



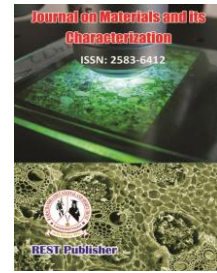
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Portable Incubator for Premature Infants

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Abstract: Premature infants require specialized neonatal care, often through incubators that maintain ideal environmental conditions. However, conventional hospital incubators are costly and not readily available in remote regions. This project presents a low-cost, IoT-based portable incubator for premature infants using edge computing with the Raspberry Pi Zero 2W. The system monitors physiological parameters such as body temperature, blood oxygen, and heart rate, along with cabin temperature and humidity. Actuators like a heater and fan are controlled to maintain optimal conditions. A multi-output neural network trained with sensor data enables prediction of medical needs and environmental adjustments. The system supports local decision-making, real-time control, and remote access via a Telegram chatbot, enhancing neonatal care in low-resource settings.

Keywords: IoT, Incubator, Neonatal Care, Edge Computing, Raspberry Pi Zero 2W, Machine Learning, Predictive Analytics, Remote Monitoring

1. INTRODUCTION

Taking care of a premature is a delicate and challenging task. They need to be kept carefully in a controlled environment to survive and grow. It should maintain a right temperature, monitor their vital signs and alerts to the caregivers. The traditional incubator provide these but they are high cost and available only at hospitals. Since technology is advancing we can make advancement in neonatal care. Our project's aim is to use IoT, edge computing and predictive analytics to develop a portable, intelligent incubator.

A. Limitations of the Existing Incubators

The incubators we use at hospitals are large, expensive and power consuming. They are well equipped medical setting but not portable. The limitations include:

- High Cost: Since these incubators are highly expensive they are not affordable by most families.
- Fixed Location: Most incubators require hospital-grade power supplies and constant supervision by medical staff.
- Lack of Remote Monitoring: Traditional systems rarely support remote alerts or control, making real-time caregiver response difficult.
- Manual Intervention: Environmental adjustments often need to be made manually, delaying critical responses to sudden changes in the infant's condition.

B. The Role of IoT in Incubator

The Internet of Things (IoT) is transforming the way we interact with the world around us. The healthcare is seeing some of the most meaningful changes. In our incubator system, intelligent sensors keep a close eye on key health indicators such as temperature, humidity, heart rate, and oxygen levels. These vital information is continuously gathered and shared through a Telegram chatbot, allowing caregivers to check on the infant's condition no matter where they are. If anything goes outside the safe range, alerts are triggered instantly, enabling quick action when it matters most. By sharing real-time physical health data to digital communication tools, our

system helps to bridge the distance between infants and caregivers, making remote monitoring both simple and reliable.

C. Role of Edge Computing

Traditional IoT systems often rely on sending data to the cloud for analysis, but that approach can introduce delays and in critical setups like incubators, every second counts. That's where edge computing is needed. In our incubator, a Raspberry Pi Zero 2W takes on the role of the system's local brain. It processes data from the sensors right on the spot, with no need for internet access. Using a built-in machine learning model, it can quickly respond to changes, whether that means adjusting the heat or triggering an alert. This approach not only keeps the incubator responsive and efficient, but also ensures it works reliably even in areas with limited or no network coverage. With edge computing, the system stays fast, secure, and ready, no matter the environment.

D. Role of Predictive Analysis

Rather than waiting for issues to arise, our incubator takes a proactive approach. It is trained using real sensor data. This model doesn't just monitor, it predicts. It can assess the potential health concerns, estimate how much warmth the baby might soon require, and decide whether caregiver attention is needed. Based on these predictions, the system automatically adjusts its environment. This goes beyond what traditional systems can offer.

