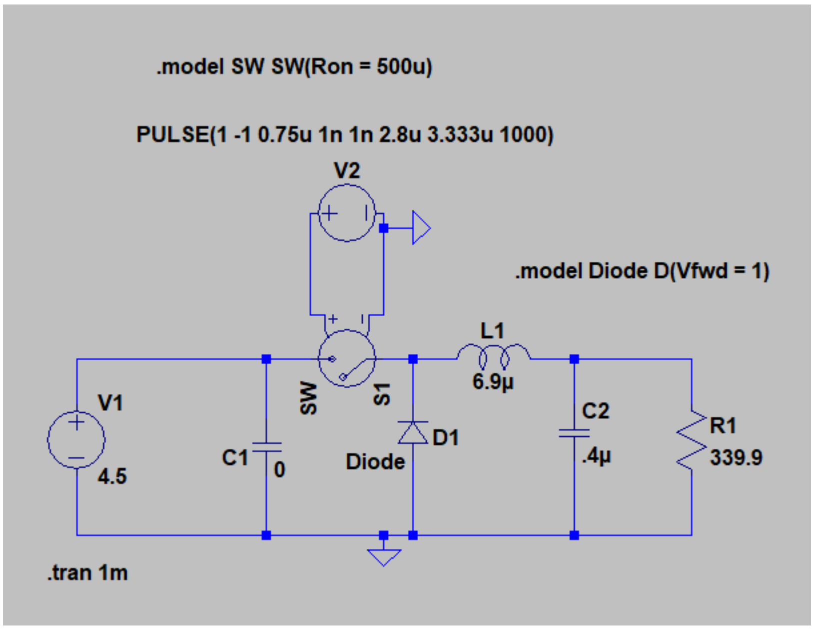

Figure 6: Simulation - Buck Converter Schematic

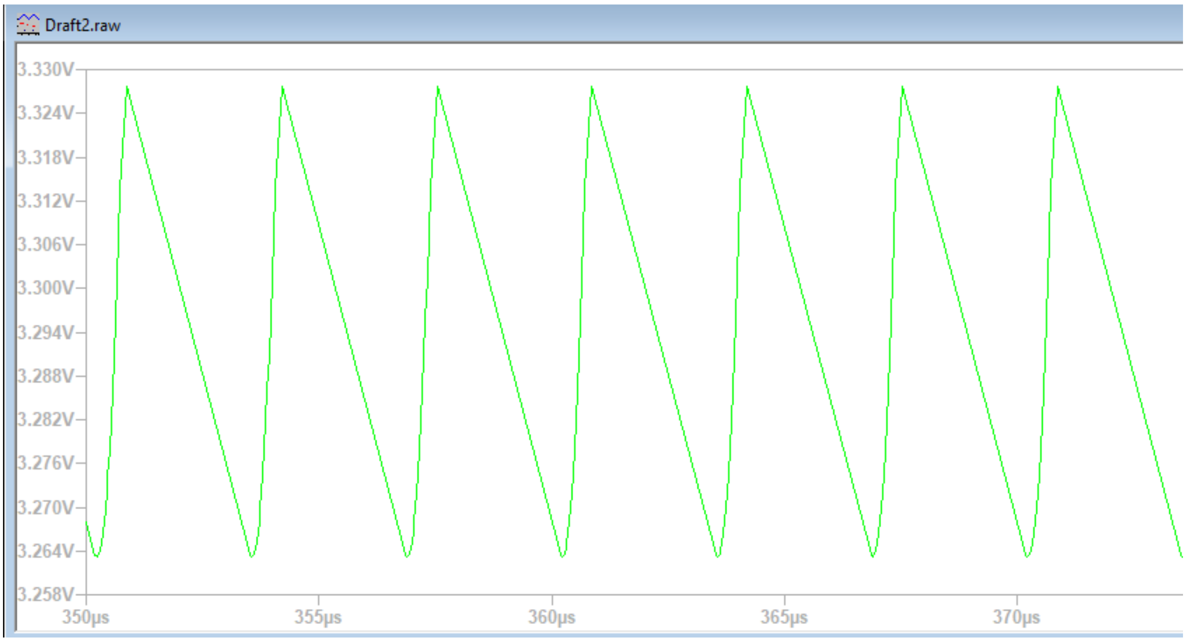

Figure 7: Simulation - Output Voltage

Other opportunities to explore would be to design a battery recharging station that is compatible with the sensor nodes. This would heavily increase product lifetime and would eliminate the need to replace old batteries. This would be an addition to the existing baseline that we will be establishing with the battery circuit discussed earlier in this section and a task that will be completed if we have extra time.

Block Requirements	Verification & Validation
Design a DC-DC buck converter using a 4.5 V AAA battery as source, supplying 3.3 V to the rest of the circuit.	Components must have the required power to operate. Average input voltage to the components must be at 3.3 V and providing sufficient current to all component operation modes. To validate, input voltage waveforms will be obtained from the oscilloscope. Operation of individual components as load will be tested separately to verify functionality of power supply.
Voltage waveform must have +/- 0.3 V ripple from 3.3 V.	Output voltage waveform will be probed with an oscilloscope. Ripple will be measured using measurement tools in the scope. Operation of components fail above and below the ripple values and therefore ripple must constrained.
Operation time of the batteries must be at least four hours per use, for at least 20 uses.	Batteries will be stress tested at equivalent maximum load for four hours, 20 times. This will show that it is capable of handling max operation for the operation time threshold and therefore can exceed it for normal operation. Using a battery plus resistive circuit, an equivalent circuit can be made and modeled instead of the full sensor package.

