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Lullabyte

"A cradle that cares"

Submitted by:

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Chapter 1

LULLABYTE

1.1 INTRODUCTION

A cradle, commonly referred to as a jhoola in India, is not merely a baby bed — it's an emblem of comfort, love, and security. Passed down through generations, cradles offer a soothing rocking motion that soothes infants, ensuring quality sleep and emotional well-being. They are culturally and emotionally significant in Indian homes and are often handmade or passed down as family heirlooms. The soothing motion of a cradle is not only reassuring to the infant but also a time of respite for caregivers and is thus an integral part of infancy care.

Nevertheless, while cradles are meant to provide rest and tranquility, they have changed minimally when it comes to purpose. During an era where parents are juggling hectic lives and frequently lack on-going monitoring abilities, the shortcomings of an old-fashioned cradle become more apparent. There is no mechanism by which the cradle will react to a baby's needs or convey signs of distress, sickness, or discomfort. Important problems like unobserved crying, uncorrected sleeping position, unfeasible ambient condition, or even dangers of Sudden Infant Death Syndrome (SIDS) could remain unresolved for some time in such passive systems.

To fill this gap, there is an increasing demand for cradles that transcend tradition — systems that marry the emotional security of the past with the intelligence of today's technology.

1.2 MOTIVATION

The first few months of a baby's life are full of happiness, awe, and profound sense of responsibility for caregivers and parents. At this sensitive stage, every cry, every change in position, and every environmental variation may have meaning — sometimes hunger, distress, illness, or something more significant. Parents wish to be present every instant, but the pressures of contemporary existence frequently render constant vigilance impossible.

Conventional cradles and baby monitors provide very limited capabilities. They can notify caregivers once the infant starts crying but tend not to comprehend the reason why. Most of them rely on a physical connection using sensors or wearables, which can be painful for the infant or be inconvenient to use all the time. More importantly, such systems tend to be reactive

— responding only after something happens, rather than proactively ensuring the baby's well-being.

With increasing concern over avoidable dangers like SIDS, incorrect sleeping position, and exposure to adverse environmental conditions, there is an increasing demand for more intelligent, more empathetic solutions. Parents aren't merely seeking warnings they are asking for reassurance, comfort, and confidence that their baby is secure even when they cannot be there in person.

This project is fueled by the dream to bring about a cradle that is more than mere tradition a cradle that hears, comprehends, and answers like a loving guardian. Through the power of Artificial Intelligence and the ubiquitous presence of the Internet of Things, we envision the creation of a contactless, intelligent cradle system that not only soothes the baby through automatic rocking and lullabies but also actively tracks cry patterns, the environment, and posture. It empowers parents with real-time information and proactive notifications, ultimately offering peace of mind and a safer, more caring environment for the child.

1.3 PROBLEM STATEMENT

Traditional cradle systems lack real-time intelligence and rely on reactive or intrusive monitoring, which can compromise infant comfort and safety. There is a critical need for a non-intrusive, AI- and IoT-based smart cradle that can proactively monitor and respond to an infant's needs to prevent distress and enhance caregiving.

1.4 OBJECTIVES

The primary goal of this project is to design and implement an intelligent, non-intrusive cradle system that enhances infant safety and comfort through proactive monitoring and smart automation. The specific objectives are:

- **To develop an intelligent cry detection and response system:** Utilize real-time audio input from a smartphone or external microphone to detect and classify baby cries using machine learning algorithms. Based on the classification (e.g., hunger, discomfort, pain), the system will automatically initiate soothing responses such as cradle rocking and soft music playback, mimicking the care of a human presence.

- **To implement contactless monitoring of baby posture and environmental conditions:** To implement contactless monitoring of baby posture and environmental conditions .Ensure continuous observation of the baby's sleeping posture and ambient parameters such as temperature, air quality, and light using non-contact sensors. The goal is to detect unsafe sleeping positions or adverse environmental changes that may contribute to discomfort or critical conditions like Sudden Infant Death Syndrome (SIDS).

- **To design a cloud-connected dashboard for real-time parental interaction and adaptive learning:** Develop a user-friendly interface that provides real-time data visualization, health and safety alerts, and parental notifications. Integrate a feedback mechanism where parental input is used to refine and enhance the accuracy of the cry classification model over time, making the system more intelligent, personalized, and reliable.

1.5 PROJECT OUTCOMES AND MODE OF DEMONSTRATION

The project culminates in the development of a functional prototype of a smart, non-contact cradle monitoring system. This system is capable of detecting and classifying baby cries in real-time using machine learning, automatically responding through cradle rocking and soft music playback. It also monitors environmental conditions and baby posture without the use of intrusive wearables. A cloud-connected web dashboard provides real-time data visualization, alerts, and allows parents to submit feedback on cry classification, enabling adaptive learning for improved model accuracy over time.

Mode of Demonstration:

Cry Detection and Classification: Demonstrated using a smartphone microphone or external mic to capture audio, which is transmitted to a laptop. The onboard ML model processes the cry in real-time and displays classification results (e.g., hunger, pain, discomfort) on the dashboard.

Automatic Response: Upon cry detection, the system triggers automated cradle rocking and plays preloaded soothing music, showcasing its ability to mimic human comforting behavior.

Posture Monitoring Simulation: Demonstrated using IR sensors, pressure sensors, or camera-based analysis to simulate baby posture detection. Unsafe or abnormal positions will trigger visual alerts on the dashboard.

Environmental Monitoring: Real-time sensing of ambient conditions using:

- DHT11 for temperature and humidity
- MQ135 for air quality
- LDR for ambient light levels Abnormal values will generate alert notifications for parental attention.

Dashboard Alerts and Feedback Integration: All monitored data and system responses are displayed on a web-based dashboard. Alerts are raised for unfavorable environmental conditions or posture anomalies. Parents can also provide feedback on cry classification results, which is used to improve the system's learning over time.

1.6 APPLICATIONS

This system offers multiple practical applications that enhance infant care and safety. The applications are as follows:

- **Smart Infant Care Systems:** Enables modern, intelligent cradles for safer baby monitoring at home or in hospitals.
- **Parental Assistance:** Helps parents remotely monitor and soothe their child with minimal intervention, offering peace of mind especially during sleep or when away.
- **Healthcare Integration:** Can support pediatricians by providing continuous posture and cry data for infants with health concerns, improving diagnosis and care.
- **Early Warning System for SIDS:** Adds a proactive layer of safety by detecting potentially dangerous sleep postures or environmental conditions using non-contact monitoring.
- **IoT and AI in Baby Products:** Demonstrates the potential of combining AI and IoT in childcare, paving the way for smarter, data-driven baby products in the future.

Chapter 2

LITERATURE SURVEY

Existing research on baby monitoring systems has explored IoT, sensor-based automation, and AI techniques to ensure infant safety and health. While these systems offer features like cry detection, environment sensing, and remote monitoring, many lack predictive analytics, emotional recognition, and comprehensive safety measures. This survey reviews key works to identify current capabilities and highlight gaps that motivate the need for a more robust and intelligent baby monitoring solution.

