Baby Pulse Early Alarm System

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***Abstract* -- This paper describes the design process and implementation of a convenient and noninvasive device for reading quantifiable bio-markers to indicate an infant's state of health. This will be achieved by consolidating multiple sensors for reading various vital signs onto a single chip, which will then send the information onto a smartphone application wirelessly through Bluetooth for convenient monitoring from around the house.**

***Index Terms* – Accelerometer, Application, Biomarkers, Bluetooth, Embedded Chip, Serial Communication**

I. Introduction

Markets sell a variety of baby monitoring equipment that includes an abundance of features; some common features include infrared cameras and ambient temperature sensor. While many traditional monitors focus on the video as a safety feature, a baby's wellbeing is sometimes hard to decipher on a grainy screen. This project strives to improve upon the current models and involves several factors for specific medical and social considerations. Geared toward infants and young toddlers, Baby PEAS is designed to provide an empirical picture of the newborn's physical condition. If a sensor detects sudden drops in pulse or oxygen levels, a triggered alarm alerts the caretaker. Whereas, if relying on video observation, the caretaker could find his attention distracted or misread a picture on the screen and lose critical minutes in a potentially serious medical emergency. In addition to basic pulse functions, the accelerometer and the temperature sensors can help monitor against risk factors for sudden infant death syndrome (SIDS). Although no definitive cause is known, the medical community agrees on several factors that can magnify risk of SIDS. The accelerometer and temperature sensor should mitigate the risk factors.

Sudden infant death syndrome (SIDS) is the sudden and unexplained death of an infant who is younger than a year old. SIDS can affect even seemingly healthy babies [1]. Most instances of SIDS deaths are associated with sleep; where there is an infant is unable to properly react to a life-threatening situation. A SIDS diagnosis usually occurs when all other causes of death have been ruled out [3]. Most SIDS deaths occur between the ages of two and four months.

Due to the nature of usage, form and packaging comprises a large portion of design. Because the unit is planned to operate under direct contact with the baby, safety considerations include minimal invasiveness and heat dissipation. In addition, ergonomic concerns include ease of use, bulk, and portability. Power factors in as well due to the targeted length of function time.

II. Goals

When planning out the project, there must be certain specifications that need to be set in order to reach toward an achievable goal. This device is envisioned to be a small, lightweight anklet that can comfortably fit around an infant's leg for an extended period of time. To achieve a lightweight goal, the device should be left than half a pound and 50x100x15mm in volume. An infant has an average sleep time of more than twelve hours, so the battery life for the device should last that long before a recharge is required. The accuracy given is plus or minus twenty percent. While that may seem like a large range, the actual data we are worried about are large changes in the data which can indicate that the child is doing something abnormal. Finally, the range of the device should be long enough to get through the house to a couple rooms over. These goals are summarized in the table below.

Device Battery Life:	>12HRS
Weight of Device	< 5 lbs
Dimensions	< 20mm (W) < 10mm (H) <100mm (L)
Pulse Accuracy:	+- 20%
Heart Rate Accuracy:	+- 20%
Temp Accuracy on board	+- 5 Degrees C
Position Accuracy	Must let the user know whether the infant is on their front or back
Wireless Transmission Range:	100 feet
Operating Temperature:	5 degrees ~ 50 degree
Operating Humidity:	10%~90>

Figure 1. Goals for Project

III. Vital Signs

Vital signs are the initial measurements which represent the general health condition of an individual. The four main measurements in most medical settings include body temperature, heart rate, respiration rate, and blood pressure. Pain level, blood oxygenation may also be included if the appropriate medical devices are available. The BabyPeas project aims to provide parents with reliable, convenient, real time updated vital signs of their babies.

