University of Illinois at
Urbana-Champaign

ECE 445: Project Design Document
Safe Crib with Auto-Hazard Detection

SPRING 2023

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February 23, 2023

Content

1. Introduction

1.1 Problem and Solution

Ensuring a baby's safety in the crib is not an easy job, especially when the babies are athletic. It has been learned that babies can start climbing out of the crib when they are eight months old [1]. It is impossible to keep an eye on the baby all the time in the home setting because the parents are not in the baby's room at every moment. Therefore, we decide to make a safe crib with auto-detection of hazards to detect whether the baby is attempting to climb the crib. When a potentially dangerous event is happening, the crib system will notify the monitor system on the parent's side to draw their attention. Besides, when babies cry, they usually demand feeding or diaper change. Neglecting the former can lead to malnutrition, and neglecting the latter can cause skin irritation or even bladder infections. Moreover, crying refers to many different signals to parents, such as sickness or burping, which indicates the significance of crying for parents to take care of their babies [2].

Our team proposed a safe crib with hazard detection to solve this problem. This electrical approach to a safe crib is new to the market since it detects hazards and reports them to the parents. The crib can utilize several types of sensors to detect the state of the baby and alarm parents to take care of the baby if necessary. First, the crib contains ultrasonic sensors on the top of the guardrail to detect if the baby is trying to climb the guardrail and hence is in danger of falling off the crib. Second, a sound sensor is positioned on the guardrail. If the baby is crying, indicating the need for food or a diaper change, the sound sensor will detect that voice. Lastly, several pressure sensors are placed above the mattress, forming a matrix to approximately check if they are moving on the crib. The parents can use this signal to decide whether they should move their baby out of the bed for activities. The microcontroller in the crib system will analyze the signals from the sensors and report any safety event to the monitor system at the parent's side.

1.2 Visual Aid

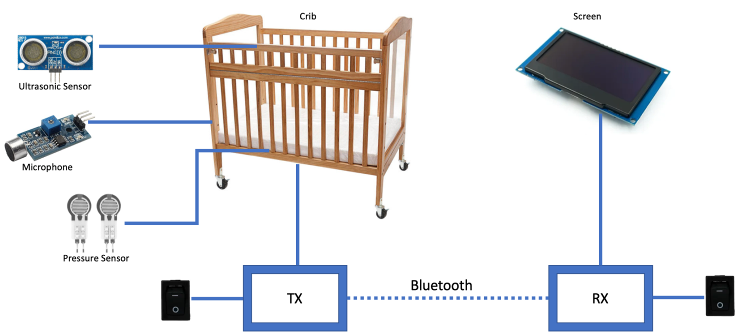

Figure 1.1 Visual Aid of the Safe Crib

1.3 High-level requirements

1. The safe crib system needs to alert the parents about whether any of the baby's body parts has reached a height of 20 in from the bottom of the crib.

2. The safe crib system needs to alert the parents about whether the baby's crying is higher than 86 dB for 2 s when measured at 34 in away.

3. When the monitor system is within 10 m of the crib and at most three 11.4 cm or thicker walls from the crib, the crib system needs to be able to send updates to the monitor system at the parent's side within 3 s of the occurrence of the safety event.

2. Design

2.1 Block Diagram

There are six subsystems contributing to the safe crib. The crib and monitor power subsystems provide a steady 5 V DC voltage supply to all the components in other subsystems. The sensor subsystem is in charge of collecting the information regarding the baby's current state and sending them to the microcontroller unit (MCU) in the crib control subsystem, which processes these data and determine the baby's current state and sends an activation signal to the monitor system through Bluetooth. The monitor control subsystem will receive and decode that activation signal and recognize which state the baby is in and control the screen of the UI subsystem to display messages about the baby's situation and induce the buzzer to alarm if necessary. Both the crib power subsystem and the monitor power subsystem step down the voltage from the 9-V-battery's voltage to the required 5 V.

