Neo Cocoon: Low-cost and Portable Neonatal Protection and Development System

A Preprint

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Abstract

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***K*eywords** NICU · Medical Device · IoMT · AI · Neonatal Protection · Portable · Monitoring · Premature Infants · Temperature · SpO2 · Heart Rate · ECG · Phototherapy · Data Logging · User-Friendly Interface · Microprocessor · Microcontroller · Healthcare · Jaundice Treatment

1 Introduction

Babies born before the completion of 37 weeks of pregnancy are classified as premature [1]. They are further categorized as follows:

1. **Extremely premature:** Less than 28 weeks
2. **Very premature:** 28 to 32 weeks
3. **Moderate to late premature:** 32 to 37 weeks

1.1 Background

1.1.1 Low Birth Weight (LBW) as consequence of Pre Mature Birth

Low Birth Weight (LBW) refers to infants born weighing less than 5 pounds, 8 ounces (2,500 grams). In contrast, the average newborn typically weighs around 8 pounds. Much of a baby's weight is accumulated in the final weeks of pregnancy, so being born prematurely often results in low birth weight [2].

Another cause of Low Birth weight is condition called **Intrauterine Growth Restriction (IUGR)** arises when a baby does not grow adequately during pregnancy.

Health Complications of Low Birth Weight Infants with low birth weight encounter numerous health complications that can adversely affect their growth and development. One of the significant issues they face is reduced oxygen levels at birth, which may lead to immediate respiratory difficulties. These infants often

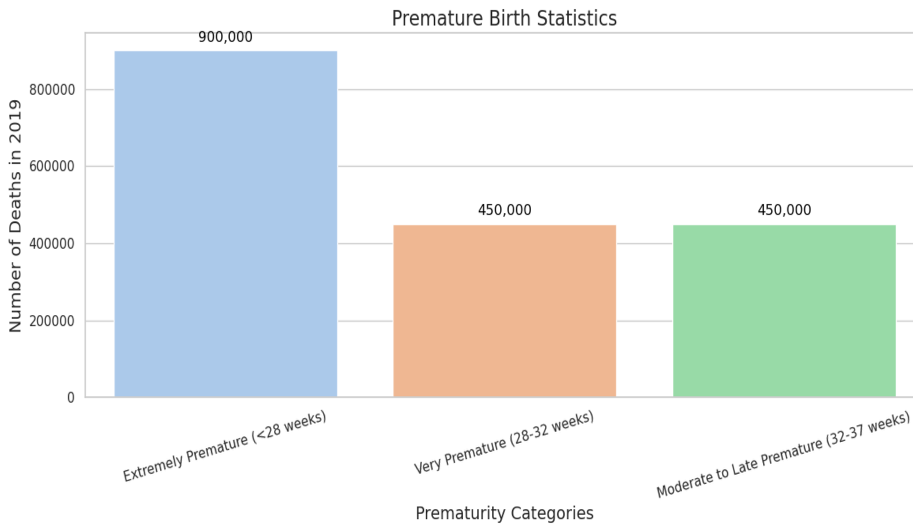

Figure 1: Sample figure caption.

struggle to maintain a stable body temperature, putting them at risk for hypothermia. Additionally, many experience feeding challenges, as their ability to suck may be compromised, resulting in inadequate weight gain. Their underdeveloped immune systems make them more susceptible to infections. Furthermore, low birth weight can lead to breathing issues like infant respiratory distress syndrome, stemming from immature lung development. Neurological problems may also arise, such as intraventricular hemorrhage, which involves bleeding within the brain. The risk of digestive complications, particularly necrotizing enterocolitis, poses further concerns. Lastly, there is an elevated risk of sudden infant death syndrome (SIDS) during the early months of life, adding to the vulnerabilities faced by these infants. [2]

3 methods to address Low Birth Weight as a Medical Electronics Engineer Management for LBW often involves:

1. Care in a neonatal intensive care unit (NICU).
2. Temperature-controlled environments such as a warmer or an infant incubator.
3. Specialized feeding methods, including tube feeding for infants unable to suck, or intravenous (IV) feeding.

While we choose the 2nd method to address the problem, we choose innovation in domain of incubators instead of warmers for the reasons listed in the latter sections.

