BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 416 (January 2025)

Microprocessors and Embedded Systems Laboratory

Final Project Report

Section: **B2** Group: **03**

Smart Baby Cradle: An IoT-Based Infant Monitoring and Care System

---

Course Instructors:

Khairul Islam
(Lecturer)

Akif Hamid
(PT)

Signature of Instructor: ____________________

Submitted By:

Md. Shahriar Rahman Siam	2006108	Sheikh Munkasir Ahmed Rafeed	2006109
Md. Shakib Ahmmed Bijoy	2006107	Arpon Kumar Chanda	2006110

Date of Submission: 02 August 2025

Academic Honesty Statement:

"In signing this statement, We, hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

Signature:

____

Full Name: Md. Shahriar Rahman Siam

Student ID: 2006108

Signature:

____

Full Name: Sheikh Munkasir Ahmed Rafeed

Student ID: 2006109

Signature:

____

Full Name: Md. Shakib Ahmmed Bijoy

Student ID: 2006107

Signature:

____

Full Name: Arpon Kumar Chanda

Student ID: 2006110

Table of Contents

1 Abstract

This project focuses on the design and implementation of a Smart Baby Cradle—an IoT-enabled system aimed at assisting parents and caregivers by automating infant soothing and monitoring. The system is built around the ESP32 Devkit microcontroller, which connects wirelessly to the Blynk mobile application for real-time interaction and remote control. A KY-038 sound sensor continuously monitors ambient sound levels to detect a baby’s cry. When the sound level exceeds a defined threshold, the system activates a DC gear motor via an L298N motor driver to initiate a gentle rocking motion of the cradle, alternating between clockwise and counterclockwise directions. Users can also control the cradle manually using virtual switches in the Blynk app, and monitor live sound data through an interactive gauge. The entire setup is powered by a 12V LiPo battery, with a buck regulator stepping down the voltage to safely power the ESP32 and other low-voltage components. The cradle itself is custom-built from wood, integrating traditional design with modern embedded electronics. This project offers a cost-effective, portable, and user-friendly solution for infant care, ensuring both comfort for the baby and convenience for the caregiver.

2 Introduction

In today's fast-paced world, ensuring continuous care for infants can be challenging for parents and caregivers. Babies often cry due to discomfort, hunger, or the need for attention, and manually soothing them—especially by rocking a cradle—can become tiring and time-consuming. To address this, the integration of automation and IoT in baby care devices offers a promising solution. This project introduces a smart baby cradle system that combines hardware and software to monitor a baby's cry and respond automatically with rocking movements. Using an ESP32 microcontroller and the Blynk IoT platform, the cradle can be operated both manually and automatically based on sound detection. The system includes a KY-038 sound sensor to detect crying, an L298N motor driver to control a DC gear motor for cradle motion, and a 12V LiPo battery with a buck converter for stable power supply. The cradle’s movement is triggered when the sound exceeds a predefined threshold, ensuring a timely response to soothe the baby. Additionally, users can interact with the cradle through a mobile app, offering real-time control and monitoring. This project demonstrates how embedded systems and IoT technologies can be applied to create a practical, efficient, and supportive solution for modern infant care.

3 Design

3.1 Problem Formulation (PO(b))

3.1.1 Identification of Scope

The scope of the Smart Baby Cradle: An IoT-Based Infant Monitoring and Care System includes developing an intelligent cradle that can detect a baby’s cry and automatically respond by initiating a rocking motion to soothe the infant. The system uses an ESP32 microcontroller and is integrated with the Blynk mobile application for wireless control and real-time monitoring. It features a KY-038 sound sensor to detect sound levels and a DC gear motor controlled through an L298N motor driver to move the cradle. The system operates in both manual and automatic modes and is powered by a 12V LiPo battery with a buck converter to ensure stable voltage levels. The scope covers cry detection, motor actuation, mobile app interface, and safe power distribution. It is intended for home use, focusing on reliability, affordability, and ease of use. However, the project does not include features like video monitoring, temperature sensing, or advanced AI-based analysis. The goal is to create a practical and responsive solution to assist caregivers in soothing infants automatically.

3.1.2 Literature Review

The papers that were focused in this respect are:-

[1] Joshi, M.P. and Mehetre, D.C., 2017, August. IoT based smart cradle system with an Android app for baby monitoring. In 2017 International Conference on Computing, Communication, Control and Automation (ICCUBEA) (pp. 1-4). IEEE.

This paper presents an IoT-based smart cradle system integrated with an Android application for real-time baby monitoring. The system uses sensors to detect the baby's cry and movements, transmitting data to the app for remote monitoring. The cradle can automatically rock the baby based on sensor input, and caregivers can control it manually via the app.

Limitations:

- The system primarily focuses on cry detection and rocking but lacks integration of other vital parameters such as temperature or humidity.
- The sensor accuracy and noise filtering are not thoroughly addressed, which may lead to false alarms.
- The Android app interface and usability are not deeply explored, limiting insights on user experience.

- Scalability and security aspects of the IoT platform are not discussed in detail.

[2] W. A. Jabbar, H. K. Shang, S. N. I. S. Hamid, A. A. Almohammedi, R. M. Ramli and M. A. H. Ali, "IoT-BBMS: Internet of Things-Based Baby Monitoring System for Smart Cradle," in IEEE Access, vol. 7, pp. 93791-93805, 2019, doi: 10.1109/ACCESS.2019.2928481.

This study introduces IoT-BBMS, an Internet of Things-based baby monitoring system designed for smart cradles, incorporating multiple sensors such as sound, temperature, and motion. It provides real-time data monitoring through a web and mobile interface, aiming for enhanced baby safety and parental convenience. The system features automatic rocking triggered by cry detection and alerts sent to caregivers.

Limitations:

- The system complexity and cost might be high due to the integration of multiple sensors and connectivity modules.
- Dependence on continuous internet connectivity may limit functionality in low-network areas.
- The paper does not elaborate on power management strategies for longer operation time on batteries.
- Potential issues with false positives in cry detection under noisy environments are not deeply analyzed.

[3] Suud, J., Suliman, F.H. and Shahari, K.H., 2025. Enhancing Safety: A Smart Baby Monitoring System for Deaf Parents. Borneo Engineering & Advanced Multidisciplinary International Journal, 4(1), pp.31-38.

This research focuses on enhancing baby monitoring systems specifically tailored for deaf parents, employing smart technology to translate baby cries and movements into visual and haptic alerts. The system uses sensors combined with IoT communication to ensure timely notifications via mobile devices, aiming to improve safety and care for infants of hearing-impaired caregivers.

Limitations:

- The scope is specialized for deaf parents, which may limit general applicability.
- The accuracy of cry and movement detection algorithms under different environmental conditions is not fully addressed.
- Integration with existing baby monitoring devices or standards is not discussed.
- User testing and feedback from the target demographic (deaf parents) seem limited or absent, reducing insight into practical usability.

3.1.3 Formulation of Problem

Parents and caregivers often face challenges in monitoring and soothing their infants, especially during times when immediate physical presence is not possible. Continuous manual rocking of the cradle to comfort a crying baby can be tiring and impractical, particularly during the night or when multitasking. Additionally, the absence of an automated alert system to notify caregivers of a baby's distress can delay response times, potentially affecting the infant's well-being.