E. Portable Incubator for Premature Infants

We propose an incubator which is a thoughtful fusion of edge computing, IoT, predictive analysis, portability. This incubator is designed to support premature infants in homes. Its controlled and portable design helps to maintain warmth and comfort in a safe way. At its core is the Raspberry Pi Zero 2W — a small yet powerful processor that handles sensor data and runs the system's predictive model entirely offline. That means no internet is required, making it reliable even in areas with weak or no connectivity. The incubator uses trusted sensors to monitor the baby's health and surroundings. DS18B20 for body temperature, DHT22 for cabin temperature and humidity, MAX30102 for heart rate and blood oxygen levels (SpO₂). A heating bulb regulate warmth, cooling fan avoid overheating, buzzer alerts, OLED display for real-time updates, power comes from a 12V, 3600mAh lithium-ion battery. The voltage is safely stepped down using a DC-DC buck converter. This incubator stand out is its user-friendly **Telegram chatbot interface**. By combining predictive intelligence, offline processing, and simple communication tools, this incubator becomes more than just a machine — it becomes a dependable companion in caring for premature babies, especially where traditional medical support is out of reach.

This paper presents the system's architecture, methodology, and experimental results of portable incubator for premature infants.

2. RELATED WORKS

The field of neonatal care has seen several technological advancements aimed at improving infant monitoring and environmental control. Existing solutions have explored IoT, AI, and portable designs to enhance care quality. However, many of these systems either depend on continuous internet connectivity or are too expensive for widespread deployment in under-resourced settings. Below, we explore key areas of innovation.

Innovative Existing Technologies

There are incubators which can maintain the body temperature, smart cradles which sense the temperature and crying but purely depends on internet connectivity. While each has made meaningful contributions, they often address isolated challenges and may not offer a comprehensive solution, especially in low-resource environment.

AI and Predictive Models

Hospitals are now using machine learning models to detect early signs of complications like apnea, sepsis, or heart irregularities by analyzing ongoing vital sign data. These systems generally depend on central servers and high-end computing infrastructure, making them impractical for personal or home-based incubators.

C. Power and Portability Constraints

Many of the solutions available today aren't optimized for mobility. They depend on wall power or bulky batteries, which limits where and how they can be used. For incubators to be truly portable and usable in rural or emergency settings, energy efficiency and battery management need to be built-in — ideally with support for sustainable options like solar charging.

D. Challenges in Current Solutions

Neonatal technologies face significant challenges such as IoT-based solutions does not work properly at places with no internet access, making them unreliable in rural settings, they respond to problems after they occur and they cannot prevent emergencies, they have high power requirements, the caregiver interface is difficult for caregivers unfamiliar with tech.

E. Directions for Future Research and Innovation

The potential improvement is the integration of a low-power camera module, which could allow for visual assessments of the infant. This would enable caregivers or AI models to detect visible signs of distress. Another exciting area is the expansion of predictive capabilities. With access to more real-world data, the system could be trained to recognize more complex conditions and even incorporate audio analysis such as detecting irregular breathing or crying patterns. User interactive dashboards, historical trend analysis, and multi-user access, allowing doctors, nurses, and family members to stay connected and informed. Additionally, optimizing the system's power usage and exploring solar-powered charging would make it more suitable for off-grid areas, improving reliability in rural and disaster-prone regions. Looking ahead, there's also great potential to adapt this incubator system for use in rural health clinics or mobile medical units. Such adaptations could bring life-saving neonatal support directly to communities that lack immediate access to hospitals, acting as a vital first-response tool.

3. METHODOLOGY

A. System Overview

The Portable Incubator for Premature Infants is a thoughtfully designed, compact solution aimed at providing safe and effective neonatal care at home. It brings together intelligent features like real-time monitoring of vital conditions, automated environmental adjustments, and on-device data processing — all within a user-friendly system. Thanks to its closed-loop control mechanism, the incubator is able to maintain stable temperature, humidity, and oxygen levels, creating a nurturing space for premature babies. By processing data locally, the system responds quickly to changing conditions without depending on the internet. Additionally, caregivers can stay connected and in control through a simple Telegram-based chatbot, making remote monitoring and management both easy and reliable.

