

IoT Integrated Infant Cradle for Jaundice care

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Abstract

Neonate and infant care are subject to continuous monitoring so as to assure the wellbeing and safety of neonates, especially of neonates from a disease such as neonatal jaundice and to avoid environmental risk factors which could lead to sudden infant death syndrome (SIDS). They include, the automation of baby monitoring modules and automatic newborn monitoring, along with a supportive care system and air quality management for babies. The cradle itself includes cry detection sensor, wetness sensor, and camera module to monitor infant activity, it is also equipped with a swing mechanism to soothe the baby. Integrated blue LED phototherapy unit to help treat mild neonatal jaundice. An air purification module based on HEPA filters is also included in the package to limit the impact of harmful airborne pathogens, allergens, and particulate matter. Low indoor pollutant environment is another aspect key to lowering the risk factors for SIDS. Through a mobile app, IoT platform real-time continuous data is transmitted to them. This makes remote management possible. The proposed system is intended to relieve caregiver workload and improve infant safety, while offering an effective, integrated neonatal care solution. It meets all the criteria for home-based phototherapy as well as hospital- or reduced-resource solutions in different environments.

Keywords: Air purification, Infant monitoring healthcare, Neonatal Jaundice, SIDS prevention.

1. Introduction

Advances in the technology of IoT system, sensing, sensor systems have greatly increased. The advances in sensing system technology including the AOQ and the sensors are advanced such as smart touch and sensors are the latest and current techniques in sensing technology have increased, in the IoT application, so can be found on various IoT sensors for data fusion with real-time vision. The development of remote infant care can help caregivers to manage baby activities and respond to the risk according to what has become a reality. Infant care is an essential part of any healthcare service network. newborns that require continuous monitoring for health care professionals to ensure that their needs and physical growth are met. Traditional cradle systems rely on parent/carer supervision and the absence of the provision of real-time monitoring and environmental control, causing caregivers' further workload and reducing

intervention time needed for emergencies. Recent years of smart cradle research in the previous 2 years (2021-2025) have witnessed remarkable developments regarding smart cradle systems aimed at enhancing infant care and safety. The early automated cradle system could detect infant crying and wetness and provide real-time alerts to the caretaker, thus making the overall manual effort less (Aarthy&catherine,2021). The creation of IoT connectivity and camera monitoring and remote supervision facilitates it (Sarwar et al., 2022). The sensor implementation as well as the advanced cloud-based monitoring platform has made the quality and comfort in the infant care environment better (Kamrul Ariffin and Markom, 2024; Kannagi et al., 2025). Infant jaundice is a universal medical condition across the globe. Which necessitates time-based phototherapy treatment in order to avert complications due to elevated serum bilirubin levels.

LED-based phototherapy treatment is commonly applied, mainly for its energy efficiency, wavelength, and the control of the exposure of light is appropriate for medical practice (Tsai et al., 2019). An existing technology is mostly concerned with tracking which has an inadequate environmental safety support. Other than infant monitoring, keeping the environment clean is also important for the health of an infant. Recent works on indoor air cleaning reveal the needs to eliminate airborne pollutants, and pathogens in order to improve indoor air quality and save the lives of vulnerable groups (Wang et al., 2021). Besides, incubators and like neonatal care environments illustrate the significance of maintaining of environmental conditions to improve neonatal quality and minimize work load (Ramaveerapathiran, 2024; Zimmer et al., 2020). These results inform us about the necessity to have a system with monitoring and environmental management. In efforts to address these issues, this study develops an IoT-integrated infant cradle that includes automated monitoring, therapeutic support with a controlled environment in a singular environment. The Idea includes sensors for monitoring infant activity, a phototherapy unit to support the treatment of mild neonatal jaundice and an air-purification module of HEPA filter (H13) grade for controlling airborne pathogens and pollutants and enhancing air quality. For caregivers, real-time infant monitoring allows them to remotely monitor the infant's status and respond as needed. It also highlights the automated swing mechanism and the use of the lullaby toy to soothe the infant. The proposed system provides an end-to-end neonatal care solution applicable to home-based care, hospitals and resource-limited settings.

