Implementation of IoT of an Electric Infant Warmer to Prevent Hypothermia in Newborns

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Abstract—**Hypothermia is a drop in body temperature below 36.5°C in newborns. It results in an internal distribution of body heat from the nucleus to the periphery, followed by heat loss greater than metabolic production. Hypothermia is one of the factors predisposing to metabolic disorders, intracranial hemorrhage, respiratory distress, and Necrotizing enterocolitis. Hypothermia problems can be treated with infant warmers. Thus, the need for a infant warmer is considered to improve survival in newborns. This study aims to improve the accuracy of temperature monitoring, increase security, and enable remote monitoring. The temperature sensor of the device is calibrated with comparable devices such as Incubator Analyzer and Thermo hygrometer while the SpO_2 sensor is calibrated with Spotlight SpO_2 Functional Tester and Thermo hygrometer. Achievement and validation of temperature and oxygen saturation use a calibration comparison tool. The results of the temperature sensor measurements, including air temperature and skin sensor temperature, namely: air temperature error tolerance ≤2°C and skin sensor temperature error tolerance ± 0.5 ° C. All two indicators have the same standard deviation value of ±0.49. The SpO_2 indicator reached an error tolerance value of ± 1% O_2 with a standard deviation value of ± 0.6-0.9 from six trials. Then the pulse rate indicator obtained an error tolerance of ±5% with a standard deviation value of ±0.6. The smart infant warmer tool provides benefits to avoid excessive heat from the heater and minimize low temperatures that cause hypothermia through the Internet of Things technology. Furthermore, this research can be improved with machine learning technology to increase efficiency and effectiveness in patient treatment.**

Keywords—Infant Warmer; IoT; Hypothermia.

I. INTRODUCTION

Hypothermia has been associated with increased mortality and morbidity in newborns [1][2]. Particularly, neonatal hypothermia is widely recognized to be one of the biggest causes of mortality and morbidity, especially among the world's poorest newborns. The prevalence of hypothermia had a percentage between 11%-92% in the community, and 8%-85% in hospitals, especially in developing countries. In another study from India, hypothermia cases reached 37% of moderate hypothermia in newborns in the Neonatal Intensive Care Unit [3][4]. This is due to the baby's body and skin temperature which decreases between 0.1°C-0.3°C per minute after the baby is born. This incidence can be prevented by using an infant warmer as the first treatment to maintain body temperature [5][6].

Hypothermia easily occurs in newborns because they cannot regulate their body temperature, unlike adults. The risk is greater, the more premature, and the smaller the newborns. Premature babies will easily experience hypothermia due to environmental factors (low delivery room temperature) and physical factors (poor vasomotor control, immature skin with minimal stratum corneum, larger skin surface area to body volume ratios, less subcutaneous fat content, and lack of non-shivering thermogenesis) [7][8]. The consequences of hypothermia can cause a variety of diseases, including compromised organ function, respiratory distress, and increased infection risk. [9][10]. Moreover, neonatal hypothermia is often defined as a body temperature <36°C and it has been associated with high mortality among premature infants [11].

Newborns have a high risk of various health problems because newborns' bodies are still vulnerable so they need medical devices to support their first life. The medical device is an infant warmer that can provide a living environment for newborns like in the womb. Indeed, an infant warmer is a life-saving & support equipment used to provide the temperature environment needed by the body of newborns [12].

Infant warmers have experienced developments in the field of technology. Several studies had created innovations for infant warmers. One of them was an infant warmer with phototherapy that used Arduino Uno, LCD, LM35 temperature sensor, and thermistor sensor with a temperature setting of 32°C to 37°C [13]. Additionally, another study also embedded a PID system with a trial and error using DHT 22 sensor & LM 35 sensor as a skin sensor [14]. Then, there was a smart infant warmer using a PID Controller and embedding a DHT 11 sensor as a temperature sensor and an LM 35 sensor as a skin sensor [15]. Furthermore, there was a recent study that created a smart infant warmer using LM 35 as a temperature sensor, DS18B20 as a skin temperature sensor, and a PID control system to stabilize the temperature [16]. The drawback of these studies is that they are still manual for patient monitoring. Moreover, this requires a tool that can monitor real-time and remote on the patient's body temperature indicator.

