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IoT Enabled Smart Cradle System (January 2024)

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ABSTRACT The increasing number of employed mothers has raised the demand for dependable monitoring of infant sleep, as conventional childcare services sometimes lack the continuous attentiveness necessary for prompt intervention, particularly with regards to sudden infant death syndrome (SIDS). This paper presents a Baby Monitoring system that utilizes an ESP32 board and is based on the IoT technology. The system aims to address the concerns of parents, particularly working women, by providing a solution that helps them balance their work responsibilities with worries about their baby's well-being. The system utilizes sensors to gather essential measurements of health and voices, allowing for immediate monitoring and analysis supported by a Blynk server. Machine learning algorithms are used to identify the state of the infant. When a cry is detected, the parent can activate a response that swings gently. This response aims to reduce discomfort and encourage peaceful sleep. This flexible system provides real-time monitoring to enable early action, automated comfort, and remote analysis of sleep patterns. It has the potential to improve infant sleep safety and provide reassurance to parents, allowing them to balance work responsibilities while ensuring their infant's well-being.

INDEX TERMS IoT, Smart Cradle, Arduino, Blynk

I. INTRODUCTION

The Internet of Things (IoT) is a network including physical things that are interconnected by sensors and software, facilitating the interchange of data and remote monitoring. It establishes a connection between the physical and virtual worlds, improving effectiveness, ease, and decision-making by means of intelligent applications and services.

The applications of IoT technology has made a significant and broad influence on the field of infant care, having a positive impact in advanced monitoring and caring practices. It enables the immediate monitoring of essential health indicators and sleep cycles by using sensors and wearable technology. Environment monitoring, including the regulation of temperature and humidity, is also improved. The IoT facilitates remote communication, enabling parents to comfort and connect with their infants using intelligent tools. This technology has improved the responsiveness, data analysis, and accessibility of infant care, therefore easing the difficulties with modern parenting and boosting the safety and comfort of infants.

A. MOTIVATION

The IoT Smart Baby Cradle project aims to bridge the gap between traditional methods of baby care and modern technology. The project combines real-time data analysis, automatic reactions to infants, and remote environment management, providing a safer environment for newborns and enhancing parental confidence. The cradle is designed with a user-friendly interface, addressing common concerns like unexpected discomfort and inconsistent sleep patterns. It also ensures ideal room settings, demonstrating safety, convenience, and creativity. The project is committed to promoting digital childcare alternatives and revolutionizing the newborn care product industry by using IoT technology. The project aims to create a reliable and accessible solution for families from all backgrounds, ensuring the quality of early life care. The IoT Smart Baby Cradle project represents a significant advancement in providing parents with essential tools to improve infant care. The IoT Smart Baby Cradle project aims to bridge the gap between traditional methods of baby care and modern technology. The project combines real-time data analysis, automatic reactions to infants, and remote environment management, providing a safer environment for newborns and enhancing parental confidence. The cradle is designed with a user-friendly interface, addressing common concerns like unexpected discomfort and inconsistent sleep patterns. It also ensures ideal room settings, demonstrating safety, convenience, and creativity. The project is committed to promoting digital childcare alternatives and revolutionizing the newborn care product industry by using IoT technology. The project aims to create a reliable and accessible solution for families from all backgrounds, ensuring the quality of early life care. The IoT Smart Baby Cradle project represents a significant advancement in providing parents with essential tools to improve infant care.

B. PAPER STRUCTURE

The paper is structured into several key sections. After the overview of IoT in infant care and the motivation in the I. INTRODUCTION, Section II. BACKGROUND provides a historical context of the evolution of infant cradles. Followed by III. PROBLEM STATEMENT that discusses the challenges and importance of smart cradles. Then, IV. LITERATURE REVIEW which analyzes existing projects and research about infant health. The V. METHODOLOGY section details the project approach including the survey conducted, hardware and software components and the implementation of the project. VI. RESULTS AND DISCUSSION reflects the project outcomes and VII. CHALLENGES highlights the challenges faced during the projects. Lastly, VIII. CONCLUSION AND FUTURE WORKS concludes the paper with further development.