1.1. Need for Constant Surveillance of Neonates

Ongoing monitoring of neonates is crucial to catch health abnormalities and to provide them with early intervention. Infants are early on vulnerable in life, in which basic physiological processes are under-developed and have to be watched for long time. The latest advances of smart cradle technology have shown that the sensors (cry detection, wetness and motion tracking systems) can be able to provide the caregivers with monitoring for the proper care and

minimise manual work burden (Aarthy & Catherine, 2021; Sarwar et al., 2022). Implementation of IoT-enabled monitoring systems further improves their working performance providing real-time transmission of data with the possibility of remote monitoring, ultimately improving care to guarantee continuous care (Kamrul Ariffin & Markom, 2024; Kannagi et al., 2025). These changes are the critical advancements of intelligent monitoring systems to modern neonatal services.

1.2. Mild Neonatal Jaundice Control by Phototherapy

Neonatal jaundice is one of the most concerning medical conditions faced by the newborn who may bring them to a life-threatening stage. It is from the abnormal level of bilirubin in blood, which they have and that can cause damage to the newborn. Untreated, extensive hyperbilirubinemia is associated with a number of neurological disorders. Phototherapy treatment is the most common non-invasive treatment that utilizes the use of light at a specified wavelength to enable the degradation of bilirubin. The technique that has become most commonly used in phototherapies is Blue (UV-light). The light emitting diode (LED) is energy-consumption-effective, wavelength controlled and heat-limited. Research on LED-based light therapy systems points out controlling the intensity and wavelength of light is necessary to guarantee the safety of treatment and efficacy (Tsai et al., 2019). This indicates that a blue LED phototherapy unit integrated inside an infant cradle may offer supportive treatment of mild jaundice in addition to a comforting and safe environment. It plays an important role in air quality and SIDS risk reduction.

1.3. Importance of air quality and SIDS reduction

Adequate indoor air quality must be controlled in the neonatal environment. Because babies' lungs are sensitive to airborne pollutants, allergens and pathogens, respiratory distress may occur. Environmental risk factors could also play a role in sudden infant death syndrome (SIDS) in some cases. Studies of air purification systems underscore the increasing necessity of minimizing airborne particulate material and airborne contaminants for the protection of susceptible peoples, especially in closed

environments (Wang et al., 2021). Hospitals have Neonatal Incubators used to obtain controlled environment by providing the temperature, humidity and air quality, which highlight the significance ensuring an environment stability for the health of infants (Wolde Amanuel & Ramaveerapathiran, 2024). The installation of HEPA filter-based air purification module in a smart cradle will assist to build cleaner environment that can reduce respiratory distress of infant which will lead to decreasing levels of inhalation of harmful particles and thus provide more assurance of infant safety.

1.4. Applications of IoT in automated infant cradle systems

The incorporation of Internet of Things (IoT) technologies in healthcare is one of the primary reasons for the development of smart monitoring platforms for remote supervision and real-time data management, thus, an Internet of Things based infant care system facilitates to monitor parameters such as infant activity, environmental conditions and device status with mobile applications that could be utilized by caregivers to make it easier to connect to the babies through smart monitoring platforms, improve accessibility and response time. It helps enhance system functionality, e.g., alerts, data logging and continuous monitoring in smart cradles are all based on IoT connectivity. This increases caregivers' efficiency to the infant and increases proactive management of health care (Sarwar et al., 2022; Kamrul Ariffin & Markom, 2024). This implementation of IoT in neonatal care is a significant step forward in intelligent and interconnected health care technologies.

2. Methodology

2.1. System Overview

It is an IoT Smart cradle system to monitor, offer assistance, and control the environment for newborns. It has a joint body of sensing module, automated soothing unit, phototherapy unit for jaundice, and air purification system in the same platform. It has an ESP32 microcontroller as the central processor which is responsible for real time data acquisition, processing and wireless communication. Using MIT App Inventor, a mobile application enables care providers to track how their baby is doing remotely – and send alerts. The

prototype was designed and tested for functionality in the prototype under consideration and validation works are presently in progress.