A. Temperature

Temperature is a vital sign that the caretaker needs to know in order to ensure the safety and health of the baby. Baby Peas can help with monitoring temperature, but accuracy may be a trade-off for convenience. Using a rectal thermometer is the most accurate but also the most invasive. Measuring the armpit, while not as accurate, is the least invasive. The danger of temperature is not necessarily in the minute degree differences, but rather in spikes or unusual declines. Using a temperature sensor that can be attached to ankle and wrapped with a sock seems reasonable as long as the normal general temperature in the certain area is taken into consideration. Knowing the long term trend of the baby's temperature tells more about the wellbeing of the baby rather than single point data.

B. Heart Rate

The heart is the vital motor to the body just like the engine is to a car. Blood is the organ being transported by heart to the rest of the body. Nutrients, wastes, oxygen are carried in the blood along with antibodies and foreign material fighting agents. There are four chambers in the heart- right atrium, right ventricle, left atrium and left ventricle. In systemic circulation, blood is pumped out from left ventricle through aortic valve (three leaflets) to the aorta during systole.

By employing a Baby peas unit, the caretaker can see the normalized heart beat rate for the baby. In a typical day, a person's heart beat rate can change due to the biological circadian rhythm. For a baby, this is no different. Having a Baby peas unit can help set a base line for the baby and alert the caretaker if a gross deviation happens.

One of the features on BabyPeas is pulse monitoring. Many candidates were considered; discrete design using various stages of operational amplifiers, analog front end sensor and PulseSensor. Using the sensor by PulseSensor offers most accurate heart rate monitoring and lowest noise interference. The waveform output can be seen via Processing. Its simplistic and compact design was easily incorporated into our project. The voltage input required by PulseSensor is only 3V. PulseSensor is an open source hardware project; the Arduino community offers great help and support.

C. Body position

Although body position itself is not considered a vital sign, it plays an important role for a person's well being. Babies spend majority of their time in the crib and their sleep time is much longer than adults. The babies do not have full control of their bodies. They may be harmed if their sleep position is off. Tragic event such as SIDS could happen. Having the right body position, it can have direct impact on other vitals signs such as respiration. Using Baby Peas, the parents can monitor the body position of their babies and ensure their safety.

IV. Sensors

A. Temperature

General parameters in this application for temperature sensors are low power consumption, easy to integrate, and small form factor. Proper power management is essential for safe operational environment. The sensor will be used to measure skin temperature on the infant. In Baby Peas project, a thermopile sensor will be used due to its capability of measuring temperature without skin contact. With high power consumption, the element may be heated and cause discomfort. Fire hazard is another issue since cloth may be used to conceal the element. With numerous temperature chips available on the market, our goal is to acquire one that can be easily used with the chosen microprocessor.

The temperature sensor used is the TMP006 from Texas Instruments. TMP006 is meant for non-contact remote temperature monitoring. TMP006 is an infrared thermopile sensor with a size of 1.6mm by 1.6mm. The temperature of the object is measured by the thermopile on the sensor. The thermopile converts thermo energy (infrared energy emitted by the object in this case) into electrical energy. An output voltage is created based on the difference to the local temperature. TMP006 operates between minus 40 degree Celsius to 125 degree Celsius. The way TMP006 communicates is thru SMBus (System

Management Bus, or SMB). SMBus is a derivative of I^2C which is compatible with our desired microprocessor CC2541 from Taxes Instruments. Two variants of TMP006 are available, TMP006 and TMP006B. The main difference is SMBus interface voltage. TMP006 is at 3.3 V while TMP006B is at 1.8 V. The two main constrain of using TMP006 are surface emissivity and target size to sensor placement. Surface emissivity- It is a measurement of a surface that emits energy (thermo energy). If an object has a potential to release an energy value of 200 Jules but only emit 150 Jules by measurement. It has an emissivity value of 0.75 from 150/200. A perfect material with a surface emissivity is called a blackbody with a value of 1. For example, concrete has surface emissivity of 0.85. In our application, the human skin has emissivity of 0.98 to 0.99. TMP006 is capable of calculating temperature from subjects with surface emissivity greater than 0.7 and preferable greater than 0.9. Target size to sensor placement- TMP006 is capable to receive signals 180s directly in front of the surface. The angle of incidence is related to percentage of infrared signal absorbed at 0 degree angle of incidence, 100% of the signal is absorbed. The sensor should be placed parallel to the surface of the object to achieve the maximum IR signal absorption.