II. BACKGROUND

Throughout history and in many societies, there have always been women who work, and the first cradle for a newborn baby has always been the mother's arm. However, in most communities, cradles have developed to serve multiple functions, aiming to enhance the mother's productivity and adapt to the area lifestyle. The baby cradle has seen significant transformations throughout time driven by the evolving requirements of newborn care. Back to history, the infant cradles have evolved, depicting cultural importance, from ancient rituals to protective and nurturing practices in different civilizations. In Cyprus between 2000 and 1600 BCE, terracotta figurines show mothers holding infants in cradleboards, used in rituals. Greeks employed beds on rollers and boats for carrying and swinging infants. Romans had two types of cradles: a moveable floor-standing cradle and a suspended bed [1].

Modern infant cradles have undergone a notable transformation, constructed from eco-friendly material and meet safety standards. One significant progress is the incorporation of technology, as several cradles now have IoT connection, remote monitoring, and integrated sensors to monitor an infant's vital signs. IoT technology is revolutionizing infant care by enhancing supervision and safety.

III. PROBLEM STATEMENT

In developed countries, there has been a significant rise in working mothers, altering traditional baby care and presenting challenges for dual-income families where both parents work full-time. This often leads to reliance on alternative childcare, such as grandparents or professional caretakers, yet concerns for the infant's safety and security remain for working parents. Moreover, the increasing incidence of health issues in infants, including the risk of Sudden Infant Death Syndrome (SIDS), heightens the need for vigilant monitoring. Challenges persist even when parents are home due to modern life pressures, affecting the ability to constantly monitor and respond to their baby's needs, especially at night. The common practice of infants sleeping in separate rooms can also delay parental response when needed. Addressing these issues, the proposed solution is the development of a real-time infant monitoring system, designed to offer continuous supervision and immediate notifications to parents about their infant's condition, including alerts for potential health risks such as abnormal sleep patterns or signs of distress. This system aims to bridge the gap between parental presence and the constraints of a modern lifestyle, using advanced technologies to ensure ongoing monitoring and enhance newborn safety, thereby alleviating parental anxiety. By providing instant alerts in critical situations, it allows for a prompt parental response, ensuring infants receive the necessary care quickly. This project seeks to innovate in newborn care and adapt parenting to the fast pace of modern society, with a particular focus on preventing SIDS and other health issues in infants.

IV. LITERATURE REVIEW

Adding to this technological transformation, recent advancements have been made in the development of smart cradles that integrate infant monitoring systems, addressing concerns like Sudden Infant Death Syndrome (SIDS), also known as crib death. SIDS is a critical issue in infant care, where seemingly healthy babies unexpectedly die during sleep. Research indicates that certain sleep-related factors can increase SIDS risk, such as the sleep position of the infant, the sleeping environment, and bedding materials. Smart cradles equipped with sensors and IoT platforms offer real-time monitoring and data analytics to alert parents and caregivers about sleep positions and environmental conditions, thereby helping to mitigate these risk factors [2].

Furthermore, the importance of understanding and adapting to the sleep patterns of infants has become a focal point in modern childcare technology. Recent research highlights the intricate relationship between an infant's sleep environment and their overall health and development. This includes not only the physical aspects, such as room temperature and bedding but also the role of sensory stimuli in promoting restful sleep. Technological advancements in cradles now seek to align with these findings, integrating features that create a conducive sleep environment while monitoring vital signs to ensure safety and comfort. This alignment with infant sleep research reflects a deeper understanding of the developmental needs of babies, further evolving the role of cradles in modern childcare [3].

In examining existing projects in the realm of infant care technology, it is essential to analyze their design, functionality, and limitations to understand how they contribute to the field and identify areas for improvement. The following review delves into three distinct projects, each offering innovative solutions for infant monitoring and care, yet also presenting unique challenges and shortcomings that highlight the need for continuous advancement in this critical area.

In this project [4], the author incorporates an Arduino-based system for an energy-efficient cradle that responds to infant cries using fundamental frequency analysis. It optimizes energy usage through a resonant design and integrates cry recognition for responsive care. However, this project doesn't address the complexity of infant cries beyond basic recognition. The system, while energy-efficient, may not accurately differentiate between various needs signaled by different cry patterns. Also, it lacks remote monitoring capabilities, which limits caregivers' ability to monitor and respond to the infant's needs when not in immediate proximity to the cradle.

