UNIVERSITY OF ILLINOIS AT
URBANA-CHAMPAIGN

# ECE 445: Project Proposal
## Safe Crib with Auto-hazard Detection

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# DESCRIPTION

## 1. Introduction

### 1.1 Problem

Parents with babies at home are most worried about the safety of their babies. Even at home, they always worry that when dealing with things in another room, the baby will not accidentally climb out of the crib or bump into the head of the bed, which might fall off the bed and therefore induce serious injuries [1]. Besides, when babies cry, they usually demand feeding or diaper change. Neglecting the former leads to malnutrition, and the latter causes parents to spend extra time cleaning the bed sheets. Other than that, crying refers to many different signals to parents, such as sickness and burping, indicating the significance of crying for parents to take care of their babies [2]. Based on these considerations, our team aims to design a device to remind parents to take care of their babies.

### 1.2 Solution

Our team proposed a safe crib with hazard detection to solve this problem. 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.

1. The crib contains ultrasonic sensors on the top of the guardrail, detecting if the baby is trying to climb the guardrail, which might induce falling off the crib.
2. Several pressure sensors are placed beneath the mattress of the bed, forming a matrix to detect the rough position of the baby and if they are crawling.
3. A sound sensor is positioned on the guardrail. If the baby is crying, indicating the need for food or a restroom, the sound sensor will detect that voice.
4. A transmitter analyzes the above situations and sends activation signals to a remote device to display the message.
5. A remote device is necessary to receive the activation signal from the crib. A screen on this device would display the message indicating the following states of the baby, which are:
    a. Climbing (background will turn yellow)
    b. Crying (background will turn red)
    c. Crawling (background will turn red)

The buzzer would sound once the abnormal situations b and c happen. The screen will show the default display if the baby is asleep and not in the above states.

## 1.3 Visual Aid

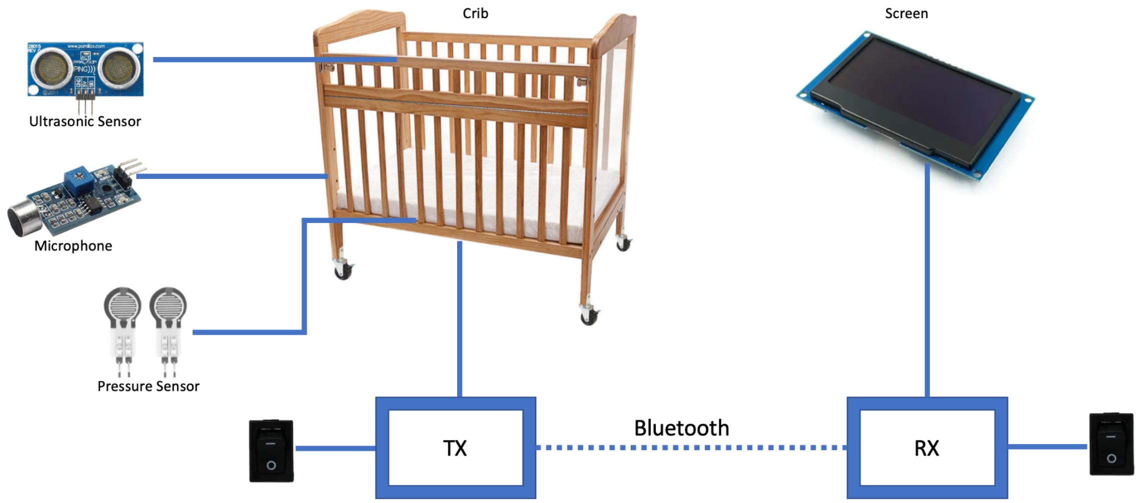


Figure 1.1 Visual Aid of Smart Crib

## 1.4 High-level requirements list

1. The crib must be capable of alarming parents once their children perform abnormal or hazardous actions, such as crying or trying to climb the guardrails when parents are within 10 m of the crib.
2. The crib must continuously send a “safe” signal when there is no anomaly or send the quiet “baby is crawling” signal.
3. After the crib system processes data from sensors and sends a signal to the receiver, the receiver at the parents’ side must obtain all the information and sound the alarm within 0.5 s;
4. The sound sensor must be able to detect a baby’s crying by sending information to parents once the amplitude exceeds 110 dB.