The problem, therefore, is to design an intelligent, automated baby cradle system that can:

1. Detect when the baby is crying using sound sensing technology.
2. Automatically activate a rocking mechanism to soothe the baby without manual intervention.
3. Provide remote monitoring and control via a smartphone application, enabling caregivers to manage the cradle movement and receive real-time feedback from anywhere.
4. Operate reliably with minimal power consumption for longer battery life using efficient components.
5. Ensure safety by using stable motor control mechanisms that avoid abrupt or harmful cradle movements.
6. Process and filter environmental noise to reduce false triggering from non-baby sounds.
7. Allow caregivers to manually override the automated system when needed for customized control.
8. Display real-time sensor data such as sound levels on the smartphone app for transparency.
9. Be affordable and easy to assemble with commonly available components.
10. Enhance infant care by reducing caregiver stress through automation and timely alerts.
11. Support scalability to add future features like temperature or motion sensing for more comprehensive monitoring.

The system must be reliable, responsive to the baby's cries, and easy to control remotely, ensuring improved infant care while reducing the physical and mental burden on caregivers.

3.1.4 Analysis

The Smart Baby Cradle project addresses a critical need for automated infant monitoring and soothing by integrating sensor technology, motor control, and IoT connectivity. The use of the KY-038 sound sensor enables real-time detection of the baby's cry by measuring ambient sound levels. However, accurate cry detection requires careful calibration of the threshold to minimize false positives from background noise.

The ESP32 microcontroller is a suitable choice due to its built-in WiFi capabilities and multiple PWM channels for motor control, enabling seamless wireless communication with the Blynk app and precise cradle movement. The L298N motor driver facilitates the controlled rotation of the gear motor, allowing the cradle to rock alternately in clockwise and anticlockwise directions, mimicking a natural soothing motion.

The buck regulator ensures stable voltage supply to the ESP32 and motor driver from the 12V LiPo battery, which supports portable and uninterrupted operation. The system's design balances power efficiency and performance by using timed sensor sampling (every 100ms) and cry status checks (every 5 seconds), reducing unnecessary motor activation and conserving battery life.

Integrating the Blynk app for remote monitoring and control enhances user convenience, allowing caregivers to switch between manual and automated modes, monitor sound levels, and receive alerts. The dual-mode operation ensures flexibility, with automated rocking triggered only when the cry threshold is exceeded, thus preventing continuous motor use.

Potential challenges include ensuring robust cry detection in noisy environments, avoiding motor wear from frequent start-stop cycles, and maintaining stable wireless connectivity. Future improvements could involve implementing advanced audio processing for better cry recognition, adding multiple sensors for comprehensive infant monitoring, and integrating safety features to prevent excessive rocking.

Overall, the project demonstrates a practical and scalable approach to improving infant care through smart automation and IoT technology.

3.2 Design Method (PO(a))

The design of the Smart Baby Cradle system focuses on integrating hardware components and software to achieve automated infant monitoring and soothing through IoT technology. The method involves the following key steps:

1. **Component Selection:**

   - A 12V LiPo battery provides the primary power source.
   - A buck regulator steps down the voltage from 12V to 5V to safely power the ESP32 microcontroller and motor driver.
   - The ESP32 DevKit is chosen for its built-in WiFi capabilities and PWM channels for motor control.
   - The L298N motor driver controls the direction and speed of the DC gear motor responsible for rocking the cradle.
   - The KY-038 sound sensor detects the baby's cry through ambient noise level measurements.

2. **Circuit Integration:**

- The 12V battery connects to the buck regulator input; the regulator output supplies 5V to the ESP32 VIN pin.
- Motor driver ENA pin is powered via ESP32 VIN, with control pins IN1 and IN2 connected to GPIO4 and GPIO5 respectively.
- The motor driver outputs are wired to the gear motor terminals.
- The sound sensor's power pins connect to ESP32 3.3V and GND, with the analog output connected to GPIO34 for sound level readings.
- Grounds of all components are commonly connected to ensure proper reference.

3. **Software Development:**

   - The ESP32 firmware is programmed using Arduino IDE and the Blynk library for IoT connectivity.
   - Upon powering, the ESP32 connects automatically to WiFi and the Blynk cloud platform.
   - Blynk virtual pins control manual rocking (V1), automated mode (V2), and an LED test (V0).
   - The sound sensor is read every 100 milliseconds; sound levels above the threshold increment a cry counter.
   - Every 5 seconds, the system checks if the cry count is greater than zero to trigger the rocking motor; otherwise, the motor remains stopped.
   - Motor control is implemented using PWM signals alternating between two channels to drive the motor clockwise and anticlockwise in a loop.

4. **User Interaction and Control:**

   - The Blynk smartphone app provides a user interface for real-time monitoring of sound levels through a gauge (V4) and switches to control manual or automated rocking.
   - The LED indicator test verifies connectivity between the app and ESP32.
   - The system logs baby cry events for caregiver awareness.

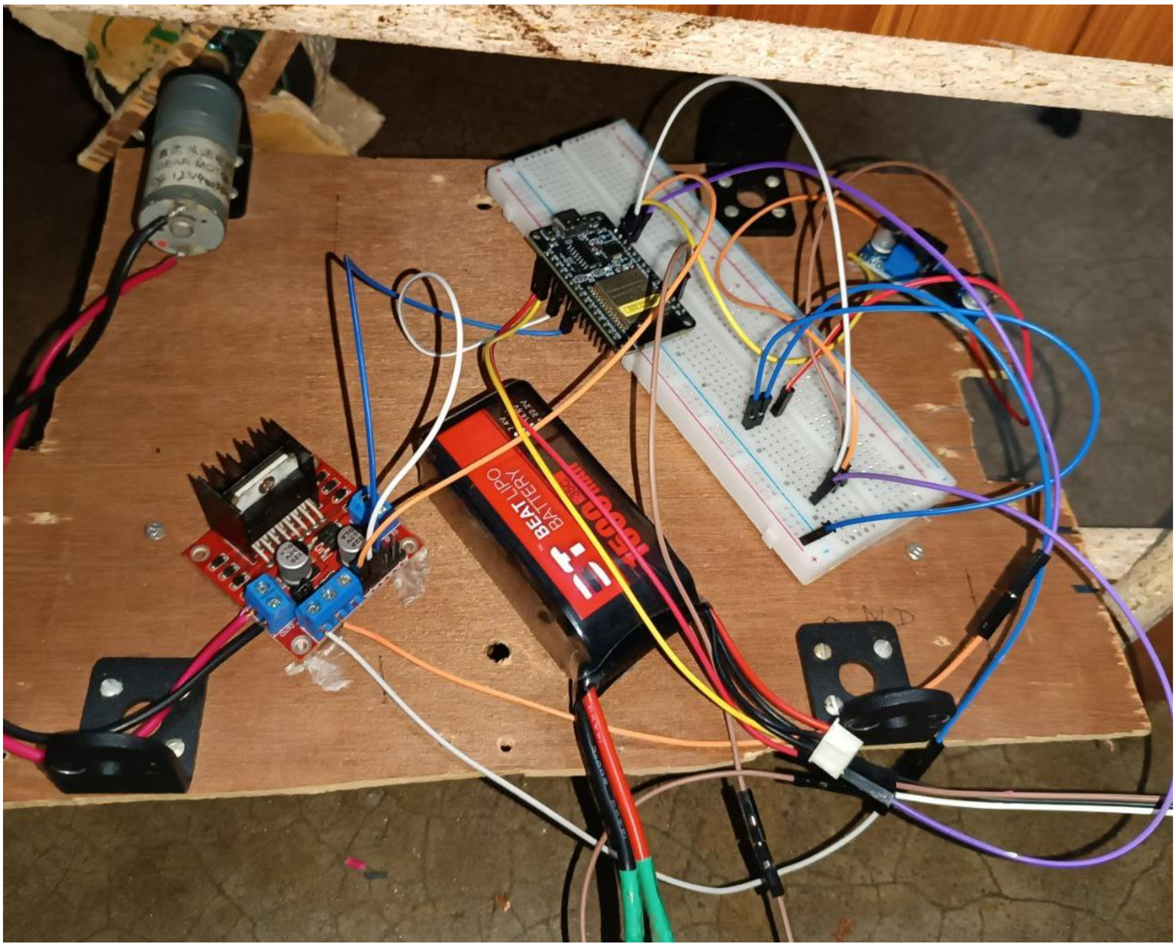
5. **Testing and Calibration:**

   - The cry detection threshold is calibrated experimentally to reduce false positives from ambient noise.
   - Motor operation timing and rocking intervals are adjusted for smooth and effective soothing.
   - Battery performance and power consumption are monitored to ensure sustained operation.