This system [5] is designed for monitoring infants in incubators, focusing on tracking humidity levels and heart pulse rates. The data is collected and processed through an Arduino microcontroller, then relayed to a PC for further examination by medical personnel. However, this project doesn't offer a comprehensive monitoring solution. While it tracks humidity and pulse rate, it overlooks other critical health indicators such as oxygen levels or temperature. The system also lacks wireless data transmission capabilities, which would greatly benefit real-time monitoring in a dynamic hospital environment.

V. METHODOLOGY

In the design methodology of this project, three components are integrated, a survey, hardware development, and the application of existing software tools. The survey plays a key role in understanding user needs and preferences to meet real world requirements. For hardware, the focus is on building and assembling the physical components of the cradle. Instead of creating new software from scratch, the project utilizes Arduino for hardware control and Blynk for user interface and remote monitoring, providing a robust and tested solution for smart cradle operation.

A. SURVEY

Conducting a survey is an effective method in this project as it provides direct insights from potential users, helping to design and functionalize the smart cradle to meet the actual needs and preferences. To gain a deeper understanding of mothers' perspectives on smart cradle technology, a survey was conducted, garnering 181 responses [6]. This participation provided valuable insights into the preferences and needs of potential users and guided the project's development. The first question in the survey aimed to determine the age range of the respondents to understand the primary demographic of potential users, which could influence their familiarity with and openness to using technology in baby care. The analysis revealed that most participants fell within the 25-34 age group, *Figure 1*. This finding is significant as it suggests the product's primary users are likely to be young parents, good with technology, and searching for modern solutions to enhance their baby care experience. The second question in the survey focused on the age of the youngest child to identify the primary age group of children who would potentially use the smart cradle, which is crucial for tailoring its features to specific developmental stages. Analysis of this question revealed that most respondents have children aged between 1 and 3 years, *Figure 2*. This suggests a demand for a cradle that supports infants beyond their first year, possibly incorporating adaptable features that evolve as the child grows. The third survey question explored their interest in integrating smart technology into baby care routines to assess the enthusiasm among parents for using advanced technology in managing their infant care tasks. The results indicated a high interest in smart technology for baby care, demonstrating the potential for widespread acceptance of such a product among modern parents, *Figure 3*. The fourth question focused on the prior experience with smart baby care products to determine the level of familiarity and acceptance of such products among potential users. Analysis of the responses, *Figure 4*, revealed that a significant number of participants have already used smart baby care products. This indicates an existing user base that is already acquainted with technology in baby care, potentially lowering the hurdle for introducing new smart products in this space. The fifth question aimed to identify the key features that users consider essential in a smart cradle crucial to understand their priorities and expectations. The analysis revealed a strong preference for features related to temperature measurement, calming mechanisms, and monitoring capabilities, underscoring the importance of designing a smart cradle that prioritizes not only the safety and comfort of the infant but also addresses the parents' need for reassurance and ease of monitoring.