Based on the above identification results, the authors have developed an intelligent infant warmer with IoT (Internet of Things). This makes it easier for medical personnel to monitor patients. The tool can monitor newborns in real time through gadgets. It monitors not only the patient's body temperature but also the oxygen saturation level. This is what distinguishes it from previous infant warmer developments. IoT technology allows remote and real-time monitoring. IoT can also improve the patient safety system which is better than the prevention segment. This technology can be a good choice for the shortcomings of previous developments. The purpose of this study is to create a smart infant warmer in monitoring temperature and oxygen saturation levels in newborns in real-time. This monitoring detects changes in the patient's body temperature and oxygen saturation levels. This can improve the intervention schedule and reduce the potential risk of such changes to the patient's condition. This tool uses a SpO_2 sensor as an oxygen saturation level sensor, a skin sensor as a body temperature sensor, and OLED as a digital display. SpO_2 sensor aims to let nurses know the oxygen saturation level of newborns and the skin sensor aims to know the newborn's body temperature. The contribution of this development is to improve the accuracy rate, increase the use of tools, and remote monitoring of patient capabilities by medical personnel.

II. Materials and Methods

A. Experimental Setup

This research used calculations of the temperature's body in the range of 35°C-37°C by taking calculations at experiments taken 6 times for data collection. This experiment measured the room temperature and relative humidity where the measurement results get a temperature of (26.0 ± 0.7) °C and a relative humidity (of 68 ± 4) %. This experiment checks the physical condition and function of the tool components first with the results of the inspection in good condition. The experiment was conducted on one subject only with repetition for one hour of the experiment.

1) Material and Tools

This study used an ESP32 microcontroller for data processing. This research used the DHT11 sensor as the temperature's room reading and the DS18B20 sensor was used as the newborn's skin temperature reading by using a 2500-watt power heater element. This study also used LCD/OLED to display all parameters in infant warmer devices. Moreover, the SpO2 sensor measures the oxygen saturation level of the newborns. The use of ESP32 has embedded WIFI to support the IoT program. While the DHT11 and DS18B20 Sensors have a better level of accuracy than other temperature sensors [17][18].

2) Experiment

The sensors were compared with a calibrator analyzer with 6 data retrieval. This study used the MK-015 calibration method with reference MK No.026, Decree of the Director General of Health Services. Indonesian Ministry of Health Number: HK.02.02/V/0412/2020 for the DS18B20 sensor. Calibration was carried out under conditions of room temperature (26.0 ± 0.7) °C and relative humidity (68 ± 4) %. The calibration apparatus used a FLUKE Brand Incubator Analyzer with certification number 3909/AMK/III/2022 and a Thermo hygrometer with certification number 4706/AMK/IV/2023.

The SpO2 calibration used the MK-011 method with references MK No. 041, Decree of the Director General of Health Services, Indonesian Ministry of Health Number: HK.02.02/V/0412/2020, and Medical Equipment Quality Assurance, Fluke Biomedical. Calibration was carried out under conditions of room temperature (26.7 ± 0.3) °C and relative humidity (68 ± 4) %. The calibration comparison tool used the Spotlight SpO_2 Functional Tester Brand FLUKE with certification number CAL/031/3691015-02/16/21.

3) Statistical Analysis

The statistical analysis used a 95% confidence level with a coverage factor of k= 2. Furthermore, each SpO_2 reading was corrected by the addition of its correction value.

4) Ethical Clearance

This study has received ethical clearance from the Faculty of Medicine, Universitas Muhammadiyah Surakarta with number 5013/B.2/KEPK-FKUMS/VII/202.3.

B. Diagram Block

In the diagram block as shown in Fig. 1, it is explained that; in the first setting, the device is checked for internet connection through the ESP32 webserver IP connected to WIFI. Then, the user sets the lower (35°C) and upper (37°C) temperatures of the infant warmer with the keypad. The results of the settings are displayed on the LCD connected to the Arduino Uno. Next, the heater is turned on by placing the DS18B20 sensor on the patient's skin to detect the patient's body temperature.

