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Development and Deployment of an IoT-Based Telemedicine System for Infant Warming Devices

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ABSTRACT

Neonatal hypothermia is a serious health concern, especially for premature babies and those with low birth weight, often resulting in complications like metabolic acidosis, hypoxia, and an increased risk of other health issues. To address this, newborn warming technologies have been developed, offering a controlled environment to regulate the baby's body temperature. This study focuses on creating and implementing an IoT-powered telemedicine system that works with an infant warming device to enhance neonatal care. The system includes sensors to monitor temperature and heart rate in real time, ensuring the baby's safety and promoting the best possible clinical outcomes. With IoT architecture, healthcare professionals can remotely manage and monitor the baby's condition, making quick decisions when necessary. This approach overcomes the limitations of current devices by incorporating fuzzy logic control alongside real-time telemedicine features, all accessible via portable devices. By integrating these technologies, the system offers a solution to managing neonatal hypothermia, especially in settings with limited resources. Additionally, it has the potential to cut down on hospital transfers, improve outcomes for newborns, and ease the burden on caregivers and families. The research suggests that this IoT-enabled infant warming system could significantly boost the effectiveness of neonatal care, making it an invaluable tool for healthcare professionals.

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1. INTRODUCTION

A newborn's body temperature can drop by about 0.1°C to 0.3°C per minute after birth, which can pose significant health risks [1]. This decrease in body temperature, known as hypothermia, is a critical condition experienced by many babies, especially premature babies and babies with low birth weight. Every year, more than 20 million babies are born prematurely or with low birth weight, with the majority of cases occurring in developing countries, which account for about 95% of that number. In addition, more than three million babies die in the first 28 days of life due to hypothermia [2].

Hypothermia in newborns is often considered one of the leading causes of death and serious disability in neonates [3]. Handling babies with hypothermia requires medical devices that can independently monitor body temperature and heart rate in real-time. One of the most important devices is the Infant Warmer, which is designed to provide warmth for premature babies as well as babies with normal conditions who have difficulty maintaining their body temperature in a new environment [4]. Infant Warmer is used to keep the baby's body temperature stable within the required temperature range, which is between 34°C to 37°C, which is similar to the temperature in the mother's womb. The use of infant warmers is closely related to the prevalence of neonatal hypothermia in newborns, especially in premature babies. A number of previous studies have developed baby heating systems using DHT11 sensors for temperature measurement, heating devices, and the ATMega8535 microcontroller [5].

Further research also added a warning signal element to start warming up the baby using the ATMega8535 microprocessor [6]. Previous studies have also resulted in some breakthroughs in baby heating technology. One of them is an infant warmer with phototherapy that uses an Arduino Uno, LCD, LM35 temperature sensor, with a temperature setting between 32°C to 37°C [7]. Another study combines PID controllers with a fail-prone approach, using DHT22 and LM35 sensors as epidermal sensors[8]. In addition, there is a smart infant warmer that uses a PID controller, environmental sensor (DHT11), and an external sensor (LM35) to keep the baby's body temperature stable [9]. The latest research has even developed a smart infant warmer that uses LM35 sensors for body temperature and DS18B20 for skin temperature, equipped with a PID control system to ensure optimal temperature stability [10].

Although various innovations in infant warmer technology have been made, most existing devices still have limitations in terms of functionality and integration of the latest technology. Many existing devices still do not utilize Internet of Things (IoT) technology for real-time analysis and more efficient temperature control. In addition, existing systems are often not equipped with heart rate monitoring and remote medical surveillance that are essential for improving patient safety.

This research aims to develop a more innovative and integrated baby heating device with IoT technology, pulse detection, body temperature detectors, and fuzzy logic technology equipped with a telemedicine system. This technology allows real-time monitoring of the baby's condition, making it easier to control the patient's condition more efficiently and improve the safety of newborns. Thus, this study aims to provide a better solution in dealing with neonatal hypothermia, especially for premature babies, which can help reduce mortality and disability rates in newborns.

2. METHOD

Research Methods

This research aims to develop a baby heating device based on Internet of Things (IoT) technology that is integrated with a telemedicine system to monitor the baby's body temperature and heart rate in real-time. This research consists of several stages, ranging from system design, hardware and software development, to testing and analysis of results.

1. Research Design

The design of this study uses an experimental approach with system development consisting of tool design, functionality testing, and analysis of the data obtained. The study adopts an IoT-based design system, which allows real-time monitoring of the baby's body temperature and heart rate through a device connected to the telemedicine system. This system is designed to monitor the baby's condition continuously and transmit health data through the internet network.