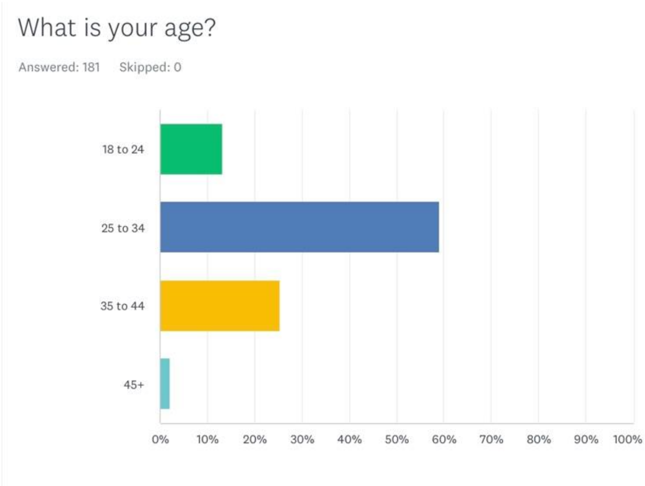

Figure 1 Survey Question about age

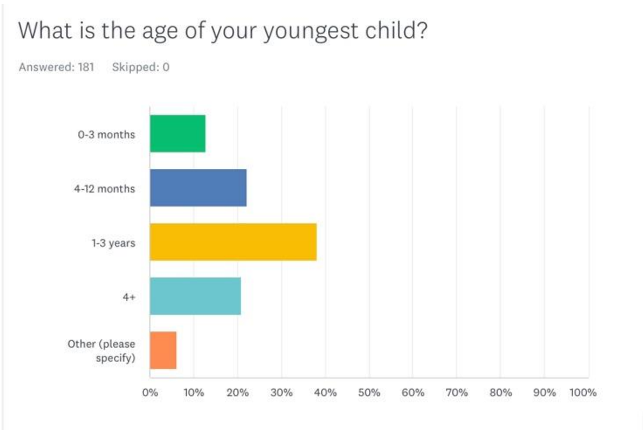

Figure 2 Survey Question about child age

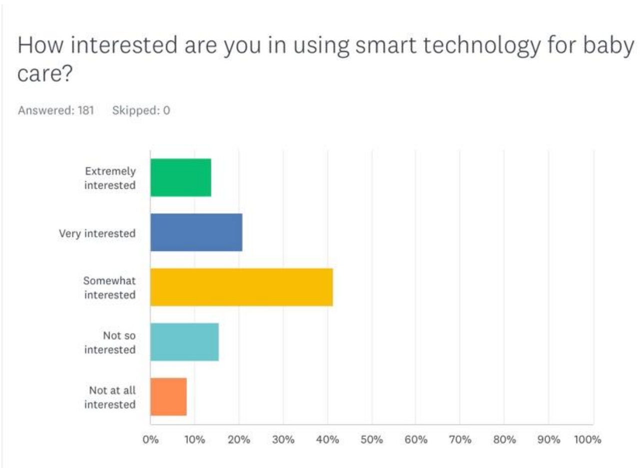

Figure 3 Survey question about interest in smart technology

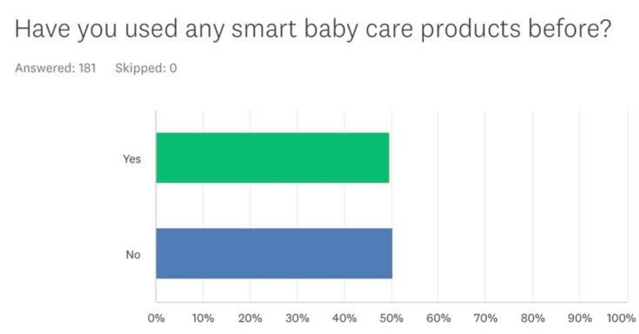

Figure 4 Survey question about smart technology usage

B. HARDWARE COMPONENTS

ESP32 Board

The ESP32 board in *Figure 5* is a microcontroller that is widely used in IoT projects due to its significant computing power. This board supports both Wi-Fi and Bluetooth which are essential for IoT devices that require remote data transmission and control. One of the key advantages of the ESP32 is its low power consumption, making it ideal for battery operated devices like smart cradles. It is used to gather and process data from different sensors, such as those monitoring temperature, humidity, motion, or sound, which are critical in ensuring the baby's safety and comfort. Additionally, the ESP32 can control mechanical components in the cradle, such as motors for rocking the cradle, thereby offering a soothing experience for the baby. Its ability to connect to the internet also allows for the implementation of features like remote monitoring and control, enabling parents to check on their baby's status and control cradle functions through their smartphones or other devices. The ESP32's integration into smart cradles exemplifies its suitability for innovative childcare solutions, combining technology and convenience to enhance infant care.

Figure 5 ESP32 Board

DHT11 Temperature and Humidity Sensor

The DHT11 sensor is a fundamental element of the IoT Smart Baby Cradle's environmental monitoring system. It is a digital sensor capable of measuring ambient temperature and relative humidity. The DHT11 is chosen for its simplicity and cost-effectiveness, making it suitable for consumer-grade products. In the cradle, it continuously monitors the nursery's ambient conditions to ensure they remain within safe and comfortable thresholds for the infant. *Figure 6* below shows the DHT11 sensor.

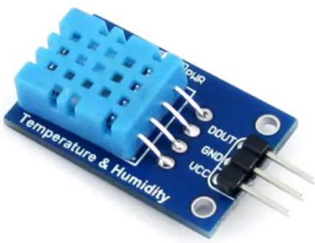

Figure 6 DHT11 Sensor

ESP32-CAM Camera Module

The ESP32-CAM module is a crucial component of the IoT Smart Baby Cradle's monitoring system. It is a small-sized camera module integrated with an ESP32 chip, offering both Wi-Fi and Bluetooth functionalities. The ESP32-CAM is selected for its compact size, wireless capabilities, and versatility. It enables real-time video monitoring of the baby, facilitating remote visual supervision by parents.