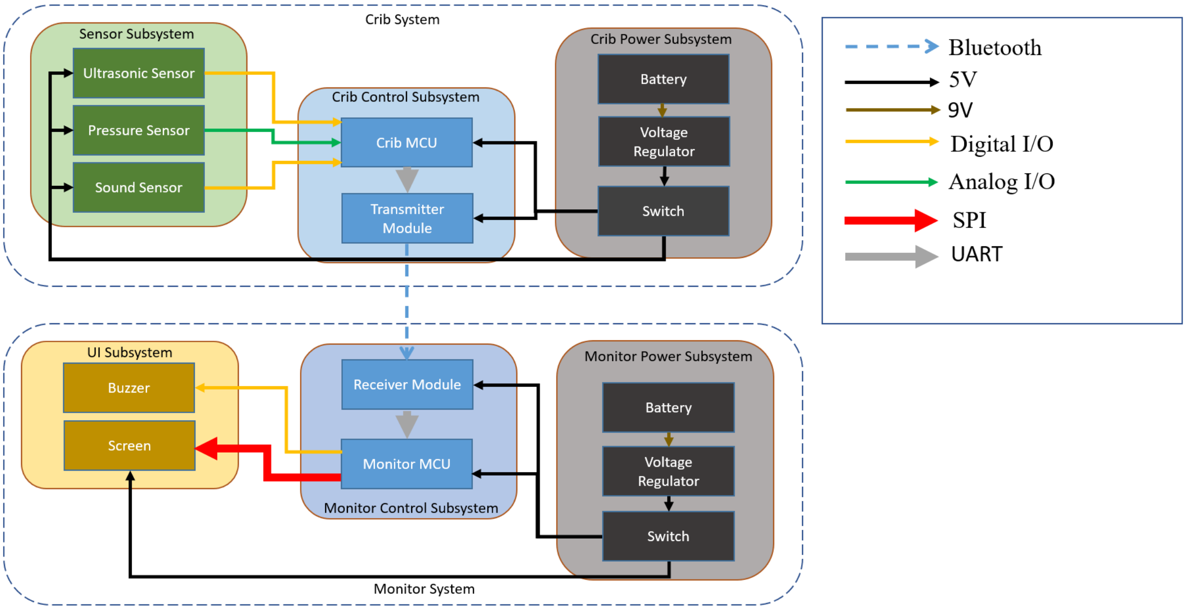

Figure 2.1 Block Diagram of the Safe Crib System

2.2 Physical Design

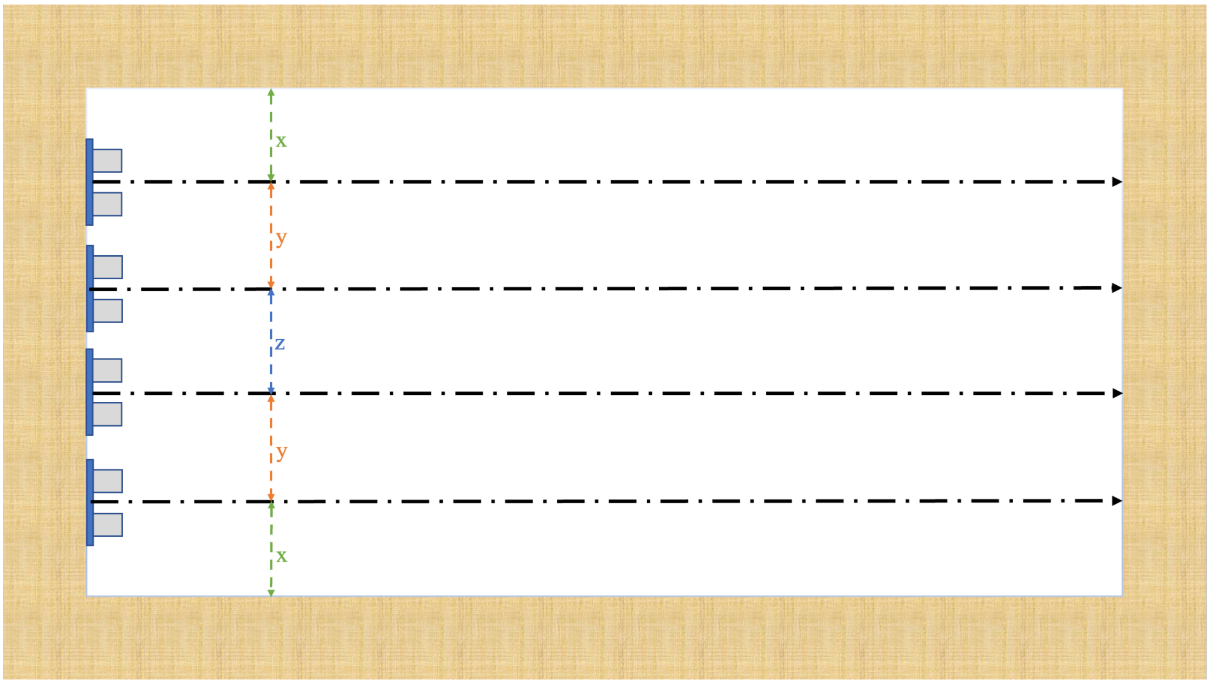

Figure 2.2 Physical design of Safe Crib with the ultrasonic sensor array

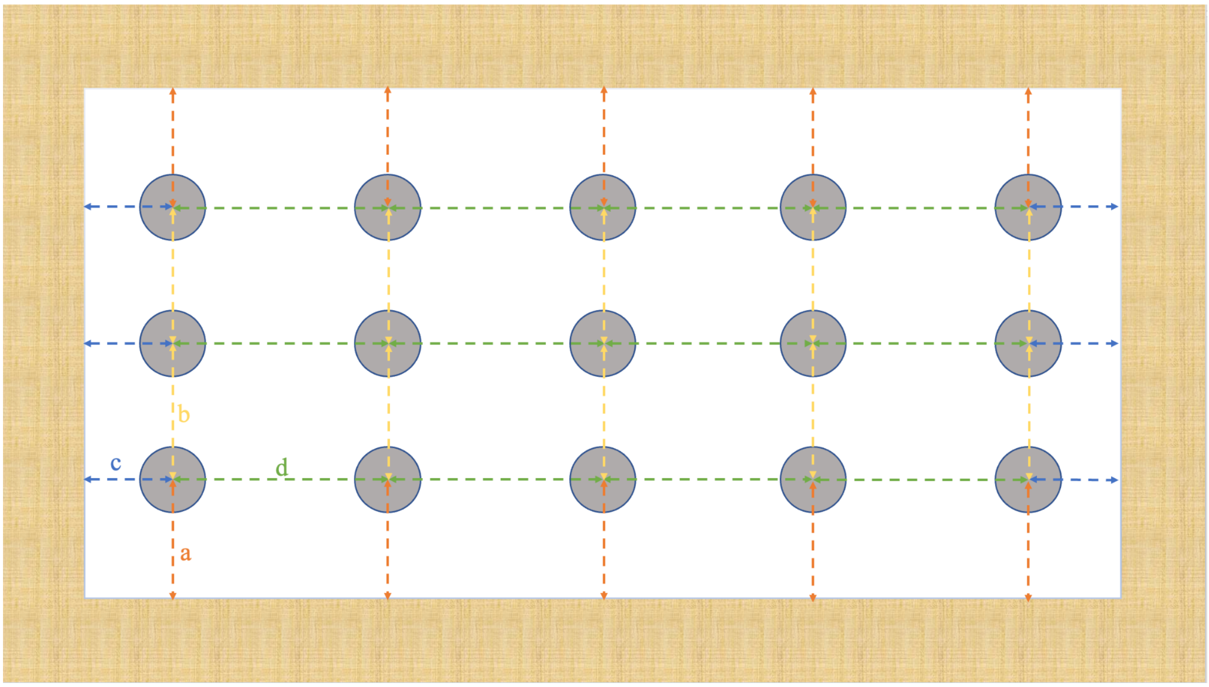

Figure 2.3 Physical design of Safe Crib with 3-by-5 pressure sensor matrix (not to scale)

Figure 2.2 and 2.3 illustrates our physical design of the Safe crib. We will use a big box to model the real crib and insert our sensors based on the above layout. The distances between sensors are represented by variables. We use x, y, and z for ultrasonic sensors and a,b,c, and d for pressure sensors. The values of each distance variable are estimated in table 1, based on a Walmart moving box with dimensions listed in Table 2.2. They may be changed based on real-life scenarios. We will make the thickness of the mattress between 1 in and 2 in and simulate a firm mattress surface.