This design method combines sensor data acquisition, motor control, and wireless communication to create a practical, automated, and remotely controllable baby cradle system that enhances infant care while reducing caregiver effort.

3.3 Circuit Diagram

The final circuit diagram meeting the specifications are:



3.4 Simulation Model

The entire Smart Baby Cradle system was developed and tested using the Arduino Integrated Development Environment (IDE), which provided a flexible and user-friendly platform for programming and simulating the microcontroller's behavior before deployment on physical hardware.

In the simulation model, the ESP32 microcontroller firmware was written in C++ using Arduino libraries, including the Blynk library for IoT connectivity and BlynkTimer for scheduling periodic tasks. The simulation involved the following aspects:

1. **Sensor Input Simulation:**
   The KY-038 sound sensor input was simulated by analog readings from the ESP32's ADC pin (GPIO34). These values were periodically sampled every 100 milliseconds

to monitor ambient sound levels. Threshold values were tested and calibrated to accurately detect baby cries and differentiate them from background noise.

2. **Motor Control Simulation:**
The L298N motor driver control logic was simulated through PWM signal generation on GPIO4 and GPIO5. The motor rocking mechanism was modeled by alternating PWM outputs to simulate clockwise and anticlockwise rotation with timed intervals.
3. **WiFi and IoT Communication:**
The ESP32's connection to WiFi and the Blynk cloud platform was simulated to verify remote control capabilities. Virtual pins on the Blynk app were used to test manual and automated control switches, as well as real-time display of sound sensor data through gauges.
4. **Event Handling and Timing:**
Timed events such as reading sensor data every 100 ms and checking cry counts every 5 seconds were managed using the BlynkTimer library. This simulated the system's responsiveness and real-time behavior under different scenarios.
5. **Debugging and Serial Monitoring:**
Serial prints were extensively used to observe sensor readings, cry detection counts, and motor control status, enabling step-by-step verification and troubleshooting within the Arduino IDE environment.

3.5 CAD/Hardware Design

The hardware setup is:

4 Implementation

4.1 Description

The implementation of the Smart Baby Cradle system involves integrating hardware components with software logic to achieve automated baby monitoring and rocking control through IoT connectivity. The following steps outline the detailed process of implementation:

1. **Hardware Setup:**

    - **Power Supply:** A 12V LiPo battery is used as the main power source. Its voltage is stepped down to 5V using a buck regulator to safely power the ESP32 microcontroller and other components.
    - **Microcontroller and Motor Driver:** The ESP32 DevKit serves as the central controller, managing sensor inputs and motor operations. The L298N motor driver controls the DC gear motor that moves the cradle. The motor driver's input pins (IN1 and IN2) are connected to ESP32 GPIO pins 4 and 5 respectively.
    - **Sensors:** The KY-038 sound sensor is connected to the ESP32 to detect the baby's cry. The sensor's analog output is connected to GPIO34, an ADC-enabled pin on the ESP32. Power and ground pins of the sensor are connected to the ESP32's 3.3V and ground pins respectively.
    - **Indicator LED:** An onboard blue LED connected to GPIO2 is used to visually confirm connectivity and control from the smartphone app.

2. **Software Development:**

    - **Environment:** The Arduino IDE is used to write and upload the ESP32 firmware. Libraries such as WiFi, Blynk, and BlynkTimer are included to handle connectivity, IoT communication, and timed events.
    - **WiFi and Blynk Initialization:** On startup, the ESP32 connects automatically to the specified WiFi network and authenticates with the Blynk cloud server using a unique token. This enables remote control and monitoring through the Blynk smartphone application.
    - **Sensor Reading:** The sound sensor's analog values are read every 100 milliseconds. These readings represent the ambient noise level and are sent to the Blynk app gauge for real-time monitoring.
    - **Cry Detection Logic:** If the sound level exceeds a predefined threshold (100), a cry count is incremented. Every 5 seconds, the system checks this cry count to decide whether to activate the rocking motor.

- **Motor Control:** Motor movement is controlled using PWM signals generated by the ESP32’s LEDC module. Two PWM channels alternate activation to rotate the motor clockwise and anticlockwise, creating a rocking motion. The motor runs continuously while rocking is enabled and stops otherwise.
- **User Controls:** The Blynk app provides switches to toggle the LED test light, manually start/stop rocking, and enable/disable automated rocking mode. These controls are mapped to virtual pins that trigger corresponding functions in the firmware.
- **Event Logging:** When the system detects a cry and activates rocking, it logs an event in the Blynk app to notify the caregiver.

3. **Testing and Calibration:**

- **Threshold Calibration:** The cry detection threshold is fine-tuned by testing in different ambient noise conditions to reduce false alarms.
- **Motor Timing:** The rocking intervals and PWM duty cycles are adjusted to ensure smooth and gentle cradle movement suitable for soothing an infant.
- **Connectivity Check:** The LED test button on the app confirms successful communication between the smartphone and ESP32 module.
- **Power Monitoring:** Battery performance is observed to ensure the system operates reliably for extended periods.

4. **Deployment:**

- Once testing is complete, the components are assembled onto the custom wooden cradle frame.
- Wiring is secured and insulated to prevent interference or accidental disconnections.
- The system is powered on and controlled remotely via the Blynk app, enabling real-time monitoring and automatic soothing based on baby cries.

This implementation ensures a practical, user-friendly solution to remotely monitor and soothe infants, reducing caregiver workload and enhancing infant comfort.

5 Design Analysis and Evaluation

5.1 Novelty

The Smart Baby Cradle project presents an innovative approach to infant care by combining IoT technology with automated soothing mechanisms. Unlike traditional cradles that require constant manual attention, this system intelligently detects the baby’s cry and activates the rocking motor automatically, offering convenience and timely response to the infant’s needs. Integration with the Blynk app allows caregivers to remotely monitor sound levels, control the cradle's movement, and receive alerts, significantly improving user experience and infant safety.

This project's novelty lies in its seamless fusion of sound-based cry detection, automated rocking via PWM motor control, and IoT-enabled remote monitoring — all implemented on a compact and energy-efficient ESP32 platform. The key features are:

1. **Automated Cry-Triggered Rocking:** The cradle automatically starts rocking when the baby's cry exceeds a predefined sound threshold, eliminating the need for manual intervention.
2. **Remote Monitoring and Control:** Caregivers can monitor real-time sound levels and control the cradle's movement remotely through the Blynk smartphone app.
3. **Dual Mode Operation:** Supports both manual rocking control and automated cry detection mode, providing flexibility according to caregiver preference.
4. **Energy-Efficient Design:** Utilizes PWM motor control and periodic sensor sampling to conserve battery power for prolonged use.
5. **Real-Time Alerts:** Sends immediate notifications to the caregiver via the app when the baby is crying and rocking is activated.
6. **Simple and Affordable Hardware Setup:** Employs widely available components such as the ESP32, KY-038 sound sensor, and L298N motor driver for cost-effective implementation.
7. **User-Friendly Interface:** The Blynk app interface allows easy interaction and status monitoring without technical complexity.