B. Body Position

Being able to tell what position the baby is in is a critical design specification of the Baby Peas' project. Position of the baby was at the top of a list of 10 steps to help prevent SIDS from a current WebMD article sponsored by Johnson's baby [1]. The CDC (Center for disease control) states since the 1990's, SIDS related deaths have decreased in the United States by over 50% since the steps to prevent SIDS have been instituted [2]. The Journal of American Academy of Pediatrics suggests babies should be positioned on their back while they sleep. If the baby is placed on their side or in the prone position (sleeping on their stomach) then the risk of SIDS is much higher due to rebreathing of expired gases and also overheating. Stress is also placed on the baby's cardiovascular system during prone sleeping which can increase heart rates to abnormal levels [3]. Since the main goal of this project is to help and aid in the prevention of SIDS, being able to tell whether the baby is in the prone, side, or back position is vital to success. Position of the baby can be monitored through a couple of different methods. The Baby peas' project could keep a camera on the baby being monitored. This idea fits into the goal to achieve non-evasiveness in the project but creates another external peripheral to integrate into the system. Since the main peripheral to be implemented has other sensors attached to it a solution need to be found which can be integrated alongside the other vital signs sensors to keep costs and development time at a minimum. Some technology solutions include the accelerometer or gyroscope.

Accelerometers measure acceleration (time rate of change of velocity) of an object with respect to the Earth's gravitation. While acceleration is not the object of concern for the Baby peas' project, one can derive position from acceleration data because the second derivative of position leads to solving for acceleration. The following equation models acceleration as a function of position:

$$a(t) = \frac{dv(t)}{dt} = \frac{d\big(x(t)\big)^2}{dt^2}$$

a = acceleration
v = velocity
x = distance/position
t = time
d = derivative notation

Since we are measuring acceleration with the accelerometer, we would need to use the mathematical method of integration to solve for the position. Now how these devices actual measure the acceleration ranges from device to device. Some devices use the piezoelectric effect, which means they contain microscopic crystals which are stressed by the forces of accelerations. These crystals begin to slightly vibrate which will cause a voltage to be generated. Voltage proportions can be used to determine levels of accelerations. The MPU6000 is an IMU which are integrated onto one chip providing 3-axis accelerometer measurements along with 3 axis gyroscope measurements. The chip is also scalable in it provides a dedicated I2C bus to accept an external 3-axis magnometer which would give 9 axis data measurements. Range of the accelerometer portion consists of +/- 2g, +/- 4g, +/- 8g, +/- 16g, which are user programmable which means if only +/- 4g range is needed it can be selected and reduce the amount of current the IC would draw. The gyroscope range is selectable as well consisting of +/-250 degrees per second (dps), +/- 500, +/- 1000, +/- 2000 dps. The chip also consists of 6 16bit analog to digital converters (ADCs) to sample all axis points of both the accelerometer and gyroscope. It boasts an onboard 1024 byte FIFO which allows for the microcontroller interfaced with it to read data output from the MPU-60x0 series in bursts. This allows the microcontroller to go into a sleep mode while the MPU collects more samples. I2C data rates are up to 400 kHz and SPI data rates are up to 1MHz. The input voltage to the chip is between 2.375v -3.46v which is in the boundaries of usable input voltage for this project. Price is around 10 dollars if purchased through Digikey with a lead time of around 2-3 weeks. The MPU6000 also has an additional temperature sensor on the device but this most likely will not be used since another sensor being used in this project will take care of skin temperature.