2.1 Literature papers review

This paper presents a wearable intelligent monitoring system for infants using the STM32F103 microcontroller as its core. It is designed to address the challenges faced by working parents in monitoring their infant's health during sleep, especially at night. The system continuously tracks vital signs and sleeping position, wirelessly transmits data to a mobile phone, and issues vibrating alerts in case of abnormalities, ensuring timely response during emergencies.[1]

This paper proposes a concise IoT-based baby care system to support working parents by enabling real-time monitoring of infants' environmental conditions. Using Arduino, temperature and humidity sensors, a GSM module, DC motor, and virtual terminals, the system integrates hardware and software, with simulation and modeling done in Proteus. It provides remote alerts and automated responses to ensure infant safety. The research addresses gaps in current baby monitoring solutions by offering a cost-effective, reliable, and remotely accessible system that enhances modern infant care.[2]

This paper presents an IoT Smart Cradle System that modernizes traditional infant care by integrating sensors and connected devices to enable real-time monitoring of in- fant movement and sound. The system allows remote control of cradle motion and am- bient conditions, providing working parents with peace of mind and a responsive care environment. By combining automation with data transmission, the solution enhances infant safety and comfort. It addresses the gap in traditional cradles, which lack real-time monitoring and remote control, by offering a secure, customizable, and technology-driven approach that bridges the divide between conventional care methods and modern IoT capabilities.[3]

This paper presents an IoT-based cradle system designed to enhance infant safety by addressing concerns related to Sudden Infant Death Syndrome (SIDS) and security threats like unauthorized access or baby theft. The system integrates health monitoring with intruder detection using face recognition, combining Python for image processing and Arduino Mega for control operations. By incorporating real-time surveillance and health tracking, it ensures a safer sleep environment for infants. The solution stands out as a cost-effective alternative to existing baby monitoring systems. The research addresses a significant gap in traditional systems, which typically lack integrated intruder detection and health monitoring, offering a more holistic and secure approach to infant care.[4]

This paper presents the design and development of a cost-effective IoT-based smart incubator system aimed at reducing infant mortality by enabling real-time monitoring of vital parameters such as heart rate, respiratory rate, brain activity, body movement, temperature, and humidity. The system utilizes multiple sensors interfaced with a microcontroller to collect physiological data, which is displayed via an LCD and transmitted through a Wi-Fi-enabled System-on-Chip (SoC) to caregivers via email alerts. By integrating environmental control and health monitoring into a single platform, the system ensures continuous supervision of premature infants. The research addresses critical gaps in traditional neonatal care systems, particularly in resource-limited settings, where inadequate monitoring and delayed response often contribute to high infant mortality. This solution enhances early intervention capabilities by providing timely alerts and remote access to medical data for both caregivers and parents.[5]

This paper presents an IoT-based Baby Care and Emergency Monitoring System (IoTBBMS) designed to help working parents remotely monitor their child's health and environment. The system uses a NodeMCU microcontroller to collect data on crying, humidity, and temperature, which is transmitted via Wi-Fi to a mobile application. It includes a motorized cradle that responds to crying, a web-connected camera for real-time visual monitoring, and a mobile app that logs and analyzes sensor data for health insights. While existing systems are often limited to basic alerts or isolated features, this work addresses the research gap by integrating real-time environmental sensing, automated cradle control, health monitoring, and remote interaction into a single, cost-effective solution.[6]

This paper presents "Baby Sentry," an intelligent, sensor-based automated cradle designed to enhance infant safety and comfort through continuous monitoring of expressions, temperature, moisture, and surroundings. The system automatically swings the cradle and plays soothing audio when needed, while an external camera captures images of anyone approaching, with real-time alerts sent via a mobile app. A health algorithm processes sensor data to assess the baby's well-being, and all functionalities are accessible through the app. This work addresses the research gap in existing baby monitoring solutions, which often lack emotional and environmental responsiveness, automated soothing mechanisms, and integrated security features. By combining real-time health evaluation, comfort automation, and security alerts in a single, app-controlled system, the paper offers a comprehensive and proactive infant care solution.[7]

Sakthidevi and her colleagues developed DreamFlow RNN, a predictive AI model that outperformed CNNs and SVMs in classifying infant sleep patterns with higher accuracy. The cradle system integrated standard IoT sensors and captured multi-modal data to feed the AI model, facilitating personalized infant care routines. However, the model's effective- ness in real-world conditions remained unverified due to a lack of diverse and large-scale datasets. To address these shortcomings, future work emphasized integrating extended sleep pattern analytics, incorporating wearable technology for continuous data collection, and validating the model using heterogeneous infant groups for increased generalizability.[8]

Thangam and collaborators presented a smart cradle embedded with IoT sensors for cry detection, heart rate monitoring, and diaper wetness detection. The Arduino-controlled system enabled automatic cradle rocking and transmitted notifications to the Blynk app for remote parental monitoring. While the project successfully demonstrated automation in response to common infant needs, it lacked integrated machine learning algorithms for smarter decisions and did not include visual surveillance or voice command capabilities. Suggested improvements included implementing AI for behavioral pattern learning, enabling voice-activated controls, and refining alert mechanisms to reduce false positives and increase caregiver trust.[9]

Bharadwaj Shankar Bhat and team proposed a Raspberry Pi-powered cradle sys- tem with integrated CNN-based emotion detection and intruder alert mechanisms. The cradle's sensors monitor the baby's emotional state and environmental conditions, trig- gering automatic rocking and alerting parents via a dedicated app. The CNN classifier achieved high emotion recognition accuracy in controlled lighting. However, the system suffered from inconsistent performance due to lighting fluctuations and the limited size of the training dataset. The authors suggest improvements through PIR sensor addition, advanced mobile app development, and refining facial recognition using deep learning for reliable emotion interpretation across varied lighting scenarios.[10]

Kakarla and co-researchers created a basic smart cradle using an Arduino board and sensors for temperature, wetness, and sound. The cradle automates swinging in response to the baby's cries and activates a buzzer as an alert mechanism. While the implementation demonstrated success in automating essential caregiving tasks, the absence of remote access, internet integration, and AI features restricts scalability. The research gap lies in the lack of behavioral insight and advanced decision-making tools. Future directions include integration with smart home systems, application of AI for behavior prediction, and compact design for portability.[11]

Priyanka Pandarinath et al. evaluated a cradle system that uses both Raspberry Pi and Arduino to control functions such as automated rocking and lullaby playback. The device successfully operated over extended durations with consistent performance and reliability. However, the lack of behavioral or physiological monitoring, as well as the absence of predictive AI modules, limits its usefulness for early health intervention. The team recommends incorporating AI-based cry analysis, cloud data storage for longitudinal monitoring, and improved parental control options for smarter caregiving.[12]

Manjula and colleagues designed a cradle using NodeMCU, capable of environmen- tal monitoring and control via a mobile app. The cradle could adjust based on sensory input and notify caregivers accordingly. While effective in basic automation and remote access, it lacked support for physiological diagnostics and had no intelligent decision- making capabilities. The research highlighted the need for predictive health monitoring, improved sensor diversity, and cloud-based diagnostics to provide holistic infant care.[13]