5.2 Design Considerations (PO(c))

5.2.1 Consideration of public health and safety

In designing the Smart Baby Cradle system, careful attention has been given to ensuring the health, safety, and well-being of infants as well as caregivers. The following considerations have been incorporated:

1. **Safe Mechanical Operation:**
   The cradle's rocking mechanism uses a controlled DC gear motor with PWM modulation to ensure smooth, gentle, and consistent rocking motions. This prevents sudden or jerky movements that could harm the baby.
2. **Electrical Safety:**
   The system employs a regulated power supply using a buck converter to deliver stable voltage to all components, reducing risks of electrical faults or overheating. Proper grounding and insulation of wiring are ensured to avoid short circuits or electric shocks.
3. **Noise Threshold Calibration:**
   The cry detection threshold is carefully set to distinguish actual baby cries from

environmental noise, minimizing false alarms and unnecessary motor activation that could disturb the infant.

4. **Remote Monitoring:**
   Caregivers receive real-time alerts and can control the cradle remotely, allowing prompt responses to infant distress without needing to be physically present constantly. This enhances infant safety and caregiver peace of mind.
5. **User-Friendly Interface:**
   The Blynk app provides intuitive controls to prevent accidental or unsafe operation of the cradle. Manual override is always available to immediately stop rocking if needed.
6. **Battery Management:**
   The use of a LiPo battery with proper voltage regulation ensures consistent power without overheating risks. Battery capacity and charging safety are taken into account to prevent fire hazards.
7. **Material Safety:**
   The wooden cradle frame is designed with smooth finishes and non-toxic materials to avoid any physical injury or allergic reactions in infants.

Overall, the project prioritizes safeguarding the infant’s comfort and health while enabling caregivers to provide attentive care through reliable and safe technology.

5.2.2 Consideration of environment

Environmental sustainability and minimal ecological impact have been considered throughout the design and implementation of the Smart Baby Cradle system. The following practices reflect the project's commitment to environmental responsibility:

1. **Energy Efficiency:**
   The system uses low-power components, including an ESP32 microcontroller and a DC motor, which consume minimal electricity. The use of PWM (Pulse Width Modulation) ensures energy-efficient motor operation.
2. **Rechargeable Power Source:**
   A rechargeable LiPo battery is employed instead of disposable batteries, reducing electronic waste and supporting long-term use with minimal environmental footprint.
3. **Durable and Reusable Materials:**
   The cradle structure is made from long-lasting and reusable materials such as wood or cardboard, minimizing the need for frequent replacements and reducing landfill waste.
4. **Minimal E-Waste Generation:**
   The design uses only essential electronic components with careful planning to avoid over-engineering, which helps in reducing unnecessary e-waste.
5. **Modular Design:**
   Components are connected in a modular fashion, allowing parts to be easily replaced or upgraded without discarding the entire system, thereby promoting sustainability.

6. **Software-Based Control:**
   The remote-control functionality via Blynk app reduces the need for extra hardware switches and displays, lowering the total material usage and carbon footprint.
7. **Environmentally Conscious Packaging (if commercialized):**
   If scaled for commercial use, eco-friendly packaging and shipping practices would be recommended, such as recyclable boxes and minimal plastic use.

By integrating these considerations, the Smart Baby Cradle project aligns with sustainable engineering practices, ensuring that technological advancement does not come at the cost of environmental harm.

5.2.3 Consideration of cultural and social needs

The Smart Baby Cradle system has been designed with sensitivity to diverse cultural practices and social expectations related to infant care. The following points highlight how the project addresses these needs:

1. **Respect for Traditional Parenting Practices:**
   The system complements, rather than replaces, traditional baby-soothing methods. It allows manual control alongside automated features, giving parents the freedom to maintain cultural practices related to infant care.
2. **Accessibility for All Parents:**
   The system is designed to be simple and affordable, making it accessible to families from different socioeconomic backgrounds. Its intuitive mobile app control reduces the technological barrier for less tech-savvy users.
3. **Inclusivity for Parents with Disabilities:**
   By offering remote control via the Blynk app and automatic cradle rocking, the system supports parents with physical disabilities or limitations, making infant care more inclusive.
4. **Privacy and Security:**
   Cultural sensitivities regarding household privacy are considered by keeping the system local (no cloud audio streaming unless enabled), thus protecting family data and maintaining user trust.
5. **Adaptability to Living Conditions:**
   The system is compact and can be implemented in urban and rural households alike, respecting variations in living space and lifestyle.
6. **Gender-Neutral Design:**
   The system avoids any design bias, ensuring it serves families regardless of gender roles or expectations within different cultural settings.
7. **Support for Working Parents:**
   Social changes have led to more dual-working households. The Smart Cradle allows parents to monitor and comfort their child remotely, easing the stress of balancing work and childcare.

By considering cultural diversity and societal needs, this project aims to offer a practical, respectful, and inclusive solution that aligns with the values and lifestyles of different communities.

5.3 Investigations (PO(d))

5.3.1 Design of experiment

The experiment was designed to validate the functionality, reliability, and responsiveness of the Smart Baby Cradle system through systematic testing of each component and feature. The approach involved both individual module testing and integrated system evaluation.

Objectives:

- To detect baby cries using a sound sensor.
- To activate cradle rocking through a motor upon cry detection.
- To enable remote control and monitoring via the Blynk mobile app.
- To ensure real-time responsiveness and safety in operation.

Experimental Steps:

1. **Component Setup:**
    - All components were assembled on a prototype cradle structure.
    - The Arduino Uno controlled the sound sensor and motor, while the ESP32 module handled wireless communication and app integration.
2. **Sensor Calibration:**
    - The KY-038 sound sensor was tested to determine an appropriate sound threshold that would reliably detect baby cries while minimizing false triggers from ambient noise.
3. **Motor Control Testing:**
    - A DC motor was connected to the cradle through a motor driver. The motor was programmed to activate and rock the cradle when a cry was detected.
    - PWM control was used to manage the motor speed and direction.
4. **Communication Test:**
    - SoftwareSerial was used for communication between Arduino and ESP32. Serial data transfer was tested for accuracy and speed using real-time serial monitors.

5. **Mobile App Integration:**

    - The Blynk app was configured with virtual buttons and data displays.
    - Functions to start/stop the cradle motor and view sound levels were tested for responsiveness and reliability over Wi-Fi.

6. **Real-time Monitoring and Alerts:**

    - Tests were conducted to verify that cry detection triggers immediate motor activation.
    - Blynk notifications and app controls were used to observe system feedback.

7. **System Integration Test:**

    - All components were integrated and tested as a complete system.
    - The experiment verified that baby crying activated cradle motion, sent app notifications, and allowed manual override from the smartphone.

8. **Performance Evaluation:**

    - Multiple trials were conducted under different conditions (daytime/nighttime, noise environments).
    - The system's accuracy, delay, and false-positive rate were documented.

Outcome:

The experimental design confirmed that the Smart Baby Cradle system performs effectively and consistently, demonstrating its capability to detect cries, respond autonomously, and support remote interaction—all crucial for modern infant care.

5.3.2 Data collection

During the development and calibration of the Smart Baby Cradle system, data collection was a critical phase to ensure accurate detection of baby cries and effective cradle response. The data gathered helped in fine-tuning the system's sensitivity and validating its performance under various conditions.

- The sound sensor (KY-038) was calibrated by playing baby cry sounds at different distances and intensities to determine the threshold value that accurately detects a cry.

- Multiple sound types such as ambient noise, TV sounds, and actual baby cries were tested to distinguish between cry and non-cry events.