B. Pulse sensor

By employing a Baby peas unit, the caretaker can see the normalized heart beat rate for the baby. In a typical day, a person's heart beat rate can change due to the biological circadian rhythm. For a baby, this is no different. Having a Baby peas unit can help set a base line for the baby and alert the caretaker if a gross deviation happens. The pulse sensor measures the light that is allowed to transmit through a thin tissue sample such as finger or earlobe. As the light passes through the LED, it some is absorbed through the finger. Depending on which portion of the beat at the time, different volumes of blood is pooled in the venous and arterial capillaries. This differential causes differing amounts of light to pass through to the sensor sitting on the other side. The sensor allows differing amounts of current according to the amount of light that it detects. Using an algorithm, this information can be deconstructed and the constructed into a heartbeat on the screen. Using highly vascularized body parts is advantageous to accurate readings.

V. Power

The best packaging for the portable power source is the button cell package. It offers a slim fit but has a very long continuous current capacity of around 15mA. The LRI2450 has a voltage rating of 3.7v with a peak current rating of 35mA and current capacity of 160mAh. The current Baby Peas hardware runs at around 40-50mA peak so the LIR2450 would be pushing the limits. Finally it was determined an CR123a would work best. Although the package size is significantly bigger it provides 3.6v output with a capacity of 650mAh and peak currents of around 100mA. This would work well for the Baby Peas device. Ideally, during a day of normal usage, the user charges the battery once every two days. At this rate, the battery should have an average lifetime of over 3 years. The cut off voltage of the battery is 3 volts.

The LP2985 Linear regulator was the chosen device to regulate power for the Baby Peas Project. While linear regulators aren't as efficient as switch mode regulators, linear regulators proved a much easier hardware implementation and quitter output voltage to the circuit. This is critical for the baby peas to work correctly because there are extremely sensitive circuits involving the pulse sensor and the RF module. If a switch mode is used some unwanted harmonics could potential cause problems in these circuits and cause incorrect data to be passed through.

Figure 2 show the schematic capture for the LP2985 and its implementation in the Baby Peas project. As one can see the ease of which this is implemented is quite simple. The LP2985 series offers a wide range of set output voltages so no voltage divider network is necessary to set the output voltage. The LP2985-33DBVR was chosen because all circuits in the baby peas project can run off of 3.3v. This also allows for the room for the regulator to stay stable with the input voltage being around 3.6-4.2v. The package for the LP2985 is a simple SOT-23 which is a very simple part to be soldered to the PCB and no special layout instructions are needed when laying out the PCB because of the Linear Regulators robustness. Another great feature of the LP2985 is it allows for low cost ceramic capacitors to be used due to its low ESR friendly circuitry. This not only allows the circuit to be physically smaller but cheaper. Tantalum capacitors are traditionally used because of their low ESR which helps with regulators remaining stable, but they are much more bulky and are polarized. Having the advantage of using ceramic capacitors allows for easier implementation, lower cost, and reduces the risk of building the board improperly due to polarity reversal. From Figure 2 R35 is a "do no place" resistor. We implemented this feature for testing purposes so a high and low load could be inserted and checked for stability over a wide range of loads.