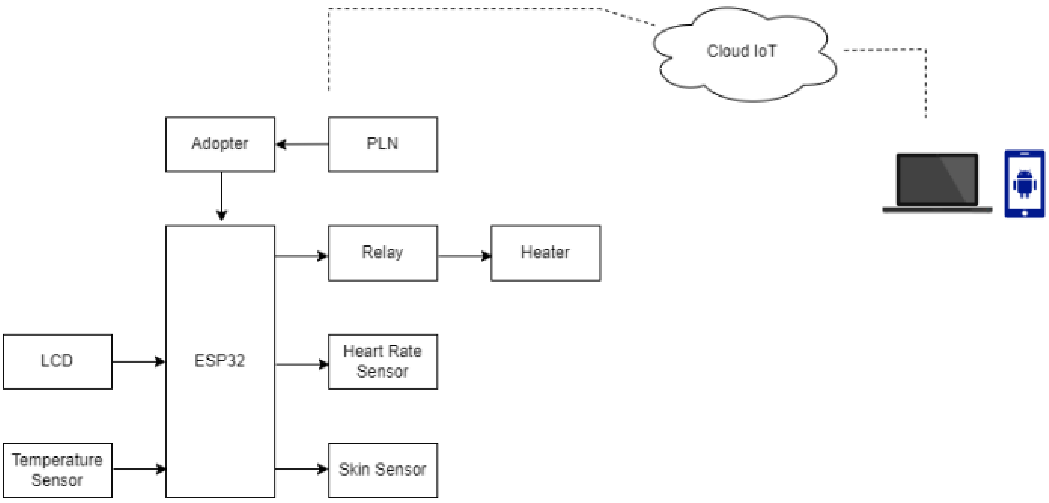

Figure 1. IoT Architecture Design

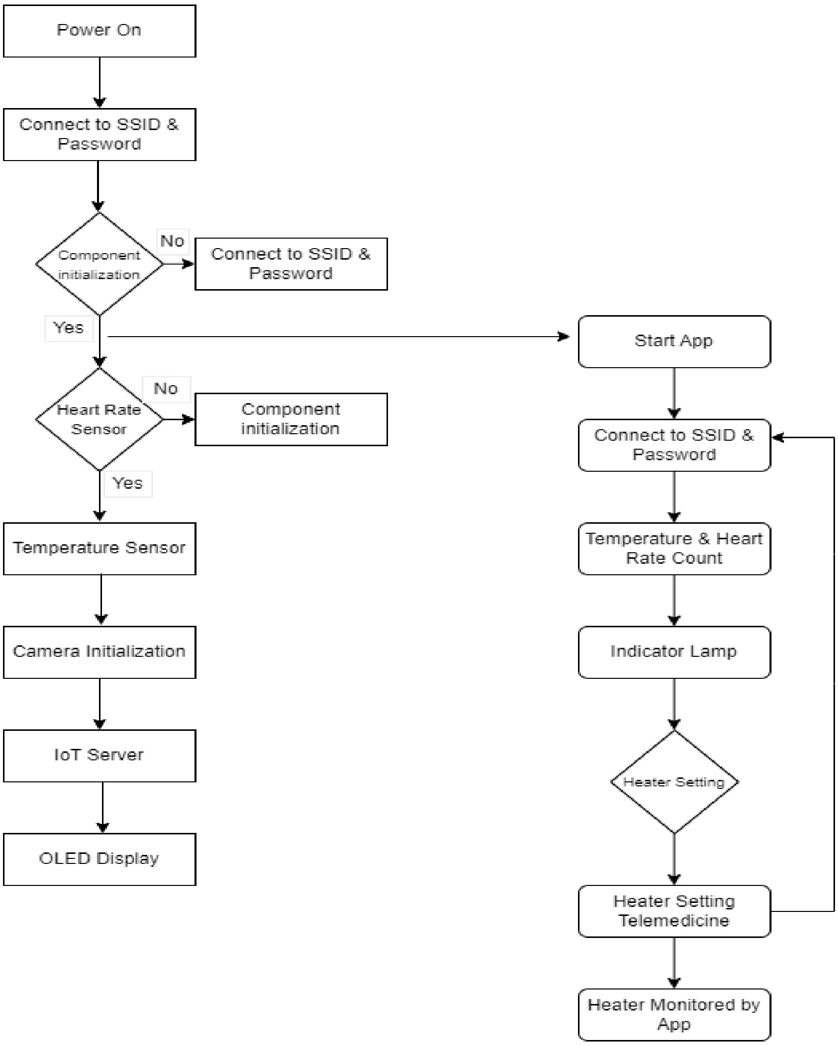

Figure 2. Flow Chart

2. Tools and Materials

Some of the main components used in this study include:

- ESP32: A microcontroller that functions as the control center of the system, equipped with a Wi-Fi module for data communication over the internet network. ESP32 allows the device to connect with telemedicine systems wirelessly [21].
- DS18B20 Temperature Sensor: A digital sensor used to measure the baby's body temperature with high accuracy. These sensors use a 1-wire communication protocol, which allows the use of multiple sensors in a single communication line [19].
- Pulse Sensor: An optical sensor used to detect a baby's pulse by measuring the variation in light reflected from the baby's skin. These sensors provide a signal that can be processed to determine the pulse frequency [20].
- Space Warmer: A device used to create a warm environment for babies. This heater is controlled by an ESP32 microcontroller to ensure the baby's body temperature stays within a safe range.
- Telemedicine System: An IoT-based platform that enables real-time transmission of temperature and pulse data to medical personnel, enabling remote surveillance to improve medical response [16].

3. System Development Procedure

System development is carried out through several stages as follows:

1. **System Planning**:
   - The system design includes a hardware schematic design that connects the temperature sensor, pulse sensor, and heater to the ESP32 microcontroller. The system flowchart is compiled to illustrate the flow of data collection and control of the device.

- The structure of IoT devices is built to allow devices to connect with telemedicine systems over the internet network.

2. **Hardware Development**:
    - Install the DS18B20 temperature sensor in a suitable area to measure the baby's body temperature. The sensor is calibrated to provide accurate temperature readings in the range of 34°C to 37°C.
    - Installing a pulse sensor on the surface of the baby's body to accurately detect the frequency of the heart rate.
    - Setting and connecting the room heater to create a stable temperature according to the needs of the premature baby.
3. **Software Development**:
    - Development of programming code for the ESP32 microcontroller that includes data retrieval from sensors, data processing, and data transmission to the telemedicine system.
    - Penggunaan platform *Arduino IDE* untuk menulis dan mengunggah kode ke mikrokontroler.
    - Implementasi sistem kontrol suhu menggunakan algoritma PID (Proportional-Integral-Derivative) untuk menjaga suhu tubuh bayi tetap stabil, serta sistem pemantauan denyut nadi yang memberikan peringatan jika ada perubahan yang signifikan.
4. **Integrasi Sistem dengan Telemedicine**:
    - Real-time transmission of temperature and pulse data to a telemedicine platform that can be accessed by medical personnel. This data is used to monitor the baby's condition and provide the information necessary for medical treatment.