name	x	y	z	a	b	c	d
value (cm)	10	10	15	10	15	15	11.25

Table 2.1. Estimated Distance between Sensors

L (inch)	W (inch)	H (inch)
34	20	20

Table 2.2 Crib Dimensions

2.3 Crib System

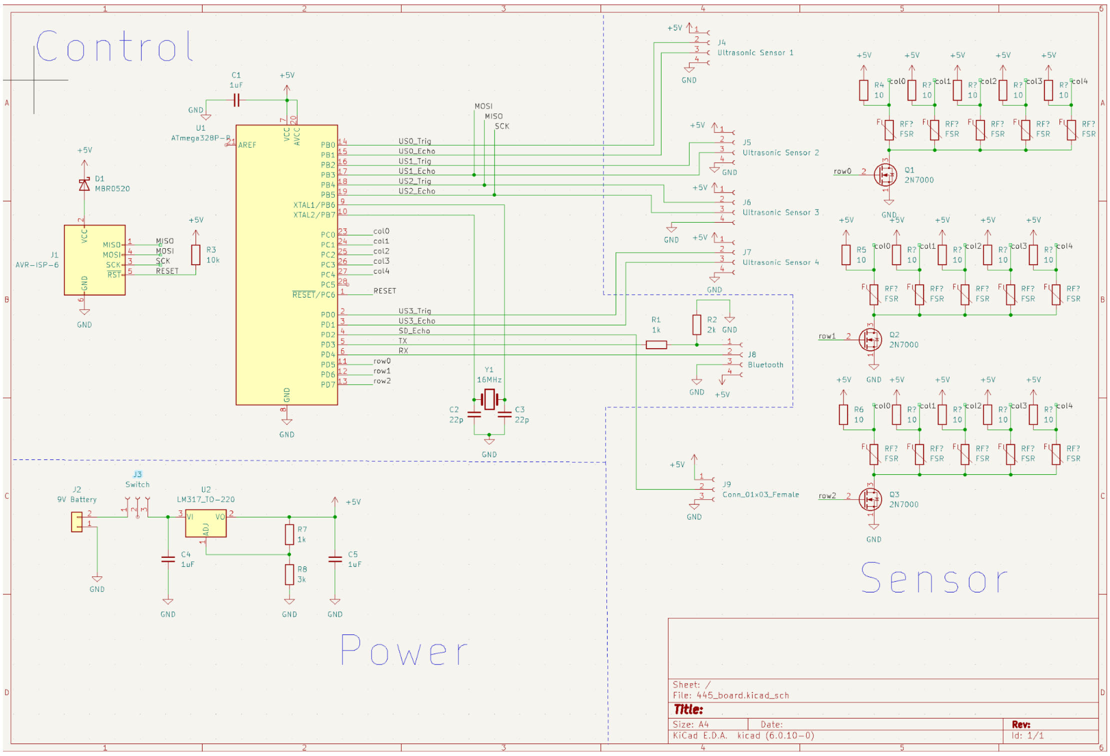

Figure 2.4 Crib PCB Schematic

2.3.1 Subsystem 1: Crib Control Subsystem

The crib control subsystem mainly consists of a microcontroller and a Bluetooth module.

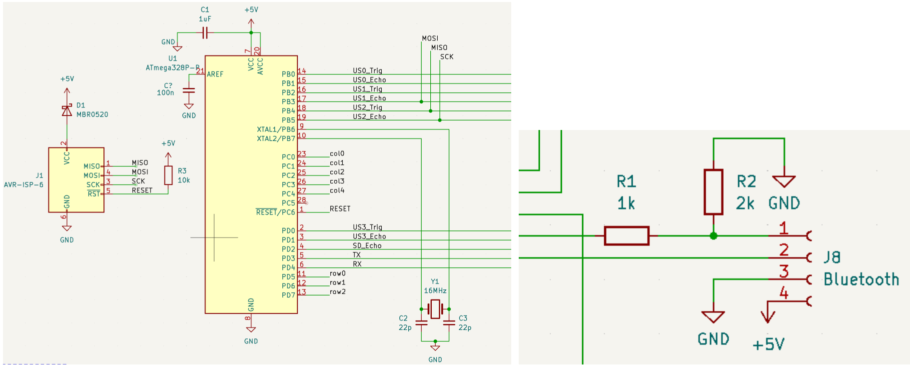

Figure 2.5 Crib Control Subsystem with Bluetooth Module Schematic

The microcontroller aims to implement several functionalities, such as data collection and analysis from the sensors. It obtains the distance measurements from ultrasonic sensors, the analog voltage output from pressure sensors, and the confirmation of sound detection TTL pulse through digital and analog pins. Then it determines whether the baby is crying based on whether the sound sensor is returning a TTL signal. It also uses the results from the ultrasonic sensors to decide whether the baby is trying to climb the guardrail if the measured distance is smaller than the length of the crib. Finally, when the microcontroller receives measurements from each pressure sensor array, the internal Analog-to-Digital Converter converts analog outputs from 0 V to 5 V into integers from 0 to 1023. Finally, the subsystem sends a message indicating the baby's current state to the receiver end of the monitor subsystem. There is a 16 MHz Quartz crystal oscillator with two 22 pF capacitors for clock generation. A programmer connector is wired to the microcontroller, so we can connect the computer to the controller through a USB programmer to flash our own code into the chip.

The Bluetooth module connects the digital pinout from the microcontroller. It sends out the message regarding the baby's current state, such as whether they are safe, moving their body, crying, or trying to climb the guard rail, to the other Bluetooth module on the monitor control subsystem. Therefore the monitor control subsystem receives these messages and implements the corresponding display and alarm.

Requirement	Verification
The microcontroller can process data from all sensors and generate informational data about the safety status in the crib at all times. (1) The alert data for "Climbing" is generated if the reading of any of the ultrasonic sensors is less than 32 in or greater than 34 in; (2) that for "Crying" is generated if the GATE signal from the sound detector is high for at least 2 s; (3) that for "Moving" is generated if the	Write a program that converts sensor readings into a three-bit bit code, where each bit represents the occurrence of one safety event. (1) Generate the alert for "Climbing" if the reading of any of the ultrasonic sensors is less than 32 in or greater than 34 in. (2) Generate the alert for "Crying" if the GATE signal from the sound detector is high for at least 2 s. (3) Generate the notification for "Moving" if the number or positions of

number or positions of readings above 5 N changed when compared to the readings stored at most 2 s ago.	pressure sensors that feel a force greater than 5 N changed when compared to readings stored at most 2 s ago. Verify that the correct alert or notification is made on the LCD screen every time an event is identified.
The microcontroller can deliver the informational data to another device with its Bluetooth within 10 m and with at most three 11.4 cm or thicker walls in between. The time it takes to send the data should be within 3 s.	Send the bit-code representing the data through Bluetooth to another Bluetooth device 10 m away and with at most three 11.4 cm or thicker walls in between to show that the notification made is correct on the LCD screen. Time the process starting from the occurrence of the event to the display of the message and verify that it is within 3 s.