Functional Overview - Main Hub

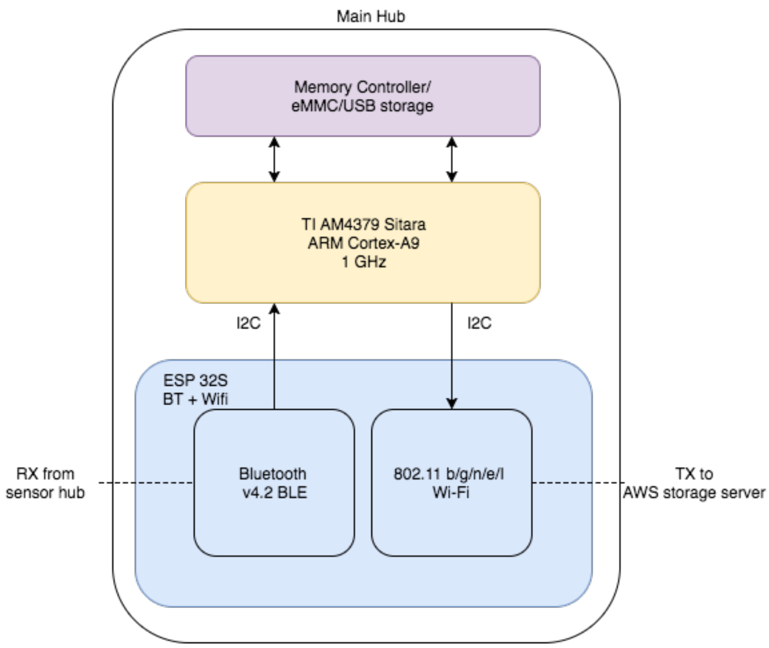

Figure 8: Main Hub Modular Block Diagram

The main hub will be the processing unit of our system. All of the sensor node data will be transmitted across Bluetooth and then processed by the microcontroller before being pushed either to local memory or cloud storage via WiFi. We chose to have most of the high consumption components away from the child to prevent any unwanted harm. Figure 8 shows the modular breakdown of the components in the main hub which consist of a microcontroller, BT + WiFi module, and some form of memory storage. Here we have chosen for each component what we think suits our needs best. A TI Sitara ARM A9 microprocessor, ESP 32S Bluetooth and WiFi combo module. In terms of storage, ideally all collected data points will be pushed to some form of cloud storage, in this case AWS S3. But for debugging and prototyping purposes, local storage will be helpful.

Microcontroller

We are considering between a high powered, fully featured microcontroller or a low powered, cost efficient microcontroller. In terms of power draw, it is not a concern since the main hub will be plugged into the wall. So the main factors would be port I/O, developer friendliness, and cost. Below we will list the differences between the 2 microcontrollers one from each category.

On the high end side of the spectrum is the TI AM4379 Sitara with an ARM Cortex-A9 CPU clocked at 1 GHz which might be excessive for our needs. However, the extra processing power can come in handy when multiple sensor nodes are connected to a single main hub. Serial port I/O is not a problem in this case with all of the common protocols, I2C, UART, SPI, and USB.

On the other end of the spectrum is the TI MSP432/MSP430 which has an ARM Cortex-M4 processor clocked at 48 MHz. This is an ultra low powered microcontroller with an active consumption of 80 μA/MHz [10]. One advantage of this particular model is that it has SimpleLink SDK, a widely-used development platform so open source projects are available to reference which might speed up wireless application development.

Wireless Transmission

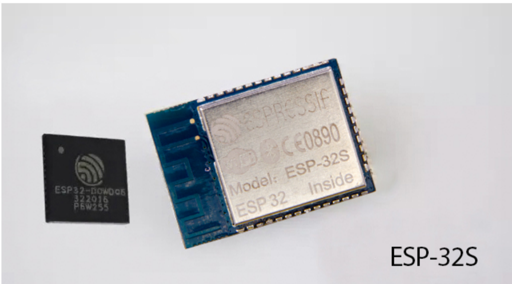

Figure 9: ESP32 Wifi & BLE module, dimensions: 16mm x 24mm x 3mm

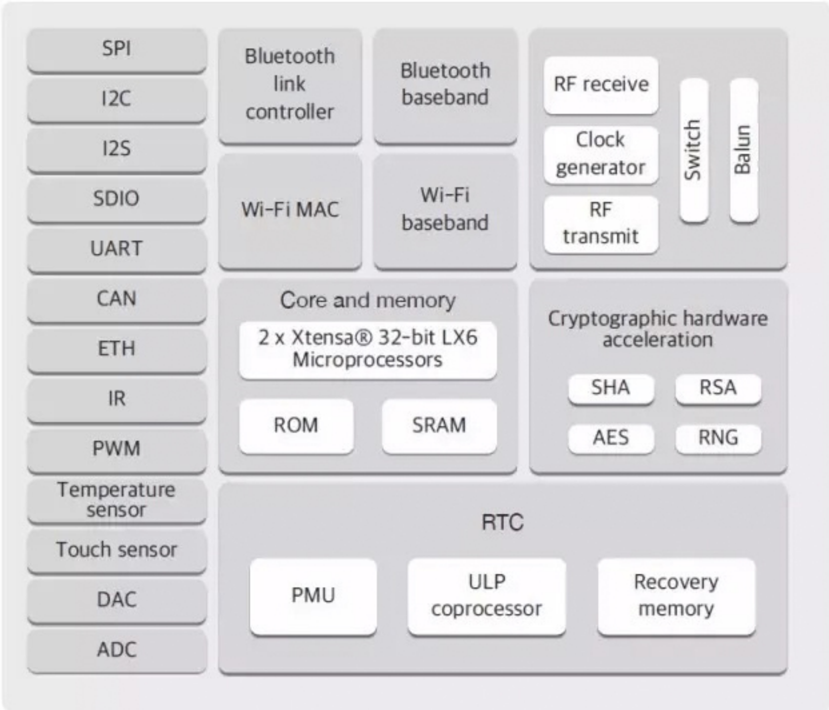

Figure 10: ESP32 Wifi & BLE module features

Bluetooth and WiFi transmission modules are needed. Bluetooth modules are mainly used as a master to receive all the data streams from the sensor node. Since the main hub will be stationary and powered by a wall plug, there is no constraints to the maximum power rating of the Bluetooth module. If there is a need to use a powerful Bluetooth module with large range, for example, if we need to monitor a child's outdoor activity, it is possible to use a powerful Bluetooth module even though it is of a different type as compared to the one on the sensor node. As long as they transmit at the same rate and frequency, we can use a powerful Bluetooth module to extend the communication range.

After receiving all the data, there is a need to push it onto a cloud server so that users can access it anywhere. We will use a WiFi module to achieve this task. A simple 2.4 GHz WiFi module should do the task since it is stationary and it can be placed right beside a router. We will not consider a 5GHz module because it costs more and a typical 80MHz bandwidth is sufficient for our needs. Furthermore, lower frequency offers more range.

The module we are considering now is the ESP32 chip, as shown in Figure 9, which is a compact combination of a Bluetooth and a WiFi module. It features a BLE v4.2 module with about 100m range, an integrated antenna, and a WiFi 2.4 GHz module featuring built in RTC, core memory, security features, and various common protocols like I2C, I2S and UART [11].

