ISSN 2277-2685
IJESR/Jan-Mar. 2026/ Vol-16/Issue-1/504-512
Ms. K Srinidhi Reddy *et. al.*, / International Journal of Engineering & Science Research

Full Length Article

Smart Baby Cradle Monitoring System

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Accepted 27-03-2026

Abstract
The Smart Baby Cradle Monitoring System is an Internet of Things (IoT) based solution developed to enhance infant safety, comfort, and continuous supervision while minimizing manual effort from caregivers. The system incorporates multiple sensors to track important parameters such as infant movement, crying, ambient temperature, and bed wetness. When discomfort is detected, particularly through crying, the cradle automatically initiates a gentle rocking motion to calm the infant. Environmental conditions are continuously monitored to ensure a safe and comfortable atmosphere.If abnormal situations such as excessive crying, temperature variations, or inactivity are identified, instant alerts are transmitted to parents or caregivers through a mobile application or SMS notifications. The system supports real-time monitoring and remote accessibility, making it suitable for working parents and healthcare environments. By integrating embedded systems with IoT technology, the proposed design offers a reliable and cost-effective approach for infant care.The system also features a user-friendly interface that allows caregivers to observe the infant's condition remotely. Automated cradle movement combined with timely alerts reduces the risk of delayed attention and improves emergency response. The use of low-power sensors and economical microcontrollers makes the solution energy-efficient and affordable. Future enhancements such as live video streaming, cloud-based data storage, and health analytics can further improve system scalability and performance.

Keywords: *Smart Baby Cradle, IoT Infant Monitoring, Arduino, Cry Detection, Automatic Rocking, GSM Alert System, Moisture Detection, Embedded Systems, Baby Activity Monitoring.*

Introduction

Infant care demands continuous supervision, especially during the early stages of development when babies rely entirely on caregivers. Infants frequently require attention for soothing, feeding, or comfort due to wetness or discomfort. However, providing constant monitoring becomes challenging for parents, particularly working professionals, due to busy schedules and household responsibilities. Conventional cradles require manual rocking and lack any monitoring or alert mechanism, making infant care physically demanding and time-consuming.

To overcome these limitations, a Smart Baby Cradle Monitoring System is proposed. The system integrates sensors, actuators, and a microcontroller to automate cradle movement and monitor the infant's condition in real time. It detects crying, movement, temperature changes, and wetness, and sends instant notifications to caregivers. This automation ensures infant comfort while reducing the need for continuous manual supervision.The proposed system is applicable not only in homes but also in maternity hospitals and daycare centers where caregivers must manage multiple infants simultaneously. By automating routine tasks and providing real-time alerts, the system improves efficiency and enhances infant safety.

Problem Statement

Caregivers often struggle to continuously monitor infants due to work commitments and household responsibilities. Traditional cradles require manual effort and do not provide any form of monitoring or notification. Existing automatic cradle systems are expensive and lack integrated monitoring features. Therefore, there is a need for an affordable smart cradle system capable of automatic soothing, real-time monitoring, and timely alerts to ensure infant safety and comfort.

Literature Survey

Traditional Baby Cradles

Conventional cradles rely on manual rocking to comfort infants. Although simple and inexpensive, these systems require continuous human effort and do not provide monitoring capabilities. As a result, caregivers must frequently check the infant's condition.

Automatic Cradle Systems

Some studies propose automated cradles that initiate rocking based on sound detection. These systems reduce manual effort but often lack comprehensive monitoring features such as wetness detection or temperature monitoring.

Sensor-Based Monitoring Systems

Sensor-based infant monitoring systems detect parameters such as sound, motion, and temperature. While these systems improve safety, they typically operate independently and do not include automated cradle control.

GSM-Based Alert Systems

Communication technologies like GSM modules have been used to send SMS alerts regarding infant conditions. These systems provide remote monitoring but are often complex and expensive.

Embedded Systems

In modern society, embedded systems have become an integral part of everyday life. These systems are dedicated computing units incorporated within larger devices to perform specific control or monitoring functions. Unlike general-purpose computers, embedded systems are designed to execute predefined tasks with high efficiency and reliability. Because of their task-specific nature, they can be optimized for performance, size, power consumption, and cost.A significant percentage of processors manufactured today are used in embedded applications rather than traditional computing systems. These processors operate behind the scenes in various electronic products, making them invisible to users. Embedded systems are typically implemented using microcontrollers or microprocessors, with application software stored in non-volatile memory. In many cases, the system operates without a full-scale operating system, relying instead on firmware designed for a particular application.