Table 2.3 Requirements and Verifications for Crib Control Subsystem

2.3.2 Subsystem 2: Crib Sensor Subsystem

The sensor subsystem contains three types of sensors: ultrasonic sensors, pressure sensors, and a sound sensor. Each of them is responsible for gathering information regarding the baby's behaviors and reporting to the microcontroller.

The ultrasonic sensors collect the distance measurement between themselves and the closest object in front of them. They will constantly measure the distance from one side of the crib to another. When the baby stands up and breaks the measurement, we can tell that the baby has reached the height limit. In principle, the sensor sends an ultrasound, which will soon be echoed back if it hits some objects. The programmable MCU in the control subsystem records the time it takes for the ultrasound to propagate and reflect back to the sensor and calculates the distance based on the recorded time multiplied by the sound speed [3]. The calculation is based on the following approach:

$$distance = speed \times time = \frac{34\ cm}{ms} \times duration(ms) \tag{2.1}$$

The pressure sensors are responsible for detecting the baby's weight. If the baby is on top of a pressure sensor, the sensor will act as a force-sensing resistor, which corresponds to a decrease in its internal resistance. In this case, the voltage can be sent to the MCU on the crib control subsystem for further analysis.

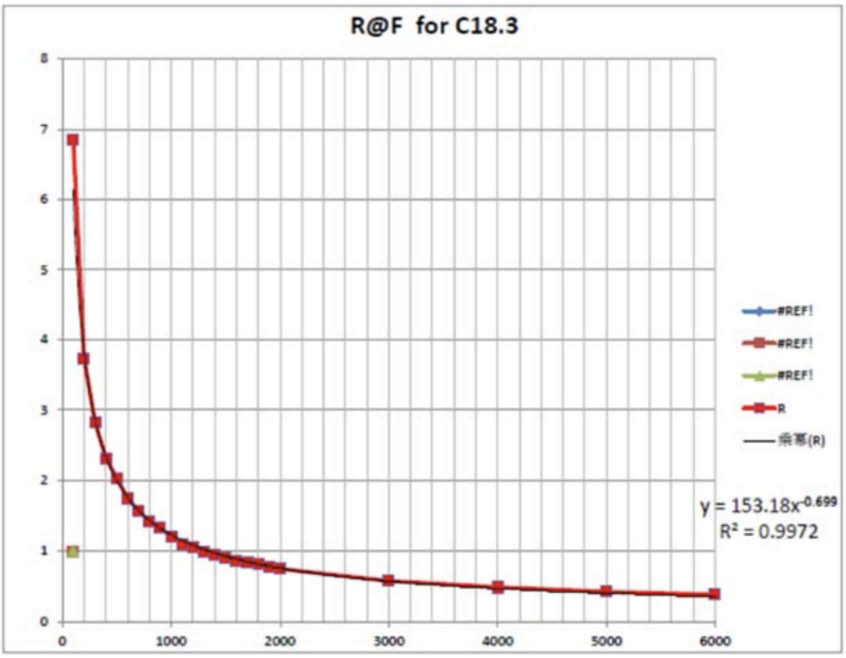

Figure 2.6 Force vs. Resistance of SEN0294 Pressure Sensor [4]

Since the MCU we demand lacks enough analog pins for simultaneously receiving the data from more than six pressure sensors, we construct three pressure sensor arrays, each controlled by an N-channel MOSFET, to receive the measurements with a negligible amount of timestamp.

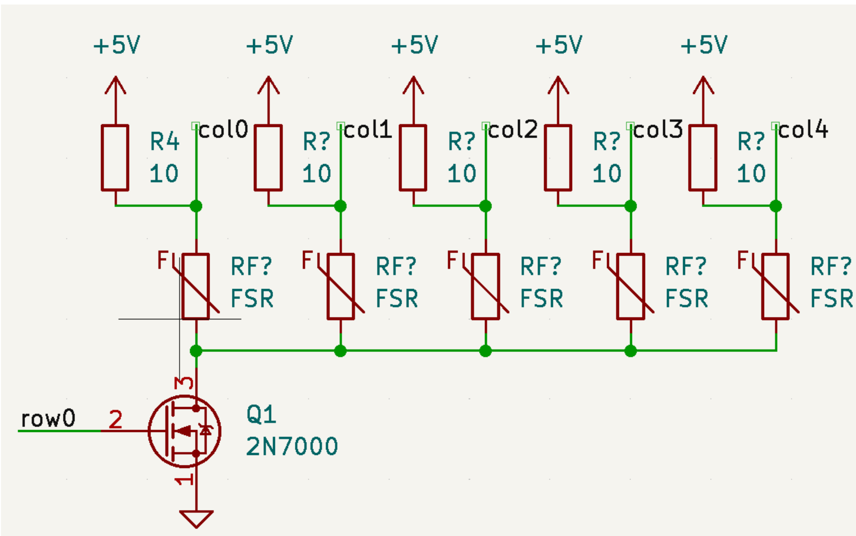

Figure 2.7 One Pressure Sensor Array Controlled by an NMOS

Each pressure sensor array is composed of five pressure sensors. Therefore a three-by-five pressure sensor matrix is constructed. The pins from row0 to row2 are connected to the digital pins on the MCU of the crib control subsystem, which sends the activation signal to each row in a serial manner. Once the gate of the N-Channel transistor receives a TTL signal, it will soon become a pull-down device and generate current from the drain to the source. So all five pressure sensors will be powered and form a resistance array, and the voltage array will be correspondingly generated and sent to the analog pins of the MCU through the connections from col0 to col4.

The sound sensor detects the nearby noise amplitude. Once the noise level reaches its threshold, the sensor will send a TTL signal through a digital pin to the MCU, which considers the signal as the baby is crying. The threshold is usually represented by the voltage gain inside the amplifier, which can be tuned manually by a potentiometer or soldering an additional resistance onto the board. In our design, we utilize a three-pin female connector with the sensor.

To generalize the interfacing, we construct a table to illustrate the output types from the sensors to connect them to the correct pin of the MCU.

Sensors	Ultrasonic Sensor	Pressure Sensor	Sound Sensor
Output Type	Digital(TTL)	Analog	Digital(TTL)

Table 2.4 Sensor Output Category

In the TTL standard, the data is considered as a "1" as the voltage is between 2.4 V and 5 V and a "0" as the voltage is between 0 V and 0.4 V. Based on this protocol, the digital outputs can be directly connected with the digital pins of the MCU. The analog output, on the other hand, needs to be connected to the MCU pins with analog-to-digital converters (ADC), which convert the analog voltage to a digital quantitative number that can be read and processed by the MCU.