Key Features:

- **Real-Time Health Monitoring:** Vital signs like body temperature, cabin temperature, humidity, heart rate, and oxygen saturation (SpO₂) using accurate and reliable sensors.
- **Automatic Control:** Adjusts the heater and fan through PWM signals to maintain a comfortable and safe environment for the infant.
- **Edge Computing with Raspberry Zero 2 W :** All sensor data locally on the device, enabling fast reactions without needing an internet connection.
- **Intelligent Feedback Loop:** Continuously evaluates sensor data to automatically fine-tune the system's response, ensuring internal stability.
- **On-Device Data Logging (SQLite):** Stores all readings and control actions in a local database (ibi.db), allowing both real-time decision-making and historical analysis.
- **Remote Access via Telegram Chatbot:** Lets caregivers check status, receive updates, and control settings easily using basic chat commands—no app installation required.
- **Smart Alert System:** Provides audio alerts and remote notifications for issues like abnormal temperature or low oxygen, ensuring prompt caregiver response.
- **Built-in Fault Tolerance:** Includes mechanisms to handle power loss, sensor failures, and data errors to keep the system running reliably.
- **Portable & Energy Efficient:** Designed to be compact and low-power, making it ideal for use at home or in areas with limited resources.
- **Easy-to-Use Interface:** Simple enough for non-technical users—no special training needed to operate or monitor the incubator.

B. Hardware Components and Their Roles

TABLE 1. Components table

Components	Function
DHT22	Temperature and humidity sensor
MAX30102	Oximeter heartrate sensor
DSB1820	Temperature sensor
Fan	Regulates internal airflow for temperature control
Heating element	Warms the incubator when internal temperature drops
Buzzer	Provides audible alerts during critical conditions
Raspberry Pi Zero 2 w	Edge controller for data processing, control logic, and Telegram interaction
SQLite (ibi.db)	Local database for storing sensor data and actuator settings
Power Supply Module	Provides regulated power to all system components

C. System Working Principle & Data Flow

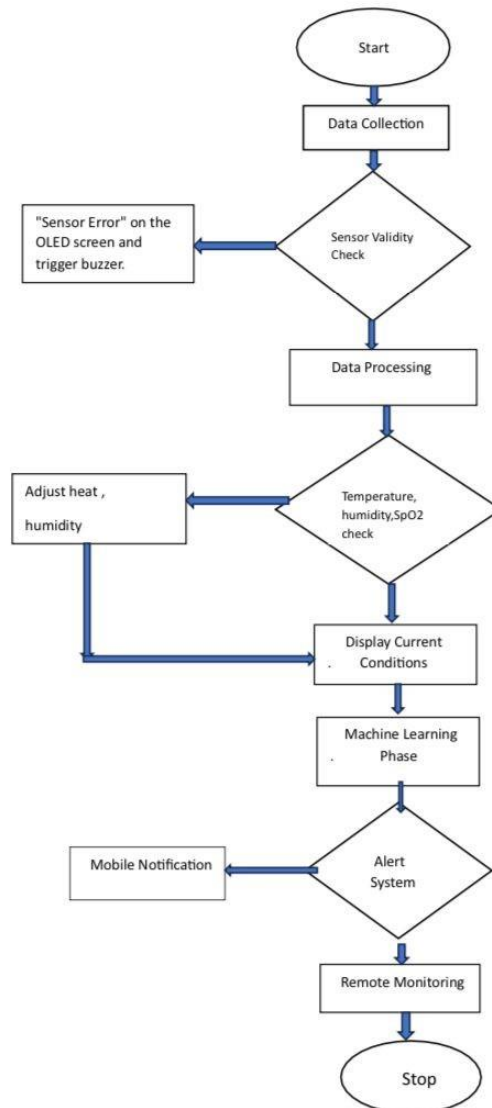


Figure 2: Flow Chart

Step 1: System Start & Continuous Monitoring

- Incubator powers on and all connected sensors begin tracking real-time conditions.
- Vital data—such as temperature, humidity, oxygen saturation (SpO₂), and heart rate—is continuously recorded and saved into a local database for monitoring and analysis.