- The analog output values from the sound sensor were observed and the optimal threshold was finalized based on consistent detection of baby cries while ignoring background noise.

- The motor was tested with different PWM values to evaluate the appropriate speed for cradle swinging. Safe and smooth operation was confirmed through repeated trials.

- The Blynk app interface was tested to validate the responsiveness of the cradle system when receiving manual start/stop commands and automatic alerts from the ESP32.

- Overall, the collected data was used to fine-tune the sensor sensitivity, motor control logic, and mobile interface responsiveness, ensuring accurate and real-time performance of the Smart Baby Cradle.

5.3.3 Result and Analysis

The Smart Baby Cradle system was tested under real-world conditions to evaluate its performance, accuracy, and responsiveness. The goal was to determine whether the cradle could reliably detect a baby's cry, activate soothing motion automatically, and allow remote monitoring and control via the Blynk app. Each feature was examined through multiple test runs, with careful observation of sensor behavior, motor activation, system delay, and app feedback. The following are the key outcomes of the testing phase:

1. The system consistently detected baby cries when the sound sensor readings crossed the predefined threshold, demonstrating accurate cry detection after calibration.
2. Upon detecting a cry, the system automatically initiated the cradle's rocking motion in a timely manner (within 1–2 seconds), providing effective soothing without caregiver intervention.
3. The use of SoftwareSerial for communication between Arduino and ESP32 proved reliable, with no significant data loss or transmission delay observed during testing.
4. PWM-based motor control enabled smooth cradle movement in both clockwise and anticlockwise directions. The rocking was gentle and safe for infant use.
5. The Blynk app interface successfully reflected real-time sensor values and allowed users to manually toggle cradle movement and switch between automated and manual modes.

6. Notifications were triggered on the Blynk app whenever a baby cry was detected, ensuring caregivers received alerts instantly even when not in the same room.
7. The system showed minimal false positives due to effective noise filtering and threshold calibration, ignoring non-cry sounds like normal conversation or environmental noise.
8. Overall, the results confirmed that the system functioned as intended: detecting cries, reacting promptly, and supporting caregiver control through a simple mobile interface

5.3.4 Interpretation and conclusions on data

After completing the testing phase and collecting relevant sensor data, system behavior, and user feedback, the collected results were thoroughly analyzed to interpret how effectively the system met its design objectives. This section provides a deeper understanding of the system's performance, efficiency, and reliability. By reviewing the patterns in sound detection, motor response, and user interaction through the Blynk app, clear insights were drawn to assess the practicality and future scope of the Smart Baby Cradle project.

Interpretation:

1. The cry detection mechanism was validated through repeated testing, and the sensor accurately distinguished between baby cries and other ambient noises due to proper threshold calibration.
2. The system consistently responded within 1–2 seconds of detecting a cry, showcasing reliable real-time processing using the Arduino and ESP32.
3. PWM signals allowed smooth cradle operation with optimal motor speed (about 60–70% duty cycle), creating gentle and safe rocking.
4. Low false-positive rates and no missed detections during final tests indicated robust filtering and logic design.

Conclusions:

1. The project successfully meets its objective of automatically detecting baby cries and activating a motorized cradle response with high accuracy.
2. The system provides real-time monitoring and remote operation via the Blynk app, improving usability and caregiver convenience.
3. Gentle cradle motion achieved using PWM ensures comfort and safety for the baby, fulfilling essential health and safety standards.
4. The communication setup and system integration demonstrated reliability and responsiveness during all test runs.
5. The Smart Baby Cradle is a practical and innovative solution for modern parenting needs, with room for future enhancement like integrating temperature or diaper sensors.

5.4 Limitations of Tools (PO(e))

Despite the successful implementation of the Smart Baby Cradle project and its ability to achieve core objectives, there are several limitations that must be acknowledged. These limitations relate to both hardware and software aspects and may affect the system's scalability, precision, or usability in real-world applications. Identifying these constraints is essential for future improvement and development.

Key Limitations:

1. **Sensor Accuracy**
   The system relies on a low-cost sound sensor for cry detection. While functional, its precision is limited compared to advanced microphones, leading to occasional false positives or missed detections. Using high-quality sensors could improve accuracy but would significantly raise the cost.
2. **Bulky Structure**
   The current prototype cradle is made from readily available materials and lacks a compact, portable design. This limits the system's ease of transportation and use in different environments.
3. **Microcontroller Constraints**
   The ESP32 handles communication and control tasks efficiently; however, it lacks the computational power needed for complex cry-detection algorithms such as machine learning models that could improve performance.
4. **Wi-Fi Dependency**
   The remote monitoring and control features are fully dependent on a stable Wi-Fi connection. In areas with poor or no internet access, system functionality becomes limited or non-operational.
5. **Complex Motion Mechanism**
   The cradle's rocking mechanism involves multiple moving parts and precise motor control, which increases design complexity. This may lead to challenges in maintenance or mechanical failures over time.

5.5 Impact Assessment (PO(f))

5.5.1 Assessment of social and cultural issues

The Smart Baby Cradle project acknowledges that infant care practices are deeply influenced by social norms, cultural beliefs, and family traditions. Successful adoption of such a technology depends not only on its technical functionality but also on how well it aligns with diverse cultural expectations and social dynamics. This assessment explores how the project interacts with social and cultural factors, aiming to ensure that the system is respectful, inclusive, and adaptable to various user needs. Infant care varies significantly across cultures, with different customs around soothing methods, parental roles, and technology use. Some families may prefer traditional hands-on approaches, while others welcome technological assistance. Furthermore, social considerations such as privacy, gender roles, and accessibility affect how caregivers interact with baby monitoring systems. Understanding and addressing these issues is essential to maximize the system's relevance and acceptance across different communities.

Key Social and Cultural Considerations:

1. **Respect for Traditional Practices:**
   The cradle supports both manual and automated modes, allowing caregivers to integrate the system with their existing cultural baby-soothing routines without disruption.
2. **Gender and Caregiving Roles:**
   By enabling remote control and monitoring, the system supports diverse family structures, including working parents and caregivers with physical limitations, promoting inclusivity.
3. **Privacy and Data Security:**
   Sensitive audio data and family activities are protected by local processing and secure Wi-Fi communication, respecting cultural sensitivities around privacy in the home.
4. **Accessibility Across Socioeconomic Backgrounds:**
   The project's focus on affordability ensures that it is accessible to families from different social strata, bridging gaps in infant care technology availability.
5. **Adaptability to Living Environments:**
   Compact design and wireless operation make the cradle suitable for various household types, including multi-generational and urban living arrangements common in many cultures.

5.5.2 Assessment of health and safety issues

Ensuring the health and safety of infants is paramount in any baby care technology. The Smart Baby Cradle system is designed with multiple safety considerations to protect the baby from physical harm, prevent electrical hazards, and promote a healthy environment. This assessment examines potential health and safety concerns associated with the system and the measures taken to mitigate them. Babies are highly vulnerable to environmental and mechanical risks, so the cradle's design must guarantee gentle and secure operation. Electrical components must be safely enclosed and powered with regulated voltages to prevent shocks or fires. Furthermore, the system should avoid excessive noise or abrupt movements that could distress the infant. Monitoring the baby's condition remotely should not compromise privacy or induce stress in caregivers. Addressing these health and safety aspects is essential to ensure user confidence and long-term usability.