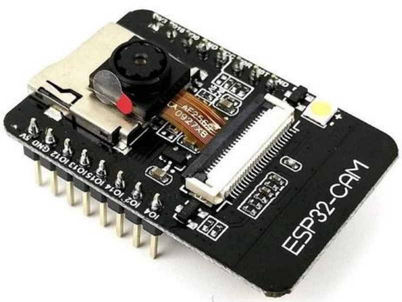

Figure 7 ESP32 Camera

Sound Sensor

The sound sensor module plays a vital role in the auditory monitoring aspect of the IoT Smart Baby Cradle. It is designed to detect noises within the nursery, especially those made by the baby. The sound sensor is chosen for its ability to accurately detect and respond to auditory cues, such as a baby's cry. In the cradle system, it ensures that parents are alerted to any significant noises, aiding in prompt response to the baby's needs.

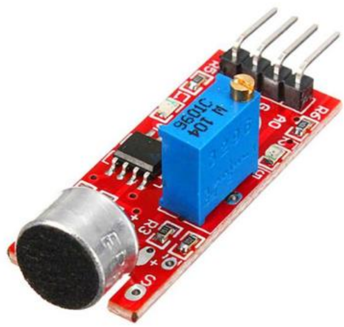

Figure 8 Sound Sensor

Servo Motor

The servo motor is a key component in the IoT Smart Baby Cradle, primarily responsible for the mechanical movements required for certain functionalities of the cradle. The servo motor is selected for its precision and reliability. It is used to gently rock or sway the cradle, simulating soothing movements to help the baby sleep or calm down.

Figure 9 Servo Motor

C. SOFTWARE

The software components I'm using in the smart baby cradle are discussed below. Each of these software components plays a fundamental role in the functionality of the smart baby cradle.

Blynk
A digital platform widely used in IoT projects which offers a user-friendly way to build mobile apps for controlling and monitoring IoT devices. Blynk provides an app builder with

a variety of widgets like buttons, sliders, graphs, and more, which can be connected to IoT hardware. In this project, Blynk acts as the interface between the user and the smart cradle. It allows parents to receive notifications, control actuators like the servo motor for rocking the cradle, and monitor sensor data such as temperature, humidity, and baby's mood.

Arduino IDE

Arduino IDE is an open-source development environment that is used to write and upload code to compatible boards. The Arduino software is used to program the ESP32 board. The code written in the Arduino IDE dictates how the ESP32 interacts with various sensors, processes the data, controls hardware like the servo motor, and communicates with the Blynk app.

IP Scanner

A software tool that scans a network to identify the devices connected to it and lists their IP addresses. It's often used for network troubleshooting and setup. It identifies the ESP32 camera's IP address on the network. Once the IP address is known, it can be entered into a web browser or an app to access the live video feed from the ESP32 camera. This is particularly useful for setting up the camera or troubleshooting network issues.

D. SYSTEM IMPLEMENTATION

1. The first step is to assemble the hardware components. This phase involves carefully connecting each element to the mini breadboard and ensuring each component is properly placed and securely connected. The ESP32 camera will not be connected to the mini breadboard. Instead, it will be placed on top of the cradle for optimal functionality, as it allows the camera to have an unobstructed view as shown in *Figure 10*.

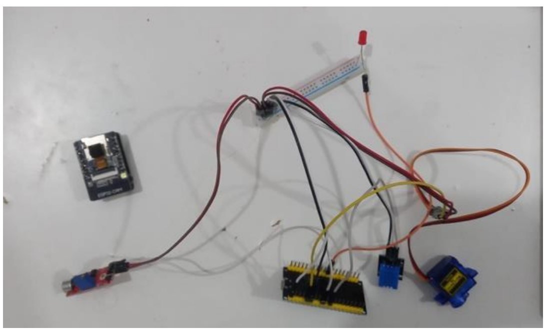

Figure 10 Hardware Components Assembly

2. The second step is installing the necessary libraries in Arduino IDE for handling WiFi connections, the Blynk app, DHT11, servo motor, and any required library for the ESP32 camera.

```
#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
#include <FirebaseESP32.h>
#include <ArduinoJson.h>
#include <DHT.h>
#include <Servo.h>
```

Figure 11 Arduino Libraries

3. Thirdly, write the initial code to interface the ESP32 with the servo motor and all sensors. This will involve reading data from the DHT11 sensor, detecting sound levels from the sound sensor and controlling the servo motor based on commands.