Step 2: Reliability in Fault Scenarios

- In case of unexpected issues like power failure or sensor malfunction, the system uses built-in backup logic and restores the last known safe state, ensuring that the incubator remains functional and safe for the infant.

Step 3: Intelligent Climate Adjustment

- Based on the incoming sensor data, the system automatically adjusts the heater and fan using PWM signals to maintain a safe and comfortable environment for the infant. Predefined threshold values guide how and when each actuator responds.

Step 4: Emergency Alerts & Smart Decisions

- If any monitored value, like body temperature or SpO₂, moves beyond safe limits, the system immediately triggers a buzzer
- Sends an alert through Telegram to notify caregivers of the potential emergency.

Step 5: Caregiver Interaction

- Through a simple Telegram chatbot interface, caregivers can check current status, does not need technical knowledge.

Step 6: Adaptive Feedback Control

- Change in environmental conditions, is immediately sensed and analyzed. This creates a continuous feedback loop to keep conditions stable.

D. Edge Processing and Remote Accessibility

1. Edge Processing & Local Storage

- All sensor data is saved directly on the device using an onboard SQLite database.
- The system makes real-time decisions locally, so it doesn't rely on internet or cloud services to function.

2. Remote Access Through Telegram

- Caregivers can easily interact with the system by sending simple commands on Telegram.
- They can request live sensor updates or adjust system settings without needing a separate app.
- If anything unusual is detected—like low oxygen or high temperature—the system sends instant alerts via Telegram.

3. Security & System Reliability

- Smart error-handling routines are in place to keep things running smoothly, even if there's a network issue or a component fails.
- Redundancy checks are used to confirm unusual readings before triggering alerts, helping prevent false alarms.

4. RESULT AND DISCUSSION

A. Results

Our Portable Incubator underwent extensive testing to evaluate its effectiveness in delivering stable and safe neonatal care within a home environment. Throughout these evaluations, several key outcomes highlighted the system's performance and reliability. The temperature sensors—DHT22 for cabin temperature and DS18B20 for body temperature—demonstrated consistent accuracy within $\pm 0.5^{\circ}\text{C}$, while the MAX30102 sensor accurately monitored heart rate and oxygen saturation in real time. Local monitoring was enhanced by an OLED display, which continuously showed live status updates.

In terms of maintaining a stable internal environment, the heater and fan, controlled through PWM signals, responded efficiently to fluctuating conditions. The system could correct temperature variations within two to three minutes, doing so gradually to avoid sudden environmental shifts. This quick response was supported by the system's real-time operation; actuators reacted within three seconds of detecting irregularities, thanks to the edge-processing capabilities of the Raspberry Pi Zero 2 W. This allowed the incubator to operate independently of cloud services, ensuring uninterrupted performance even without internet access.

A machine learning component, built using TensorFlow, added an extra layer of intelligence to the incubator. By training the model on 250 real-time data samples, the system learned to predict necessary actuator adjustments and even detect early signs of potential medical issues. These predictions were processed directly on the Raspberry Pi, enabling fast and intelligent responses.

The alert system, which included both a buzzer and visual indicators, effectively warned caregivers during emergencies. In addition, the integrated Telegram chatbot sent timely alerts—usually within 2 to 4 seconds of anomaly detection—keeping caregivers informed and engaged. This chatbot interface also provided live access to sensor data, allowed manual control of actuators, and remained responsive even in areas with low network bandwidth. Power efficiency was another highlight, with the system operating on just 2.5 to 3 watts. A rechargeable 12V, 3600mAh lithium-ion battery with a built-in BMS supported continuous use for up to eight hours during outages, ensuring reliable operation in locations with unstable power supply.