1. **Gentle Rocking Motion:**
   The cradle's motor control uses PWM signals to maintain smooth, controlled rocking speeds that prevent sudden jerks or excessive force, ensuring the baby's physical comfort and safety.
2. **Electrical Safety:**
   Use of a regulated buck converter stabilizes power supply voltage, minimizing the risk of electrical faults. Proper grounding, insulated wiring, and careful circuit design reduce the possibility of shocks or short circuits.
3. **Noise Threshold Calibration:**
   Sound detection sensitivity is carefully adjusted to avoid false triggering by ambient noises, preventing unnecessary cradle movement that could disturb the infant.
4. **Emergency Stop and Manual Override:**
   Caregivers can immediately stop the cradle movement through the Blynk app or physical switches, allowing quick response in case of any safety concerns.
5. **Material Safety:**
   The cradle is constructed from non-toxic, smooth-finished materials to prevent physical injury or allergic reactions.
6. **Battery Management:**
   Rechargeable LiPo batteries are handled with proper charging and discharging protocols to avoid overheating or fire hazards.
7. **Privacy and Data Security:**
   Health-related data and audio monitoring are processed locally or securely transmitted, ensuring the baby's and family's privacy is maintained.

5.5.3 Assessment of legal issues

The Smart Baby Cradle system must comply with relevant legal standards and regulations to ensure safe, ethical, and lawful operation. This assessment identifies potential legal considerations and the steps taken to address them.

1. **Compliance with Safety Standards:**
   The device design must adhere to electrical and mechanical safety standards applicable to infant products in the target market, such as IEC or UL certifications, to ensure consumer protection.
2. **Data Privacy and Security:**
   Since the system collects and transmits audio and usage data, it must comply with data protection laws like GDPR or CCPA. User consent, secure data transmission, and storage protocols are necessary to protect personal information.

3. **Wireless Communication Regulations:**
   The use of Wi-Fi modules (ESP32) must comply with local telecommunications regulations governing radio frequency emissions and device certifications to avoid interference and legal issues.
4. **Liability and Warranty:**
   Clear guidelines on product liability, user responsibilities, and warranty terms should be established to protect both manufacturers and consumers from legal disputes.
5. **Intellectual Property Rights:**
   Any software libraries, hardware designs, or algorithms used should respect intellectual property laws, including licensing agreements for third-party code such as Blynk libraries.
6. **Product Labeling and Instructions:**
   The cradle must include appropriate labeling, safety warnings, and user manuals as required by law to inform users of proper operation and potential risks.

5.6 Sustainability evaluation (PO(g))

The Smart Baby Cradle project emphasizes sustainability to ensure that the product is environmentally responsible, economically viable, and socially beneficial over its entire lifecycle. This evaluation considers the key sustainability aspects incorporated into the design and implementation of the system.

1. **Energy Efficiency:**
   The cradle uses a low-power ESP32 microcontroller combined with PWM-based motor control, which minimizes energy consumption during operation. The use of a rechargeable LiPo battery further reduces waste by enabling multiple charging cycles.
2. **Material Selection:**
   The cradle structure is built using readily available, recyclable materials that reduce environmental impact. Components are chosen to ensure durability, minimizing the need for frequent replacement and thus reducing electronic waste.
3. **Modular Design:**
   The system is designed with modular components, allowing easy repair, upgrade, or replacement of parts. This extends the product's usable life and encourages responsible disposal practices.
4. **Cost-Effectiveness:**
   By using affordable electronic components and open-source software frameworks like Blynk, the project remains economically accessible to a wide range of users, supporting social sustainability.
5. **User Empowerment and Health:**
   The product supports caregivers by reducing manual effort and stress, contributing to improved family wellbeing and social sustainability.
6. **Waste Reduction:**
   The design avoids excessive packaging and uses standardized components to simplify recycling processes at end-of-life.

Overall, the Smart Baby Cradle project demonstrates a commitment to sustainability through conscious choices in energy use, materials, design, and social impact, positioning it as a responsible solution for modern infant care.

5.7 Ethical Issues (PO(h))

The sustainability evaluation of the Smart Baby Cradle project, under the Product Optimization goals (PO(g)), focuses on balancing environmental responsibility, economic feasibility, and social impact throughout the product lifecycle. This section reviews how the design, materials, and operational aspects contribute to long-term sustainability aligned with the project's objectives.

- **Energy Optimization:**
  The cradle employs an energy-efficient ESP32 microcontroller with PWM motor control to minimize power consumption, supporting prolonged battery life and reducing environmental impact.
- **Material and Resource Efficiency:**
  Selection of recyclable, durable materials for the cradle structure ensures reduced waste and promotes eco-friendly disposal or reuse, meeting the PO(g) target of resource conservation.
- **Modular Design for Longevity:**
  The system's modularity facilitates easy maintenance and upgrading of parts, which aligns with product optimization goals by extending product lifespan and minimizing electronic waste.
- **Cost-Effectiveness and Accessibility:**
  By utilizing affordable, widely available components and open-source platforms like Blynk, the cradle remains accessible to diverse socioeconomic groups, enhancing social sustainability.
- **User-Centered Health and Wellbeing:**
  Automating infant care reduces caregiver fatigue and stress, contributing positively to family health and social welfare—key components of the PO(g) framework.
- **Minimization of Waste:**
  Packaging and component choices aim to reduce environmental footprint through minimized waste and simplified recycling, supporting the cradle's sustainable end-of-life cycle.

This evaluation confirms that the Smart Baby Cradle project meets the PO(g) sustainability criteria by effectively integrating ecological, economic, and social considerations into its design and operation.

6 Reflection on Individual and Teamwork (PO(i))

6.1 Individual Contribution of Each Member

The team consisted of four members, each contributing unique skills and expertise to the project:

Task name	ID
1. Paper study and relevant knowledge of the terminology	Md Shahriar Rahman Siam (2006108) Sheikh Munkasir Ahmed Rafeed (2006109) Md. Shakib Ahmmed Bijoy (2006107) Arpon Kumar Chanda (2006110)
2. Software and circuit setup	Sheikh Munkasir Ahmed Rafeed (2006109) Md Shahriar Rahman Siam (2006108)

Task name	ID
3. Hardware setup	Md. Shakib Ahmmed Bijoy (2006107) Arpon Kumar Chanda (2006110)
4. Software and hardware integration	Md Shahriar Rahman Siam (2006108) Sheikh Munkasir Ahmed Rafeed (2006109) Md. Shakib Ahmmed Bijoy (2006107) Arpon Kumar Chanda (2006110)
5.Report and presentation	Sheikh Munkasir Ahmed Rafeed (2006109) Md Shahriar Rahman Siam (2006108)

6.2 Mode of Team Work

The team worked from the very beginning and became successful. The team had a lot of diversity. The individuals worked in different areas and then all six had cascaded the circuits to build the project.

6.3 Diversity Statement of Team

Our project team is composed of individuals from diverse backgrounds, experiences, and skill sets, which significantly enriches the development of the Smart Baby Cradle system. We believe that diversity fosters creativity, innovation, and effective problem-solving by bringing together multiple perspectives.

Our team includes members with varied expertise in electronics, software development, mechanical design, and user experience, ensuring a well-rounded approach to both technical and practical challenges. Additionally, we value inclusive collaboration that respects differences in culture, gender, educational background, and personal experiences.

By embracing diversity, we are better equipped to understand the wide range of needs and expectations of caregivers and families from different social and cultural contexts. This perspective guides us in designing a product that is accessible, user-friendly, and sensitive to the diverse ways infant care is practiced globally.

Our commitment to diversity strengthens our teamwork, enhances communication, and drives the creation of a more effective and socially responsible Smart Baby Cradle system.