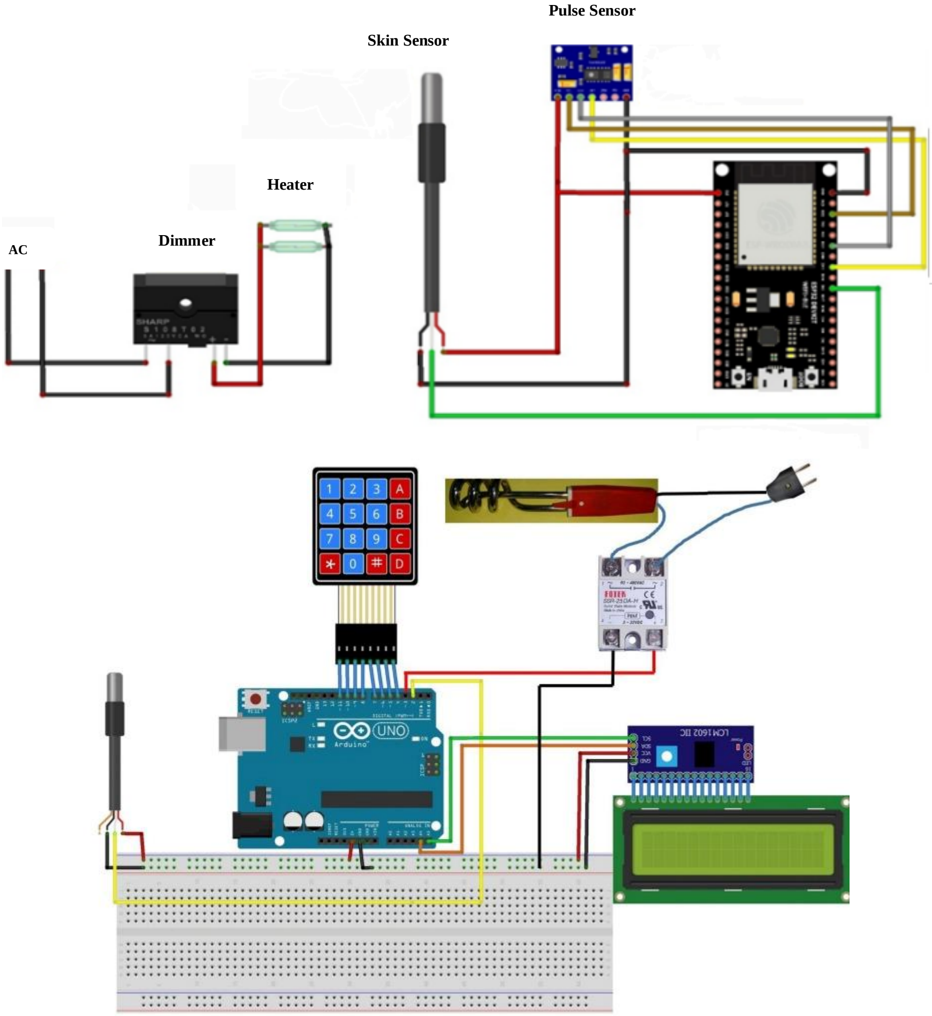

Figure 3. Wiring of Telemedicine Baby Warmer

Figure 3 explains how the embedded system connects to IoT technologies via ESP32. The human body detector then detects heart rate using the DS18B20 and a pulse sensor. The space warmer is utilized to offer a warm environment for the individual being treated.

4. Analysis Methods

The analysis was carried out on several aspects to evaluate the effectiveness of the developed system, including:

- System Performance Evaluation: Measure the performance of the system in maintaining the baby's body temperature and monitoring the pulse. The test is carried out by observing the system's ability to maintain a stable temperature within the desired range and ensure the accuracy of pulse readings.
- Telemedicine System Testing: Measures how effective the telemedicine platform is in receiving and displaying health data in real-time. It was also tested to what extent this system supports communication between devices and medical personnel.
- Security and Reliability Analysis: Conduct resistance tests to signal interference and system failures. Testing is carried out to ensure that data sent through the internet network is maintained in integrity and can be easily accessed by medical personnel.

The results of this analysis are expected to provide an overview of the extent to which the developed system can improve the safety of newborns, especially premature babies, with more effective and efficient monitoring of body conditions.

3. RESULTS AND DISCUSSION

I have developed the *Infant Warmer with Telemedicine*, a device specifically designed to regulate the body temperature of newborns. This tool is equipped with an accurate DS18B20 temperature sensor for real-time monitoring of the patient's body temperature, as well as a heart rate sensor to track the baby's cardiac condition. The system also utilizes a heater to control the surrounding environment, providing optimal warmth to keep the baby comfortable and safe. Additionally, this device is integrated with a telemedicine system that allows healthcare professionals to monitor the baby remotely, enabling prompt intervention when necessary.

Table 1. Heart Rate Measurement

Experiment	Actual Data (bpm)	Observed Data (bpm)	Error
1	75	74	0.01%
2	81	80	0.01%
3	84	83	0.01%
4	78	77	0.01%
5	89	88	0.01%

In a series of experiments to measure heart rate, five trials were conducted with the goal of observing the difference between the recorded data and the actual data. The results show that each trial yielded nearly identical values, indicating that the instrument used is highly precise. In the first trial, the recorded heart rate was 75 bpm, while the observed value was slightly lower, at 74 bpm, resulting in an error of only 0.01%. Similarly, in the second trial, the actual heart rate was recorded at 81 bpm, while the observed value was 80 bpm, with a very small error of 0.01%. The third trial showed an actual heart rate of 84 bpm, while the observed data was 83 bpm, with a consistent small difference of 0.01%. Likewise, in the fourth trial, the actual data was recorded at 78 bpm, while the observed value was slightly lower, at 77 bpm, resulting in a very small difference of 0.01%. Finally, in the fifth trial, the recorded heart rate was 89 bpm, and the observed value was 88 bpm, with the same error of 0.01%. Overall, the very small difference between the actual and observed data across all trials indicates that the instrument used is highly accurate, with an error margin that is almost undetectable.