Data Back-end

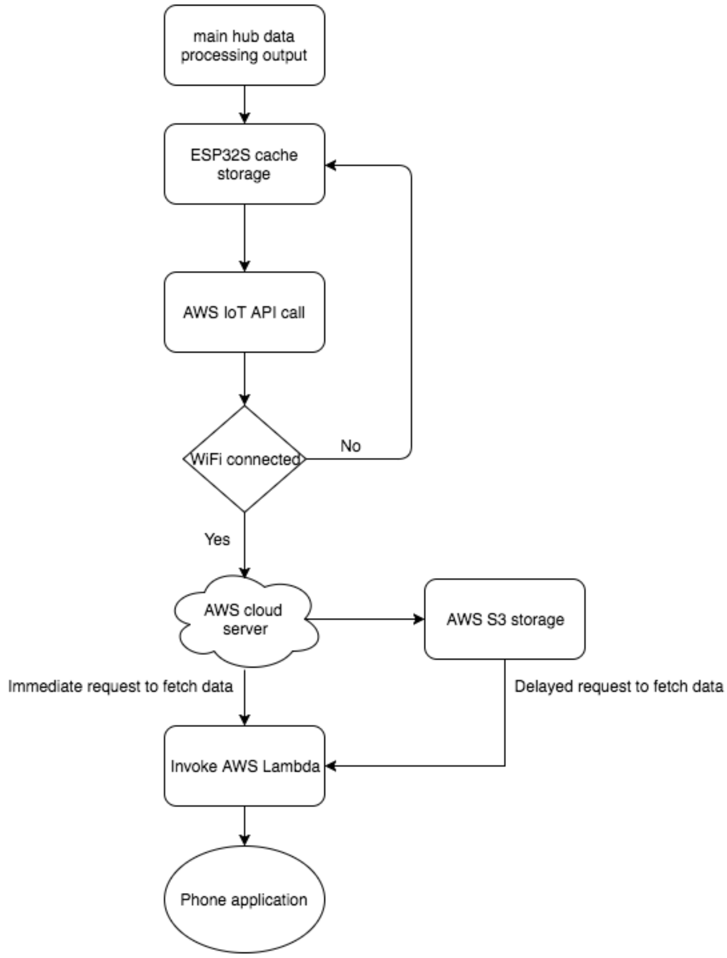

Figure 11: Flowchart for AWS data back-end.

The general idea is to have a software which compiles all the data together with time stamps so that it will be in a readable text file available for playback. Then, this data will be pushed to the AWS cloud server using AWS IoT API calls. This can be automated by using AWS Lambda pipelining that pushes files automatically to an AWS S3 storage. AWS IoT helps with the MQTT handshake which is a lightweight messaging protocol optimized for high latency. To further explain, MQTT is a machine-to-machine (M2M)/"Internet of Things" connectivity protocol. It was designed as an extremely lightweight publish/subscribe messaging transport [12].

If we are ahead of our schedule, we might also consider creating a mobile phone application or web-app that can pull selected chunks of data and scrub the timeline. A simple Ionic framework based mobile phone application can be written alongside back-end API calls to AWS. Ionic framework will be used because instead of developing Android or iOS independently, Ionic allows us to develop in HTML/Javascript then port over to either mobile OSes.

Block Requirements	Verification & Validation
Have the data collected compiled and converted into a readable file format available for playback.	Timestamps will be recorded for both ECG and voice recording data before packets are uploaded, and must match during playback.
Have the data pushed into an AWS server so that it can be fetched from different devices.	Setup to notify when data is being fetched from AWS server.

Power Electronics

The main data hub will be designed to be a stationary component that will be plugged into a wall outlet. Assuming the product will be used in the United States, the outlet will provide 120 Vrms at 60 Hz. Therefore we must convert the AC voltage to DC for our circuit applications in our hub. The hub will have various components that need DC voltage which include the communication modules for WiFi and Bluetooth and the microcontroller. Once the AC voltage is rectified into a DC voltage, we can then use a DC-DC conversion to step down the voltage to the level our components will be able to use. Another method would be to use a transformer to step down the AC voltage to a lower AC value, and rectify the now lower value to the desired DC value. This would however increase the size of our hub because transformers are relatively large. This is not a big concern because the hub is stationary and should not be moved around. However, this is not a primary concern. A 10:1 transformer would suit our needs, converting 120 V AC to 12 V AC. Then we would perform rectification to obtain the expected DC values we need. For our components in the hub, around 3.3 V is necessary.

To discuss power requirements, we must consider the maximum load power. In our main hub, there are two components: a microprocessor, TI-MSP432[10], and a Bluetooth and Wifi module, ESP32. The maximum power rating for the microprocessor can be calculated as $(100\ mA)(3.7\ V) = 0.37\ W$. The maximum power load for the communication module can be calculated to be $(240\ mA)(3.6\ V) = .864\ W$. See the total load power calculation in 8.

$$\begin{aligned} P_{OUTmax} &= P_{COMmax} + P_{MICROmax} \\ &= .864\ W + .37\ W \\ &= 1.234\ W \end{aligned} \tag{8}$$

Because we are plugged into an outlet, this maximum power load should not be a problem.

Figure 12 shows a typical circuit schematic used for full-wave rectification.

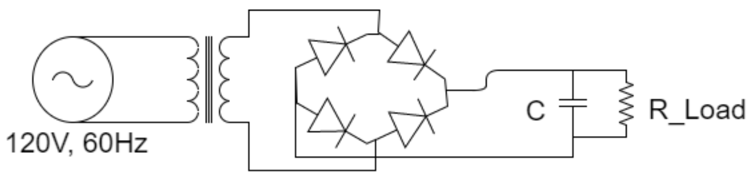

Figure 12: AC-DC Full Wave Rectification

Using Equation 8 the equivalent resistance of the load can be calculated to be:

$$R_{eq} = \frac{V^2}{P} = \frac{(3.3\ V)^2}{1.234\ W} = 8.825\ \Omega \tag{9}$$

The load current can then be calculated as:

$$I_{load} = \frac{V}{R} = \frac{3.3\ V}{8.825\ \Omega} = .374\ mA \tag{10}$$

The filter capacitance is given by the equation:

$$C = \frac{I_{load}}{2f\Delta v_c} \tag{11}$$

where Δv_c is the voltage ripple, constrained to be 0.6 V, and f is the frequency of the AC source, 60 Hz.