Recent developments in embedded technology have been influenced by the availability of cost-effective hardware platforms. The adoption of personal computer–based hardware in high-end embedded solutions has significantly reduced development costs and increased flexibility. However, software support for embedded platforms often requires careful selection due to real-time constraints and hardware limitations.Embedded systems range from small portable devices such as digital watches and MP3 players to large industrial installations like traffic control systems and factory automation units. They are widely used in household appliances, medical devices, communication systems, and automotive electronics. In automobiles, for example, embedded controllers manage functions such as engine control, braking systems, airbag deployment, and infotainment features.Embedded system development presents several challenges, including limited resources, hardware-specific programming, debugging complexity, and the need for specialized development tools. These constraints require careful design considerations to ensure reliability and efficient performance.

Need for Embedded Systems

The growing demand for automation and intelligent devices has significantly increased the importance of embedded systems. Advances in microcontrollers, processors, and programmable hardware such as FPGA devices have enabled the development of compact and efficient solutions for a wide range of applications. These systems allow designers to implement custom functionalities using software rather than developing expensive application-specific hardware.Another major advantage is their ability to perform real-time operations. Many applications, including healthcare monitoring and industrial automation, require immediate response to sensor inputs. Embedded systems are specifically designed to meet these timing constraints while maintaining stability and accuracy.

Smart Baby Cradle Monitoring System

The Smart Baby Cradle Monitoring System is designed to improve infant safety and reduce the workload on caregivers by combining automation, sensing, and communication technologies. Early-stage infant care requires constant monitoring to ensure comfort and safety, but traditional cradles demand manual rocking and continuous supervision, which can be physically exhausting for parents. To address these challenges, the proposed system automates cradle movement and continuously monitors the baby's condition using embedded sensors. The system detects parameters such as crying, movement, and wetness, and sends alerts to parents through wireless communication. By integrating a microcontroller-based embedded system with sensors and a motorized mechanism, the design offers a cost-effective and reliable solution that enhances childcare efficiency while minimizing manual intervention.

Block Diagram:

