Smart Crib

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***Abstract* — The objective of this project is to design and test a crib system that will monitor the ambient temperature, sleeping status, biometric data, and communicate these data points to the parent via a mobile application. The smart crib system will replace a wide variety of products that are currently available on the market, and combine their individual functions into one system that utilizes accurate and cost effective sensor technology. The smart crib was chosen as a project for the group due to the one of the members had a newborn baby and they wanted to come up with a product that would address the concerns they had as a new parent.**

***Index Terms* – Temperature sensor, motion sensor, smart crib, sound sensor, heart rate, rechargeable battery, weight sensor, cry detection, Wi-Fi**

I. INTRODUCTION

Parents of newborns are constantly stressed out as they have to keep an eye on the baby at all time, even during the night time. This leads to extreme fatigue that affects every aspect of the parents and indirectly that will affect the newborn. This device aims to alleviate the pressure of keeping a constant watch on their newborn baby. The Smart Crib is a two piece system that combines together to gather biometric data of the baby. The system is split into the Main printed circuit board (PCB) and the Wearable PCB. Each of the system utilizes a microcontroller unit (MCU), TIVA TM4C123G, to process all of the sensors' data. There will be a total of seven modules that will work in tandem with each other's. On the Main PCB will be a weight sensor, temperature sensor, sound sensor, and a Wi-Fi module. On the Wearable PCB has a motion sensor, pulse sensor, and a Wi-Fi module. Each of the sensors will gather their respective data that will send to the microcontroller to be processed and then the data will be transmitted to a cloud server through the Wi-Fi module, ESP8266. The cloud server will then push all of the biometric data such as the weight, temperature, and heart rate to a custom designed mobile application for the Smart Crib. This allows the parents to monitor their newborn baby at all time, especially at night time. In these next sections, the intricate details of all the sensors that are implemented in the Smart Crib will be thoroughly explained. The power management of both system will also be explored in details.

II. SMART CRIB PROJECT SYSTEM COMPONENTS

The smart crib system has been split into separate systems that operate independently of each other and communicate back to each other via Wi-Fi into an Amazon server. The system features a main PCB that is placed below the crib, a wearable PCB that is placed on the child, and a mobile application that displays sensor information to the user. The following section will provide a technical introduction to the components and system level view of the overall project design.

A. Main PCB

The Main PCB is housed underneath the crib. It will be responsible for operating the sound sensor, temperature sensor, and the weight sensors. The sensors will have wires running from the main PCB to their respective housing spots.

The Main PCB will be utilizing the microcontroller, Tiva TM4C123GH6PM. Excess components of the microcontroller were taken out such as the 32.768 kHz crystal as hibernation mode was not used. Also all of the excessive pins of the MCU were discarded as they would be taking up unnecessary space. A Wi-Fi module, ESP8266, is mounted onto the main board to interface with the microcontroller to allow it to send the sensors' data to the cloud server. An instrumentation amplifier, INA125UA, is used with four load cells connected to the respective pins of the amplifier with the output of the amplifier to an analog to digital (ADC) pin of the microcontroller. The amplifier is powered by a 5 volt regulator from the custom designed power board. The temperature sensor, MS5611, is interfaced with the microcontroller I2C clock and data lines to transmit the data gathered from the temperature sensor. The sound sensor, PZM-11LLWR, is used to detect the crying of the baby. The output of the sound sensor is fed into a noninverting amplifier which will be passed through a bandpass filter tuned to the baby's crying frequency to trigger the 555 timer output.

A power board that has four different voltages has been created to interface with the main PCB to give all the sensors and the microcontroller the appropriate voltages. The power board is designed separately on a different PCB to reduce the effect of analog noise of all the voltage regulators and allows easier hardware debugging.

B. Wearable PCB

Initially the smart crib project proposal did not contain a wearable PCB feature. The project was going to use one PCB underneath the crib with wires running to the child to measure biometrics like the pulse of the child. After analyzing applicable safety standards for small children it was seen that running any wires to child would produce a potential choking hazard. Thus it was concluded that creating a separate wearable PCB was the best option.