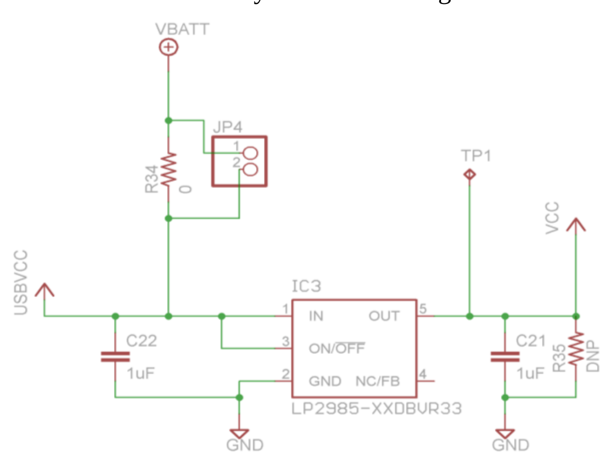

Figure 2. Linear Regulator Schematic

V. Bluetooth

Bluetooth is another widely used wireless technology. It, like WI-FI, utilizes a Master/Slave network. Bluetooth can have 1 master and 7 slaves which are formed into a piconet. It has an IEEE 802.15.1 standard protocol certification but the protocol is no longer controlled by IEEE 802 but instead is run by the Bluetooth Special Interest Group. This group is made of over 19,000 members in the consumer electronics industry. Bluetooth works in the ISM band of 2.4 GHz. It uses frequency hopping spread spectrum technology which can help in the avoidance of interference of other ISM devices transmitting in the 2.4GHz spectrum. It uses GSFK (Gaussian Frequency-shift keying) modulation and supports all Network topologies (Mesh does need special application enabling). Bluetooth is especially designed for low power consumption. Its range depends on different protocols and individual setups but can vary between 1 meter to 100 meters. This meets our specification limits for range. Components are very low cost and the design parameters for Bluetooth are geared towards a quick time to market approach. This is good for the baby peas since we have a limited time constraint for development. Bluetooth is also prevalent and almost all cell phones, laptops, and tablets. Bluetooth is also certified and one of the preferred technologies being pushed by the non-profit organization Continua Health Alliance which seeks to set industry standards for health technologies. Classic Bluetooth will be used in the Baby Peas Project. Although Bluetooth low energy is the latest version of Bluetooth; it is not yet available to all the mobile devices. The users do not need the latest mobile devices for Baby Peas. A classic Bluetooth Module called the HC-06 will be used. HC-06 is designed to transmit serial data to any Bluetooth enabled device. It is based on Bluetooth V2.0 with enhanced data rate, 3Mbps modulation, and 2.4 GHz radio. Bluetooth classic offers longer transmission range than the BLE; however, the power consumption is higher. The specific Bluetooth chip frequency. The HC-06 is a module which consists of a microcontroller and Bluetooth transceiver in the form of a BGA package. The firmware comes preloaded to receive TXD and RXD data form any serial data source.

VI. Data Communication

I2C is a multi-master serial single-ended computer bus invented by Philips and is the serial communication option needed to connect the sensors to the microcontroller. The I2C bus is single-ended, meaning it is one wire that is being connected between all master and slave devices. Certain registers are first configured to activate the I2C bus, activate the clock controlled by the master and set the microcontroller as a master [2]. The master first sends out an 8 bit slave address on the bus. If a slave device recognizes the address as its own, it sends back an acknowledgement bit and the master knows it can now send the next byte of data

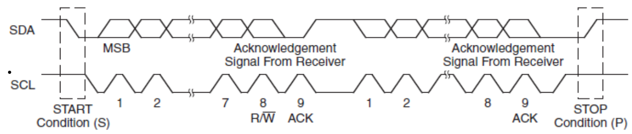

Figure 3. I2C Clock and Data Pulse Format

The master continues to send bytes of data unless it is interrupted and data flow needs to be changed. The I2C bus is mainly controlled by interrupts in its programming. The figures below show examples of I2C communication of the Baby PEAS captured by an oscilloscope. The yellow pulse is the SCL lines and the blue is the SDA line.