B. Discussion

The performance of the portable incubator shows that it is not only technically sound but also highly suitable for deployment in home and low-resource environments. Its modular design contributes to ease of assembly and maintenance, while the use of edge computing offers clear advantages in speed, reliability, and offline usability. This local processing approach helps bridge the gap between medical technology and environments where internet access is either unstable or unavailable.

The incorporation of machine learning transforms the incubator from a reactive system to a proactive one. By recognizing patterns in vital signs and environmental conditions, the system can take preventive action, which is especially valuable in critical care scenarios. This smart behavior elevates the overall functionality, offering early warning signs for caregivers.

A particularly user-friendly element is the Telegram chatbot interface, which replaces the need for a specialized mobile application. This design choice significantly lowers the barrier to entry for non-technical users. Caregivers can easily check sensor readings, receive emergency notifications, and make manual adjustments with minimal effort and no prior technical training.

Moreover, the incubator's low energy consumption makes it ideal for areas with unreliable power. The use of a rechargeable battery further enhances this, allowing for continued operation during power cuts, which are common in remote or rural regions.

5. CONCLUSION

This project successfully presents a cost-effective, intelligent, and portable incubator that brings advanced neonatal care into the home. It combines real-time environmental and physiological monitoring with intelligent actuator control, edge-based decision-making, and seamless remote access. These features work together to ensure that premature infants receive the necessary support even in the absence of hospital infrastructure.

The prototype has proven its ability to maintain optimal conditions, detect and respond to irregularities promptly, alert caregivers in a timely manner, and continue operating during power and network outages. Together, these capabilities point toward a promising solution for making neonatal care more accessible and reliable in under-resourced communities.

Looking ahead, the system can be enhanced further with features like battery health monitoring, more advanced predictive health analytics, and formal clinical testing to meet medical regulations. With these developments, the incubator could be scaled and deployed more broadly, helping to close the healthcare gap for vulnerable newborns in need of critical early support.

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REFERENCES

- [1]. N. Taufik et al., "Development of infant telemonitoring system," *Evol. Elect. Electron. Eng.*, vol.1, no. 1, pp. 153–160, 2020.
- [2]. Lakshman Pratap, N., Anuroop, K., Nirmala Devi, P., Sandeep, A., & Nalajala, S. (2021). IoT based smart cradle for baby monitoring system. In 2021 6th International Conference on Inventive Computation Technologies (ICICT) (pp. 340-344). IEEE.
- [3]. Kale, A. W., Raghuvanshi, A. H., Narule, P. S., Gawatre, P. S., & Surwade, S. B. (2018). Arduino based baby incubator using GSM technology. *International Research Journal of Engineering and Technology (IRJET)*, 5(4), 1234-1239.
- [4]. Singh, H., Bansal, A., Jain, S., Kaur, S., & Singh, J. (2019). Neo-bedside monitoring device for integrated neonatal intensive care unit (iNICU). *IEEE Access*, 7, 7803-7813.
- [5]. Ruiz-Zafra, A., Precioso, D., Salvador, B., Lubián-López, S. P., Jiménez, J., & BenaventeFernández, I. (2023). NeoCam: An edge-cloud platform for non-invasive real-time monitoring in neonatal intensive care units. *IEEE Journal of Biomedical and Health Informatics*, 27(6), 2614-2624.
- [6]. Satyanarayanan, M., & Shi, W. (2018). Overview of edge computing. IEEE.
- [7]. Charan, B., Jaswanth, D., Hemanth, E., & Naidu, M. S. (2024). Machine learning and deep learning approaches for healthcare predictive analytics. In 2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC). IEEE.
- [8]. Bonner, O., Beardsall, K., Crilly, N., & Lasenby, J. (2017). 'There were morewires than him': The potential for wireless patient monitoring in neonatal intensive care. *BMJ Innovations*, 3(1), 12-18.
- [9]. Amin, S. U., & Hossain, M. S. (2021). Edge intelligence and Internet of Things in healthcare: A survey. *IEEE Access*, 9, 101236-101254.