2.2. Hardware Architecture

These units include sensing units, components to actuate the device, and user interface capabilities. The sensing subsystem features a microphone for detect cries, temperature and humidity sensor for environmental monitoring, gas sensor to assess air quality, and raindrop sensor acting as a wetness detection system to measure diaper moisture contents. These sensors constantly send data to the ESP32 controller. A processing unit built on the ESP32 combines sensor information and controls everything. An LCD-display will provide real time indicators of temperature, humidity, and air quality in real time. The actuation subsystem includes a servo motor that aids in the gentle movement of the cradle to quiet crying infants with a calming 4-ohm 10-W speaker that plays lullabies.

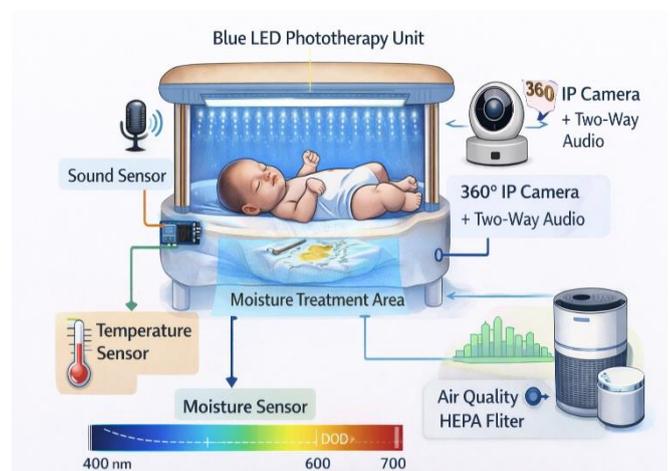


Figure 1 System Architecture

2.3. Design for the Phototherapy Module

We utilize blue light-emitting diodes (LEDs) on a 460–490 nm wavelength range in phototherapy units which is an effective spectrum for bilirubin breakdown as part of treatment of neonatal jaundice. The LEDs are switched on at approximately 20 mA and positioned 30 cm from the baby to avoid overexposure while maintaining therapeutic effectiveness. This module's operation is governed for a set period by the ESP32 controller to protect against overexposure.

2.4. Module design for air cleaning

Air purification equipment consists of an H13 grade High Efficiency Particulate Air (HEPA) filter with a 12 V exhaust fan, allowing for continuous air circulation and filtration. The module purifies airborne particulates, allergens, and pathogens from the cradle's environment. In addition, a gas sensor measures air quality, while the purification system is always running to keep clean the neonatal care microenvironment.

2.5. System Operation

In operation, the monitoring device observes not only infant activity, but also the environment. When the microphone module detects a cry, the ESP32 then activates the servo motor for motion of the child in the cradle and playback of lullaby to the speaker. The wetness detector senses moisture, which alerts the caregiver through notifications via the mobile app. Temperature, humidity, and air quality data are shown on an LCD screen and sent wirelessly so that caregivers can access them remotely. In cases where support with jaundice treatment is needed, the caregivers engage the phototherapy unit as and when necessary, whilst also maintaining a conducive atmosphere by continuing the purification module operation.

2.6. Software and IoT integration

The hardware integrates a code embedded in ESP32 with ESP32 embedded software to pick up sensor data and also deal with signals and communication tasks. The wireless layer allows a real-time data transfer across a mobile application with MIT App Inventor. It offers a viewing of important parameters with notifications by the app, as well as remote supervision of the health of the babies by the parents. Table 1 presents the major hardware components used in the proposed IoT-integrated smart infant cradle system along with their functions and specifications. The ESP32 microcontroller acts as the central processing unit, while the cry sensor and moisture sensor are used for detecting baby crying and urination conditions. The blue LED unit provides phototherapy for neonatal jaundice treatment. Additionally, the air quality sensor and air purifier ensure a safe and hygienic environment for the infant.