The wearable PCB for the smart crib uses the Tiva TM4C123GH6PM MCU, a Wi-Fi transceiver, a pulse sensor, and the MPU 6050 motion sensor. The pulse sensor is used to measure the heart rate of the child and ensures that the child is still alive while they are sleeping, eliminating the need for parents to check if their child is still breathing. The motion sensor is part of a system used for cry detection. As the motion sensor observes movement from the child in the crib, one of the conditions for cry detection will be met. The MCU will collect data from these sensors and transmit it to the web based data collection source so that the mobile application can read the data.

The MCU collects data from the pulse sensor using an analog to digital converter pin. The motion sensor utilizes I2C with data signals over SDA and clock signals from SCLK. The MCU takes the data and transmits the information to the Wi-Fi module using UART TX and RX lines.

The wearable PCB also features a rechargeable lithium ion battery as a power source. A micro USB port is used to supply power to the charging circuit for the battery. In order to safely charge and discharge the battery, the wearable PCB has a power management integrated circuit (PMIC) that monitors the battery state. The PMIC monitors the batteries overvoltage and undervoltage status ensuring that the battery does not overcharge or discharge when it in use.

C. Mobile Application

A mobile application is employed in this project to create an easy way for users to interface the system, and to do so without being at the Smart Crib itself. This mobile application was created using the Android operating system, on version 7.0 Android operating system, Nougat. The application is primarily written with Java with a small amounts of JavaScript. The main features of the mobile application will be to lookup the current biometrics that the Smart Crib system. The mobile application is connected to a database hosted on Amazon's servers and is used to query the database for datasets collected in the past from various time ranges such as hour, week, month, etc. Another function of the mobile application is to allow the parent to be able to see their baby at any time anywhere. This is done by incorporating a camera module hooked up to the Raspberry pi. Incorporating these features allows parents to be at ease as they can feel as if they are physically there checking on the baby with all the information at their fingertips.

The figure below illustrates the mobile application's role in the Smart Crib project. For the live look-up feature, the MQTT broker will be communicating with the mobile application when the user decides to utilize this feature. During this process the database is not queried at all to avoid increased load and slower speeds. The other access point of the mobile application to rest of the system is the database. This database is a NoSQL database hosted on Amazon Web Services. The data that is inserted into this database is in the JSON format in the form of key-value pairs.

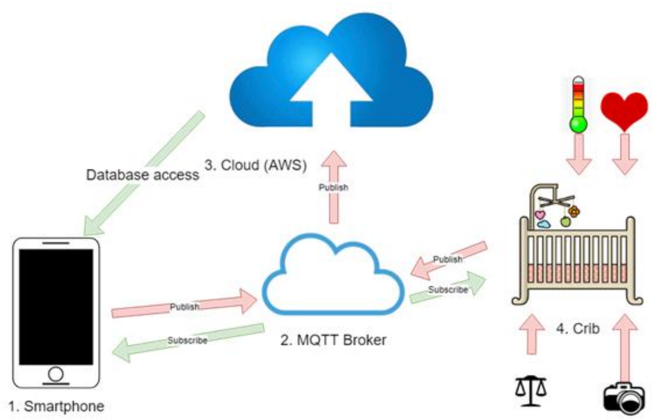

Fig. 1. Mobile Application Interactions

III. COMPONENTS AND SENSORS

A. MCU

The MCU is the focal point of this project, as it will be used to connect all the electrical subsystems together. The MCU will have to be able to communicate with all the components of the project like the weight sensor, pulse sensor, ambient temperature sensor, WI-FI transceiver, sound sensor, and the motion detection.

Smart crib project has many sensors that will be needed for all the features it includes. There are three main factors are taking in consideration when picking the MCU, GPIO (General Purpose Input Output) pins, memory, and ADC resolution. The MCU also required appropriate communication lines for each senor such as I2C, UART, ADC or interrupts. Selecting a MCU with multiple ports for each electrical communication line was as critical in aiding routing for the electrical components, especially as it pertained to the wearable PCB where size was critical. After examining different MCUs, it was concluded that the TM4C123G satisfied these requirements the best. The MCU is made by TI, and is a 64 pin Tiva Arm 4 Cortex.