The simulated converter design is shown below. This is under the assumption that using a transformer, an ideal voltage source can be used for the input to the diode bridge. Figure 13 shows a proposed schematic of the design. Figure 14 shows the output voltage waveform.

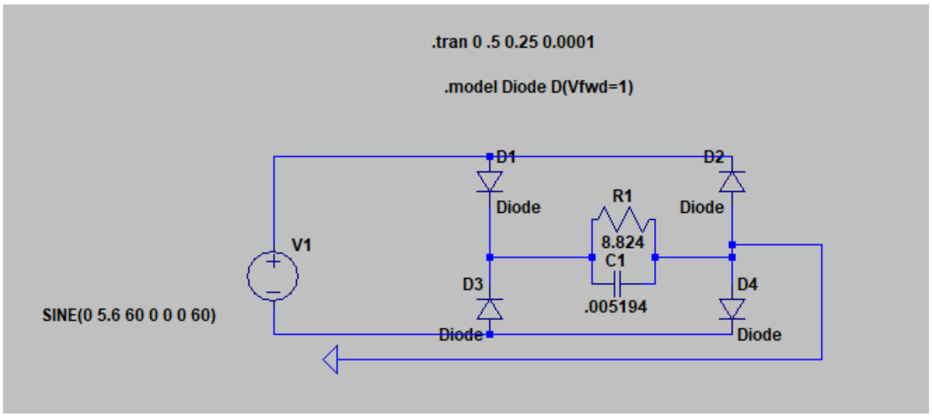

Figure 13: Simulated AC-DC Converter Schematic

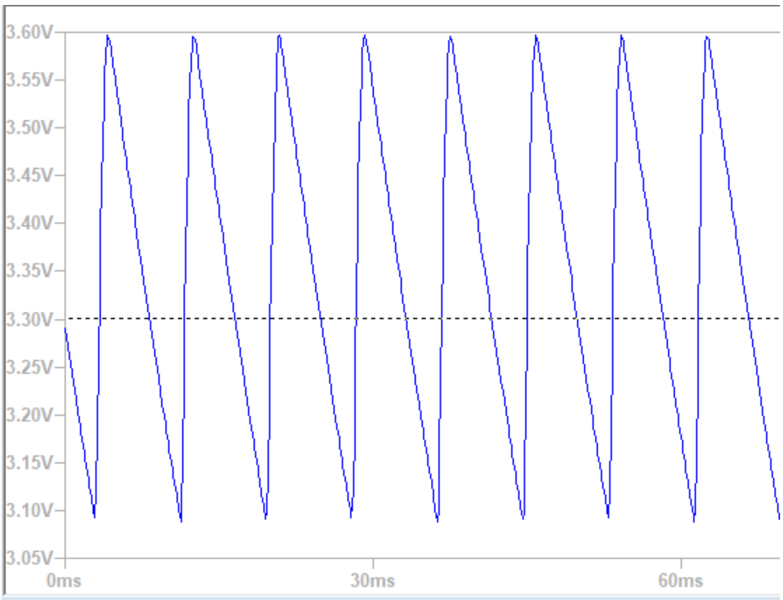

Figure 14: Simulated Output Voltage Waveform

Block Requirements	Verification & Validation
Design an AC-DC full-wave rectifier using the wall outlet as source and must supply 3.3 V to all components. All components must have the required power to function for all operations.	Average input voltage to the components must be 3.3 V and sufficient current must be supplied for all component operation modes. To validate, input voltage waveforms will be obtained from the oscilloscope. Operation of individual components as load for all operation will be tested separately to verify functionality of power supply.
Voltage waveform must have +/- 0.3 V ripple from 3.3 V.	Output voltage waveform will be probed with an oscilloscope. Ripple will be measured using measurement tools in the scope. Operation of components fail above and below the ripple values and therefore ripple must constrained.

2.4 Tolerance Analysis

The critical point of our entire design would primarily be the power electronics. This is because without power, both the main hub and the sensor node cannot function. The reverse, too much power, also hinders and is destructive to the functionality of the components receiving power. Therefore it is crucial to be attentive to the design of both power supplies.

Both the power electronics on the sensor node and main hub must both have an output DC voltage of 3.3 V. This is a shared requirement induced by the operating points of the various components on each board. Therefore similarities in the tolerance requirements exist for both designs. The main requirement must be that the supply to the components must be 3.3 V DC; however, there is often a ripple component attached to this DC output. This is due to the the components involved in the circuitry. For the DC-DC converter, the inductance and capacitance cannot be infinitely large, and therefore ripple must exist. For the AC-DC converter, the source is sinusoidal and the diode bridge simply rectifies the sinusoid so the output still retains sinusoidal ripple qualities. An output capacitor is connected in parallel to filter the signal and produce a cleaner DC average. As in DC-DC conversion, the capacitor cannot be infinitely large and therefore ripple will occur.

For DC-DC, the voltage ripple is a function of the capacitive filter and can be found to be:

$$\Delta V_{out} = \frac{\Delta i_l}{8 f_{sw} C} \tag{12}$$

Likewise, for AC-DC, the voltage ripple is seen as:

$$\Delta V_{out} = \frac{I_{load}}{2 f_{src} C} \tag{13}$$

Therefore it can be seen that as the capacitor is infinitely large, the ripple goes to zero. This cannot happen so we must set a practical limit to the ripple. Many of the components have a maximum operating voltage of 3.6 V, and a minimum of 3.0 V. Therefore the ripple limit can be seen as +/- 0.3 V. Using equations 12 and 13, a capacitive filter can be designed to meet these requirements. A tighter constraint, possibly 0.25 V ripple, could benefit this design because maximum and minimum operating points are the limits of functionality; a slight overshoot or undershoot may cause the system to not function, so these limits should be avoided.

Another point affecting the output voltage is the non-idealistic traits of the source. Primarily for the DC-DC converter, the battery source is non-ideal due to the internal resistance. A 4.5 V source from three AAA batteries would be ideal. However, there would be three additional internal resistance drops in voltage in this series connection. Therefore the design must be able to handle slightly less voltage, perhaps around 4 to 4.2 V. Batteries also have a decaying voltage due to the chemical properties and capacitive wear. Therefore control must be considered if a 3.3 V output, regardless of the reduction in source voltage, must be supplied. The AC-DC converter sees similar issues with a non-ideal source coming from a wall plug. Wall voltage is regulated by the US Department of Energy and therefore is more reliable than a decaying battery source; however, it cannot be assumed that the source will be exactly 120 V AC at 60 Hz.