2 Motivation

2.1 Pre Mature Birth Statistics

In 2020, 10% of all births worldwide, equating to approximately 13.4 million, were premature. In 2019, around 900,000 children died due to complications arising from preterm birth. In low-income countries, nearly half of the infants born at or before 32 weeks gestation (i.e., two months premature) do not survive due to a lack of effective and affordable care [1] [3]. See figure 1

Furthermore, more than 90% of extremely preterm infants (born before 28 weeks) in low-income settings die within the first few days of life, in stark contrast to less than 10% in high-income countries. It is estimated that three-quarters of these deaths could be averted with existing, cost-effective interventions. The rate of premature births in 2020 varied from 4% to 16% [3].

In 2022, nearly half (47%) of all deaths among children under five years old took place during the neonatal period, which refers to the first 28 days of life. Every day, approximately 6,500 newborns die, primarily due to inadequate quality of care at birth. Most neonatal deaths (about 75%) occur within the first week of life, highlighting the urgent need for effective interventions during this crucial timeframe. [4] See figure 2

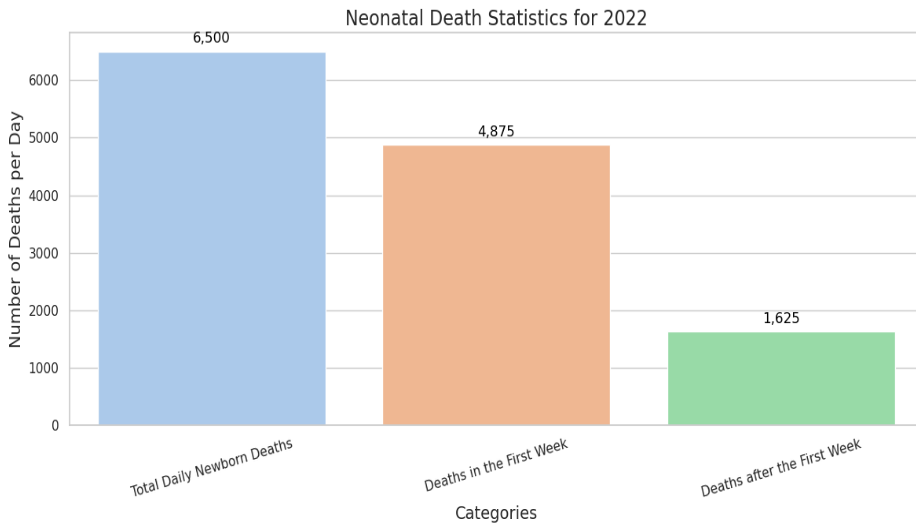

Figure 2: Sample figure caption.

Therefore the health outcomes for premature newborns in remote and resource-limited areas stems from the critical need to address the vulnerabilities these infants face. Premature babies are at a higher risk of complications due to their underdeveloped physiological systems. In regions where access to medical facilities and skilled healthcare providers is limited, traditional neonatal care may not be feasible. Thus, developing solutions that are smarter, safer, and responsive to the unique challenges of these environments is essential. These solutions should be designed to be user-friendly, minimizing the need for extensive training and allowing caregivers to provide effective support with limited resources. By focusing on reducing dependency on human supervision, we can create reliable systems that ensure consistent care for these vulnerable infants, ultimately aiming to improve their survival rates and long-term health outcomes.

3 Literature Survey

WHo claims Hypothermia is a significant contributor to neonatal illness and death, particularly among low birth weight and normal newborns. To combat this, thermal protection measures are crucial for maintaining a normal body temperature of 36.5–37.5°C after birth, as newborns are often exposed to cooler environments that cause rapid heat loss. [1]

$$SizeOfInfant \propto T_{OutsideNormal}$$

Where, $T_{OutsideNormal}$ is the Temperature outside the normal range.