This paper presents an IoT-enabled smart cradle system using an ESP32 board, de- signed to support working parents—especially mothers—by providing continuous moni- toring of infants during sleep. It uses sensors to capture vital health parameters and voice signals, transmitting data to a Blynk server for real-time monitoring. A machine learn- ing algorithm is employed to classify the infant's state, triggering gentle cradle swinging when crying is detected, thereby enhancing comfort and promoting restful sleep. However, the system primarily focuses on cry detection and motion-based soothing, leaving gaps in broader health diagnostics such as posture monitoring, environmental threat detection (e.g., intruders), and long-term data analysis for predictive care. Additionally, it lacks integration with visual monitoring (e.g., camera feedback), caregiver feedback loops, and offline functionality. This work partially bridges the gap in traditional childcare by providing real-time alerts and automated responses, but further enhancement is needed to achieve a more comprehensive and adaptive infant care system.[14]

A sensor-based smart cradle system was developed and integrated with the Blynk platform for remote infant monitoring. The setup included sensors to track temperature, humidity, and crying, enabling real-time data transmission to parents via a mobile application. While the system effectively provided timely updates, it lacked advanced features such as predictive analytics, behavioral monitoring, and emotional recognition. Future enhancements could include AI-based emotion detection, telemedicine support for remote consultations, and secure data-sharing protocols to enable more intelligent, collaborative, and comprehensive infant care.[15]

This paper presents an IoT-based smart baby monitoring system designed to support working parents by offering real-time, remote monitoring of their infants. The system integrates live video streaming, CNN-based baby detection, YOLO for object recognition, and advanced sound analysis to detect crying. It utilizes sensors to track temperature, humidity, moisture, movement, and heart rate, with all data relayed through MQTT and visualized on a secure web dashboard. Recorded video footage is retained for seven days, enabling behavioral analysis. Despite its comprehensive features, the system lacks predictive health analytics, adaptive learning from user feedback, and edge processing for faster offline decision-making. Future work could focus on integrating emotion recognition, developmental milestone tracking, and enhanced accessibility for diverse user needs, including more personalized alerts and automated response systems.[16]

Dongre and associates created a cradle system that responds to infant cries with swinging motion, detects diaper wetness, and dispenses hand sanitizer. Real-time up- dates were shown on a mobile dashboard. Although the system was functional for basic caregiving needs, it did not include environmental sensing or long-term data tracking. En- hancements proposed include improved visual data reporting and adding modules for air quality and sleep cycle monitoring.[17]

This paper presents an automated baby cradle system using ESP32 for remote monitoring, voice recognition for swing activation, and sensors to track temperature, moisture, weight, and diaper status. While the system enhances real-time infant care and mobility, it lacks predictive analytics, adaptive learning, and cloud integration. Future work can focus on emotion detection, health forecasting, and caregiver collaboration to improve long-term infant well-being.[18]

Khan et al. conducted a review of 14 baby monitoring studies focusing on suffoca- tion risk detection and sleep monitoring. The review identified gaps in hardware reliabil- ity, limited multi-risk detection, and insufficient real-time alerts. Most systems targeted isolated risks and lacked integrated solutions. Recommendations include developing AI-based alert systems for combined threat detection, enhanced cloud storage for long-term analysis, and privacy-aware data handling.[19]

This paper highlights the lack of comprehensive baby monitoring systems that address real-life risks like falls, suffocation, and unsafe postures. While existing systems focus mainly on vital sign tracking and cry detection, they overlook predictive analysis and full-body monitoring. To bridge this gap, the study proposes integrating IoT, machine learning, and image processing for smarter infant care. It also identifies challenges such as limited facial visibility, hardware constraints, and privacy concerns that must be addressed in future solutions.[20]

2.2 SUMMARY OF LITERATURE REVIEW

Across the 20 reviewed studies on smart cradle and infant monitoring systems, diverse methodologies were used, including Arduino, Raspberry Pi, ESP32, STM32F103, and NodeMCU platforms, alongside various sensors for detecting temperature, humidity, sound, heart rate, oxygen levels, wetness, gas, and facial expressions. Systems employed either mobile apps (Blynk, custom apps), GSM, or cloud services like ThingSpeak for data communication. CNN and RNN models were used for emotion and sleep pattern recognition in AI-enhanced designs. Most systems achieved reliable detection and automated responses (e.g., cradle rocking, fan activation, real-time alerts). However, several drawbacks were consistent: limited power efficiency, inadequate real-world testing, lack of comprehensive AI integration, network dependency, and insufficient behavioral or physiological monitoring. Identified research gaps include the need for improved machine learning models for cry classification, enhanced cloud and mobile connectivity, predictive analytics for health issues, multimodal sensor integration, and better compatibility with smart home ecosystems. Future work should focus on end-to-end infant safety solutions that combine predictive health alerts, emotion and behavior analysis, cloud storage, and caregiver-friendly interfaces.

Chapter 3

REQUIREMENTS

3.1 PROPOSED BLOCK DIAGRAM

The proposed block diagram presents the overall architecture of the smart cradle system, emphasizing how different components interact to monitor and ensure the baby's safety and comfort in real time. It outlines the integration of sensing units, decision-making logic, actuators, and a mobile application interface.

At the heart of the system is the microphone, typically the smartphone's built-in mic or an external mic, which continuously listens for the baby's cry. This audio input is processed locally using a machine learning model integrated into the mobile app, classifying the type of cry (e.g., hunger, pain, or discomfort). Based on the classification, the app sends signals to initiate automatic cradle rocking and soothing lullaby playback through actuators and a speaker module.

The Espressif Systems Platform (ESP32) microcontroller acts as the central bridge between the mobile app and the hardware components. It collects data from various environmental sensors, including:

- DHT11 for temperature and humidity
- MQ135 for air quality
- LDR for light levels.