The SpO_2 sensor detects the patient's oxygen saturation level by embedding the sensor in the patient's finger. The DHT11 sensor is used to measure room temperature and air humidity. The data from the sensor is processed and sent via ESP32 with its Webserver IP connection to be displayed to health workers from gadgets. Health workers can monitor patients by remote control.

This infant warmer tool is designed to turn off the heater if the temperature has exceeded the upper limit of its user settings. This can improve work efficiency and effectiveness for health workers during patient care.

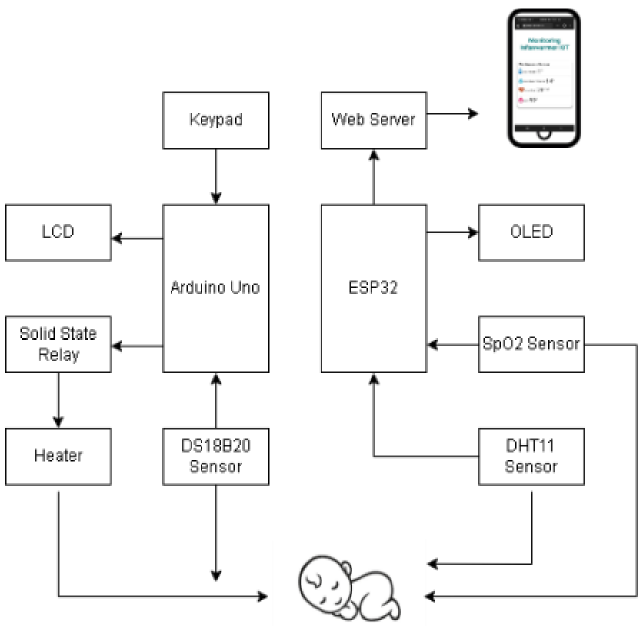

Fig. 1. Diagram block

C. The Flow Chart

The flowchart which is shown in Fig. 2 explains that; 1) the infant warmer must press the push button to become powered on; 2) After that, the infant warmer is connected to WIFI via SSID and Password; 3) Then, component initialization occurs and proceeds to activate the SpO_2 and DS18B20 sensor in measuring the patient's condition indicators of oxygen saturation and body temperature; 4) Next, the sensor measurement data is sent via webserver IP to the user's gadget and the results are displayed by OLED in the infant warmer; 5) If the infant warmer has no internet connection, then there is no component initialization to activate the sensor and the device cannot measure the patient's oxygen saturation and body temperature.

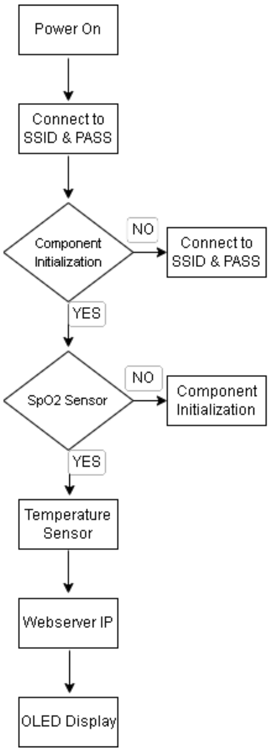

Fig. 2. The flowchart of IoT monitor

III. Results

The infant warmer uses two main sensors to measure indicators of the patient's body condition. The sensors are the SpO_2 sensor and the body temperature sensor through its placement on the patient's skin. This tool is embedded with IoT (Internet of Things) technology so that it can work remotely. This IoT technology must be connected to internet signals both infant warmers and user gadgets. Implementation of IoT can facilitate user work in the efficiency and effectiveness of health services. This tool can improve patient safety, and remote monitoring, and increase healthcare professionals' ability to supervise patients. The microcontroller on the infant warmer can transmit and process sensor measurement data to the user via its Webserver IP. Furthermore, all indicators are displayed on the LCD to set the temperature from the keypad and OLED displays the results of temperature indicators and oxygen saturation data from the sensor. Then this tool can be operated with electric power up to 200 watts to support the heater. The heater is also equipped with an insulator so that users are safe from static electricity from the infant warmer. This tool with IoT technology can increase the accuracy of temperature monitoring, increase security, and enable remote monitoring. The infant warmer can be seen in Fig. 3.

