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Improvement of the Monitoring System for the Condition of Newborns and Incubator Environmental Parameters with Remote Monitoring by Medical Staff

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Background. The study is aimed at improving the safety and effectiveness of newborn care in clinical incubators by combining the results of monitoring the operation parameters of several incubators at a physician's/ medical post. The distinguishing characteristic of this monitoring lies in its assesses both the newborn's physiological parameters and, remotely, the environmental conditions within the patient's immediate vicinity. **Method.** The autonomous monitoring is based on the Internet of Things (IoT) principle, employing a feedback mechanism. **Results.** The technology of remote monitoring of data on the infant's skin temperature, as well as air temperature, humidity and noise level in an incubator using an ESP32 microcontroller and Raspberry Pi Zero W microcomputer is substantiated. The minimum permissible measurement errors of the above parameters have been established when using this control method. **Conclusion.** The developed technological scheme for remote monitoring of the infant's skin temperature, combined with environmental parameters, when used simultaneously for several incubators will help optimize the safe and effective care of newborns in critical conditions, especially premature babies.

Keywords: newborns, premature infants, clinical incubators, vital signs monitoring, remote monitoring, environmental parameters, Internet of Things

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INTRODUCTION

Critical conditions requiring constant monitoring of vital body functions in the neonatal period are most common in premature infants, primarily those born with very low and extremely low birth weight. All functional systems of these children are characterized by deep immaturity, against which the frequency and severity of perinatal pathology increase. Therefore, for the successful care of immature newborns, it is necessary to simulate intrauterine living conditions with appropriate environmental parameters such as temperature, humidity, and noise level. A regulated environment for a child is created in a modern clinical incubator, in which individual environmental parameters can be modeled [1–3].

An important aspect of the care of extremely premature infants is the prevention of hypothermia, therefore, at birth, the premature baby is placed in a sterile plastic bag and immediately transferred to an incubator to avoid catastrophic heat loss and related multiple organ disorders. During the incubator nursing period (individually timed for each premature patient), the air temperature in it should be maintained in the range from 32 to 36 °C. The most immature thermoregulation occurs in children with a gestational age of 24–27 weeks, due to insufficient reserves of brown adipose tissue and the unavailability of central mechanisms for regulating heat production / heat loss. To ensure the vital activity of these children, it is necessary to maintain the ambient temperature close to the skin temperature (36–37 °C) [4, 5]. At the same time, overheating is extremely dangerous for infants. Immature newborns and children who have undergone

hypoxia have the highest relationship between ambient temperature and oxygen consumption. Therefore, guidelines have been developed for optimal ambient temperature with a minimum interval of 0.5 °C, depending on the gestational and postnatal age of the patient, taking into account data from skin and rectal temperature sensors [6, 7].

In addition to the need for strict observation to the thermal regime, the humidity of the surrounding air is important to prevent heat loss and insensible fluid loss by the child. The more immature the infant, the higher the humidity in the incubator should be: for children of the first hours of life with a very low birth weight, it reaches 80–85%. At the same time, when the child reaches the postnatal age of 34 weeks, humidity should be reduced to 40–50%, since high humidity promotes the reproduction of microorganisms, including opportunistic pathogens [8–10].

The practice of neonatal intensive care units in many medical institutions includes monitoring of environmental parameters in incubators using sensors, but this control is not automated (it is performed manually by staff) and does not involve self-regulation of parameters modeled on devices involved in monitoring systems based on the Internet of Things (IoT) [11–14].

TECHNOLOGICAL JUSTIFICATION FOR THE DEVELOPMENT OF A SYSTEM FOR MONITORING ENVIRONMENTAL PARAMETERS IN INCUBATORS FOR NEWBORNS

A centralized IoT-based monitoring system should be capable of tracking a range of variables, including internal incubator temperature, infant skin temperature, humidity