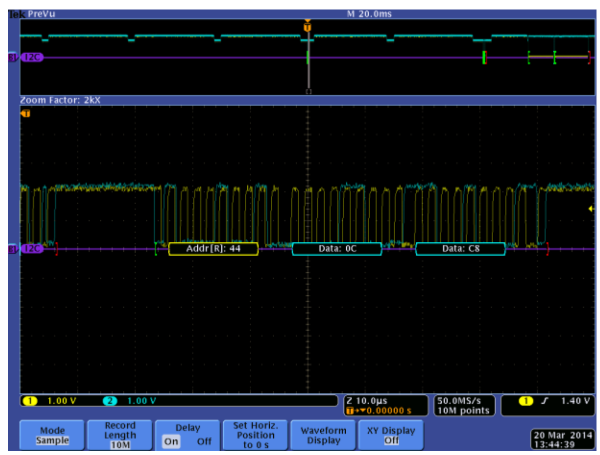

Figure 4. I2C Sample 1

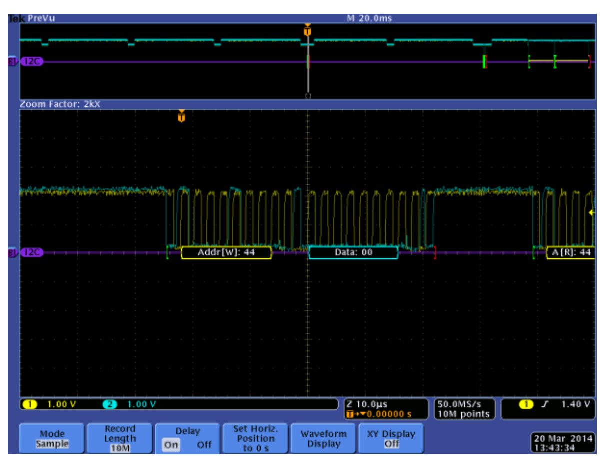

Figure 5. I2C Sample 2

VII. Smartphone Applications

Android is an operating system based on the Linux kernel. Android is owned and developed by Google. After an update is released, the operating system is open-sourced and allows the Android community and consumers to alter and add on to the operating system, where new features and improvements can be implemented if deemed appropriate. Bugs in the operating system and efficient programming can be more quickly dealt with in this way. Android applications can be downloaded through the Google Play store or the Amazon Appstore. To begin developing an application as a third party, the Android Software Development Kit must be obtained. This can be achieved by purchasing the ADT Bundle from Android. The bundle includes the Eclipse Integrated Development Environment plugin, ADT plugin, Android Platform-tools, the latest Android platform, and the latest Android system image for the emulator. Android apps are usually programmed in Java. The application that we are developing will be designed in a third party IDE that makes it simple to organize both the layout and functions of the application. The application will be designed to be both aesthetically pleasing and easy to use. It connects over Bluetooth to the Baby PEAS sensor and displays the relevant data. The application will also allow the user to display profiles for multiple children if needed. The figure below illustrates a basic application that can be easily read and designed for usability.

In addition to Eclipse, there are numerous other programs available to facilitate app design, including the web based Inventor App.