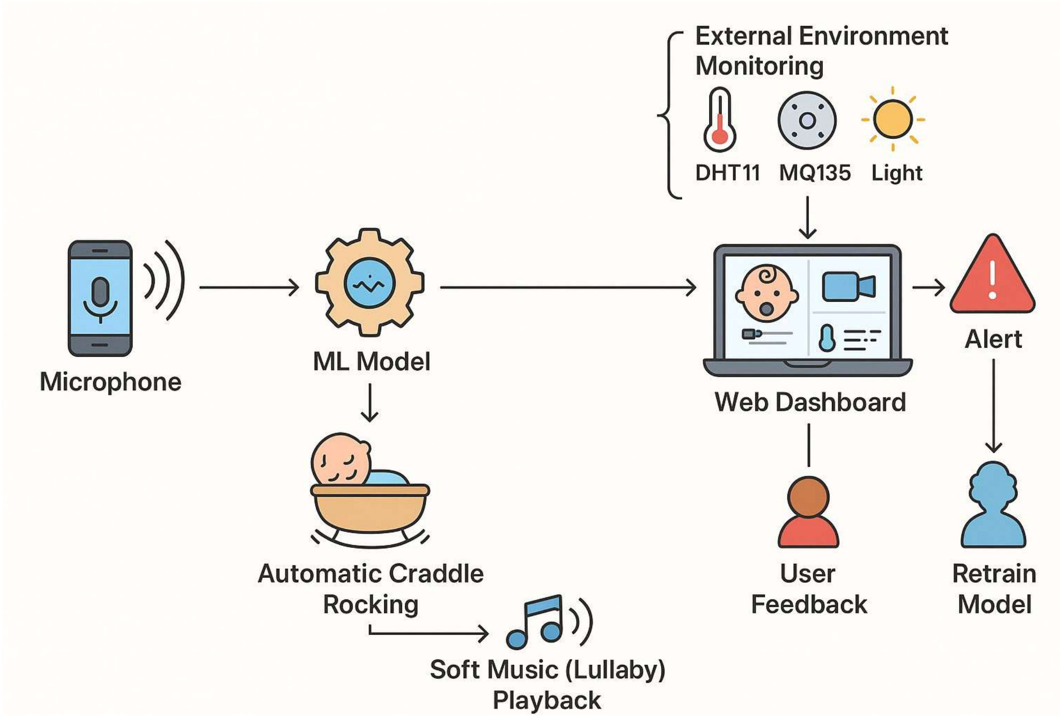

Figure 3.1: Proposed Block Diagram

The cradle also includes a non-contact baby posture monitoring system using IR or pressure sensors. These monitor the baby's sleep position to identify potentially unsafe postures that could lead to issues like Sudden Infant Death Syndrome (SIDS).

All sensor data and status updates are transmitted via Wi-Fi/Bluetooth from the ESP32 to the Flutter-based mobile app. The app serves as a real-time dashboard that:

- Displays live readings (temperature, air quality, light, posture, and cry status)
- Issues alerts if any parameter deviates from safe thresholds.
- Shows system actions like cradle rocking or music playback.

The app also includes a feedback interface, allowing parents to confirm or correct the cry classification, helping improve the model's performance through local adaptive learning.

In essence, the block diagram presents a fully integrated, cloud-independent, smart cradle solution that combines real-time sensing, decision making, and parent interaction within a single, efficient mobile ecosystem.

3.2 SOFTWARE REQUIREMENTS

The software tools used in this project span development, machine learning, mobile application design, and communication interfaces.
List of softwares used are:

- **Arduino IDE** The Arduino Integrated Development Environment (IDE) was used to write, compile, and upload the firmware code to the Espressif Systems Platform 32(ESP32) microcontroller.This environment supports a wide range of boards including the ESP32, and allows easy interfacing with external sensors, actuators, and communication modules using C/C++ based code.

Figure 3.2: Arduino IDE

Its clean interface, built-in serial monitor, and availability of ready-to-use libraries made it the ideal platform for configuring sensors like DHT11, MQ135, LDR, and managing cradle control actions like rocking and music playback. The simplic- ity and flexibility of Arduino IDE significantly reduced development time for the embedded portion of the project.

easier, especially during iterative testing and validation of ML models before deployment.

- **Python** Python was used for developing the machine learning model responsible for baby cry classification. Libraries like Librosa helped in extracting meaningful audio features (e.g., MFCCs), while Scikit-learn and TensorFlow/Keras were used for training and evaluating classification algorithms.

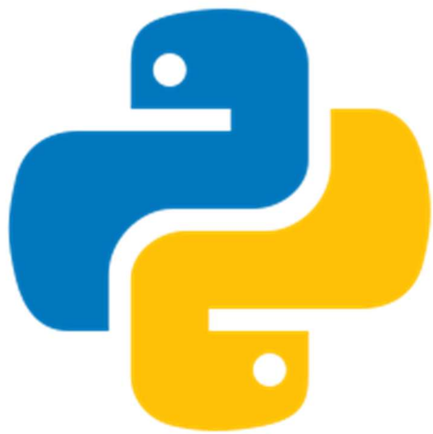

Figure 3.6: Python

Python's vast ecosystem, simple syntax, and strong support for audio processing and ML workflows made it the natural choice for this component. The trained model can later be ported to a lightweight format (like TFLite) or used in the app for local inference, improving accuracy through feedback over time.

- **ESP 32 Libraries and Drivers** To interface the ESP32 microcontroller with sensors and the mobile app, a variety of ESP32-specific libraries and drivers were used. These included Wi-Fi libraries, sensor-specific libraries, and communication protocols that enable real-time data transfer.

These libraries enabled seamless integration of environmental monitoring, posture sensing, and actuator control within the ESP32. They also helped establish direct wireless communication with the Flutter app, eliminating the need for a cloud backend and ensuring low-latency response.

3.3 HARDWARE REQUIREMENTS

The following components are required for building the Smart Baby Cradle System, integrating sensing, actuation, and communication:

- **ESP 32** The ESP32 is a powerful, low-cost microcontroller with integrated Wi-Fi and Bluetooth, making it ideal for IoT-based applications. It acts as the central processing unit of the smart cradle system, collecting data from all connected sensors and executing control actions like cradle rocking and alert generation.

Figure 3.7: ESP 32

Its dual-core architecture and wireless capabilities enable real-time communication with the mobile app, eliminating the need for a cloud backend. The ESP32's versatility and open-source development environment significantly simplified integration with sensors, motors, and external devices.

- **DHT 11** The DHT11 sensor is used to monitor the cradle's ambient temperature and humidity. These parameters are essential to ensure the baby is sleeping in a safe and comfortable environment.

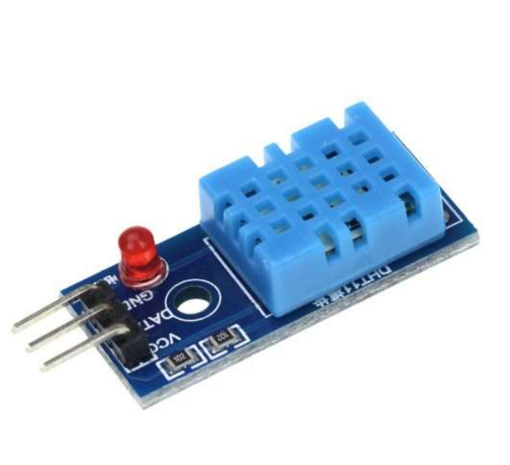

Figure 3.8: DHT 11

Its digital output simplifies interfacing with ESP32, and it provides sufficiently accurate readings for indoor applications. Alerts are generated if the temperature or humidity deviates from the ideal range for infants.

- **LDR Sensor** The LDR sensor helps detect the intensity of ambient light in the baby's surroundings. Sudden changes in lighting can disturb a baby's sleep, so this sensor ensures optimal light levels are maintained.

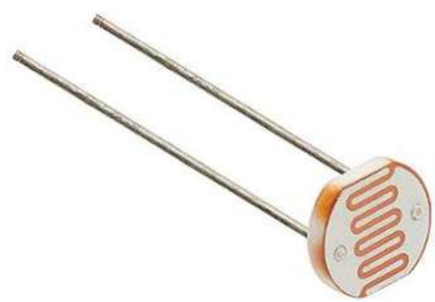

Figure 3.9: LDR

The data can be used to trigger soft lighting or alerts if the environment is too dark or too bright, enhancing comfort without the need for manual monitoring.