# 2. Design

## 2.1 Block Diagram

Figure 2.1 depicts the entire high-level design of the crib. All of the components are tolerant with an input voltage of 5 V. ATMega328 is considered to be the MCU, which has 14 digital I/O pins and six analog-read pins [3]. Since no more than five ultrasonic sensors and six pressure sensors would be used in this project (each ultrasonic sensor will occupy two digital I/O pins; the sound sensor will occupy one digital I/O pin; the transmission module will occupy two digital I/O pins), the pin assignment is sufficient. Besides, the ease of hand-soldering and basic TTL standard input-voltage tolerance make this chip suitable for our project.

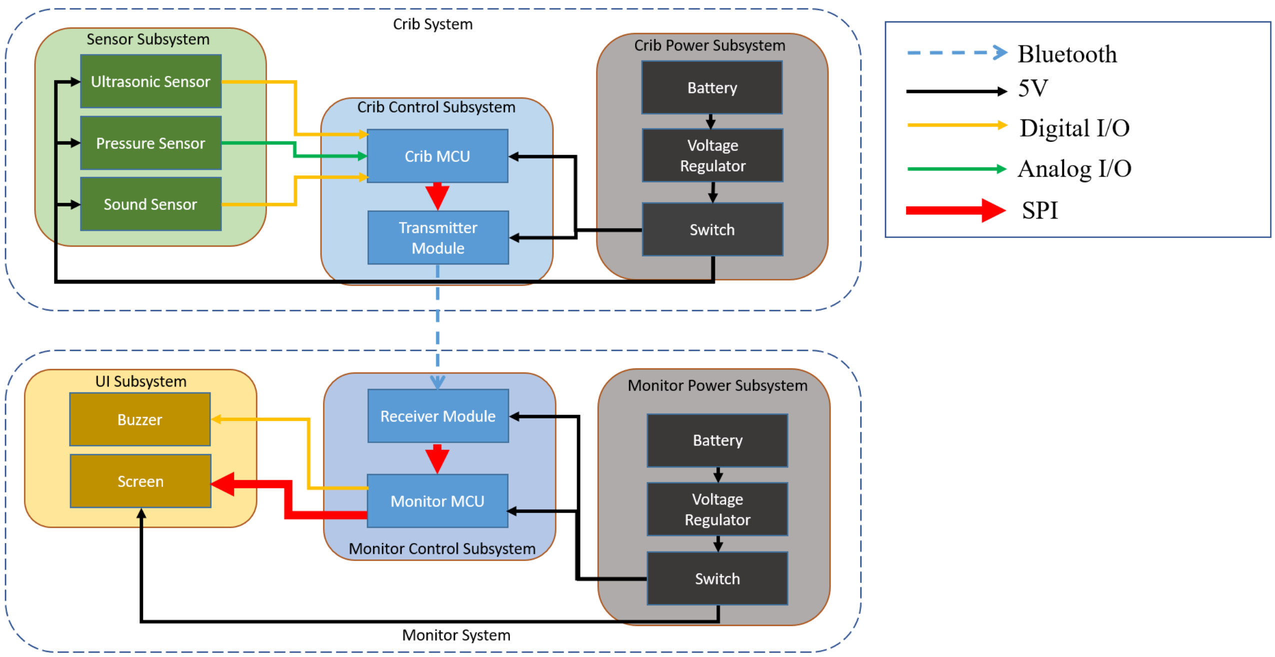


Figure 2.1 Block Diagram of Smart Crib

## 2.2 Subsystem Overview

### 2.2.1 Crib and Monitor Power Subsystems

The power subsystem offers the power supply to all other components. The 5 V power supply provides power for the transmitting and receiving PCB. The transmitting PCB will use this voltage to power the crib and monitor subsystem, sensor subsystem, and user interface subsystem. And the receiving end will use 5 V to power the monitor and buzzer. The power subsystem also has one switch on each PCB board/Raspberry Pi device to turn on/off the entire crib and monitor control subsystem and all other subsystems connected.

### 2.2.2 Sensor Subsystem

The system will use HC-SR04 (Ultrasonic Sensor) to detect the baby's current height and distance to the bed edge through several ultrasonic sensors installed at the top of the guardrail on one side of the bed. Because when lying down or climbing, their height generally does not exceed the height of the guardrail. The system can consider the baby at a potentially dangerous height if the ultrasound is blocked. The system also uses multiple pressure sensors placed between the sheet and the mattress to detect the pressure of the baby on the bed and sends data from each pressure sensor to the crib control subsystem for subsequent processing. The sound sensor is also one subsystem component that detects whether the crying sound is higher than a certain threshold. It then sends an activation signal to the MCU of the crib control subsystem.