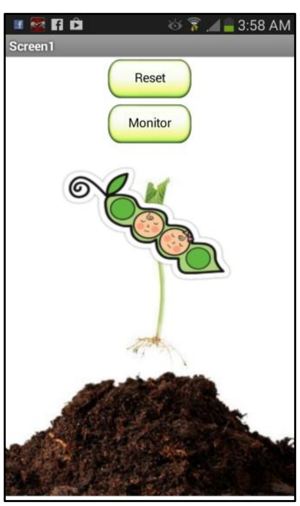

Figure 6. Sample Application Layout

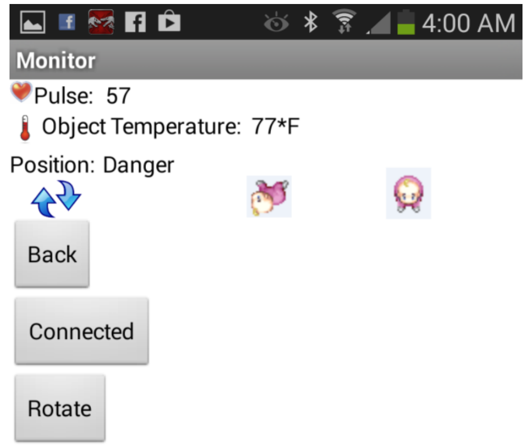

Figure 7. Sample Application Display

VIII. Microcontroller

The microcontroller is an essential part of the overall project. The function and data flow of the sensors is determined by the microcontroller. When selecting the appropriate part for the wireless sensor, the performance and power consumption are the primary specifications to consider. This is because the microcontroller will be mounted on a peripheral unit and act as part of a wireless transmitter. The MCU should use a minimal amount of power to maximize battery life while being able to achieve the necessary performance standard needed for its actions. The data processing required will have to do mostly with interpreting analog data coming off of multiple sensors measuring vital signs and position. The microcontroller needs to have at least 4 analog to digital converters, one for each sensor, and a minimum sampling rate of 8 bits of resolution. The microcontroller will also interface with a Bluetooth wireless system and thus must have communication modules in order to have the flexibility to integrate sensors into the system.

The Atmel model ATmega328P is a high performance, low power 8-Bit microcontroller. It features a RISC architecture with 32x8 general purpose registers and 23 programmable Input/Output pins. Data throughput is listed at 20MIPS at 20 MHz. It contains 32KB of programmable flash memory, 1KB EEPROM, and 2KB SRAM. The ATmega328P supports Serial USART, Master/Slave SPI Serial Interface, and is compatible with I2C data transmission. Operating voltage ranges from 1.8 - 5.5V and has a speed of 0-20 MHz. Active Mode consumes 0.2 mA, Power-down Mode at 0.1 µA, and Power-save Mode consumes 0.75 μA [4]. The ATmega328p microcontroller was chosen to be used in this project because its parameters were satisfactory for the ease of use with the Arduino prototyping platforms.

The microcontroller will be loaded with firmware to run it correctly when powered on. The initial design calls for the board to initialize and sample data from each of the sensors in a cycle and update the values on the smartphone application. The user can then request information and update profiles on the phone as they see fit.

IX. Safety

Safety is first and foremost due to the sensitive nature of the environmental conditions during operation. The satellite unit not only functions in close proximity to humans, it is primarily designed for users with limited verbal communication, making it hard for the caretaker to gauge feedback on operation and physical status of the unit in the event of a malfunction. In the worst case scenario a runaway heating issue could cause burns on the baby or a shock hazard could happen and cause irreparable damage. The unit has to have safety measures in all aspects, taking in considerations such as shorts and unduly dissipation. Admittedly, there is little chance for arc flash or arc blasts due to the voltage being less than 240, according to the National Fire Protection Association. The baby pea unit itself limits the voltage to a much lower 3.7 volts. However, since the unit is worn against the skin, electric shock and thermal damage does exist. In addition, it is not the voltage that is the primary concern, but the delivered amperage that can harm or kill a person. According to an Ohio State University resource, a shock as low as 10 milliamps can cause a painful shock to an adult. Lethal currents occur starting at 100 mA. Some of the symptoms of electric shock include muscle paralysis, difficulty in breathing, severe burns, ventricular fibrillation, cardiac arrest and death. Therefore, in order to ensure the device is safe, the anklet will be insulated both thermally and electrically while also allowing the sensors to work effectively.

X. PCB Layout

The design of the PCB board was done in Eagle Cadsoft software. A representative was available to host a workshop to make the learning curve more manageable. The figure below is the board for the Baby PEAS.