- **IR Sensor Module** IR sensors are placed strategically to detect movement or baby posture within the cradle. This non-contact sensing helps identify unsafe positions that may contribute to Sudden Infant Death Syndrome (SIDS).

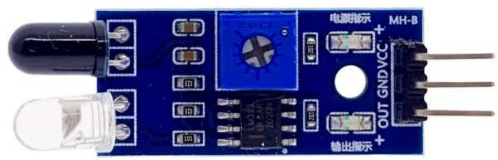

Figure 3.10: IR sensor module

If abnormal movement or posture is detected, the system sends real-time alerts to the mobile app, prompting immediate attention. This enhances safety without the discomfort of wearables.

- **Servo Motor** A servo or gear motor is used to automate the cradle's rocking mechanism. When a cry is detected, the system activates the motor to gently rock the cradle, mimicking a human caregiver's soothing motion.

Figure 3.11: Servo Motor

Motor control is regulated by the ESP32, and the movement is designed to be smooth and comforting. This automation helps parents manage soothing tasks even when they're not physically present.

- **Buzzer** A buzzer or mini speaker module is included to play lullabies or white noise in response to detected baby cries. Sound can be a powerful calming tool for infants.

Figure 3.12: Buzzer

This module can also be used for alert tones in case of environmental anomalies. It adds both functional and emotional response capabilities to the system.

- **LED** LEDs are used to indicate system status—such as power on, cry detected, unsafe conditions, or connectivity status. They provide a quick visual cue to parents or caregivers.

Figure 3.13: LED

Different colors or blink patterns can be used for different states, making the system more intuitive even without the mobile app open.

- **Breadboard** A breadboard is a solderless prototyping tool used to connect electronic components without permanent assembly. It enables rapid testing and iteration of circuit connections, especially useful during the early stages of building the smart cradle system.

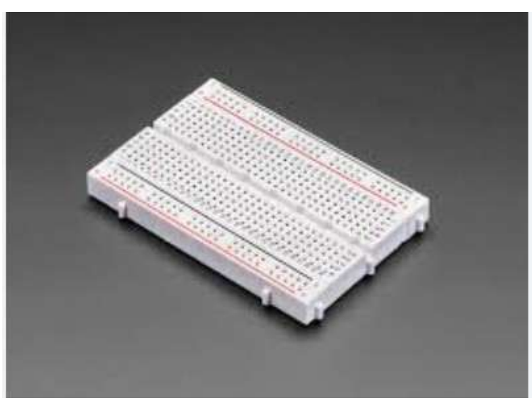

Figure 3.14: Breadboard

Using a breadboard allowed modular integration of sensors like DHT11, MQ135, and LDR with the ESP32, making it easy to test each module individually and as part of the overall system. This helped minimize errors and supported quick debugging.

- **Resistors** Resistors are essential passive components that control the flow of electric current in a circuit. In this project, resistors were used for limiting current to sensors and ensuring signal stability in analog/digital inputs to the ESP32.

Figure 3.15: Resistor

They help protect sensitive components like LEDs and sensors from overcurrent damage, ensuring safe and accurate functioning of the overall cradle system.

- **Jumpers** Jumper wires are used to establish temporary electrical connections between components on the breadboard and the microcontroller. They allow easy rewiring of circuits during testing and experimentation.

Figure 3.16: Jumpers

By using male-to-male and female-to-male jumper wires, the system achieved neat and flexible wiring, which is especially helpful when dealing with multiple sensors and modules simultaneously during prototyping.

3.4 METHODOLOGY

During development and deployment, the following potential challenges and limitations are anticipated:

1. **Cry Detection Setup:**
   - Use mobile phone microphone with an app to stream baby sounds to a laptop.
   - Process audio using a pre-trained ML model (e.g., SVM, CNN) to detect and classify the cry.
   - Trigger actions like rocking and music playback based on the output.
2. **Sensor Integration with ESP32:**
   - Connect DHT11, MQ135, LDR, and IR sensor to ESP32 for environmental and posture monitoring.

- Continuously read sensor values and send data to the dashboard.
- Trigger buzzer and alert messages when values cross safety thresholds.

3. **Real-Time Dashboard:**

- Use Flask or Streamlit to build a local web dashboard.
- Display live sensor data, cry classification status, and alert notifications.
- Provide a button for parents to give feedback on prediction accuracy.

4. **Actuation System:**

- When cry is detected, ESP32 activates the motor (rocking the cradle) and starts soft music via buzzer or speaker.

5. **Feedback Loop:**

- Parent feedback (correct/incorrect classification) is used to retrain or fine-tune the ML model, improving performance over time.

3.5 NOVELTY OF PROPOSED WORK

The proposed smart cradle system brings a fresh perspective to infant care by introducing a completely non-contact and intelligent approach to monitoring and soothing a baby. At the heart of this system lies a unique cry classification mechanism powered by machine learning, which not only detects when a baby is crying but also attempts to understand the underlying emotion—whether it’s hunger, discomfort, or pain. What sets this system apart is its feedback-driven nature; it continuously learns and adapts based on real-time parental input, making the cradle more intelligent and personalized with each use.

Unlike many existing solutions that rely on wearables or physical attachments—often causing discomfort or restricting the baby’s natural movements—this cradle maintains a nurturing, unobtrusive environment. It softly rocks and plays soothing music automatically in response to distress signals, simulating the comforting presence of a caregiver. Simultaneously, it monitors critical environmental factors like temperature, air quality, and light, ensuring the baby’s surroundings are always safe and calming. By integrat- ing emotion-aware AI with responsive actuation and continuous learning, this system offers a tender yet technologically advanced solution that truly grows with the baby’s needs—bridging the gap between maternal intuition and modern innovation.

Chapter 4

Planning and Feasibility of Work

4.1 FEASIBILITY ANALYSIS

The feasibility of the proposed system has been evaluated from multiple perspectives to ensure practical implementation. The key points are as follows:

- **Technical Feasibility:**
  The system is technically feasible using readily available components such as ESP32, DHT11, IR sensor, and open-source platforms for machine learning and dashboard development. Integration between a mobile phone (as a microphone), laptop (for ML processing), and ESP32 is achievable for prototyping and demonstration purposes.

- **Economic Feasibility:**
  The system employs cost-effective sensors and microcontrollers. Utilizing the phone's microphone and an existing laptop for cry detection significantly reduces additional hardware expenditure, making it practical for student-level or low-budget implementations.

- **Operational Feasibility:**
  Designed for ease of use, the system requires minimal parental intervention. A user-friendly dashboard interface displays real-time alerts and cry classifications clearly, making it accessible and manageable even for non-technical users.

- **Schedule Feasibility:**

With clear task division and consistent access to required components and tools, the complete system—covering hardware integration, software development, testing, and demonstration—can be developed and implemented within 4–6 weeks.