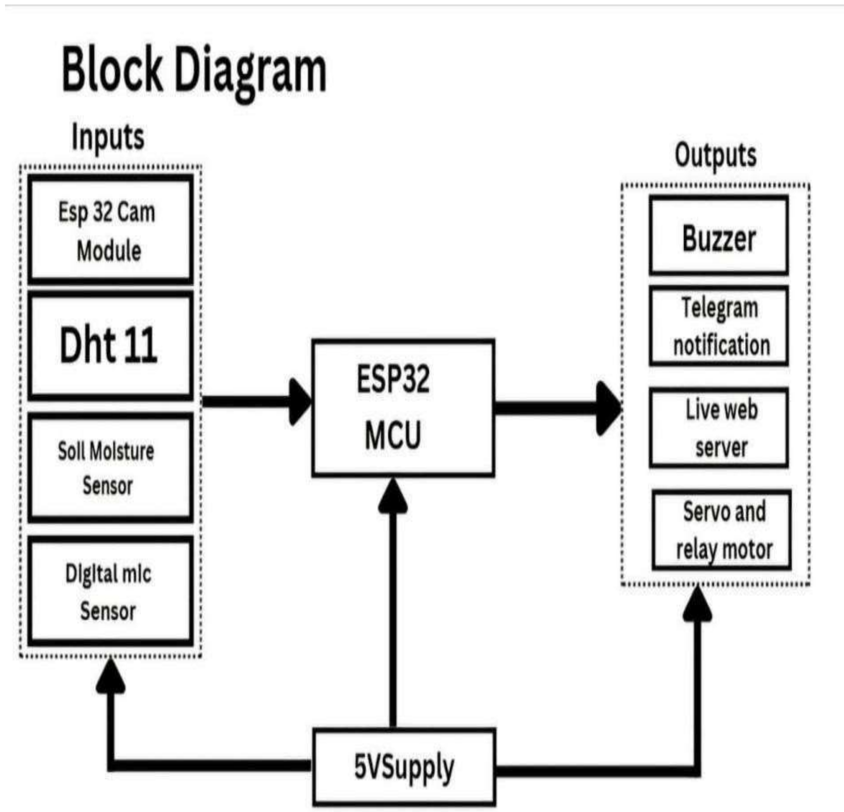

Fig 1: Block Diagram of Smart baby cradle monitoring system

Traditional infant care systems rely heavily on manual operation. Caregivers must rock the cradle manually to soothe the baby, which requires continuous effort, especially when the infant cries frequently. Additionally, constant physical supervision is necessary because conventional cradles do not provide any monitoring mechanism. This makes it difficult for caregivers to perform other household or professional activities. Traditional systems also lack activity detection features, meaning that parents must rely solely on observation to identify movement or restlessness. Crying can only be noticed if the caregiver is nearby, which may delay response time. Furthermore, conventional cradles do not include wetness detection, leading to discomfort and possible hygiene issues if not addressed promptly. These systems also lack alert mechanisms, preventing caregivers from receiving updates remotely. Although some automated cradles provide basic swinging functionality, they do not include intelligent monitoring capabilities. Moreover, commercially available smart cradles are often expensive, making them inaccessible to many families. These limitations increase physical strain and mental stress on caregivers and highlight the need for an improved solution.The proposed Smart Baby Cradle Monitoring System overcomes these limitations by integrating sensors, automation, and communication into a single platform. A microcontroller acts as the central control unit, coordinating all operations. The cradle is equipped with multiple sensors to monitor infant conditions continuously. A sound sensor detects crying, while a motion sensor identifies movement. A moisture sensor is used to detect wet conditions, ensuring timely attention and improved hygiene. When discomfort is detected, a geared motor activates to perform gentle side-to-side rocking, helping to soothe the infant automatically.The system architecture consists of input sensors, a processing unit, communication components, output devices, and a power supply. The input sensors collect data related to sound, movement, moisture, and environmental conditions. This information is transmitted to the microcontroller, which processes the data using predefined thresholds. When abnormal conditions are detected, the controller triggers output devices such as the motor for cradle movement and buzzer for alerts. Additionally, notifications are sent to caregivers through the communication module. A regulated power supply ensures stable operation of all components. This architecture allows continuous monitoring and immediate response to infant needs.

Circuit Diagram:

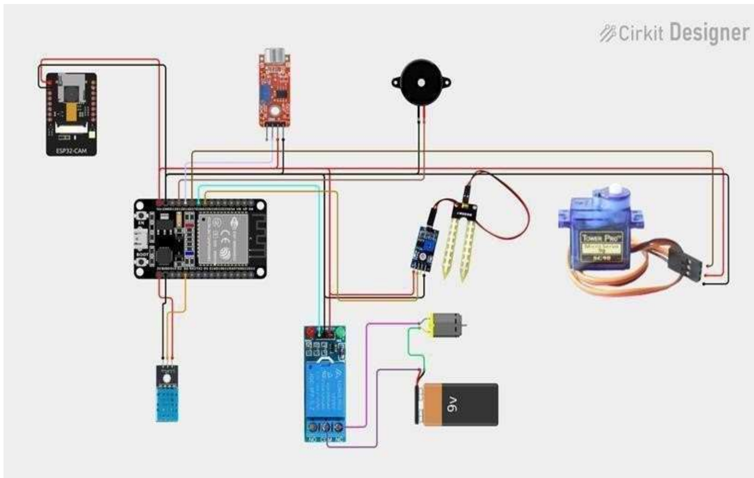

Fig 2: circuit Diagram of Smart baby cradle monitoring system

The circuit design connects various sensors to the microcontroller input pins, while actuators such as the motor and buzzer are connected to output pins. Communication modules are interfaced for remote alerting. Proper voltage regulation and grounding are maintained to ensure stable system performance. The methodology of the system begins with identifying the limitations of traditional cradle systems, followed by selecting suitable hardware components such as sensors, motor mechanisms, and communication modules. The architecture is designed in layers, including sensing, processing, communication, and output layers, ensuring modular and scalable operation.During hardware integration, sensors are connected to the microcontroller for real-time data acquisition. The motor is interfaced through a driver circuit to control cradle movement, and a buzzer is added for audible alerts. A regulated power supply provides voltage to all components. The complete system is tested to verify sensor accuracy, motor operation, and communication reliability. The testing phase confirms that the system responds correctly to different infant conditions. Result analysis shows that the sensors provide accurate readings, and the microcontroller processes data efficiently. Alerts are delivered reliably, and the automatic rocking mechanism effectively soothes the infant.Finally, the system is deployed by assembling all components within the cradle structure. The sensors, microcontroller, and communication modules are securely connected, and the system is configured for continuous operation. The deployed system demonstrates reliable performance under real-time conditions. By providing automated soothing, continuous monitoring, and remote alerting, the Smart Baby Cradle Monitoring System significantly improves infant safety and reduces caregiver workload, making it suitable for practical childcare applications.