### 2.2.3 Crib and Monitor Control Subsystems

MCU is the hardware core of the whole project. It receives the electrical pulse signal from the ultrasonic sensor subsystem and the voltage signal from the pressure sensor subsystem. Then it calculates the distance and pressure change measured by the ultrasonic wave through the code burned on the PCB to determine whether the baby is performing dangerous actions or is carrying out activities while awake. In addition, the corresponding activation signal converts the analog signal into a digital signal through Bluetooth/Wi-Fi module, transmits, and propagates through the antenna. The digital signal is converted back to an analog signal and read by the receiving end of another MCU.

### 2.2.4 User Interface Subsystem

The UI Subsystem was responsible for bringing text prompts to the screen and playing a beep through the buzzer. The system receives control signals from the MCU at the receiving end, extracts text data from the MCU memory, and feeds it into a screen. A buzzer will sound a warning (beeping), respectively.

## 2.3 Subsystem Requirements

### 2.3.1 Crib and Monitor Power Subsystems

The power subsystem offers the power supply to all other components. The 5 V power supply provides power for the transmitting and receiving PCB. Before the current enters the PCB, it passes through a voltage regulator to control the voltage at 5 V ± 0.1 V. Since all the other subsystems use 5V inputs, there is no need for any transformer after passing through the PCB board.

1. The voltage supplied to the crib subsystem needs to be at 5 V ± 0.1 V.
2. The voltage supplied to the monitor subsystem needs to be at 5 V ± 0.1 V.

### 2.3.2 Sensor Subsystem

The system contains three types of sensors: pressure, ultrasound, and sound pressure level. The pressure sensors are placed under the sheet on top of the mattress in our design. The pressure sensors are almost thin cuboids. When pressure is applied to the sensor, its upper and lower layer will connect through a pressure-sensitive layer and reduce the internal resistance. A voltage with its magnitude linearly proportional to that resistance will consequently flow into the MCU, which then detects the corresponding pressure change above the sensor based on reading the voltage difference. According to the value detected by each sensor, the baby's position and corresponding posture on the bed can be estimated. For example, when the value of only one or two sensors is large, while the value of other sensors is almost zero, the baby should be standing. When four or five sensors detect a certain pressure, the baby is considered kneeling or climbing. The baby is lying flat when nearly 70% or more of the sensors detect a certain pressure. The amount of pressure should decrease in sequence.

1. The analog output from the pressure sensor is between 1 V ± 0.1 V and 5 V ± 0.1 V according to the force exerted on it.
2. The pressure sensor needs to be able to tell 5 N differences of changes in force.

Then there is the sound sensor, which can be set to a threshold; in our design, it is 110 dB. When the sensor detects a baby crying louder than that volume, the sound sensor sends a pulse to the MCU, determining that the baby is awake.

1. The voltage supplied to the sound sensor needs to be at 5 V ± 0.1 V.
2. The output coming from the sound sensor needs to be in the range of 3.3 V to 5 V ± 0.1V when the ambient noise goes above the threshold.
3. The sound sensor needs to send a TTL signal to the MCU when it detects a sound of 110 dB.

Finally, it is the ultrasonic sensor. Several ultrasonic sensors will be arranged at the top of the guardrail on one side of the bed. Due to the directivity of the ultrasonic waves emitted by the ultrasonic sensors and the radiation angle of 14, the ultrasonic waves will not interfere too much with each other. Typically, the ultrasound is not blocked or absorbed, so it takes longer to return or fails to reflect. When the baby is standing, it blocks the ultrasound from the sensor in its position, which means it takes less time to complete a round trip. When the MCU subsystem sends a signal to the ultrasonic sensor to measure the distance, it sends a digital signal. When the ultrasonic sensor receives that signal, it starts sending ultrasonic waves. When the ultrasonic waves are blocked by the baby's body and reflected, the receiver attached to the sensor will receive the ultrasonic feedback and generate an electrical pulse in the induction circuit inside the sensor to transmit to the MCU. The MCU will calculate the time between sending the test signal and receiving the electrical pulse from the ultrasonic sensor subsystem and then multiply the speed of the sound wave to calculate the distance.