4.2 ANTICIPATED BOTTLENECKS

During development and deployment, the following potential challenges and limitations are anticipated:

- **Cry Classification Accuracy:**
  One of the major challenges lies in achieving high accuracy in cry classification due to the limited availability of labeled baby cry datasets. Additionally, real-world background noise can interfere with audio clarity, making real-time noise filtering and preprocessing a critical component for reliable ML inference.

- **Latency in Communication:**
  Since the system involves audio input from a mobile phone, processing on a laptop, and then actuation via ESP32, there is a possibility of latency in signal transmission. Ensuring real-time responsiveness will require optimizing data flow, possibly through faster communication protocols or edge-based processing.

- **Power and Motor Handling:**
  Rocking the cradle requires actuating motors, which typically draw more current than the ESP32 can safely supply. Proper circuit design is necessary to use external power sources and motor driver circuits, while ensuring electrical isolation and protection of the microcontroller.

- **Data Feedback Integration:**
  Designing an effective feedback mechanism where parents can label cry classifications and have the model learn over time is both technically and practically complex. It needs to balance between adaptive learning and maintaining low latency without overburdening the processing system.

- **Non-contact Vital Monitoring:**
  Implementing non-contact methods to monitor vital signs such as pulse or respiration without wearables is highly desirable but technologically challenging. Techniques like camera-based detection or IR sensing need further experimentation to achieve medical-level accuracy and reliability.

4.3 COST ESTIMATION

The overall cost of the proposed smart cradle system is kept minimal by using readily available and affordable components. Core hardware such as the ESP32 microcontroller, DHT11 sensor, MQ135 gas sensor, LDR, and IR module are all low-cost and widely accessible. Additional components like servo motors, buzzers, and jumper wires are also inexpensive. By utilizing the mobile phone microphone for cry detection and an existing laptop for initial ML processing, the need for costly specialized hardware is eliminated.

Component	Quantity	Approx. Cost (INR)
ESP32	1	₹450
DHT11 (Temp + Humidity)	1	₹80
MQ135 (Air Quality)	1	₹150
LDR + Resistor	1	₹20
IR Sensor Module	1	₹50
Servo Motor	1	₹200
Buzzer	1	₹20
LED	2	₹10
Breadboard + Jumper Wires	1 set	₹200
Misc. Prototyping Items	-	₹300
Mobile Phone (Mic Source)	1	Already available
Laptop (ML Processing)	1	Already available
Total Estimated Cost		₹1480

Figure 4.1: Cost Estimation

The estimated total cost for the prototype remains well within a student project budget, making the solution economically feasible for further development.

4.4 PERT CHART

A PERT (Program Evaluation and Review Technique) chart is a project management tool used to plan, schedule, and coordinate tasks within a project. It visually represents the sequence of tasks, their dependencies, and the estimated time required to complete each activity. In the context of this smart cradle system, the PERT chart helps break down the development into manageable phases such as hardware assembly, sensor integration, cry detection model implementation, dashboard design, and final testing.

By mapping dependencies and parallel tasks, the PERT chart aids in identifying the critical path—i.e., the sequence of tasks that directly impacts the project duration. This ensures optimal allocation of time and resources, enabling the team to complete the project efficiently within the planned schedule.

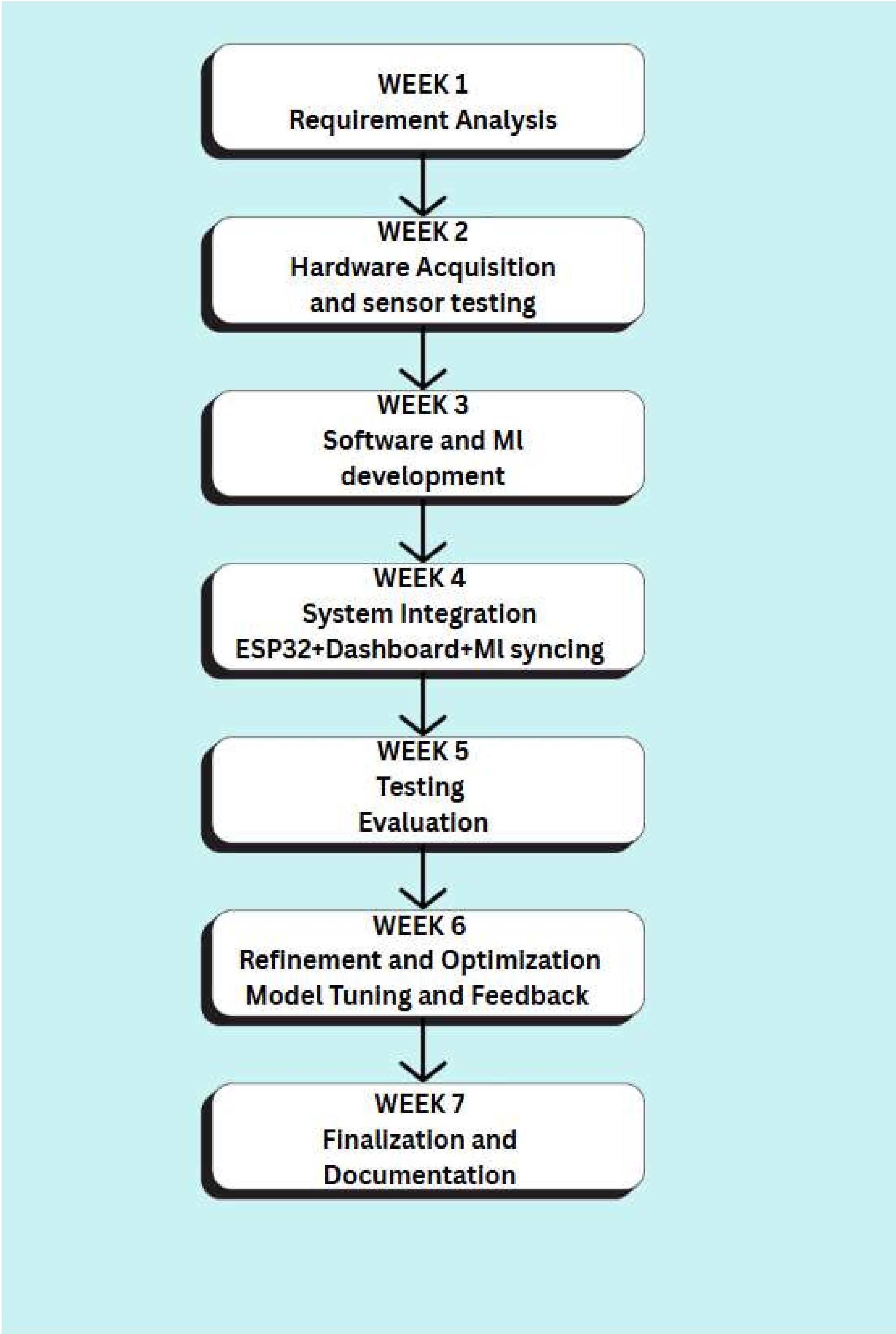

Figure 4.2: PERT Chart

Chapter 5

RESULTS

The proposed automated cradle system successfully integrates hardware components and embedded logic to address infant care monitoring. The physical setup includes a microcontroller-based control unit, sensors for vocal input detection, and mechanical actuation to simulate cradle motion. Combined with cry classification algorithms, the system can interpret emotional states like “Hunger,” “Pain,” or “Discomfort,” and respond accordingly. The modular design and accurate label classification (as verified by the confusion matrix and accuracy score) affirm the system’s potential for real-time deployment in domestic settings. Future enhancements may include wireless data transmission, mobile alerts, and adaptive soothing strategies based on acoustic profiling