B. Temperature Sensor

The Smart Crib will not only monitor the activities of the baby, but also the environment the baby is in. The ambient temperature of the room will be monitored to notify the parent of the environmental conditions of the crib that the baby is in. This is important because during the winter and summer months, the temperature can drop or raise ±30°F in states such as Florida.

Mounting of the ambient temperature sensor is important, to have an accurate reading of ambient temperature, the ambient temperature sensor need to be on an external PCB away from the main PCB to ensure the heat from the power supply will not affect the ambient temperature readings. From the main PCB to the ambient temperature sensor there are power lines and I2C lines. The I2C lines will be used to communicate the room temperature to the MCU. For this feature the MS5611_01BA03 [45] by TE Connectivity is chosen for the accuracy shown below:

TABLE I
MS5611_01BA03 VS BMP180 SPECIFICATIONS

Features	MS5611
ADC	24-bit
Power consumption	1.0uA
Accuracy	±0.8C
Supply voltage	1.8V to 3.6V
Operating Temperature	-40 to +85

C. Sound Sensor

A goal of the project was to design a system that would notify the parent when the child is awake. Typically small children cry when they wake up. Thus, it was then decided that a sound sensor would be used to know when the child begins to cry.

The sound sensor that was chosen for the project is the PZM-11LLWR. It has a frequency response range from 80 Hz to 10,000 Hz which is ideal for the frequency range of a crying child. The sensor is also weather resistance, as it is designed to withstand rainfall. This will allow it to safely operate in the crib environment where the child could potentially get it wet through touching, vomiting, or peeing.

D. Wi-Fi Module

The smart crib offers the ability to monitor and log every data point gathered from the sensors. To enable the ability to control and monitor the smart crib from anywhere in the world, there is a need to make a way to transfer the data and receive command from a control unit. To send data to the database on the web the best solution found was to transfer the data through Wi-Fi. The ESP8266[3] is capable of doing this job.

The ESP8266 is a highly integrated chip designed by Espressif. It offers a complete and self-contained Wi-Fi networking system, allowing it to either host the application or to offload all Wi-Fi networking functions from another application processor.

The ESP8266 transfers and retrieves data from the database through UART. For the MCU to send data through the ESP8266, the ESP8266 first need to connect to the local Wi-Fi network and get access to the WEB. After it has successfully connected to the WEB, the ESP8266 then needs to connect to the database server before the data can be transmit to the database. The way the database sends a command to the MCU is identical. The MCU instead of sending to the database, it will ask to read from the database for the input commands. Fig.2. shows the ESP8266 Firmware Flow Diagram below for more detail.

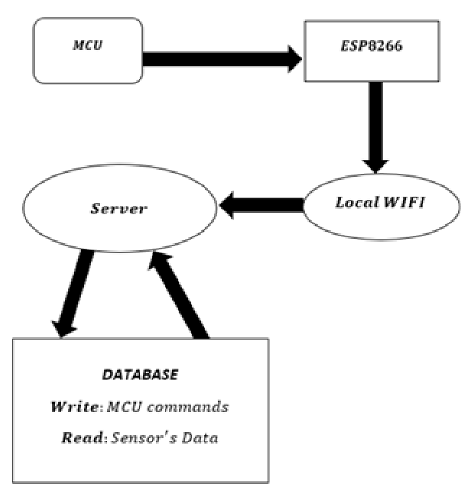

Fig. 2. ESP8266 Firmware Flow Diagram

E. Motion Sensor

The baby requires constant monitor when it is awake. The Smart Crib equipped with the ability to do so by detect motion of the baby. There are several ways to achieve this with different motion sensing technologies like ultrasonic sensor, Infrared sensor, or an accelerometer sensor. After testing these technologies it was seen that an accelerometer like the MPU6050 sensor was the best fit with the highest sensitivity so small levels of motion.

The MPU 6050 [5] will be used as an accelerometer to monitor the motion of the baby when it is inside the crib. One of our objectives for this project is to able to notify the parent when the baby is awake and needs attention. To be able to detect when be baby is awake we decided to use an accelerometer to detect movement. When the sensor detects ± 10-degree pitch/roll, the MCU will send out an alert to the parent. The motion sensor will communicate with the MCU via I2C.