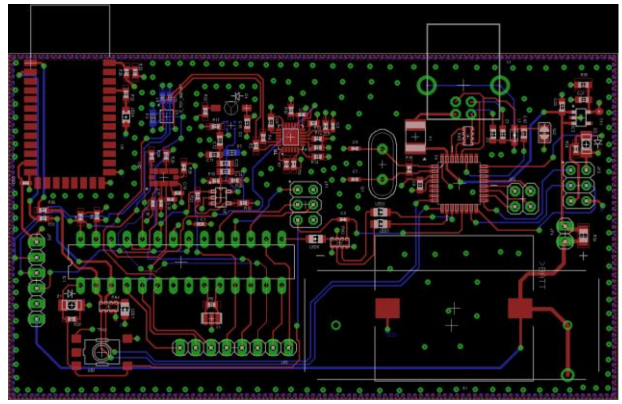

Figure 8. Baby PEAS PCB Board Layout

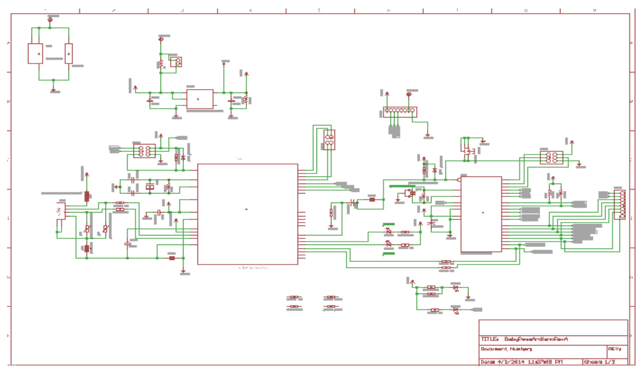

Figure 9. Baby PEAS Schematic page1

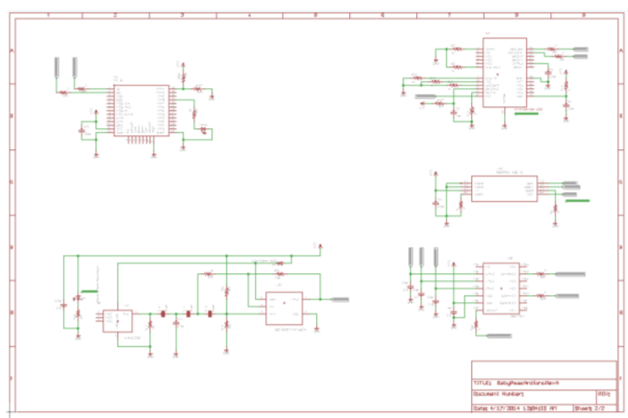

Figure 10 Baby PEAS Schematic page2

This board contains the connections necessary to implement the chosen microcontroller and sensor parts, in addition to having the flexibility to add additional parts if expansion is required the unused digital I/O pins have been pulled out to headers on the board for further development without having to start from scratch again on the design. While another PCB would have to be created out the bread boarding would be much simpler.

CONCLUSION

The project was implemented and tested using the research from the previous semester, current experience, and a large amount of trial and error. The Baby PEAS device is capable of providing a proof of concept for a convenient and reliable monitoring of vital signs on an infant. The goals we set for ourselves were satisfactorily met upon completion of the project.

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BIOGRAPHY

Xin Tong is currently a senior electrical engineering student at the University of Central Flordia. She is graduating in May 201. Along with her academic experience, she has interned at Jacobs Engineering, Disney and Universal Studios. Her interests lie in communication and optics, and she plans to find a full time position in the field when she graduates.

Christopher Ramirez will be graduating in May 2014 with a Bachelors in Electrical Engineering. His interests lie in RF/Microwave engineering and Satellite communications. Upon graduation he will start employment with the RF engineering division of Harris Corporation in Palm Bay, Florida.

Yowwu Lin is a senior at the University of Central Florida and will be graduating in May 2014 with a Bachelors of Science in Electrical Engineering. He is interested in Biomedical Engineering and wishes to pursue a career in the field. He is also interested in obtaining a Master's Degree in Electrical Engineering.

Benjamin Goolsby is a senior at the University of Central Florida and will be graduating in May 2014 with a Bachelor's of Science in Electrical Engineering. His interests lie in embedded systems and Biomedical engineering. He plans building a career and attending graduate school in the future

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