Hardware Description

The Smart Baby Cradle Monitoring System is implemented using a combination of sensors, control units, actuators, and communication modules that collectively enable automated infant monitoring. These hardware components are selected to ensure accurate sensing, efficient processing, and reliable system operation. Sensors continuously monitor parameters such as sound, temperature, and motion, while the microcontroller processes this data and controls the output devices The system reduces manual supervision by automatically responding to events. When the baby cries, the sound sensor detects the noise and triggers the servo motor to gently rock the cradle. Temperature and humidity sensors maintain environmental comfort, while additional sensors monitor safety conditions. If abnormal values are detected, notifications are transmitted to caregivers. The modular hardware architecture allows easy expansion and improves reliability, making the system suitable for modern childcare applications.

ESP32 Microcontroller

The ESP32 is a high-performance, low-power system-on-chip microcontroller designed for Internet of Things and embedded applications. It

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integrates Wi-Fi and Bluetooth connectivity with powerful processing capabilities, making it suitable for automation and real-time monitoring systems.In the Smart Baby Cradle Monitoring System,

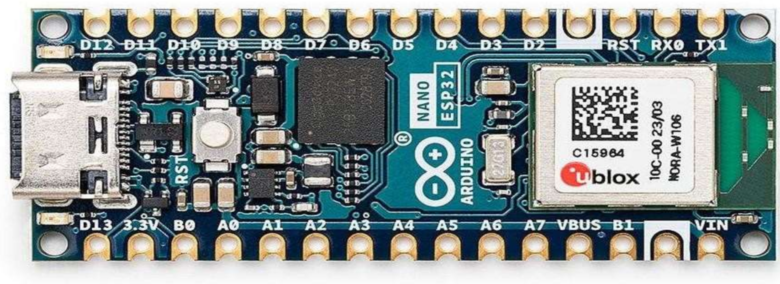


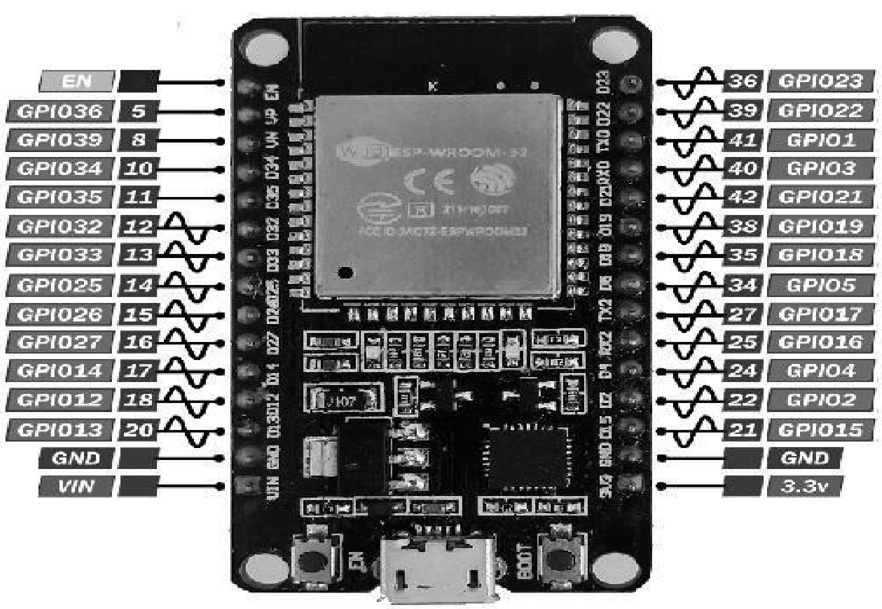
Fig 3: ESP 32 Board

the ESP32 acts as the central controller. It collects data from sensors, processes information, and controls output devices such as servo motors and buzzers. Additionally, it transmits alerts and monitoring data wirelessly to caregivers.The ESP32 provides up to 34 GPIO pins that can be configured for input or output. These pins operate at 3.3 V logic levels and support internal pull-up and pull-down resistors. ADC pins allow analog sensor interfacing, while PWM outputs enable precise control of actuators. Communication interfaces such as UART, SPI, and I2C allow connection with peripheral modules. Proper power supply and grounding ensure stable system performance.