F. Weight Sensor

Another feature of this project is the ability to keep track of the baby growth with the weight each day. Weight gain of the baby in the first year is an important factor to the baby health.

The method that was implemented for this feature is to place four strain gages IP65-YZC0 [4] at each corner of the mattress and paired with an instrumentation amplifier to amplify the analog signals from each of the strain gage before sending the signals to the MCU's ADC. For the accuracy of the weight sensor is based on three components, ADC unit, strain gages, and an instrumentation amplifier. Fig. 3. Shows the circuit diagram of the weight sensors. The weight sensor is implement with the load cell connected in a half-bridge configuration it sends signal via the red signal wire. The INA125 instrumentation amplifier is set to have around 200 gains via the 306Ω resistor connected to pin 8 & pin 9.

Another way accuracy of the weight sensors has been insured was to construct a housing to go on top of the weight sensors. The housing is constructed out of wood, and has four corners that extend down and sit on top of the sensors. The mattress will then sit on top of the housing that was created. To determine the weight with the additional components that are on the sensors, the weight will be calibrated each time before the baby is placed on the mattress to ensure accurate readings.

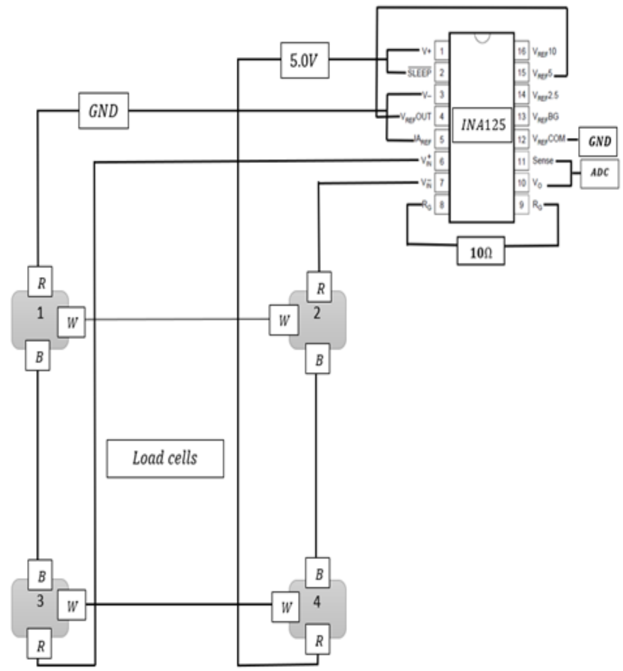

Fig. 3. Weight Sensor Circuit Diagram

G. Heart Rate Sensor

The pulse sensor [6] is the most important of all the sensors in this project, as one of the main goals of the project was aimed at Sudden Infant Death Syndrome (SIDS) prevention. The pulse sensor will be used to monitor the baby's vital signs will the child is sleeping, ensuring the baby has not succumb to SIDS. The pulse sensor will have a small cable leading from the wearable PCB with a length of less than two inches. The small length of cable is needed to ensure the pulse sensor is flush to the baby and taking proper vital signs.

The ADC pin of the MCU will be used translate the analog signal generated by the pulse sensor. To be able to have an accurate pulse detection, this pulse sensor used the ambient light sensor APDS-9008 along with the green super bright reverse mount LED AM2520ZGC09. The principle of PPG (photoplethysmogram), the heart's pulse signal is measured by the change to the current in the transmission and reflection between the green super bright LED and the ambient light sensor to detect the systolic and diastolic blood vessel rhythm. The following figure shows a reading of the pulse sensor that was captured on a oscilloscope. The pulse rate is determined by measuring the time distance between the pulses.

Fig. 4. Oscilloscope reading of the heart rate pulse

H. Camera

The camera module is run by the Raspberry Pi installed on the Smart Crib along with the rest of the system. To deploy the camera, the camera will be streamed over the router over TCP/IP. This allows a video stream to be publically available, which can be password protected. The Raspberry Pi operates on the Linux operating system, so it has access to the motion service. The motion service allows the Picam to stream the stream over a specific port on the user's router. This requires some user configuration to port forward that port so that the mobile application can view the stream from locations outside of the home network.