Lastly, a point to consider must be the load transient characteristic of each power converter. This is because our loads are often never constant. For example, the communication modules may draw more power during transmission than while idle. The effect of this on a power supply can be seen as a dip in the output voltage. The output voltage must not dip below the operating points of the other components on the board. If this occurs, functionality failures are inevitable. An example of load transient effects are seen below in Figure 15.

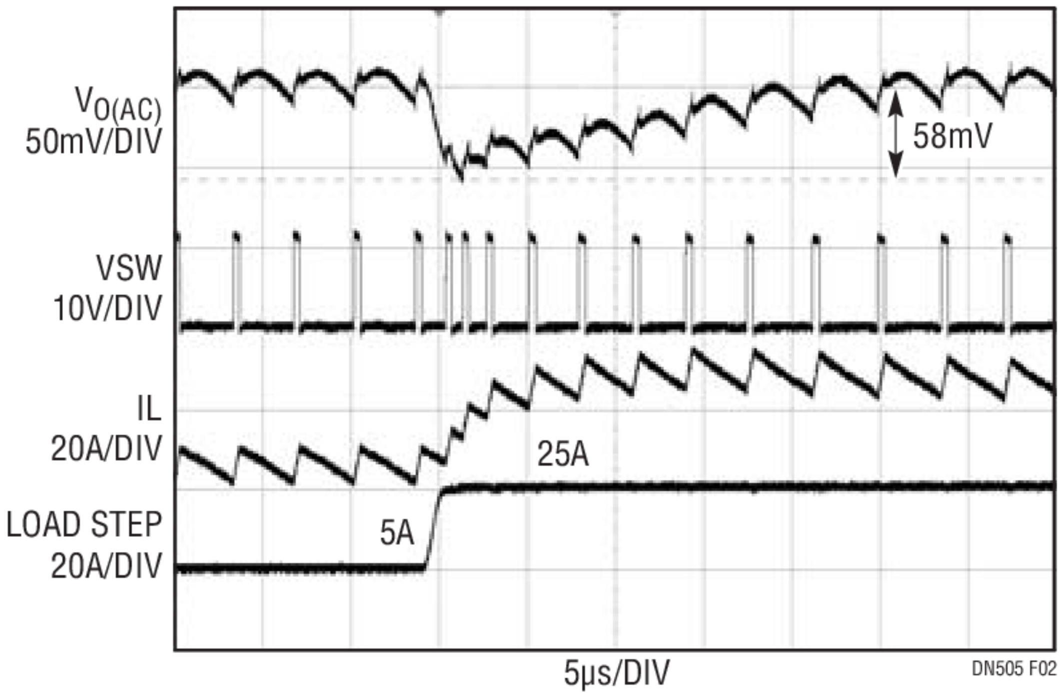

Figure 15: Example of load transient effects

With many tolerance considerations, the power electronics is clearly the most crucial point of tolerance in our design. Therefore it is important to follow a rigorous process of design, simulation, prototyping and verification. To improve on our design performance, it is clear that there are many factors to work with in our power supply design.

2.5 Risk Analysis

There are multiple points of risk to the project. The most predominant would be the accuracy of the ECG data. This is because for research purposes, we would want the ECG to provide accurate enough information for the researchers to use. Inaccurate data would obviously jeopardize the study. Drawing conclusions on faulty data is dangerous to the integrity of the study. Additionally we believe that accuracy of the ECG will be a very tricky task to optimize.

The accuracy of the ECG is dependent on a variety of variables. A variable of concern is the mechanical design of the sensor housing. If this mechanical design does not provide sufficient enough probing capabilities for our electrodes of the ECG, this will cause a big issue with determining ECG waveforms. Another task we need to focus on is the design of the electrodes. One main task that was given to us by the sponsoring professors was that these electrodes must be non-adhesive. This is because it would be tedious to replace electrodes for each use of the device. Therefore we must design the electrode such that we are able to obtain readings even without continuous contact. Most importantly, the predominant variable of concern is the child. This is because children are prone to move around quite often and therefore can easily brush off the electrodes and consequently distort ECG readings. A main task then must be to child-proof the electrode design such that we are able to obtain accurate ECG readings even when the child is in random motion.

Therefore we conclude that the ECG data is the largest risk to our project. This is because ECG data is vital to the research study but can easily be tampered with by the test subject. Therefore we must pay careful consideration to how we design the capturing mechanism for the ECG data.

3 Cost and Schedule

3.1 Cost

Item	**Cost**
Labor	
\$32.21 (per hour)[23] x 8 (hours per day) x 30 days (per month) x 3 (labor)	\$23,191.20
Parts	
MEMs Microphone (SPH0645LM4H) ECG sensor (BMD101) Electrode Cable (bundle of 3) Bluetooth & Wifi Module (ESP32) Microcontroller (MYS-437X-100-C-S) 2-sided PCB (sensor node and main hub)	\$6.95 \$69.00 \$4.95 \$30.00 = 2 x \$15.00 \$129.00 \$20.00 = 2 x \$10.00
Parts total	\$259.90
Total	\$23,451.10

The table above shows an estimate cost of development for this project. A main assumption made is that labor pay is the same as what an average graduate from ECE at Illinois makes, and that we work 8 hours everyday for a month. It is also noteworthy mentioning that this project will be funded by the MechSE department, with a budget of \$1000 on top of the \$40 given to us by the ECE department. We are also given an additional variable amount of money from the project sponsors based on need. Majority of the manufacturing cost will come from the electrical components relative to cost of housing/casing.

3.2 Schedule

At the end of this project our final deliverable would be a working prototype that will include and meet all of the above requirements. A working sensor node with ECG and voice recording, a working main hub that handles data processing and communication with the sensor node. To get things done on time we have created a Gantt chart for each individual contributor to use as a work distribution and time management guideline. See Appendix 18 for Gantt chart.

Weekly deliverables are listed in the table below.