ESP32-CAM Module

The ESP32-CAM is a compact camera module based on the ESP32 microcontroller. It includes an OV2640 camera sensor, onboard PSRAM, microSD card slot, and wireless communication capability. This module enables real-time visual monitoring of the baby.

Pin Diagram Of ESP32:



When powered, the module initializes the camera and communication interfaces. The camera captures images, which are processed and compressed into JPEG format for efficient transmission. The ESP32-CAM then streams the video wirelessly to a smartphone or web interface. The module can also store captured images on a microSD card for later review. This feature enhances safety by allowing caregivers to visually monitor the infant remotely.

Buzzer

A buzzer is an electroacoustic device used to generate audible alerts. It converts electrical signals into sound waves and provides immediate notification of abnormal conditions.

Fig 4 Buzzer

In this system, the ESP32 activates the buzzer whenever critical events occur. The buzzer functions as a local alert mechanism, ensuring notification even if internet connectivity is unavailable. This improves system reliability and safety.

Telegram Notification System

Fig 5: Telegram Notification System

The Telegram notification system enables remote alert delivery. Using Wi-Fi connectivity, the ESP32 sends messages to a predefined Telegram bot whenever abnormal conditions are detected. These alerts may include baby crying, temperature variations, or other safety-related events. This remote notification capability allows caregivers to respond quickly regardless of their location.

SG90 Servo Motor

The SG90 is a compact micro servo motor commonly used for precise angular control. It operates at 4.8 V to 6 V and provides rotation from 0° to 180°. The servo consists of a DC motor, gear mechanism, potentiometer, and control circuit.The servo motor is controlled using PWM signals from the ESP32. By varying pulse width, the motor rotates to the desired position. In this system, the SG90 provides gentle rocking motion for the cradle when the baby cries. Its low power consumption, compact size, and accurate positioning make it ideal for infant care applications.

Digital Microphone Sensor

The digital microphone sensor detects sound intensity and provides a digital output. It consists of a microphone, amplifier, and comparator circuit. When sound exceeds a predefined threshold, the sensor outputs a HIGH signal.

In the smart cradle system, the microphone detects baby crying. The microcontroller then activates the servo motor to rock the cradle and optionally triggers alerts. Digital sound sensors offer fast response, low power consumption, and reliable noise detection

DHT11 Temperature and Humidity Sensor

The DHT11 is a digital sensor used to measure ambient temperature and humidity. It contains a humidity sensing element, temperature sensor, and internal microcontroller that provides calibrated digital output.

The sensor communicates using a single-wire protocol. In this system, it monitors environmental conditions around the cradle. If temperature or humidity exceeds safe limits, alerts are generated. The DHT11 is cost-effective and suitable for basic environmental monitoring.

Soil Moisture Sensor

The digital soil moisture sensor measures moisture levels using conductive probes. The electrical resistance between probes changes depending on moisture content. An onboard comparator generates a digital output indicating wet or dry conditions.

Although primarily designed for agricultural applications, this sensor is used in the system for demonstration and additional environmental sensing. Its digital output simplifies interfacing with the ESP32.

Working

The Smart Baby Cradle Monitoring System was designed and implemented successfully, and experimental testing confirmed its reliable functionality. When power is supplied, all hardware components such as the ESP32 microcontroller, sensors, ESP32-CAM, servo motor, and buzzer are initialized. After initialization, the system enters continuous monitoring mode, where sensor data is read periodically to maintain real-time operation.The digital microphone sensor monitors sound levels near the cradle. When the baby cries and the sound intensity exceeds the predefined threshold, the microcontroller processes the signal and activates the SG90 servo motor. The servo motor produces gentle rocking motion within a safe angle range, which helps soothe the baby. If the crying continues beyond a certain duration, the buzzer is activated to alert caregivers, ensuring timely attention.

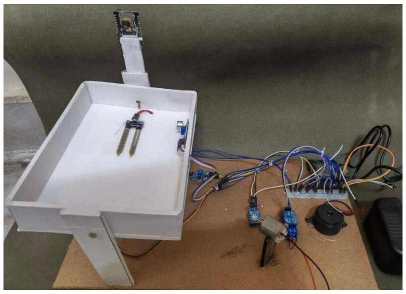


Figure 6: Smart Baby Cradle Monitoring system

The DHT11 sensor continuously measures temperature and humidity around the cradle. If environmental values move beyond safe limits, the system generates alerts through the buzzer and also sends notifications to caregivers. This feature ensures that the infant remains in a comfortable and safe environment.