Requirement	Verification
The ultrasonic sensor should correctly inform the MCU if the baby rises to a height of 20 in ± 0.5 in from the bottom of the crib.	Mount the ultrasonic sensors along the short side of the crib at a height of 20 in ± 0.5 in from the bottom of the crib. Write and upload a program that controls the ultrasonic sensors to measure the distance from one short side of the crib to another and programmatically check whether the distance measured is equivalent to 34 in ± 1 in. Verify that the LCD screen shows the "Baby is climbing out of the crib" alert when the distance measured is out of the range of 34 in ± 1 in.

The sound sensor should correctly report to the MCU when there is a sound above 86 dB measured at 34 in ± 1 in from the sensor.	Place a consistent sound source at 34 in ± 1 in from the sound sensor, place a decibel meter within 1 in from the sound sensor, and adjust the volume of the sound source such that the readings from the decibel meter is above 86 dB. Verify that the LCD screen shows the "Baby is crying" alert.
The pressure sensor array should correctly detect the change in the number and positions of the 15 pressure sensors that feel a perpendicular force greater than 5 N.	Run a program that scans the readings of pressure sensors. Verify that the LCD screen displays the "Baby is moving on the crib" notification on the screen if the pressure sensor matrix detects a change in the number or position of pressure sensors that detect a force above 5 N.

Table 2.5 Requirements and Verifications for Crib Sensor Subsystem

2.3.3 Subsystem 3: Crib Power Subsystem

This subsystem provides power to the crib PCB board, which is composed of a 9 V-1300 mAh battery source and a linear voltage regulator. The regulator converts the DC 9 V source into a voltage of 5 V based on the following formula [5]:

$$V_{OUT} = 1.25\,V \times (1 + \frac{R_2}{R_1}) \qquad (2.2)$$

Therefore, we choose the value of R2 and R1 such that the proportion is three, so the output voltage is 5 V. The sensors and MCU are the majorities to be powered, and they all require 5 V as the supply.

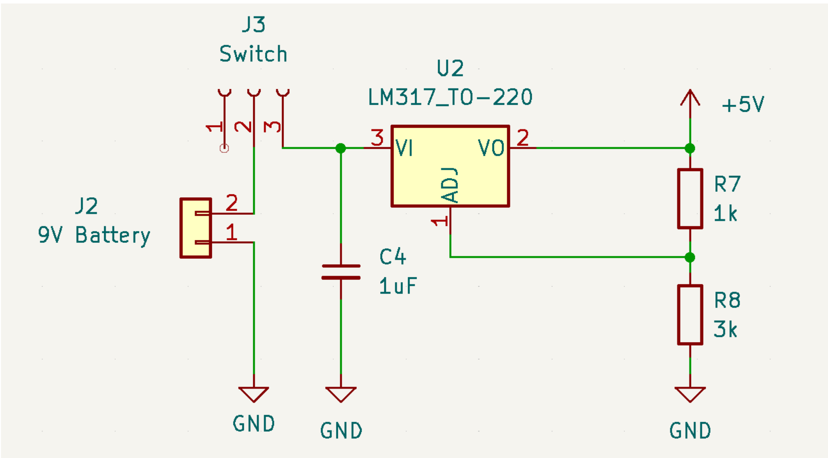

Figure 2.8 Crib Power Subsystem

Requirement	Verification
The input to the VI pin of the voltage regulator is 9 V ± 0.5 V.	Connect the anode of the battery to VI and the cathode to the ground. Close the switch. Use a multimeter, place one probe at VI and another at the GND, and verify that the voltage difference is 9 V ± 0.5 V.
The output of the VO pin of the voltage regulator, the input to the crib sensor subsystem, and the input to the crib control subsystem is 5 V ± 0.3 V.	Connect the anode of the battery to VI and the cathode to the ground. Close the switch. Use a multimeter, place one probe at VO and another at the GND, and verify that the voltage difference is 5 V ± 0.3 V. Repeat the measurement for the power input to the chips, Bluetooth module and the sensors.

Table 2.6 Requirements and Verifications for Crib Power Subsystem

2.4 Monitor System

2.4.1 Subsystem 4: Monitor Control Subsystem

The monitor control subsystem controls the functional peripherals in the monitor subsystem and communicates with the crib subsystem. It consists of an ATMega328P microcontroller and an HC-05 Bluetooth module. To make the microcontroller work, we need to use an in-circuit programmer to load a program into the chip, so we place an ISP connector on our board. Our schematics have the minimum connections needed to program the chip [6]. The Bluetooth only needs 5 V as its power, and TX and RX pins are connected to two I/O pins on the microcontroller. A flowchart that can demonstrate the working logic of the monitor control subsystem is below.