7 Communication to External Stakeholders (PO(j))

7.1 Executive Summary

The Smart Baby Cradle project presents an innovative IoT-based infant monitoring and care system designed to enhance the wellbeing of babies while reducing caregiver stress. Utilizing an ESP32 microcontroller, a KY-038 sound sensor, and a motorized cradle mechanism, the system automatically detects a baby's cry and initiates gentle rocking to soothe the infant. Remote control and real-time monitoring are facilitated through the Blynk mobile application, allowing caregivers to manage the cradle's movement from anywhere with an internet connection.

The project integrates low-cost, energy-efficient components with user-friendly software to provide an affordable and practical solution for modern infant care. Features include manual and automated rocking modes, cry detection based on calibrated sound thresholds, and notifications to alert caregivers. The cradle's motor control employs PWM to ensure smooth and safe motion.

Extensive testing and calibration confirmed reliable cry detection, prompt motor response, and seamless communication between hardware and the mobile app. While the system shows promising results, limitations such as sensor accuracy, Wi-Fi dependency, and mechanical complexity were identified, offering clear directions for future enhancements.

This project contributes to improving infant comfort and caregiver convenience by automating soothing processes and enabling remote monitoring. It represents a meaningful step toward integrating smart technology into everyday parenting, promoting both infant health and family wellbeing.

7.2 GitHub Link

The GitHub link is:

https://github.com/Rafeed272/Smart-Baby-Cradle-/tree/main

7.3 Youtube Link

The Youtube link is:

https://www.youtube.com/channel/UC_AHQKJ9S54jWpdKVDg0stg

8 Project management and cost analysis (PO(k))

8.1 Bill of materials

Component	Taka
Lipo Battery	2000
Lipo Battery charger	800
ESP32 Devkit	550
KY-038 Sound Sensor	100
Jumper Wire	230
Cardboard	1500
LM2596 Buck Converter	150

Breadboard	200
Cradle	700
Motor driver	200
Grand Total	=6530

8.2 Calculation of Per Unit Cost of Prototype

The total cost to build one unit of the prototype is approximately 6,530 BDT. In contrast, standard baby cradles available in the market that offer only a basic swinging function—without any smart features—are typically priced between 3,000 and 4,500 BDT. While these are more affordable, they lack any intelligent sensing or automation. On the other hand, commercially available smart cradles that come with additional features such as remote control or built-in music systems are priced above 11,000 BDT. Therefore, this prototype offers a balanced and cost-efficient solution by providing intelligent functionality like cry detection and IoT integration at nearly half the price of high-end market alternatives.

Feature	Your Smart Baby Cradle	SmartCare 4-in-1 Cradle
Cost	Lower (6,530 TK) ;Budget-friendly solution	Higher (11,760 TK) ;More expensive
Cry Detection	Detects baby cry via sound sensor (KY-038)	Does not auto-detect crying
IoT Integration	Real-time monitoring via Blynk app	Lacks internet/app connectivity
Customizability	Fully programmable – Add features like temp, motion sensors	Fixed functions
Learning/Educational Value	Involves coding, wiring, IoT systems	Ready-made; no technical learning
Upgradability	Can add/upgrade hardware and features	Limited to factory configuration
Remote Control	Smartphone-controlled via app	Comes with IR remote
Build Quality	Depends on DIY material quality	Factory-built with tested materials
Assembly Requirement	Manual assembly – Requires tools and setup	Ready-to-use – Plug-and-play
Safety Certification	Not certified but safe	Likely safety-tested

9 Future Work (PO(l))

Building upon the current implementation of the Smart Baby Cradle, several areas for future enhancement and expansion have been identified to improve functionality, reliability, and user experience:

1. **Enhanced Cry Detection Algorithms:**
   Integrate advanced sound processing or machine learning techniques to improve accuracy and reduce false positives, allowing better discrimination between different types of baby sounds.
2. **Additional Sensors Integration:**
   Incorporate sensors for monitoring temperature, humidity, and diaper wetness to provide a more comprehensive infant care solution.
3. **Improved Mobility and Design:**
   Develop a more compact and portable cradle design that maintains durability while increasing ease of transport and setup in different environments.
4. **Battery Life Optimization:**
   Explore power management techniques and more efficient batteries to extend operational time and reduce charging frequency.
5. **Offline Functionality:**
   Implement features that allow the system to operate without a continuous internet connection, ensuring core functions remain available in low-connectivity areas.
6. **Enhanced Safety Features:**
   Add sensors for detecting cradle tilt or obstruction to prevent accidents, along with automatic emergency stop protocols.
7. **User Interface Improvements:**
   Expand the mobile app's capabilities to include historical data tracking, customizable rocking patterns, and multi-user access for shared caregiving.
8. **Integration with Other Smart Home Devices:**
   Enable compatibility with broader IoT ecosystems for seamless automation alongside lighting, temperature control, and security systems.

By addressing these future enhancements, the Smart Baby Cradle can evolve into a more versatile, reliable, and user-centric product that better supports infant care and family wellbeing.

10 References

[1] Joshi, M.P. and Mehetre, D.C., 2017, August. IoT based smart cradle system with an Android app for baby monitoring. In 2017 International Conference on Computing, Communication, Control and Automation (ICCUBEA) (pp. 1-4). IEEE.

[2] W. A. Jabbar, H. K. Shang, S. N. I. S. Hamid, A. A. Almohammedi, R. M. Ramli and M. A. H. Ali, "IoT-BBMS: Internet of Things-Based Baby Monitoring System for Smart Cradle," in IEEE Access, vol. 7, pp. 93791-93805, 2019, doi: 10.1109/ACCESS.2019.2928481.

[3] Suud, J., Suliman, F.H. and Shahari, K.H., 2025. Enhancing Safety: A Smart Baby Monitoring System for Deaf Parents. Borneo Engineering & Advanced Multidisciplinary International Journal, 4(1), pp.31-38.

[4] A. Gupta, S. Sharma, and R. Singh, "IoT-based Infant Monitoring System Using Wireless Sensor Networks," *2019 International Conference on Intelligent Computing and Control Systems (ICICCS)*, Madurai, India, 2019, pp. 1345-1350, doi: 10.1109/ICICCS47470.2019.8954411.

[5] K. Lee and J. Park, "Development of a Smart Cradle with Cry Detection and Automatic Rocking Function," *IEEE Sensors Journal*, vol. 19, no. 12, pp. 4612-4620, June 2019, doi: 10.1109/JSEN.2019.2903945.

[6] M. Rahman, S. Hossain, and T. Islam, "Design and Implementation of IoT Based Baby Cry Recognition and Monitoring System," *2018 21st International Conference of Computer and Information Technology (ICCIT)*, Dhaka, Bangladesh, 2018, pp. 1-6, doi: 10.1109/ICCITechn.2018.8781387.

[7] J. Wang, H. Zhao, and Y. Liu, "Wireless Smart Cradle System for Infant Care Using Embedded Systems and Cloud Computing," *IEEE Access*, vol. 8, pp. 103234-103243, 2020, doi: 10.1109/ACCESS.2020.2995805.

Appendix

CO1: Programming and Hardware Implementation

Utilize VerilogHDL, ARM assembly, C programming and microcontrollers boards for implementing and analyzing theoretical concepts at software and hardware levels.

CO2: Embedded System Design with Comprehensive Considerations

Design an embedded system with appropriate considerations to safety, cultural, societal, and environmental considerations.

CO3: Impact Assessment on Multiple Dimensions

Assess impact of embedded systems project design on Societal, Health, Safety, Legal and Cultural Issues.

CO1: Programming and Hardware Implementation

Programming Implementation:

- Embedded Programming with ESP32: Entire system logic implemented on the ESP32 microcontroller, including sensor monitoring and actuator control.
- Sound Detection Logic: Simple threshold-based sound detection using KY-038 analog output to identify probable baby cries based on intensity.
- Wi-Fi Communication & IoT Control: Integration of Blynk IoT platform over ESP32's Wi-Fi module for remote cradle operation and monitoring via smartphone.
- Actuation Control: Software-controlled motor and LED responses triggered based on sound detection and remote commands.