Deliverables	**Due Dates**
Prototyping and characterization of each sensor node module.	14th October
Validated and tested individual sensor node modules.(ECG, audio recording, BT, power electronics)	25th October
Completed circuit schematic and layout of PCB.	9th November
Working main hub components. (microcontroller, BT + WiFi, power electronics)	16th November
Final testing of PCB.	25th November
Optional phone application and AWS back-end developed.	27th November
Full system testing and validation.	2nd December

The project will be broken down into three main parts, sensor development, wireless transmission, and power electronics. Eu Hong Woo will lead wiring and firmware development for the ECG sensor and audio recorder (sensor development). Yang An Tang will be in charge of microcontroller, Bluetooth, and WiFi module firmware development for both the sensor node and main hub (wireless transmission). Eu Hong Woo and Yang An Tang will work closely to integrate and interface the ECG and audio recordings with Bluetooth module to complete the sensor node prototyping. Xiang Wen will be designing and implementing the power electronics for both the sensor node and main hub (power electronics). Once each individual block has been tested and validated, all three members will work together to design circuit schematics and PCB layout. Documentation for each functional block will be done in conjunction with prototyping and development.

4 Ethics and Safety

Firstly, the sensor node that will be worn by an infant/toddler has to have safety features implemented into the design which aligns with the IEEE Code of Ethics #1. It states "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment." [13] For example, since there will be a battery pack strapped onto the child, overcharging or extreme temperatures can cause overheating or potentially explode. To counter this problem, we will closely monitor battery cell temperatures with a thermistor. Also, over-charging the battery can lead to a breakdown of the cathode, a highly exothermic process. We would have to ensure that our charging circuitry does not go over the threshold voltage. Also following the IEEE Code of Ethics, sources must be correctly cited and plagiarism must be avoided [13].

Since there will be a microphone constantly recording, we have to align with the ACM Code of ethics "Respect the privacy of others." [14] It is our responsibility as engineers to maintain the privacy and integrity of data of other individuals. This includes taking precautions to ensure the accuracy of data, as well as protecting it from unauthorized access or accidental disclosure to inappropriate individuals. [14] To overcome privacy issues, all collected and streamed data will be hardware and software encrypted and only authorized users will be able to decrypt and use said data/information. Most of the briefly mentioned hardware components above do have built-in hardware encryption accelerators and software encryption can be realized by first encrypting each and every packet of data before transmitting. On the server side, encryption will be enabled for each step of the way. Also, all of the wireless communication components comply with the requirements by the FCC.

We intend to test our system on children towards the end for validation purposes in conjunction with Professor Nancy McElwain from the College of HDFS. To protect the rights and welfare of human subjects in research, we would have to abide to the Institutional Review Board (IRB) which takes oversight of research involving human subjects, and to comply with the Federal Policy for the Protection of Human Subjects and applicable federal laws and regulations. [15] The IRB ensures that appropriate safeguards exist to protect the rights and welfare of research subjects. [16] With the research coordinators leading the IRB review process, we will have all the required approval in order to carry out testing with proper consent and in accordance to IRB protocol.

References

[1] McElwain, N. L., Pomerantz, E.M., Bub, K. L., Hahn, L. J. W., Johnson, H. T., & Bernhard, J (2017) Children in the Wild: Engineering Tools to Capture Child Development in Real-World Contexts, `SBSRI Small Grants Program`

[2] Porges, S. W. (2007). The polyvagal perspective. `Biological Psychology`, 74(2):116–143.

[3] Porges, S. W. (2011). `polyvagal theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation`. New York, NY: Norton.

[4] Bub, K. L., Buckhalt, J. A., & El-Sheikh, M. (2011). Children's sleep and cognitive performance: a cross-domain analysis of change over time. `Developmental psychology`, 47(6), 1504.

[5] Cole, J., Berry, D., McElwain, N. L., Bulkes, N., Mahrt, T., & Emery, H. T. (June 2015). `Linking pitch prosody and affective behavior in mother-child interaction`. Paper presented at the Workshop on Prosodic Development at the International Biennial Conference on Phonetics and Phonology. Cambridge, United Kingdom.

[6] McElwain, N. L., Berry, D., & Cole, J. (May 2016). The sound of sensitivity: In-the-moment relations between maternal pitch prosody and mother-toddler interaction quality. In A. Bernier (Chair), `Recent advances in the study of early maternal behavior`. Paper symposium to be conducted at the XXth Biennial International Conference on Infant Studies, New Orleans, Louisiana.

[7] BMD 101 [Online]. Available:
`http://m5.img.dxcdn.com/CDDriver/CD/sku.241178.pdf`

[8] BT832F [Online]. Available:
`https://gridconnect.com/bt832f-extended-range-Bluetooth-ble-module-mesh-network.html`

[9] MEMS microphones vs Electret microphones [Online]. Available:
`https://ez.analog.com/thread/11410`

[10] TI MSP432 Ultra Low Powered Microcontroller [Online]. Available:
`http://www.ti.com/product/MSP432P401R/datasheet`

[11] ESP32 WiFi & BLE module [Online]. Available:
`https://www.seeedstudio.com/ESP-32S-Wifi-Bluetooth-Combo-Module-p-2706.html`

[12] MQTT [Online]. Available:
`http://mqtt.org/`

[13] IEEE Code of Ethics [Online]. Available:
`http://www.ieee.org/about/corporate/governance/p7-8.html`

[14] ACM Code of Ethics [Online]. Available:
`https://www.acm.org/about-acm/acm-code-of-ethics-and-professional-conduct`

[15] Urbana-Champaign Policy Governing the Use of Human Subjects in Research [Online]. Available:
`http://cam.illinois.edu/xi/xi-1.htm`

[16] Review Processes and Checklists [Online]. Available:
`https://oprs.research.illinois.edu/review-processes-checklists`

[17] ECG Measurement [Online]. Available:
http://www.cisl.columbia.edu/kinget_group/student_projects/ECG/Report/E6001/ECG/final/report.htm

[18] Digital Sampling Rate and ECG Analysis [Online]. Available:
http://www.sciencedirect.com/science/article/pii/0141542585900275

[19] SPH0645LM4H Datasheet [Online]. Available:
https://cdn-shop.adafruit.com/product-files/3421/i2S+Datasheet.PDF

[20] BT832 Evaluation board schematic [Online]. Available:
https://static1.squarespace.com/static/561459a2e4b0b39f5cefa12e/t/58b0b33129687f881c6778e2/148797521

[21] ESP32 WROOM schematic [Online]. Available:
https://dl.espressif.com/dl/schematics/ESP-WROOM-32-v3.2_sch.pdf

[22] Example Load Transient [Online]. Available:
http://cds.linear.com/image/18701.png

[23] Average ECE salary [Online]. Available:
https://ece.illinois.edu/admissions/why-ece/salary-averages.asp