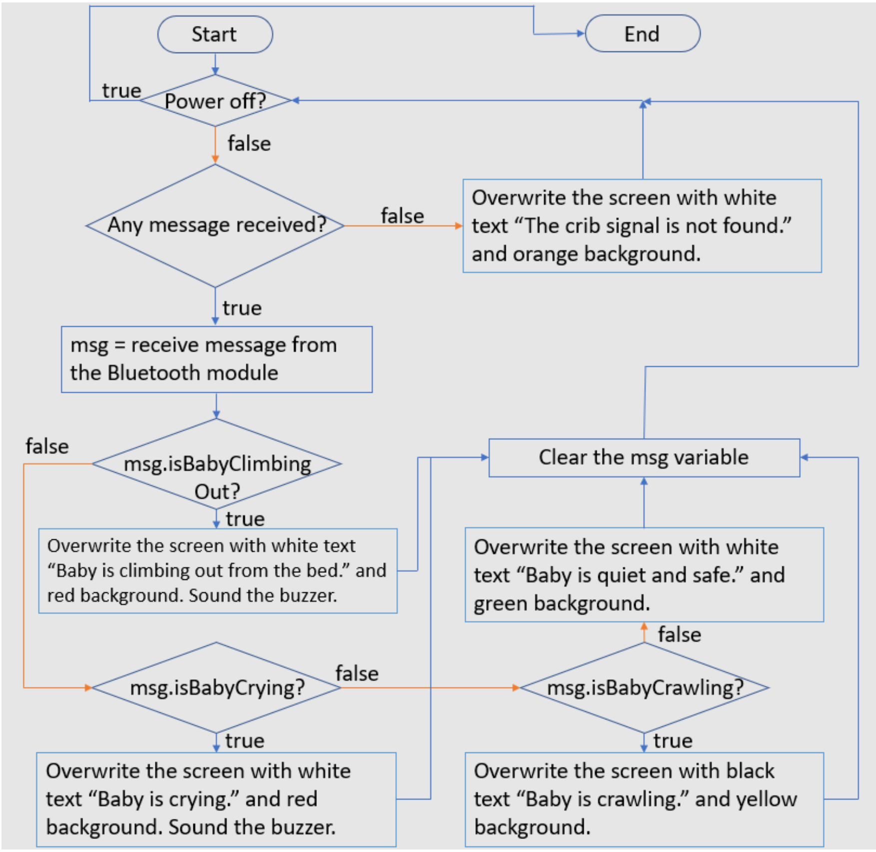

Figure 2.9 Monitor System Flow Chart

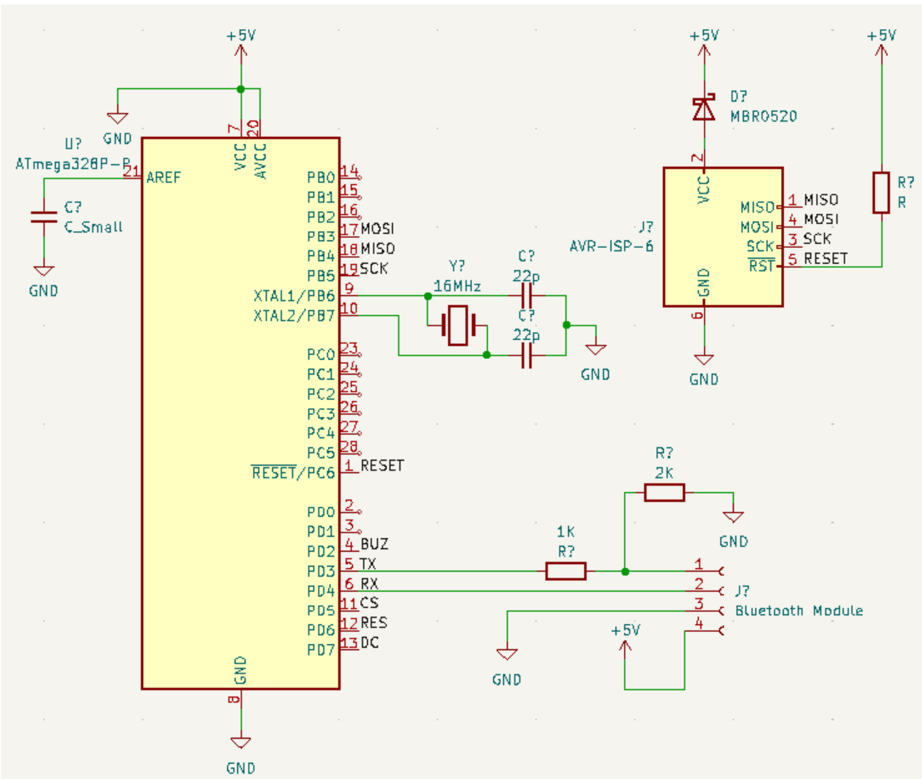

Figure 2.10 Monitor Control Subsystem Circuit Schematics

Requirement	Verification
The Bluetooth module can receive messages from another Bluetooth device and deliver them correctly to the microcontroller. The microcontroller can use the messages to control the peripherals at all times.	Send a bit code representing the safety status to the Bluetooth module at the monitor system. Control the display to show the user message corresponding to the bit code on the screen. Verify that the screen displays the correct message. Check whether the buzzer sounds when the bit code indicates code-red events (either the bit for “climbing” or “crying” is set).
The time elapsed from a safety event starts to the generated alert should be within 3 s.	Time the process with a stopwatch from the event start to the occurrence of the alert and check whether it takes smaller than 3 s.

Table 2.7 Requirements and Verifications for Monitor Control Subsystem

2.4.2 Subsystem 5: UI Subsystem

The UI subsystem is responsible for notifying the guardian about any event happening in the crib. The LCD Screen provides a striking visual prompt for the parent. In order to differentiate the level of emergency, we assign different background colors to different levels of emergency. For instance, the screen will display white text with a red background when the baby is attempting to climb out of the crib or crying (code red). The screen will display black text with a yellow background when the baby is crawling around or rolling from tummy to back (code yellow). The screen will display white text with a green background when nothing is happening (code green); for example, the baby is asleep. In terms of the auditory stimuli, we will place a buzzer along with the screen. The buzzer will only sound when the screen turns red. In other words, it alarms when the most emergent situation happens. Ideally, the reaction time of the screen and the buzzer is counted in the three-second reaction time specified in the high-level requirements.

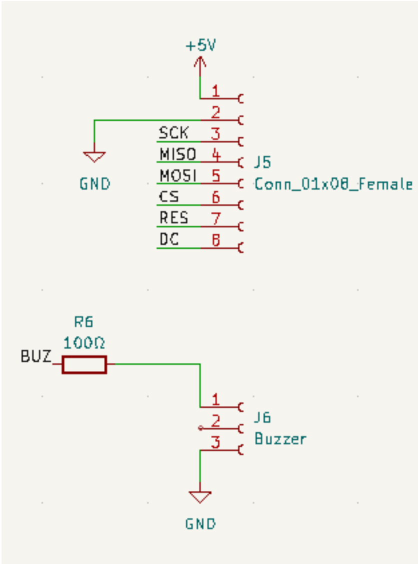

Figure 2.11 Buzzer and Monitor Schematic

Requirement	Verification
The microcontroller can control the screen to display five different contents under the five corresponding situations: climbing, crying, moving, safe, and not-connected.	Send different possible safety status messages to the microcontroller such that each of the five different contents can show up once. Verify that the five different contents are as follows: (a) “Your baby is climbing out of the crib.” (white text with a red background), (b) “Your baby is crying.” (white text with a red background), (c) “Your baby is moving on the crib.” (black text with a yellow background), (d) “Your baby is safe and quiet. :)” (white text with a green background), (e) “The crib signal is not found.” (white text with orange background)
The buzzer can emit a sound greater than 80 dB when connected in series with a 100 Ω ± 10 Ω.	Connect one end of the buzzer in series with a 100 Ω ± 10 Ω resistor and another end to GND, use a sound pressure level detector on a phone, and place the microphone of the phone within 20 cm of the buzzer to verify that the emitted sound is above 80 dB.