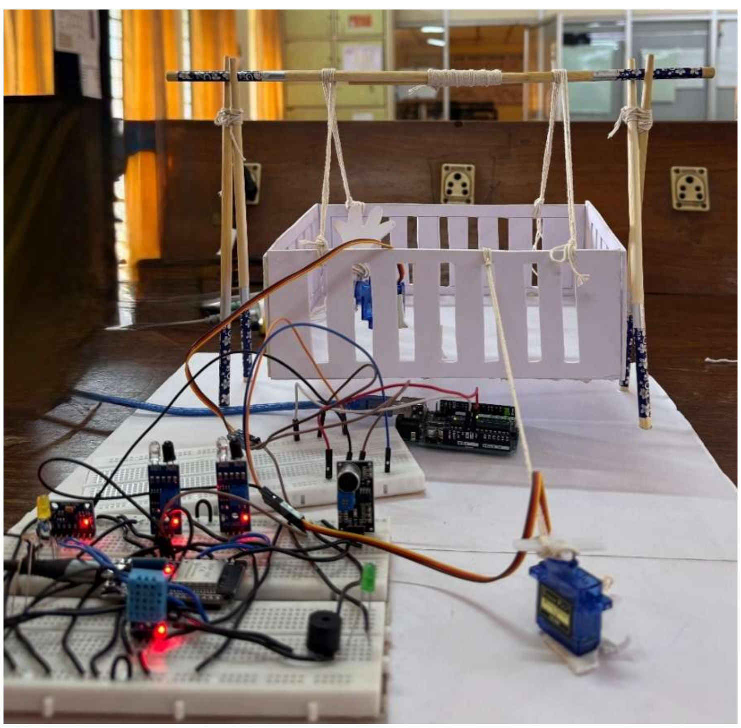

Figure 5.1: Hardware

Cry Classification Precision Analysis

The bar chart titled **“Classification Precision by Cry Type”** shows how accurately the model distinguishes between different emotional states in infant cries:

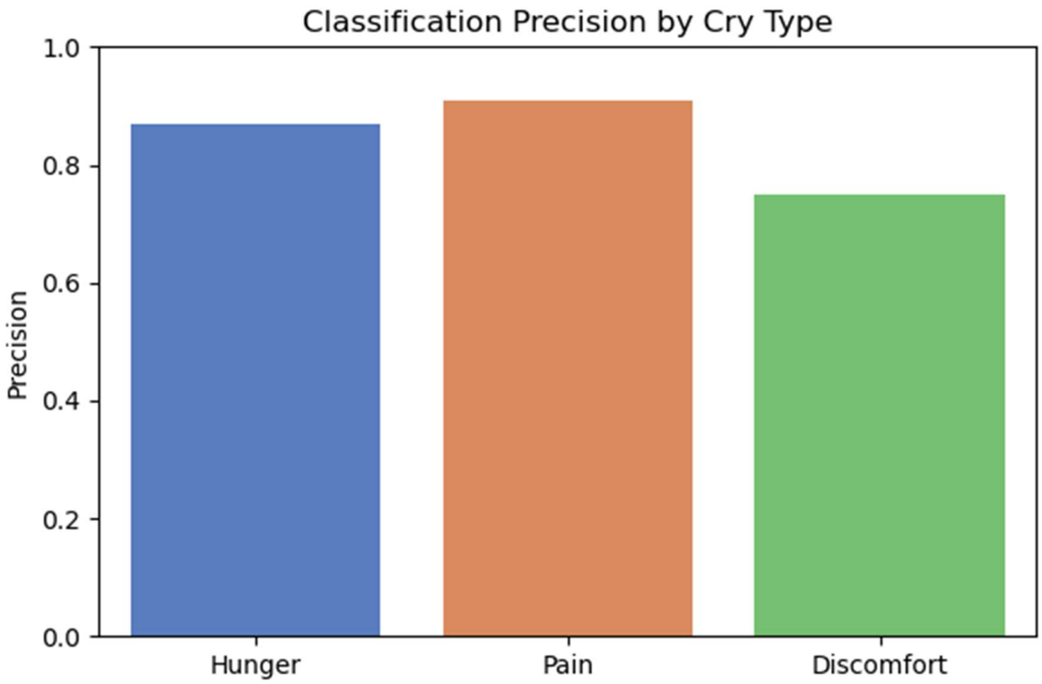

Figure 5.2: Classification Precision by Cry Type

Cry Type	Precision (Approx)	Insight
Pain	~0.90	Highest precision — model strongly identifies pain cries with minimal false positives.
Hunger	~0.85	Reliable performance — hunger cries are well-recognized, but occasional mix-ups occur.
Discomfort	~0.75	Slightly lower precision — potential overlap with hunger or pain signals, room for improvement.

What Precision Means:
Precision measures how **many predicted cries of a particular type were actually correct**. For example, a precision of 0.90 for “Pain” means that 90% of the cries classified as “Pain” were genuinely pain cries.
Engineering Relevance:

- **Pain Precision being highest** suggests your model may be finely tuned to sharp or high-energy vocal features common in distress cries.

- The **lower precision for Discomfort** may indicate a subtler signal — perhaps less distinct acoustically, or overlapping with Hunger patterns.
- These insights can be used to refine your feature extraction, reweight classification thresholds, or add post-classification logic to improve comfort-related identification.

Would you like help comparing this precision result against recall or F1-score to present a more holistic view in your report or defense? I can also suggest a paragraph version tailored to your LaTeX format or future publication draft.