1. The voltage supplied to the ultrasonic sensor needs to be at 5 V ± 0.1 V.
2. The input to the ultrasonic sensor needs to be at 5 V ± 0.1 V when an ultrasound beam needs to be emitted.
3. The output from the ultrasonic sensor needs to be at 5 V ± 0.1 V when the emitted ultrasound beam is reflected and collected.

4. The ultrasonic sensor needs to be able to detect a change in distance within 2 m.

### 2.3.3 Crib and Monitor Control Subsystems

These subsystems are for the judgment of situations and data transmission. When the MCU communicates with the sensor subsystem, it will send an electrical signal to notify the sensor to start working and read from the sensors. For example, the pressure sensor will report analog voltages; the ultrasonic sensor will receive a TTL pulse when MCU asks it to emit an ultrasound and send one back when the ultrasound is received; the sound sensor will send a TTL signal when the detected sound exceeds the threshold.

The MCU analyzes and processes this information and performs the following filters. Under usual conditions, the sound sensor does not alarm, while the pressure sensor constantly reports the pressure distribution on the bed. Based on this data, the MCU will determine if the baby crawls on the bed and transmit the corresponding encrypted signal ("crawling") via Bluetooth or Wi-Fi to the receiving Bluetooth/Wi-Fi module. When the baby cries, the "crying" signal will be sent, and the alarm will sound. Whenever the ultrasonic sensor detects the baby crossing a safe altitude, the MCU determines that the baby is performing a dangerous action and immediately sends a corresponding encrypted signal ("the baby has exceeded the safe altitude") to the receiver. In these three cases, the MCU of the receiving end will decode the encrypted signal, extract the text information stored in memory according to the decoded content and show it on the screen. At the same time, it will activate the buzzer installed on the PCB of the receiving end for the sound alarm.

1. The voltage supplied to the MCU needs to be at 5 V ± 0.1 V.
2. The MCU working in the crib system needs to work at a clock frequency of at least 10 kHz.

### 2.3.4 User Interface Subsystem

The UI subsystem consists of the screen and the buzzer. When the system receives the text information and activation signal from the PCB at the receiving end, the screen will display the text image by arranging pixels on the pixel screen. At the same time, the buzzer will buzz.

1. The voltage supplied to the screen needs to be at 5 V ± 0.1 V.
2. The screen requires a data transfer rate of 1.2 Mbit/s.
3. The buzzer needs to maintain each alarm at 10 s ± 0.1 s.

## 2.4 Tolerance Analysis

The most likely error in this project is the measurement 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 lightest of the target population, a seven-month-old baby whose average weight is 8.4 kg (18.5 lbs). According to the formula G = mg with g = 9.8 m/s, the pressure exerted by the baby on the bed surface is 8.4 × 9.8 = 82.32 N. Due to the baby's small size, when the infant is in a standing position, the projected area on the ground will only occupy the detection range of one sensor so that the sensor will measure the pressure of 82.32 N. When the infant crawls on all fours in a kneeling position, the contact area between the infant's body and the ground will occupy the range of about four sensors. Because the contact area has been expanded four times, ideally, the pressure measured by each sensor should be one-quarter of the original, that is, 82.32 N / 4 = 20.58 N. Similarly, when the baby is lying, we can think of it as occupying six pressure sensors, and each sensor should measure some value close to 82.32 N / 6 = 13.72 N. We can see that the values detected by each sensor differ greatly in the infant's standing and lying posture, and the difference between kneeling and lying posture is close to 7 N directly, while the error of the general pressure sensor is between 1 N and 2 N. Therefore, the difference between these three postures is very large, and it is not easy to misjudge. There is little difference between the pressure measured when the baby's body occupies a range of six sensors for the lying position. Therefore, to avoid wrong judgment, we should define the tolerance as 7 N.

## 3. Ethics and Safety

We will thoroughly discuss any ethical issues related to this project in this section. The IEEE Policies [4] has 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 [5], 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 [6]. 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 [7]. 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. When the user wants to wash the lining, they should only wash the waterproof layer after separating it from the lining. When the crib system is not in use, the guardian should unplug the system and put the power cable away so that the baby does not get tripped or entangled by the cable or injured by electricity.

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 [5-7]. The ultrasonic sensor will not directly radiate the developers 99% of the time. The developers will need to ensure safe operation and insulation measures when using 5 V power. We will ensure that the development process reflects sustainable development. We will plan ahead all the materials needed and avoid as much waste as possible.

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 [8], 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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