Table 2.8 Requirements and Verifications for UI Subsystem

2.4.3 Subsystem 6: Monitor Power Subsystem

We need this subsystem to ensure that other subsystems in the monitor system can acquire their required voltage. We use a voltage regulator to step down from a 9 V battery because the rated voltage of other components in the circuit is mostly 5 V. We referred to the datasheet to draw the connections to the voltage regulator such that the output voltage is around 5 V [5].

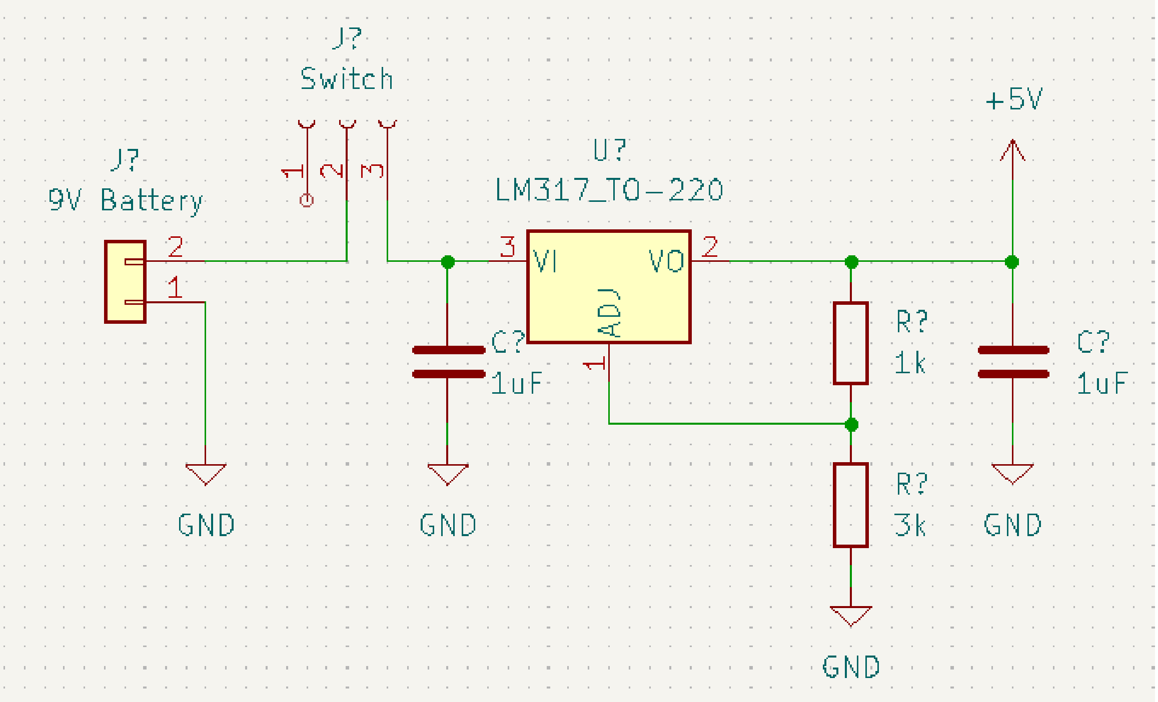

Figure 2.12 Monitor Power Subsystem

Requirement	Verification
The input to the VI pin of the voltage regulator is 9 V ± 0.5 V.	Connect the anode of the battery to VI and the cathode to the ground. Close the switch. Use a multimeter, place one probe at VI and another at the GND, and verify that the voltage difference is 9 V ± 0.5 V.
The output of the VO pin of the voltage regulator, the input to the UI subsystem, and the input to the monitor control subsystem is 5 V ± 0.3 V.	Connect the anode of the battery to VI and the cathode to the ground. Close the switch. Use a multimeter, place one probe at VO and another at the GND, and verify that the voltage difference is 5 V ± 0.3 V. Repeat the measurement and verify the readings for the

	power input to the microcontroller, screen, and buzzer.

Table 2.9 Requirements and Verifications for Monitor Power Subsystem

2.5 Tolerance Analysis

The most likely error in this project is the measurement of accuracy and error of the pressure sensor. Tolerance analysis is therefore required to analyze the extent to which potential measurement errors affect the operation of pressure sensors. We can take the fifth percentile of the target population as the worst-case scenario, a seven-month-old baby whose weight is 6.66 kg [7]. Taking the elasticity of the mattress and errors from the pressure sensors into consideration, we believe a 5 N force is a sufficient amount to determine that the baby has placed a significant weight on a pressure sensor. Therefore, we are concerned about whether any pressure sensor can give a false alarm when there is no or tiny weight on a pressure sensor. We can analyze how likely it is that a pressure sensor can have an error of 5 N when the measurement error of a pressure sensor is 2 N at maximum. We can use hypothesis testing to examine the probability that a single sensor's error is 5 N. Our null hypothesis is that the observed mean is greater than 2 N. If we assume the standard deviation is one and use 2 N as the true mean, the test statistics of the null hypothesis is $Z = \frac{(\bar{x} - \mu)}{\sigma / \sqrt{n}} = \frac{(5-2)}{1 / \sqrt{1}} = 3$, which corresponds to a probability of 0.00135 under the z-distribution. Therefore, it is not likely that a pressure sensor will give a false alarm when the baby does not exert a force on it.

3. Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor

We assume the salary per hour is $ 35. And each of us contributes to the project for 12 hours every week. Since there are 15 weeks in a semester, then the labor cost for each member is:

$$Labor\ Cost\ =\ 35\frac{dollars}{hour}\times\ 2.5\ \times\ 12\frac{hours}{week}\times\ 15\ weeks\ =\ \$\ 15750 \qquad (3.1)$$

The total labor cost for a group of three is also calculated:

$$Total\ Labor\ Cost\ =\ 3\ \times\ \$\ 15750\ =\ \$\ 47250 \qquad (3.2)$$

3.1.2 Parts

Description	Manufacturer	Part #	Quantity	Individual Cost ($)	Bulk Cost ($)
Ultrasonic Sensor	EPLZON	HC-SR04	4	$ 2.60	$ 10.40
Pressure Sensor	DFRobot	SEN0294	15	$ 5.00	$ 75.00
Sound Sensor	Sparkfun	SEN-14262	1	$ 13.25	$ 13.25
Microcontroller	Microchip Technology	ATMega328p	2	$ 7.70	$ 15.40
Bluetooth Module	DEVMO	HC-05	2	$ 11.33	$ 22.66
Buzzer	CUI Devices	CMI-1295IC-0585T	1	$ 1.18	$ 1.18
Screen	Adafruit	ST7789	1	$ 17.50	$ 17.50
Battery	TQTHL	N/A	2	$ 5.22	$ 10.44
Voltage Regulator	Texas Instruments	LM317KCT	1	$ 0.69	$ 0.69
Switch	Adafruit	805	2	$ 0.95	$ 1.90
NMOS Transistor	ONSEMI	2N7000	3	$ 0.51	$ 1.53
Total					$ 169.95

Table 3.1 Parts Cost

Since we make the mechanical structure of the crib, the machine shop labor does not need any hour to work on the project; thus, their costs are zero.