This heat loss can occur through various mechanisms, including evaporation, conduction, convection, and radiation, and can result in significant temperature drops within the first 10-20 minutes post-delivery. It's important to maintain a delivery room temperature between 25–28°C, with a maximum tolerable temperature of around 35°C for naked newborns. Separating newborns from their mothers complicates thermal protection efforts and increases the risk of infections; thus, immediate drying and wrapping of newborns are essential practices. Hypothermia can be classified into three categories: mild (36–36.4°C), moderate (32–35.9°C), and severe (<32°C), with prolonged exposure leading to impaired growth and increased mortality rates. See figure 3

Effective management includes assessing for infections and implementing safe heating practices to avoid burns. Conversely, hyperthermia, defined as a body temperature exceeding 37.5°C, can result in dehydration and necessitates quick evaluation for infections. Guidelines for incubator use specify maintaining an air temperature of 35–36°C, conducting regular temperature checks, ensuring cleanliness, and encouraging skin-to-skin contact between newborns and their mothers. [1]

The MQTT protocol has been evaluated in both the biomedical engineering laboratory and the hospital's neonatology unit. Premature infants often lack sufficient body fat and organ development to maintain their

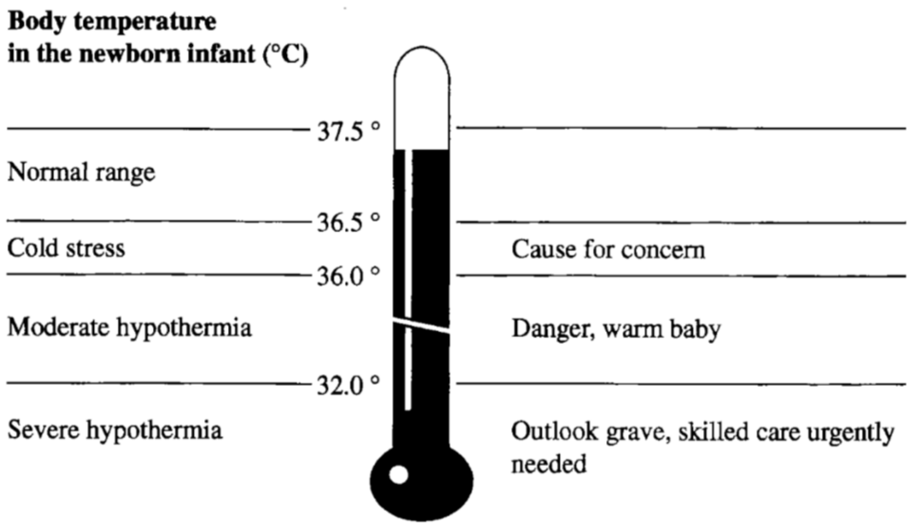

Figure 3: Sample figure caption.

body temperature, which should be kept between 28°C and 34°C. Reducing access time to newborns is vital to minimize heat and oxygen loss. [5]

The BreathAnalyzer, a smartwatch that uses an AI model based on decision trees, improves accuracy in detecting respiratory sinus arrhythmia (RSA) from 35.37% to 80%, achieving an average of 42% accuracy across various scenarios. Calibration tests were conducted in accordance with the ISO/IEC 1725:2017 standard to ensure measurement reliability. Despite advancements, there are no existing devices that fully meet the needs of the medical field. The Internet of Things in medicine (IoMT) is essential for developing comprehensive technological solutions. However, a progressive web application (SiMCa-Bio) was created to monitor incubator conditions in real-time, focusing only on temperature, humidity, and sound, with a sampling frequency of 5 minutes and data transmission every 10 minutes [5]. Hoever Elevated levels of relative humidity are not advisable for infants, as they can encourage the growth of bacteria and germs [6]

The transition from traditional monitoring methods to wearable devices focuses on reducing adhesive-related skin injuries. This approach promotes the use of soft, flexible materials and gentler adhesion techniques while emphasizing the design of all-in-one devices. The priority is on non-invasive monitoring solutions that enhance accessibility, particularly for high-risk patients, such as those born prematurely (with a gestational age of less than 37 weeks) or with low birth weight (typically less than 2.5 kg) [7]

Smart infant incubator monitoring and control system that utilizes a gas sensor, accelerometer, and Peltier module, which are not part of our current design was developed by K C N Raju [8]. The system automatically adjusts the Peltier module and humidifier when temperatures exceed 36°C to 37.2°C and humidity exceeds 60%, ensuring an optimal environment for premature and critically ill newborns.