Table 2. Temperature Measurement

Experiment	Actual Data (°C)	Observed Data (°C)	Error (°C)
1	36	36.58	0.00
2	36	36.33	-0.25
3	36	36.06	-0.52
4	36	37.56	0.98
5	36	36.33	-0.25

In a series of experiments to measure body temperature, five trials were conducted, comparing the actual data with the observed data. The results revealed minor variations between the two values, reflecting the performance of the measurement instrument used. In the first trial, the recorded temperature was 36°C, while the observed data was slightly higher at 36.58°C, resulting in an error of 0.00°C. In the second trial, the actual temperature was recorded as 36°C, while the observed value was 36.33°C, showing an error of -0.25°C. Moving to the third trial, the actual temperature remained 36°C, but the observed data was slightly lower at 36.06°C, yielding a small difference of -0.52°C. In the fourth trial, the observed temperature saw a slight rise to 37.56°C, while the actual temperature stayed at 36°C, leading to a more significant error of 0.98°C. Lastly, in the fifth trial, the observed value was 36.33°C, with an error identical to the second trial, -0.25°C. Overall, while there were minor differences between the recorded and observed temperatures across all five trials, the errors detected were still relatively small, indicating that the instrument used was quite accurate in monitoring body temperature.

Figure 4. Infant Warmer with Telemedicine

This research is a design that integrates telemedicine technology into an infant warming device. The telemedicine system provides benefits in terms of effectiveness indicators for remote patient monitoring in the management of hypothermia, based on sensor measurement results. Telemedicine has the potential to improve clinical outcomes, quality of life, and financial sustainability of patient care initiatives [11]. In addition, telemedicine can address transportation issues, reduce the number of unnecessary visits, and improve self-awareness, diagnosis, and management for patients with vascular disease [12]–[15].

Telehealth has assisted in an extensive variety of newborn treatments globally, involving retinal of prematurity (ROP) assessment, tele-echocardiography, baby rehabilitation, and additionally parental assistance. Tele-rounds are an effective and reliable technique of delivering care for NICU patients [16]. Presently, a study is underway at (ClinicalTrials.gov) to explore the practicality and usefulness of telemedicine in challenging settings in the NICU [17]. In an additional study, parents who were selected at random to get care via telemedicine exhibited better levels of fulfillment and a more favorable assessment of the overall quality of care compared to normal techniques [18]. Many newborn units have embraced care that is family-centered, including assistance with transferring from hospital to home, enhanced parental participation, and ongoing communication with parents. Telemedicine supports several parts of family-centered care; major treatments involve webcam-based remote visits, educating parents, and virtual parental involvement in care rounds [19]. Furthermore, while the preterm newborns remain periods in a NICU, families typically experience stress and isolation. This disparity can be overcome owing to the adoption of electronics. at first, parents could watch movies and photographs of their newborns before switching to the utilization of computers [20]. Currently, many NICUs are equipped with webcams, allowing relatives and parents to continuously view their babies from anywhere in the world. According to a recent review by Gibson et al., webcam visits can significantly enhance parental bonding and reduce stress levels [21]. Gutmann et al. observed an identical result: using webcams to watch newborns distantly decreased stress on caregivers, as evaluated using the Maternal Anxiety Scale [22].

Parents of preterm newborns revealed that updates via text messages improved communication [23]. Furthermore, a different research demonstrated that getting weekly message alerts describing the infant's status enhanced parental fulfillment and attitudes toward the accessibility of clinicians [24]. In previous research, telemonitoring was used to identify patients with heart failure (HF) to predict episodes of acute decompensation and the need to optimize therapy [25]. During the Remote monitoring to Enhance Cardiovascular Results (Tele-HF) experiment, 1,653 subjects were assigned at random to either normal treatment or an interactive vocal response method via phone after thirty days of admission. Patients used their phones' keypads to submit replies to a series of questions about their overall well-being and heart attack signs in the automated reply program [26]. According to a 2018 publication on the pediatric telehealth landscape, neonatology is one of the few subspecialties that has adopted telemedicine, which also highlights the state of pediatric telemedicine [27].

4. CONCLUSION

This research developed an Infant Warmer device based on the Internet of Things (IoT) and telemedicine for real-time monitoring of the baby's body temperature and heart rate. The results of the experiment showed that the system was very accurate, with a heart rate measurement error of only about 0.01% and a body temperature error ranging from -0.52°C to 0.98°C. This device is effective in keeping the baby's body temperature stable, as well as allowing remote monitoring by medical personnel. This system has the potential to reduce unnecessary patient transfers, improve clinical outcomes, and make it easier to monitor patients in resource-limited facilities. With IoT and telemedicine technology, these devices can improve patient safety and

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