3.1.3 Sum of Costs

$$Sum\ of\ Costs\ =\ \$\,47250\ +\ \$\,169.95\ =\ \$\,47419.95 \qquad (3.3)$$

3.2 Schedule

	Yuhao	Xinlong	Feng
2/5/2022-2/11/2022	Research part number of the microcontroller & voltage regulator (Including writing the design document)	Research how the screen works. Draw the schematics of the UI system	Prepare all three types of sensors. Research about the testing parameter of the sensor system
2/12/2022-2/18/2022	Design the Schematics of the Microcontroller & Power Subsystem (Including writing the design document)	Draw the schematics of the UI subsystem & PCB layout. Write design document	Design the connection to the Microcontroller & Power Subsystem and signal processing method
2/19/2022-2/25/2022	Draw the PCB Layout of the Microcontroller & Power subsystem. Write the design document	Design PCB layout of the UI subsystem. Write the design document	Design a supporting circuit to operate as a central terminal for all pressure sensors. Write the team contract document and the design document
2/26/2022-3/4/2023	Prepare for the design review. Design the prototype of the crib control subsystem	Prepare for the design review. Design the prototype of the monitor control subsystem	Prepare for the design review. Design the prototype of the crib control subsystem and adjust sensor parameters.
3/5/2023-3/11/2023	Adjust the prototype of the crib control and power subsystems	Adjust the prototype of the monitor control and power subsystems	Adjust the prototype of the crib control and power subsystems
3/12/2023-3/18/2023	Spring Break	Spring Break	Spring Break
3/19/2023-3/25/2023	Fix the crib control and power subsystem PCB design if errors	Fix the monitor system PCB design if errors are	Fix the sensor subsystem and PCB design if errors are

	are identified in the prototype	identified in the prototype	identified in the prototype
3/26/2023-4/1/2023	Order a new PCB in the second round if needed. Write the individual progress report. Integrate parts into the crib system on PCB	Order a new PCB in the second round if needed. Write the individual progress report. Integrate parts into the monitor system on PCB	Order a new PCB in the second round if needed. Write the individual progress report. Integrate parts into the crib system on PCB
4/2/2023-4/8/2023	Integrate parts into the crib system PCB. Verify the hardware on the same system	Integrate parts into the monitor system PCB. Verify the hardware on the same system	Integrate parts into the crib system PCB. Verify the hardware on the same system
4/9/2023-4/15/2023	Finish hardware verification. Put subsystems together, and prepare for the mock demo	Finish hardware verification. Put subsystems together, and prepare for the mock demo	Finish hardware verification. Put subsystems together, and prepare for the mock demo
4/16/2023-4/22/2023	Work on project revision based on the feedback from the mock demo	Work on project revision based on the feedback from the mock demo	Work on project revision based on the feedback from the mock demo
4/23/2023-4/29/2023	Prepare for the final demo and start the final report	Prepare for the final demo and start the final report	Prepare for the final demo and start the final report
4/30/2023-5/3/2023	Prepare for the final presentation and finish the final report	Prepare for the final presentation and finish the final report	Prepare for the final presentation and finish the final report

Table 3.2 Parts Cost

4. Discussion of Ethics and Safety

We will thoroughly discuss any ethical issues related to this project in this section. The IEEE Policies [8] have recognized the possible impact of new technologies on the world and emphasized the standard that IEEE members should hold in professional activities. Those more relevant to our project include putting public safety, health, and welfare in the first place, maintaining sustainability, and disclosing possible harms during the use of our product.

We will discuss possible ethical issues related to the product and its development process and will first go through those about the product. When a user considers our product, a primary concern is its safety. Due to the lack of studies on the influence of ultrasound on post-natal infants, we can learn some insights from how ultrasound affects humans in general. We will use sensors that emit ultrasounds with a frequency of around 40 kHz. According to [9], there has been no demonstration showing that ultrasound with 40 kHz and below 120 dB sound pressure level can affect human hearing. Ultrasound with the same scale will also not affect cognitive functions [10]. The working power of our ultrasonic sensor is 75 mW. Assuming all the power is converted to sound, the sound pressure level is 108 dB, which is less than 120 dB. In terms of the influence on biological tissues, ultrasonic devices used at the diagnostic level will not damage human tissue because the produced heat is negligible compared to physiological thermal temperature [11]. Since our product controls the angle and pattern of ultrasound emissions, the baby will not be directly radiated by the ultrasound unless they go beyond the guardrail of the crib, at which time the guardian alarm will sound. The ultrasound radiation time will be less than five minutes per day, assuming the product is turned on for 24 hours per day. In order to prevent fire caused by a short circuit in the pressure sensor lining, we will use special fireproof, waterproof, and insulating materials to package the circuit.

There are fewer concerns in terms of ethical issues in the product development process. The ultrasonic transducer will not cause damage to the developers, as indicated by [9-11]. The ultrasonic sensor will not directly radiate the developers 99 % of the time. The power we use in this project is not greater than 9 V, which is safe for the developers in most circumstances. We will check carefully for safe connections between elements and avoid short circuits during assembly and testing. We will ensure that the development process reflects sustainable development, plan ahead all the materials needed, and avoid as much waste as possible. Based on this and the previous paragraph, no person will be hurt by the product in testing or operations.

There is no safety and regulatory standard on the limit of the frequency and acoustic intensity of ultrasound for non-clinical and consumer products. If we compare our product against the limit specified in part 2 of IEC 60601 for clinical-use products [12], our estimated ultrasound intensity – which is 0.0133 W/cm^2 – is much less than the 3 W/cm^2 limit, and the frequency is much higher than human audible range while in the low-frequency ultrasound range which is safe for human.

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