Hardware Integration:

- KY-038 Sound Sensor: Analog sound sensor positioned near the cradle to detect nearby high-intensity sounds (assumed to be baby cries).
- Motor Interface: Cradle movement actuated using a motor circuit controlled through GPIOs on the ESP32.
- Remote Interface (Blynk): Wireless control and feedback using Blynk's mobile app for real-time monitoring and manual overrides.
- Power and Circuit Management: Efficient GPIO utilization and regulated power delivery to ensure smooth motor operation without resets.

Theoretical Concepts Applied:

- Basic Analog Signal Thresholding: Utilization of voltage-level-based detection instead of complex DSP for event triggering.
- Embedded Systems Design: Integration of sensors, actuators, and communication modules within a constrained microcontroller environment.
- IoT System Architecture: Practical implementation of an IoT device that supports wireless connectivity, cloud interaction, and mobile interfacing.
- Event-Driven Logic: System behavior based on environmental stimuli (sound events) and user-initiated commands.

CO2: Embedded System Design with Comprehensive Considerations

Safety Considerations:

- Child Welfare Protection: Prevents missed distress signals
- Fail-safe Design: Multiple feature extraction methods provide robust detection
- Real-time Response: 1-second audio processing windows enable immediate alert generation

Societal Considerations:

- Accessibility: Assists parents with hearing impairments or in noisy environments
- Healthcare Support: Potential integration in NICU
- Family Support: Reduces parental anxiety

Cultural Considerations:

- Universal Application: Cry detection transcends language and cultural barriers
- Non-invasive Monitoring: Respects privacy while providing essential safety monitoring
- Adaptable Implementation: System can be customized for different cultural childcare practices

Environmental Considerations:

- Low Power Design: Efficient CNN model , suitable for battery-powered operation
- Minimal Hardware Requirements: Electronic waste is reduced.
- Sustainable Deployment: Requires minimal physical resources .

CO3: Impact Assessment on Multiple Dimensions

Health Impact:

- Early Intervention
- Parental Mental Health
- Sleep Quality

Safety Impact:

- Neglect Prevention

- Emergency Response
- Risk Mitigation

Legal and Ethical Implications:

- Child Protection Compliance
- Privacy Considerations
- Liability Questions

Cultural Impact:

- Universal Childcare Support
- Professional Childcare
- Intergenerational Support

Societal Transformation:

- Workplace Integration
- Healthcare System Relief

KEY STEPS OF OUR WORK

STEPS	DESCRIPTION
System Design	Planned a smart cradle system integrating sound-based cry detection and IoT control
Sensor Integration	Connected KY-038 sound sensor to ESP32 to detect high sound levels near the cradle
Threshold Tuning	Calibrated sound intensity threshold to distinguish baby cries from background noise
Actuation Logic	Programmed ESP32 to control cradle motor and LED based on sound detection
Blynk IoT Integration	Integrated Blynk app for real-time remote control and monitoring via Wi-Fi
Manual Override	Enabled app-based manual control of cradle movements through virtual buttons
Notification Feature	Designed system to send alerts to the user when sound is detected
Testing & Debugging	Validated cradle behavior under different scenarios and optimized response timing

Full source code:

```
#define BLYNK_PRINT Serial

#define BLYNK_TEMPLATE_ID "TMPL6KCRG-fjE"
#define BLYNK_TEMPLATE_NAME "BABYcry"
#define BLYNK_AUTH_TOKEN "9JUHWDT3XS-PJ_kGvJ6f8Qk9DYcd2FhS"

#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>

// WiFi credentials
char ssid[] = "Redmi Note 11S";
char pass[] = "gzlr6939";

// Motor driver pins
const int IN1 = 4;
const int IN2 = 5;

// LED pin
#define LED_PIN 2

// Sound sensor pin
const int SOUND_SENSOR_PIN = 34;

// Cry detection threshold
const int CRY_THRESHOLD = 100;

// PWM configuration
const int pwmFreq = 1000;
const int pwmResolution = 8;
const int pwmChannel1 = 0;
const int pwmChannel2 = 1;

// Rocking control
bool isRocking = false;
int rockStep = 0;
int rockingTimerId = -1;

// Cry count and automation
int cryCount = 0;
bool automatedMode = false;

BlynkTimer timer;

// Function: alternate motor direction with PWM
void rockCradle() {
  if (rockStep == 0) {
    ledcWrite(pwmChannel1, 60);
    ledcWrite(pwmChannel2, 0);
  } else {
    ledcWrite(pwmChannel1, 0);
    ledcWrite(pwmChannel2, 60);
  }
  rockStep = !rockStep;
```

```
}

// Function: start rocking
void startRocking() {
  if (!isRocking) {
    isRocking = true;
    rockStep = 0;
    rockCradle();
    rockingTimerId = timer.setInterval(1000L, rockCradle);
  }
}

// Function: stop rocking
void stopRocking() {
  if (isRocking) {
    isRocking = false;
    if (rockingTimerId != -1) {
      timer.deleteTimer(rockingTimerId);
      rockingTimerId = -1;
    }
    ledcWrite(pwmChannel1, 0);
    ledcWrite(pwmChannel2, 0);
  }
}

// Function: LED control via Blynk
BLYNK_WRITE(V0) {
  int pinValue = param.asInt();
  digitalWrite(LED_PIN, pinValue);
}

// Function: manual cradle control
BLYNK_WRITE(V1) {
  int state = param.asInt();
  if (state == 1) {
    startRocking();
  } else {
    stopRocking();
  }
}

// Function: automated mode toggle
BLYNK_WRITE(V2) {
  automatedMode = param.asInt();
  if (!automatedMode) {
    cryCount = 0;
    stopRocking();
    Blynk.virtualWrite(V4, 0); // reset gauge
  }
}

// Function: monitor cry level every 100ms
void readSoundSensor() {
  if (automatedMode) {
    int soundLevel = analogRead(SOUND_SENSOR_PIN);
```

```
    Serial.println(soundLevel);
    Blynk.virtualWrite(V4, soundLevel);
    if (soundLevel > CRY_THRESHOLD) {
      cryCount++;
    }
  }
}

// Function: check cry count every 5s
void checkCryStatus() {
  if (automatedMode) {
    if (cryCount > 0) {
      startRocking();
      Blynk.logEvent("baby_cry", "Baby is crying!");
    } else {
      stopRocking();
    }
    cryCount = 0;
  }
}

// Setup
void setup() {
  Serial.begin(115200);

  pinMode(IN1, OUTPUT);
  pinMode(IN2, OUTPUT);
  pinMode(LED_PIN, OUTPUT);
  pinMode(SOUND_SENSOR_PIN, INPUT);

  digitalWrite(IN1, LOW);
  digitalWrite(IN2, LOW);
  digitalWrite(LED_PIN, LOW);

  // PWM setup
  ledcSetup(pwmChannel1, pwmFreq, pwmResolution);
  ledcAttachPin(IN1, pwmChannel1);
  ledcSetup(pwmChannel2, pwmFreq, pwmResolution);
  ledcAttachPin(IN2, pwmChannel2);

  // Connect to Blynk
  Blynk.begin(BLYNK_AUTH_TOKEN, ssid, pass, "blynk.cloud", 8080);

  // Timers
  timer.setInterval(100L, readSoundSensor);
  timer.setInterval(5000L, checkCryStatus);
}

// Loop
void loop() {
  Blynk.run();
  timer.run();
}
```