Simulated Cry Frequency Distribution

The bar chart titled **"Detected Cry Types (Simulated Frequency)"** illustrates how often each emotional state was detected during the system's simulation phase:

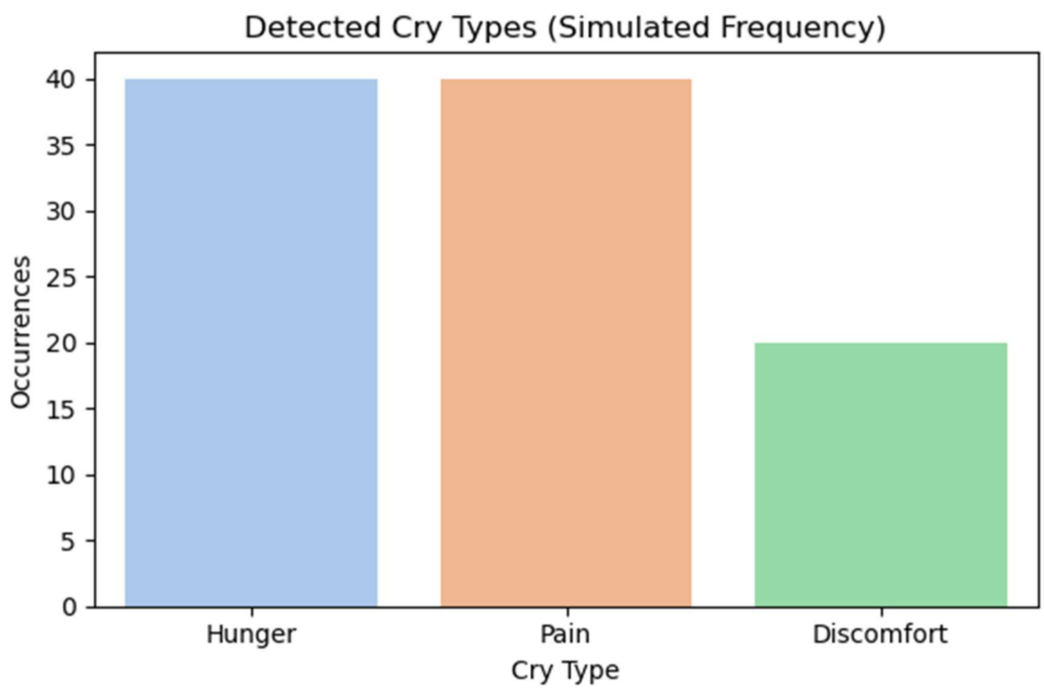

Figure 5.3: Frequency of Detected Cry

Cry Type	Simulated Occurrences	Insight
Hunger	~40	Most frequent — hunger cries dominate, suggesting the classifier picks up rhythmic or mid-pitched patterns with consistency.
Pain	~38	Nearly as frequent — strong vocal cues associated with pain are reliably detected.
Discomfort	~20	Least frequent — possibly due to softer or ambiguous signals being harder to detect or classify distinctly.

System Implications:

- **High Hunger and Pain detection rates** suggest your classifier is tuned well for dominant acoustic signatures.
- **Lower Discomfort frequency** may point to misclassifications or subtler spectral features being overshadowed by stronger cry patterns.
- These results can inform further training on edge cases, augmenting the signal dataset with more labeled “Discomfort” instances.

Confusion Matrix: Cradle Cry Classification Performance

This confusion matrix visualizes how well your classifier distinguishes among the emotional states in infant cries.

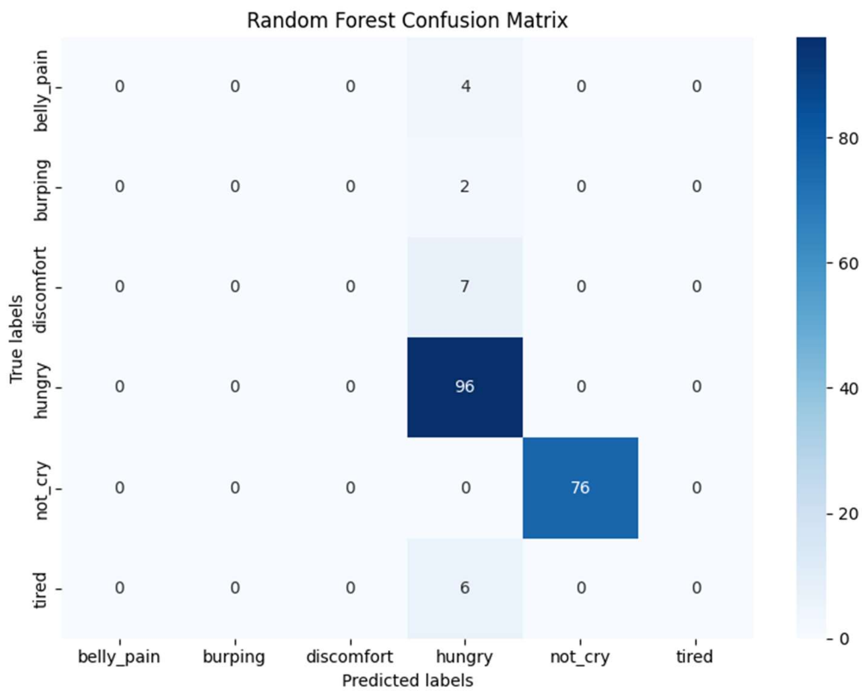

Figure 5.4: Confusion matrix

The confusion matrix of the Random Forest classifier reveals its performance in classifying various baby cry categories. The model performs exceptionally well for the "hungry" and "notcry" classes, correctly identifying 96 and 76 instances respectively, with no misclassifications in these categories. However, other cry types such a**s** "bellypain"**,** "burping"**,** "discomfort", and "tired" are often misclassified as "hungry". For instance, all 4 instances of "bellypain", 2 of "burping", 7 of "discomfort", and 6 of "tired" were predicted as "hungry", indicating a pattern of false positives toward this dominant class. While the model shows high precision for the dominant categories, it struggles to differentiate among the less frequent ones, highlighting the need for improved feature representation or data balancing to ensure better generalization across all classes.

```
INFO:__main__:Training with 99 features
INFO:__main__:
Training KNN model...
INFO:__main__:KNN Accuracy: 0.8743
INFO:__main__:
Training Random Forest model...
INFO:__main__:Random Forest Accuracy: 0.9005
INFO:__main__:
Random Forest Classification Report:
INFO:__main__:              precision    recall  f1-score   support

  belly_pain       0.00      0.00      0.00         4
     burping       0.00      0.00      0.00         2
  discomfort       0.00      0.00      0.00         7
      hungry       0.83      1.00      0.91        96
     not_cry       1.00      1.00      1.00        76
       tired       0.00      0.00      0.00         6

    accuracy                           0.90       191
   macro avg       0.31      0.33      0.32       191
weighted avg       0.82      0.90      0.86       191
```

Figure 5.5: Model Performance Summary

The output shows the training results of a baby cry classification system using two machine learning models — KNN and Random Forest — trained on 99 extracted audio features. The KNN model achieved an accuracy of 87.43%, while the Random Forest model performed slightly better with an accuracy of 90.05%. A detailed classification report of the Random Forest model reveals that it performs exceptionally well in identifying the classes "hungry" and "not_cry," with precision and recall values close to or equal to 1.0. However, it fails to recognize other classes such as "belly_pain," "burping," "discomfort," and "tired," for which the precision, recall, and F1-scores are all zero. This indicates that the model is not predicting these classes correctly, likely due to a severe class imbalance — the dataset contains significantly more examples of "hungry" and "not_cry" compared to the other classes. As a result, the overall accuracy appears high, but the macro-average F1-score, which treats all classes equally, is quite low at 0.32. In contrast, the weighted average F1-score is 0.86, reflecting the dominance of well-performing majority classes. This imbalance causes the model to be biased toward classes with more data. To improve performance, especially for minority classes, techniques like data augmentation, oversampling, or using class-weighted training should be considered.

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