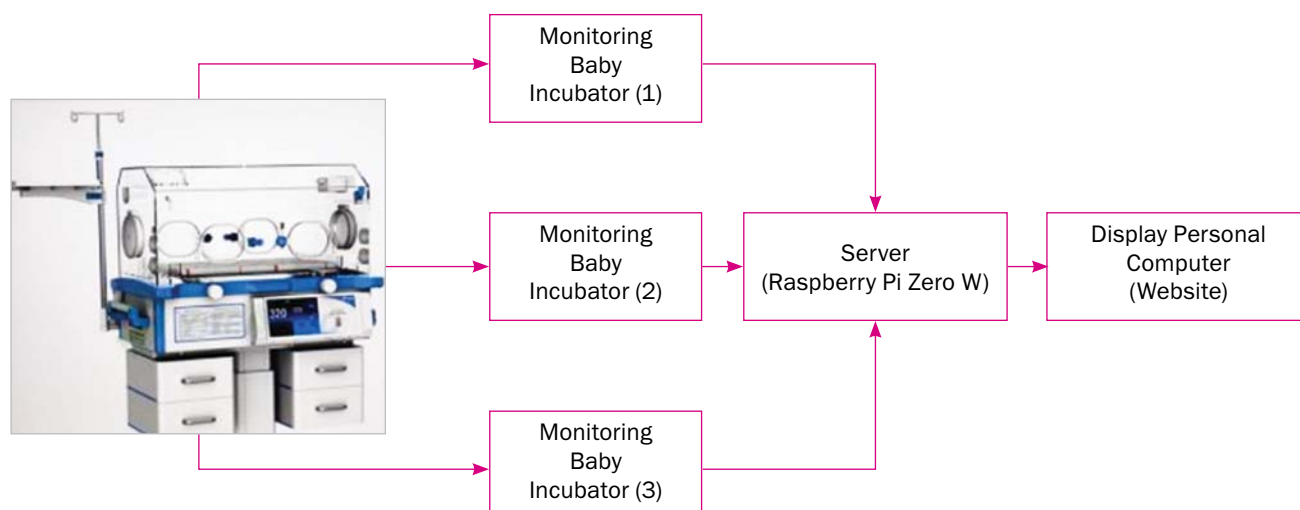


Fig. 1. Schematic diagram of the newborn incubator monitoring system

levels, and ambient noise. The website will serve as the visual interface for the monitoring system, displaying the acquired data on a computer screen. Considering accuracy and affordability, the DS18B20 sensor was selected for skin temperature monitoring, while the DHT22 sensor was chosen for measuring internal incubator temperature. Online monitoring, analysis and management of physical parameters in real time is made possible by the IoT, an interconnected network of sensors that can be independently configured using standard communication protocols. The Raspberry Pi Zero W microcomputer was used in this study.

The aim of developing this monitoring method is to increase the efficiency of monitoring the operation of several incubators for newborns. The medical staff can easily assess skin temperature, humidity level, noise level, and temperature inside the incubator by viewing the monitoring data on the computer screen. Enhanced monitoring capabilities are needed to reduce the likelihood of accidents. Staff can quickly identify deviations in controlled parameters thanks to a user-friendly interface and real-time data visualization. The IoT technology ensures uninterrupted connection and communication between the central computer and the monitoring system, which makes it possible to make informed decisions on the modification of care protocols and significantly improves the outcomes in perinatal pathology.

The newborn incubator monitoring system, shown in Fig. 1, consists of several sensors, including incubator temperature, humidity, skin temperature, and noise sensors. The ESP32 monitoring module transmits the collected data in real time. Raspberry Pi Zero W processes this data upon receipt and displays the results on a personal computer screen. This system provides continuous monitoring of critical incubator parameters, offering medical staff timely information and the ability to address any discrepancies.

METHODS

In this study, a pre- and post-experimental design was employed. The experimental monitoring system included DS18B20, DHT22, and Analog Sound V2.2 sensors. An ESP32 microcontroller was connected to these sensors, converting the circuit's output data into digital format.

Three identical newborn incubators were used for data collection. After the temperature inside the incubators had stabilized, measurements were taken 5 times at 10-minute

intervals. The temperature regimes 32 °C, 34 °C, and 36 °C were investigated. The incubator analyzer readings were then compared with the data obtained by monitoring.

Along with this, the infants' skin temperature was measured, as well as the room temperature.