The mobile application will use this video stream as a source to display the stream on demand once a user presses a button to activate it. If a user finds that their baby is crying or awake via push notifications. They can use the camera module to confirm in fact that the baby is indeed wake or crying to prevent false positives. Fig. 5. App Camera below demonstrate the Picam in use.

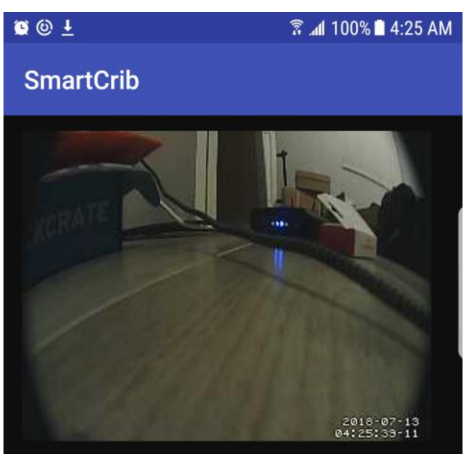

Fig. 5. App Camera

IV. Rechargeable Battery System

The wearable PCB features a rechargeable battery system. The system uses a lithium ion battery, charging circuit, and a PMIC system.

A. Battery Selection

For the battery selection process the search was narrowed down to lithium ion batteries because they have the highest density ratings of all battery chemistries that were examined. The coin size lithium ion batteries were selected due to their small size and weight made them ideal for a wearable PCB application. The RJD3555 was chosen as the battery for the project due to it having the highest current capacity at 500mAh, at the standard 3.7V rating for lithium ion coin batteries.

B. Battery Protection

The battery protection circuit that was chosen is the AP9101CK6-CQTRG1 PMIC. This PMIC will allow safe use of the rechargeable battery by providing overvoltage, undervoltage, and short circuit protection for lithium ion batteries. The table shows the battery limitations versus the coverage provided by the PMIC.

TABLE II
Battery and PMIC Comparison

	RJD3555	AP9101CK6
High Voltage	4.28V	4.2V
Low Voltage	2.35V	2.8V
Discharge Capacity	1 A	Short circuit

The PMIC uses two N-MOSFETs connected at their sources to control the return path for the battery. The first MOSFET is turned on when the battery is below the high voltage threshold and the second MOSFET is turned on when the battery is above the low voltage threshold. As both MOSFETs are turned on, a short is created between the ground of the circuit and the return path of the battery. Any operation of the battery outside these overvoltage and undervoltage threshold will cause the PMIC to turn off one of MOSFETs, which will disable the return path of the battery and shutdown all circuit operations.

C. Charging System

In order to charge the battery, the wearable PCB contains an onboard charging system. The STBC08PMR was selected as the battery charging integrated circuit. It is designed to work with USB port power, with a programmable charging current, and to work with single cell lithium ion batteries. The IC uses the required constant current and constant voltage method needed for the RJD3555 battery.

The required charging current for the RJD3555 battery is half of its rated charge capacity of 500 mAh which is 250 mA. For further safety measures, the charge current was cut in half giving the charge current goal of 125mA. This causes the charging of the battery to take longer than prescribed, but ensures that the charging does not exceed the acceptable peak charging current. In order to calculate the value of the programmable resistor, V_{PROG} was set to 1V, and the following equation was used:

$$R_{PROG} = 1000 \times \frac{V_{PROG}}{I_{RAT}} \quad (1)$$

V. CRY DETECTION SYSTEM

The smart crib project uses a cry detection system to notify parents when the child is awake. The cry detection system will utilize the sound sensor from the main PCB and the motion sensor from the wearable PCB to function. Additional hardware was also used to communicate to aid the sound sensor in communicating directly with the MCU.