The ESP32-CAM module provides real-time video monitoring. It captures images and streams live video over Wi-Fi, allowing caregivers to observe the baby remotely using a smartphone or computer. This capability enables continuous supervision even when caregivers are not physically present.

Figure 7 : Telegram notification and Live Camera access

All system operations run in a continuous loop, ensuring uninterrupted monitoring. The microcontroller also checks the operational status of connected components. If abnormal readings or sensor failures are detected, the buzzer generates a warning. This self-monitoring capability improves system reliability and prevents unnoticed faults.

Results

The implemented Smart Baby Cradle Monitoring System was tested under different scenarios to evaluate performance. The experimental setup demonstrated that the system accurately detected baby crying and responded automatically. Whenever the sound level exceeded the preset threshold, the digital microphone sensor generated a signal that triggered the SG90 servo motor. The cradle was rocked smoothly, providing comfort without manual intervention. During prolonged crying, the buzzer alert was activated, ensuring caregivers were notified immediately.

The DHT11 sensor successfully monitored environmental temperature and humidity. During normal conditions, readings remained within acceptable limits. When temperature or humidity values exceeded predefined thresholds, the system generated alerts, confirming effective environmental monitoring. This functionality ensured that the cradle environment remained safe and comfortable.

The ESP32-CAM module streamed live video successfully over Wi-Fi. Caregivers were able to remotely access real-time video through mobile devices or computers. This feature enhanced system usability by allowing continuous visual supervision. Additionally, Telegram notifications were transmitted correctly whenever abnormal events occurred, demonstrating reliable wireless communication.The combined operation of sensors, actuators, and communication modules confirmed the effectiveness of the proposed system. The automatic cradle rocking mechanism reduced manual effort, while alert features improved safety. The system maintained stable performance throughout testing, with minimal delay between event detection and response.

Conclusion

The Smart Baby Cradle Monitoring System demonstrates the practical application of smart embedded technology in infant care by combining sensing, automation, and alert mechanisms. The system continuously monitors important parameters such as crying sound, temperature, humidity, moisture levels, and cradle movement, ensuring that the baby's needs are identified and addressed promptly. When the baby cries, the sound sensor detects the audio signal and activates the servo motor to gently rock the cradle, helping to soothe the baby automatically. At the same time, the buzzer and notification system alert caregivers, ensuring timely human intervention whenever required. This dual approach of automated response and caregiver notification improves reliability and enhances confidence in the system. By minimizing the need for constant manual supervision, the system allows parents to manage their time effectively while maintaining proper attention toward infant care.

The integration of multiple sensors enhances system robustness by providing real-time environmental monitoring, which is especially useful during nighttime or when caregivers are busy. The use of low-cost hardware components and simple control logic makes the system affordable, energy-efficient, and easy to implement. Furthermore, the modular architecture allows future expansion, enabling additional features such as mobile application support, camera-based monitoring, and cloud data storage. Overall, the Smart Baby Cradle Monitoring System provides a practical and innovative solution that improves infant safety, comfort, and monitoring efficiency while demonstrating the importance of smart automation in modern childcare applications.

Future Scope

The Smart Baby Cradle Monitoring System offers significant opportunities for future enhancements to further improve safety and convenience. One possible improvement is the integration of IoT technology with a mobile application, allowing caregivers to monitor real-time data such as baby movement, temperature, humidity, and crying alerts from anywhere. This remote monitoring capability would increase convenience and ensure quick response. Additionally, incorporating a camera module with night vision support would provide live video streaming and recording, enabling visual monitoring along with sensor-based alerts, especially during night hours.

Advanced sound processing or artificial intelligence techniques can also be implemented to classify different types of baby cries such as hunger, discomfort, pain, or sleep-related signals. Based on the analysis, the system could respond more intelligently by adjusting cradle movement or sending specific notifications. Further improvements may include integrating wearable sensors to monitor vital parameters such as heart rate, body temperature, and oxygen levels, thereby transforming the cradle into a basic health monitoring platform. Cloud connectivity can also be introduced to store long-term data, allowing analysis of sleep patterns, crying frequency, and environmental conditions, which may assist caregivers and healthcare professionals.

Future versions may also incorporate improved power management features such as battery backup or solar power to ensure uninterrupted operation during power failures. Additional safety mechanisms and smart home integration with voice assistants could provide hands-free control and improved usability. With these enhancements, the Smart Baby Cradle Monitoring System has the potential to evolve into a comprehensive intelligent childcare solution, offering advanced monitoring, improved automation, and enhanced infant safety.

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