4. Each component is tested to verify that they are functioning as expected. In this stage, the code is uploaded to the ESP32 and then observe the outputs. This is the practical testing phase where the functionality of the components is verified individually.

5. Integrating the project with the Blynk app for remote monitoring and control. A new project is created in Blynk app, *Figure 12*, and it send an Auth token that is important for connecting ESP32 to the Blynk app. This step transforms the project into an IoT device, enabling remote monitoring and control.

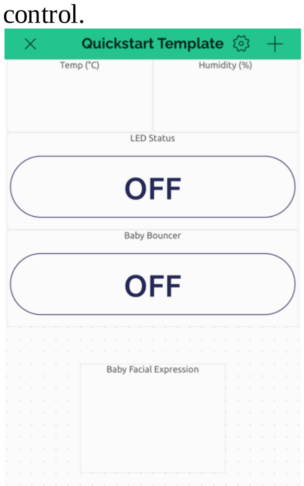

Figure 12 Blynk Setup

6. Then the ESP32 is programmed to stream the video by establishing a web server.

7. For face detection, a Convolutional Neural Network (CNN) pre-trained CNN model is selected from TensorFlow Library in a TensorFlow Lite format, which is optimized for low power devices like the ESP32 and is optimized to fit.

8. A prototype of the smart cradle is constructed from cork boards to provide a stable platform for the circuit and visually clarify the design of the smart cradle. The circuit was secured using glue gun and tapes as shown in *Figure 13*.

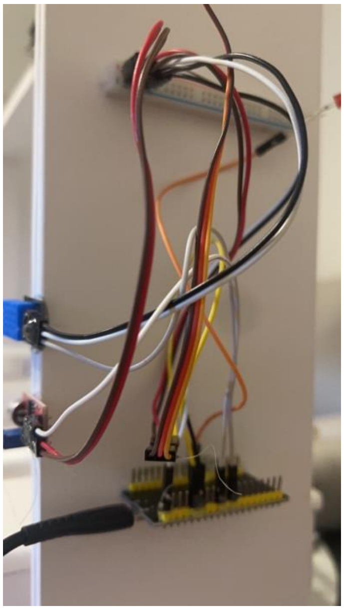

Figure 13 Circuit Placed on the cradle.

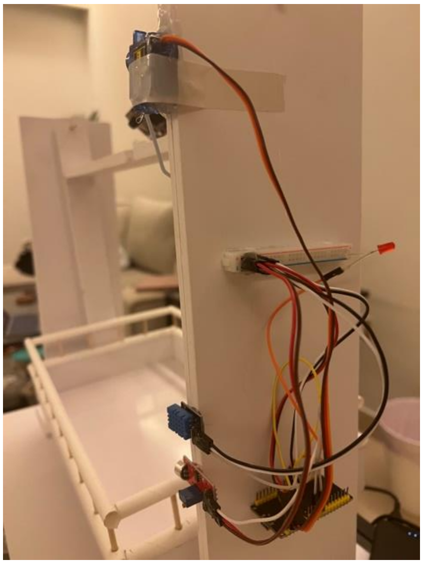

Figure 15 Side/ Circuit View of Smart Cradle

Figure 16 Top View of Smart Baby Cradle

VI. RESULTS

The figures below show the prototype of the Smart baby cradle.

Figure 14 Front View of Smart Cradle

To run the project, I scanned the IP address of the ESP32 camera to obtain its current IP address and then pasted this address into a web browser for live video streaming.
Subsequently, I simulated a baby crying scenario by playing the sound of a crying baby. This action triggered the Blynk app to send notifications, alerting that the baby is crying.
To test the mood detection feature, I positioned an image of a baby's face under the camera, *Figure 18*, which then analyzed the facial expressions and categorized the baby's mood as either sad, happy, or neutral. This feature simplifies parental monitoring, enabling them to quickly

ascertain whether the sound they heard was indeed the baby crying. Furthermore, when parents open the app, they have the option to remotely activate the servo motor, which gently rocks the cradle. This control adds a comforting element, soothing the baby without the parent needing to be in the room. In addition, the app provides real-time data on the room's temperature and humidity, ensuring the baby's environment is always optimal. These functionalities combine to offer a comprehensive monitoring system, augmenting traditional baby care methods with modern technological conveniences.