A major challenge identified is the imbalance between caregivers and patients, leading to increased workloads and compromised monitoring of incubators. The study emphasizes maintaining temperatures between 36°C and 37.5°C, with a targeted rectal temperature of around 36°C, and humidity levels between 40% and 60%. Additionally, the integration of artificial intelligence and live monitoring through cameras enhances the care provided. However, limitations include the use of an Arduino Wi-Fi R3 and reliance on an LCD display and ThingSpeak for IoT applications.

Another study [9] focuses on an IoT-based baby incubator monitoring system utilizing Raspberry Pi Zero W. It monitors critical environmental parameters, including temperature, humidity, and oxygen levels, in real-time to safeguard infants in incubators. The system is connected to a central computer for data visualization, alarms, and alerts, enabling healthcare professionals to monitor the situation remotely. The incubator is maintained at a temperature range of 32 to 36 degrees Celsius to ensure the baby's skin remains at a healthy temperature of 37 degrees Celsius. Additionally, appropriate humidity levels warm the baby's breath and facilitate the entry of moist air into the lungs.

Adding on to it, [10] emphasized that heating systems require careful management, particularly during the winter months, to maintain a consistent temperature for optimal comfort. Humidity levels in solids and liquids are measured using hygrometers. Various methods for measuring moisture include assessing changes in resistivity, variations in capacitance, or monitoring the attenuation of microwaves.

This literature [10] provided information regarding checksum [11] for a typical DHT22 sensor that was in communication via I2C protocol:

$$DataStructure = 8bits(RH_{int}) + 8bits(RH_{dec}) + 8bits(T_{int}) + 8bits(T_{dec}) + 8ChecksumBits$$

Where, RH_{int} = Integer Relative Humidity, RH_{dec} = Decimal Relative Humidity, T_{int} = Integer Temperature and T_{dec} = Decimal Temperature

4 Objectives

4.1 Primary Objectives

1. **Affordablity**: Develop a low-cost yet cutting-edge device that enhances healthcare delivery in resource-limited settings, ensuring accessibility for all.
2. **Real-Time Monitoring of Essential Health Metrics**: Implement continuous monitoring capabilities for vital health parameters that includes body temperature, ambient temperature, ambient humidity levels, neonatal heart rate, blood oxygen saturation (SpO_2) and Electrocardiogram (ECG).
3. **User-Friendly Touch Screen Interface**: Design an intuitive touch-screen user interface that simplifies interaction with the device.
4. **Comprehensive Data Logging**: Facilitate automatic logging of health data over time, enabling caregivers to track trends and make informed decisions regarding the care of premature newborns.
5. **Remote Data Accessibility via IoT**: Enable remote access to device data through IoT integration, allowing healthcare professionals to monitor patients' conditions from distant locations, enhancing collaboration and response times.
6. **Critical Alarm System**: Integrate a robust alarm system that alerts caregivers to critical changes in health parameters, ensuring prompt action can be taken in emergencies.
7. **Phototherapy Capabilities**: Include a phototherapy function for the treatment of neonatal jaundice, utilizing advanced light therapy to support the health and recovery of affected infants.

4.2 Secondary Objectives

1. **AI-Driven Jaundice Detection and Classification**: Explore the potential for AI integration to enhance jaundice detection and classification based on Kramer's rule. Availability of data is the major problem to implement this. A potential dataset [12] was found that can help us meet this objective.
2. **Produce Instantaneous Reports**: Create a reporting function that generates up-to-date health status reports, enabling healthcare professionals to swiftly evaluate the condition of premature infants without the need for manual data input.
3. **Compliance and Record Keeping**: Establish automated reporting that aligns with healthcare standards and regulations, simplifying the record-keeping process for neonatal care and ensuring accessibility for audits and assessments.

5 Materials and Methods

5.1 Materials

5.1.1 Hardware requirements

5.2 Footnotes

Here is how you add footnotes. [ˆSample of the first footnote.]

Table 1: Sample table title

Part		
Name	Description	Size (μm)
Dendrite	Input terminal	$\sim$100
Axon	Output terminal	$\sim$10
Soma	Cell body	up to 10^6

5.3 Tables

See awesome Table~1 which is written directly in LaTeX in source Rmd file.

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