A. *Cry Frequency Range Research*

Researching the cry frequency range of small children yielded little results and conflicting data. It was determined that it was best to conduct our own research into the cry frequency range. To find the frequency range an oscilloscope using Fast Fourier Transforms with audio recordings of children crying played directly into the scope probes. It can be seen from the oscilloscope reading that there are spikes throughout the frequency, but no consistent harmonics were found and there was a wide range of frequencies that were being used by the children.

The experiment was conducted using both male and female children at the ages of newborn, 1 year old, and 2 years old. The data shows that there is a consistency in the frequency range of male and female children of the same age. This data was helpful in selecting an applicable sound sensor that will operate within this frequency range, and designing a filter to isolate the cry frequency range.

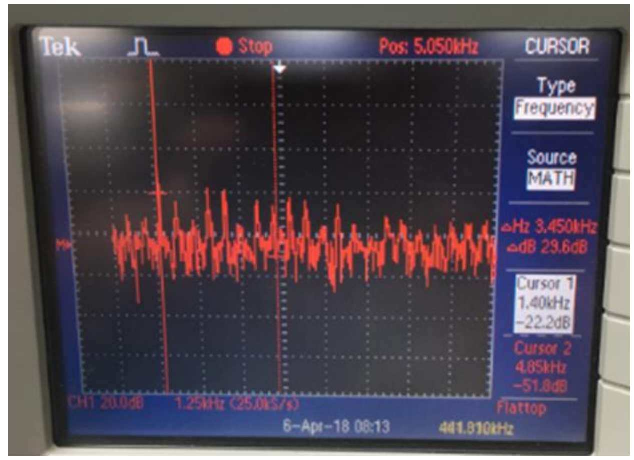

Fig. 4. Fast Fourier Transforms of an audio signal of a child crying

TABLE III
CRY FREQUENCY RANGE OF CHILDREN

Sex	Age	Low Frequency (Hz)	High Frequency (kHz)
Female	Newborn	250	4.25
	1 year	400	6.10
	2 year	500	6.25
Male	Newborn	310	4.20
	1 year	350	6.20
	2 year	500	6.65

B. *Electronic Hardware*

The sound sensor needed additional electrical hardware in order to communicate with MCU. After researching clap circuits using 555 timers [2], it was determined that a similar method could be used to transmit audio signals from the sound sensor to pulses that the MCU can read. The design for the hardware used a modified clap switch circuit using the ICM7555IPAZ 555 timer in monostable mode. A BC547BTA BJT was implemented to work as a switch. As an audio signal hits the base of the BJT, the transistor turns on allowing the 555 timer trigger capacitor to discharge which sends a square wave signal to the MCU.

Additionally an 3rd order bandpass filter was implemented between the audio signal and the base of the BJT with -3dB limits set to frequencies of the lowest and highest range values found in the cry frequency range research. The OP213 op-amp was used to create the filter, and as a non-inverting amplifier to give the audio signal enough voltage to pass through the filtering.

C. *Cry Detection System Software*

The cry detection firmware will analyze the data from both the sound sensor hardware and the motion sensor to determine if a child is awake. Both sensors are being utilized in order to reduce false notifications to the parents. The firmware will look for 5 pulses from the sound sensor within a 3 second interval, and for activity from the motion sensor to determine if the child is crying. If both of these conditions are met the parent will be sent a notification over the mobile application that the child is awake. The notification on the mobile application also includes a live camera feed of the child in the crib, so the user can determine if the child is awake without entering the room.

VI. VOLTAGE REGULATORS

The first step of knowing what kind of regulator to choose is to determine what kind of voltages the entire system needs. For each component of the Main PCB and Wearable PCB, the required voltages and currents were recorded. By analyzing the voltage and current requirements, the proper selection of each of the voltage regulators was determined.

A. *Main PCB Regulators*

The Main PCB requires the use of four different voltages: 12 volts, 5 volts, 3.3 volts, and -12 volts. For the 12 volts, an AC adaptor was bought instead of being designed as designing a switching power mode for 120VAC to 12 volts DC was out of reach. Next was the 12 volts to 5 volts DC to DC conversion. A switching regulator was chosen as dropping 7 volts across the linear regulator with an output current of at least 120 mA would cause excessive heat. Shown below is the comparison between three different switching regulators. The TPS5653208 was chosen due to the high efficiency of the regulator. It also had the least amount of external components required to operate.