2.7. Prototypes Development and Testing

This smart cradle system has already been

implemented, and is a prototype of the system and operational potential in terms of integration with the hardware. In this stage, reliable sensor readings were verified along with responsive actuation mechanism and reliable wireless transmission. The next steps will consist of comprehensive performance validation along with

Table 1 Components and Specifications

Component	Function	Output Type	Purpose
Cry Sensor	Detects baby crying	Analog/Digital	Auto soothing
Wet Sensor	Detects urination	Analog	Hygiene alert
ESP32	Data processing & IoT	Digital	Control unit
Blue LED	Phototherapy	Light output	Jaundice treatment

3. Results and Discussion

3.1. Results

The prototype for the IoT-integrated smart infant cradle was successfully designed, assembled and tested to evaluate the system performance and the integration of various monitoring, therapeutic and environmental modules. The ESP32 microcontroller showed stable behavior in reading data received from a multitude of sensors, such as temperature, humidity, gas concentration, cry detection, and wetness monitoring. Environmental parameters were displayed on the LCD interface as they were measured, thus providing local monitoring, and the same information could be transmitted to the mobile application for remote supervision. The cry detection module was set up using a microphone sensor, which detected the changes in intensity of the sound due to infants crying. When detected, the controller powered on the servo motor to start cradle movement with gentle motion, then it sent lullaby plays through the 4-ohm 10-W speaker. Short response time between cry detection and the actuation was found, indicating efficient real-time system response. This feature verifies the possibility of the automatic soothing in the system and possibly diminish caregiver intervention. Based on the raindrop sensor, the wetness detection system could accurately detect moisture conditions that mimic the wetness in diapers. As soon as wetness was detected, alerts were

activated and sent to the mobile app to alert the caregiver of the need for attention. Continuous monitoring of temperature and humidity was used to provide environmental feedback and keep the cradle environment within comfortable ranges for infant care. The phototherapy module consists of blue LEDs that operate at a wavelength range of 460–490 nm showing stable illumination behavior. At a distance of about 30 cm and 20 mA of operating current, the LED array generated uniform distribution of light without producing excessive heat, which made it suitable for mild jaundice support. Operational capability was safe and demonstrated the controlled activation of the phototherapy unit.

3.2. Discussion

The proposed smart cradle project illustrates the possibilities to bring together several healthcare-support-features in a compact and accessible neonatal healthcare solution. This system eliminates many of the limitations of monitoring of infants, including multiple monitoring problems, by integrating sensing technologies, automated responding and remote interaction enabling the enhancement of safety and awareness of caregivers. Compared to conventional cradles that depend upon almost 100% manual supervision, the novel system achieves automated monitoring which enables continuous infant monitoring.

Table 2 Experimental Results of Cradle System

Test Condition	Sensor Input	System Action	Result
Baby Crying	High sound detected	Cradle swings	Successful
Wet detected	Moisture high	Alert sent	Successful
Phototherapy ON	Blue LED active	Light exposure	Stable

Table 2 presents the experimental results of the system, demonstrating successful detection of baby crying, wet conditions, and stable operation of the blue LED phototherapy unit in real-time monitoring. The use of cry surveillance/alarm recognition and automatic swinging provide instant infant comfort, which can lead to improved sleep as well as decreased stress. With the addition of lullaby playback, it makes the soothing effect more exaggerated by replicating caregiver presence. The system conceptually lies on

the integration of a phototherapy module inside the cradle. Traditional phototherapy methods usually require specialized clinical equipment which is not easily accessible (or hard to come by) at home and resource-constrained environments. By integrating a blue LED phototherapy unit, the system is used as adjunct to treatment for mild jaundice with convenience and portability. This incorporation accentuates the potential of decentralized neonatal care solutions that range beyond hospital-mediated care settings. An H13 HEPA-based air purification module is added as well, to address health aspects of environmental treatment. Infants are at all-risk for exposure to airborne particles, particulate matter and allergens owing to the developing respiratory systems of this age group. Keeping the air around the infant clean might help minimize exposure to irritants and make sleeping more comfortable. The integration of air purification and environmental monitoring closely follow the approach used in neonatal incubators, where proper control is paramount for infant health. ESP32 and mobile application provide the IoT connectivity for caregivers to monitor infant condition remotely with a view to reducing response time and providing reassurance. The real-time notifications mean that caregivers will be aware of changes (such as crying or wetness) and their action, whether they are physically present or not, will be prompted instantly. This feature offers great benefits to working mothers and carers caring for several infants. Although the prototype proved to be quite effective, some deficiencies need to be acknowledged. The present evaluation is more focused on functional testing versus extensive clinical validation. The long run performance, stability in continuous operation and clinical efficiency of phototherapy module need to be addressed next. This will make analysis of new signal processing in the future work, including the need to address environmental aspects which might affect cry detection accuracy, for example ambient noise. The addition of machine learning algorithms will greatly enhance cry classification and thus discrimination between hunger, discomfort and medical distress. For continuous improvement, the application of non-invasive physiological monitoring (e.g., heart rate, oxygen saturation) will be a strong consideration.