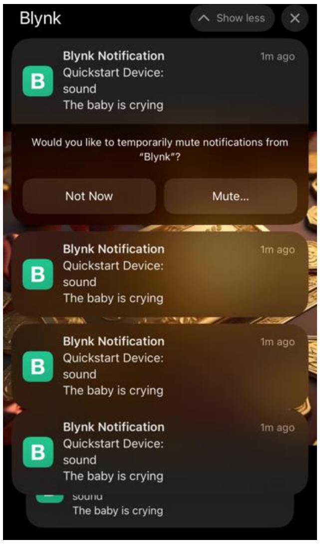

Figure 17 Blynk app notifications

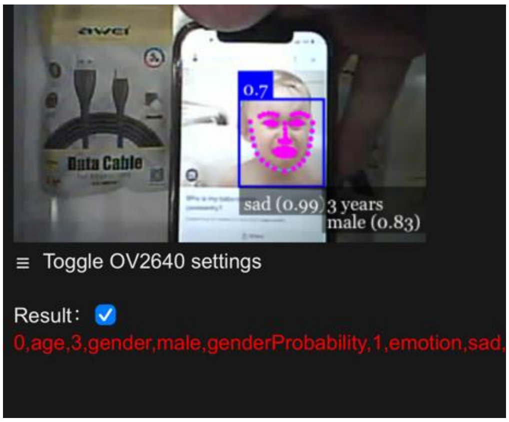

Figure 18 Infant Face Detection

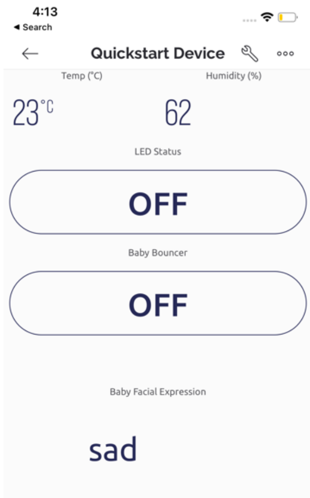

Figure 19 Blynk Controls

VII. CHALLENGES

1. Using cork boards posed challenges in terms of durability and stability. Components became loose or disconnected, affecting the reliability of the prototype.

2. The limitation of having to connect to a specific router is challenge, especially in different devices. The initial program was with a router that had its own name and password, and if I must keep connecting to the same router. Otherwise, I must change the username and password of any other router to be the same as the previous one.

3. The project was prepared in a lab which was difficult to test with actual babies in the lab is a limitation. Therefore, the testing was using images from a mobile.

5. The accuracy of the CNN in correctly interpreting a baby's mood was sometimes a challenge, particularly in varying light conditions or different baby postures. Some of them were smiling but labelled as crying.

6. Sound detection is sensitive, and the notifications were sent when there were random sounds that are not related to the infant.

VIII. CONCLUSION AND FUTURE DIRECTIONS

The IoT Smart Baby Cradle project represents a significant advancement in infant care by combining modern technology with traditional parenting practices. Utilizing the hardware, the system offers real-time monitoring of vital parameters like temperature, humidity, and infant vocalizations. This is particularly beneficial for working parents, who face the challenge of balancing childcare with professional responsibilities. The cradle's automated response to a baby's cries, using a motorized mechanism, is a notable feature that mimics comforting actions traditionally provided by parents. The integration of the Blynk server for data transmission and a user-friendly interface ensures ease of use and accessibility for parents.

Looking ahead, future work could focus on enhancing the system's health monitoring capabilities by incorporating sensors for heart rate and oxygen levels. The application of machine learning algorithms could offer predictive insights into infants' needs, based on data patterns, thereby improving the system's responsiveness and effectiveness. Additionally, enhancing network connectivity to support various home setups without manual reconfiguration would increase the system's adaptability. Conducting extensive real-world testing, including trials with actual infants and feedback from parents, would be crucial. Such improvements and validations could establish the IoT Smart Baby Cradle as an essential tool in modern parenting, offering safety, convenience, and peace of mind.

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