5 Appendix

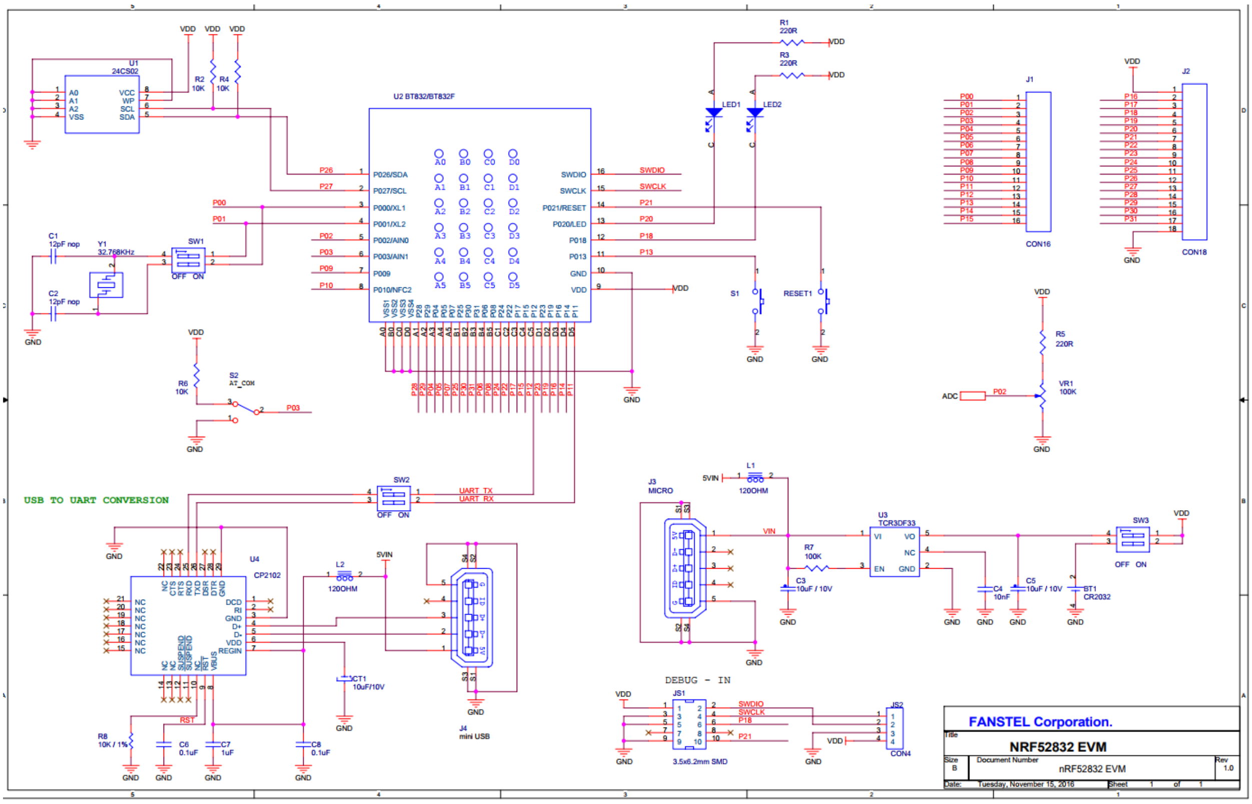

Figure 16: BT832 evaluation board schematics. [20]

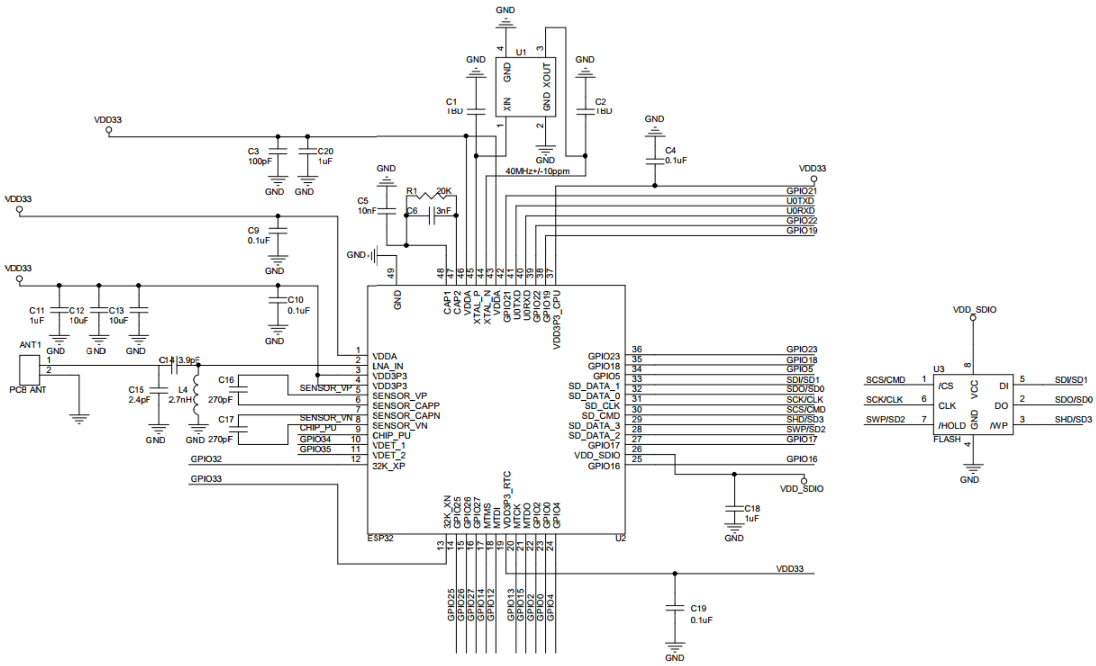

Figure 17: ESP32 WROOM schematics. [21]