The statistical approach included calculating the mean value of the measurements by summing all obtained results and dividing by the number of data points. As an indicator of a system error, a percentage error was determined, showing how much the model deviates from the expected standard.

RESULTS

Figure 2 shows the monitoring module enhanced in the framework of this study, featuring the Analog Sound V2.2 sensor, DS18B20 and DHT22 sensors, and the ESP32 microcontroller. This module is designed for effective monitoring of a range of newborn incubator parameters. To ensure the operation of the module, a rechargeable battery is built into it, and a lithium battery is used as a power source.

A special website provides access to the user-friendly interface of the newborn incubator monitoring system



Fig. 2. The design of the module for monitoring the parameters of the newborns' incubator



Fig. 3. The display screen displays the investigated incubator parameters in real time

Table 1. Incubator temperature monitoring using an incubator analyzer and a test module

Setting	Incubator			Module			Error		
	1	2	3	1	2	3	1	2	3
32 °C	31.2	30.8	30.1	31.2	31	29.8	0.001	0.006	0.009
34 °C	33.3	33	34.1	33.2	33.1	32.8	0.002	0.001	0.001
36 °C	35.1	34.7	34.1	35	34.9	34.4	0.001	0.004	0.008

Table 2. Skin Temperature Measurements Results

Setting	Incubator			Module			Error		
	1	2	3	1	2	3	1	2	3
32 °C	31.8	30	30	31.8	30.5	30.3	0.0006	0.01	0.01
34 °C	34	33.7	33.4	34	33.7	33.8	0.0005	0.0005	0.01
36 °C	36	34.6	34.4	35.9	34.6	34.9	0.001	0.002	0.01

(Fig. 3). Since the interface provides real-time updates, caregivers can effectively monitor and evaluate the incubator’s performance.

A comparative analysis of the set temperature in each of the three incubators and its average values obtained based on the readings of the incubator and the module under study, indicating the measurement error, is presented in Table 1.

As shown in Table 1, at the set temperature of 32 °C, the average temperature in Module 1 was 31.2 °C, in Module 2 — 31 °C, in Module 3 — 29.8 °C. At the set temperature of 34 °C, the evaluation results of Module 1 were 33.2 °C, Module 2 — 33.1 °C, Module 3 — 32.8 °C. At a set temperature of 36 °C, Module 1 recorded 35 °C, Module 2 — 34.9 °C, Module 3 — 34.4 °C. The measurements showed that the difference between the data of Module 3 and the incubator analyzer at a temperature of 32 °C was the greatest. At a temperature of 34 °C, all modules showed the same difference with the data from the incubator analyzer; however, Module 3 showed the greatest difference at 36 °C.

A comparative analysis of the set temperature in each of the three incubators and the mean skin temperature

values—derived from the incubator analyzer and the module under test, including measurement uncertainty—is presented in Table 2.

For modules 1, 2, and 3, the Incu Analyzer averaged 31,8 °C, 30,5 °C, and 30,3 °C, respectively. Module 1 recorded 34 °C, Module 2 recorded 33,7 °C, and Module 3 recorded 33,8 °C. Lastly, the values were 35,9 °C for Module 1, 34,6 °C for Module 2, and 34,9 °C for Module 3 at a temperature of 36 °C. At 32 °C, Module 2 displayed the largest departure from the Incu Analyzer data, whereas Module 3 displayed the largest deviation at 34 °C and 36 °C.

CONCLUSION

The main objective of this study is to develop an effective tool for remote monitoring of several newborns’ incubators, which will optimize the care of critically ill infants, improve their treatment outcomes, and reduce the workload on medical staff. The developed monitoring system demonstrates reliability in providing accurate readings of the environmental temperature surrounding the newborn with reasonable error margins. All measurements confirmed the accuracy of the incubator temperature and patient skin

temperature readings. The developed monitoring system for clinical incubators enables the detection and correction of potential problems in maintaining neonatal homeostasis, which is of critical importance for optimizing treatment and reducing neonatal and infant mortality.

AUTHORS' CONTRIBUTION

M. Farhan — study design, data analysis, writing and editing.

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