TABLE IV
5V SWITCHING REGULATOR

Part Number	Efficiency	Iout	Frequency	Adjustable
TPS5653208	96%	3A	580kHz	Yes
LM2576	77%	3A	52kHz	Yes
TPS621	90%	2A	1241kHz	Yes

The 5 volt regulator output is then converted to 3.3 volts for the operation of the microcontroller, temperature sensor, and the Wi-Fi module. For the 5 volts to 3.3 volts, a linear regulator will be used as the voltage drop is acceptable and therefore the heat will be at a minimum. Shown below is a table of 3.3 volts linear regulators. The chosen regulators are also considered low drop-out voltage regulators as we are operating below the standard 2 volts minimum for Vout-Vin. In this case, the regulators chosen will be able to operate at a minimum of 1 volts and at a maximum of 200mV for Vout-Vin. We chose the TPS73601 for our 3.3 volts regulator as it required no external decoupling capacitors for the regulator to be stable and operates.

TABLE V
3.3V LINEAR REGULATOR

Part Number	Vin	Vout	Iout	Adjustable
LDBL20	5.5v	3.3V	200mA	Yes
LD111733TR	5V	3.3V	3A	No
TPS73601	5V	3.3V	400mA	Yes

B. *Wearable PCB regulator*

Selecting a voltage regulator for the wearable PCB presented a greater challenge. The challenge was that the required voltage for MCU, Wi-Fi module, pulse sensor and motion sensor all require 3.3V. The power source for the wearable PCB is a rechargeable battery that does not provide a constant voltage source. The RJD3555 battery has a supply voltage range from 4.2V at fully charged and low voltage of 2.8V. These voltages ranges made it impossible to simply buck or boost the voltage to the required 3.3V. The next solution was to raise the voltage to 5V with a switching regulator, and then step it back to 3.3V with a linear regulator. This method would have required the battery to work harder to provide extra current because of the losses due to lack of efficiency of both regulators.

The solution to the problem of having two regulators was found in an application notes document from Maxim Integrated for the MAX1701 boost regulator. The application note featured a single regulator that was designed to work with wireless devices using lithium ion batteries, and would act as a buck linear regulator when the battery voltage was greater than 3.3V and then behave as a boosting switching regulator when the battery voltage fell below 3.3V [1].

VII. Conclusion

The Smart Crib design proved itself to function as advertised. The sensors on the both of the PCB serves as a safety feature for protecting the newborn in the crib. With the temperature sensor indicating how hot or cold the ambient temperature of the crib as the baby needs that goldilock zone. The sound sensor is able to detect any kind of sounds that the baby makes such as crying or if there is something else in the near vicinity of the baby's crib. This adds an extra layer of protection for the baby. In addition to that is the weight sensors that are located on the four corners of the crib to detect if the baby is in the crib and as well as track the weight of the baby over the first couple of years. The motion sensor on the Wearable PCB proved to be useful as well as it allows another layer of notification that the baby is awake or moving around in the crib. The crucial sensor is the pulse sensor, which detects the heart rate of the baby. Given a baseline, any abnormalities would be detected by the sensor which would alert the parents. The final sensor is the camera which allows the parents to view the baby with a live feed. All in all, the Smart Crib was designed with a clear goal in alleviate the stress of the parents of the newborn and keeping the baby in a safe and well monitored environment.

VII. Biography

David M. Brunat: Electrical Engineering major at UCF who is graduating in the summer of 2018. Specialized in control systems. Desires to work on training simulation devices intended for military use. Currently works at Lockheed Martin as a hardware engineer intern where he will begin work upon graduation.

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Phuoc Nguyen: Computer Engineer that specializes in embedded system. Will be earning his Bachelor of Science in Computer Engineering in Summer 2018. Plans to work in the Federal Government as an Computer Engineer after graduation.

Thinh Nguyen: Studying Electrical Engineering at UCF and will be earning a Bachelor of Science in Electrical Engineering in Summer 2018. Currently the area of interest is in analog power circuits. Will be working in the field of visual simulations after graduation.

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