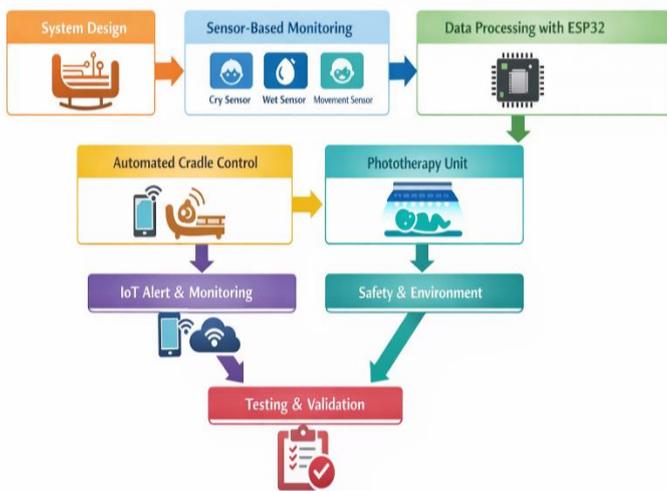


Figure 2 Operational Framework of Smart Infant Cradle

Increased sensor calibration and safety levels will also require practical implementation. In addition, improved energy consumption and efficient thermal management may optimize the system and improve reliability. Adding aspects such as data logging and trend analysis to the mobile application would allow caregivers to monitor infant health trajectory over time to better enable preventive strategies. In effect, the smart cradle described presents a holistic approach to newborn care, integrating monitoring, therapeutic support, and environmental management at the same place, in one interface. Incorporating a number of such integrated systems has been shown in the prototype results demonstrate potential benefits to enhance infant safety, decrease caregiver burden, and increase access to vital neonatal support technologies.

Conclusion

Proposed and developed an IoT-integrated smart infant cradle to improve neonatal care by providing real-time monitoring, automated comfort, therapeutic support, and environmental management. By combining multiple sensing modules such as cry detection, wetness monitoring, temperature and humidity sensing, and air quality assessment, this system allows the real-time monitoring of the infant characteristics, thereby cutting back on the human intervention by monitoring every second of the infancy condition. An ESP32 microcontroller and mobile application for easy wireless communication

and monitoring the baby from a distance will prompt the carers to receive alerts when necessary. One significant contribution was the introduction of a blue LED phototherapy module with therapeutic wavelength range of 460–490 nm for support of mild neonatal jaundice. Furthermore, to keep indoor air cleaner and safer by removing airborne pollutants and environmental hazards, an H13 HEPA-based air purification module has been integrated. Automated cradle swinging and lullaby playback provide gentle comfort by responding to an immediate cry from the infant. The prototype developed showed dependable operation of the sensing, actuation, and communication modules in a compact system, thus proving the possibility of integrating monitoring, therapy, and environmental control in a compact system. This design facilitates neonatal care in home, hospital, and resource-limited settings by improving caregiver awareness as well as increasing infant safety; but full evaluation of the therapeutic efficacy and safety of the system should be performed for a full clinical validation and long-term performance assessment. The further development plans of future work include controlled testing and refining sensor calibration together with advanced features like intelligent cry analysis and additional physiological monitoring to increase system functionality even further. The smart cradle presents a promising solution that introduces modern IoT solutions into the neonatal care setting in such a way that supports a high degree of health with low technology overload. The air purifying modules had constant airflow around the cradle as it connected to an H13 HEPA filter and a 12 V exhaust fan. The gas sensor readings showed better operating air quality, which can indicate good removal of airborne pollutants. The wireless communication between the ESP32 and the mobile application was reliable, with consistent data updates and alerts. On the whole, the prototype achieved successful integration of a platform with monitoring, automation, phototherapy support, and purification in a new form factor, supporting the feasibility of the proposed design.

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