ECE445 - Gantt Chart

PROJECT TITLE Child Development Sensor

TA Rebecca Chen

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PROGRESS (%)
1	Sensor Node					
1.1	**ECG Module**	Eu Hong	10/1/17	10/18/17	18	0%
1.1.1	Getting ECG development board to work	Eu Hong	10/1/17	10/4/17	4	0%
1.1.2	Design circuit to replace dev board	Eu Hong	10/5/17	10/11/17	7	0%
1.1.3	Interface ECG with Bluetooth	Eu Hong	10/12/17	10/18/17	7	0%
1.2	**Voice Recorder**	Eu Hong	10/19/17	11/8/17	20	0%
1.2.1	Get readable data from the recorder	Eu Hong	10/19/17	10/25/17	7	0%
1.2.2	Achieve timestamps and playback function	Eu Hong	10/26/17	11/1/17	6	0%
1.2.3	Sync Audio and ECG data	Eu Hong	11/2/17	11/8/17	7	0%
1.3	**BT832F (BT Module)**	Tang	9/29/17	10/19/17	21	1%
1.3.1	BT832F dev board to send test data	Tang	9/29/17	10/6/17	8	1%
1.3.2	Firmware to send packets to main hub	Tang	10/7/17	10/11/17	5	0%
1.3.3	Read datalines from sensors	Tang	10/12/17	10/19/17	8	0%
1.4	**Power Electronics**	Xiang	9/28/17	10/29/17	32	0%
1.4.1	DC-DC Converter Design	Xiang	9/28/17	10/8/17	11	0%
1.4.2	Converter Simulation	Xiang	10/8/17	10/14/17	7	0%
1.4.3	Converter Breadboard Prototyping	Xiang	10/15/17	10/29/17	15	0%
1.5	**Overall**	All	10/25/17	11/25/17	31	0%
1.5.2	PCB design and layout	All	10/25/17	11/9/17	15	0%
1.5.3	Debug and test PCB	All	11/10/17	11/25/17	16	0%
2	Main Hub					
2.1	**ESP32 (BT+WiFi Module)**	Tang	9/29/17	10/19/17	21	10%
2.1.1	ESP32 dev board to RX/TX test data	Tang	9/29/17	10/7/17	9	10%
2.1.2	RX/TX interface with sensor node	Tang	10/7/17	10/19/17	13	0%
2.2	**MSP432 (Microcontroller)**	Tang	10/20/17	11/25/17	36	0%
2.2.1	Learn SimpleLink SDK	Tang	10/20/17	10/30/17	11	0%
2.2.2	Sync with ESP32	Tang	10/31/17	11/10/17	11	0%
2.2.3	Local storage setup	Tang	11/11/17	11/17/17	7	0%
2.2.4	Cloud integration (AWS API)	Tang	11/20/17	11/25/17	6	0%
2.3	**Power Electronics**	Xiang	10/22/17	11/16/17	25	0%
2.3.1	AC-DC Converter Design	Xiang	10/22/17	10/29/17	8	0%
2.3.2	Converter Simulation	Xiang	10/30/17	11/5/17	6	0%
2.3.3	Converter Breadboard Prototyping	Xiang	11/6/17	11/16/17	11	0%
3	Software					
3.1	**AWS setup**	Eu Hong	11/18/17	11/27/17	10	0%
3.1.1	AWS IoT and S3 setup	Eu Hong	11/18/17	11/20/17	3	0%
3.1.2	Data sorting	Eu Hong	11/25/17	11/27/17	3	0%
3.2	**Android/iOS app (optional)**	Xiang	11/18/17	11/27/17	10	0%
3.2.1	Ionic front-end development	Xiang	11/18/17	11/20/17	3	0%
3.3.1	Back-end development	Xiang	11/21/17	11/27/17	7	0%
4	Administration					
4.1	**Project Proposal**	All	9/17/17	9/21/17	5	100%
4.2	**Design Report**	All			1	0%
4.3	**Demo**	All			1	0%
4.4	**Final Presentation**	All			1	0%

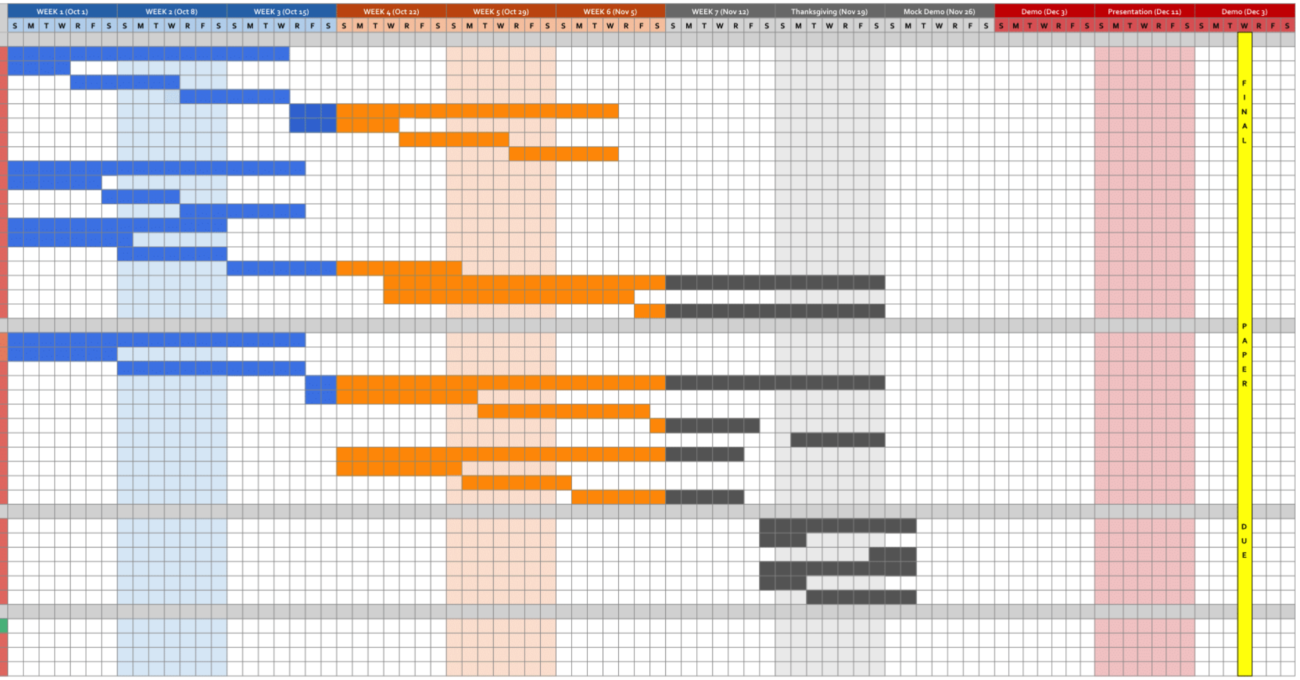

Figure 18: Team #14 Child Development Sensor Gantt Chart