Fig. 3. Infant warmer

1) The Listing Program for Infant Warmer Device

1. Sensor and WIFI Initialization Program
2. OLED Initialization Program with I2C
3. SpO_2 and DHT11 Sensor Installation Reading Program to Web Server
4. Sensor Reading Results Appearance on OLED
5. Program Appearance on Web Server SpO_2, Heart Rate, Temperature, and Humidity
6. LCD, DS18b20, Keypad Initialization Program
7. Keypad to SSR & DS18B20 Sensor Initialization Program
8. Setup Program on Setting & Differential Mode Selection
9. Temperature & Differential Setting and Display to LCD

2) The Measurement Result

Sensor measurements were taken to ensure the device was fit for use. The device's sensors measure the patient's body temperature, oxygen saturation, and pulse rate. This measurement data is sent to the user with IoT technology via Webserver IP to the user's gadget. This is remote monitoring that can make it easier for users to monitor the patient's body condition in real time. If the heater temperature has increased for the patient, the infant warmer responds by turning off the heater according to the settings of the user. The measurement results are also compared with the calibrator. Each indicator is calibrated with its respective calibrator. This can improve the system accuracy of measurement results, improve patient safety, and improve the expertise of health workers to supervise patients.

Table I states that the results of six measurements reached the highest correction value of two numbers. Standard measurement 70 obtained 68 in the sensor measurement with a correction value of two and the highest Standard deviation value of ±0.9. While the standard measurements of 90 and 95 attained the same value on the sensor measurement with a correction value and relative error of zero. Standard measurements less than 90 obtained a correction difference of one to two numbers with the highest relative error of three percent.

Table II states that the results of four measurements reached the highest correction value of one number. Standard settings 30, 60, and 120 obtained the same sensor reading value as the standard setting value and the correction & relative error value was zero. While the standard setting of 180 attained a sensor reading value of 179 with a correction value and relative error worth one point. Standard settings less than 180 reached the same correction value and relative error of zero point.

Table III states that the results of six times setting the temperature standard of 36°C for the patient's body temperature reached a sensor reading value of 35.65°C with a correction value of -0.23 and a tolerance of approximately 0.5°C. While setting the 36°C standard for room temperature water, the sensor reading value obtained 35.37°C with a correction value of -0.51 tolerance of less than equal to 2°C.

IV. DISCUSSION

In the measurement results, it was found that the pulse rate reached an error value of around 0.6 with a tolerance of 5% or 5 BPM. According to Matthew E. Wieler [19], the results of his research obtained an error value of around 0.53%, while other studies also attained an error value of 0.37% [20], 0.87% [21] <1.702% [22], 2.702% [23], and 3.23% [24]. The allowable error value for patient care was less than 5%.

The SpO_2 sensor measurement results reached the highest correction result of only two and the highest relative error of three percent. Based on M. Syahrul Azam [25], the results of his research obtained the error value of the highest SpO_2 sensor of 0.68% and the smallest 0.17%. While other similar studies stated the error value in the range of 0.0123% [26], 1% [27], >3% [28], 0.38% [29], 0.81% [30], 1% [31], and other study revealed deviation value approximately 1.62% [32].

In the measurement results, it was found that the skin sensor temperature was read at 35.65°C with a correction error of 0.23 from the indicator temperature. Then the error tolerance reached approximately 0.5°C. This also happened in the previous study, the difference in temperature sensor measurements was only about 0.13-0.182°C with the largest error of the system reaching 0.517% [33] and other studies achieved an error rate of only 0.28% [25]. Then based on other research, the results obtained for the error value were also less than 0.5°C [34]–[36]. The error value obtained from the DS18B20 sensor measurement was about 1% [37][38] or 0.3°C. The previous research also stated the results of the error value which obtained an error value of around 0.15 - 0.29°C [39], 1.02% [21], 0.06% [16], 0.37% [36], and 2.18% [23]. These studies, in measuring temperature, calibrate with the same Incubator Analyzer tool used in this study.

Previous research used a PID control infant warmer system to improve temperature stability performance. The experiment showed a temperature setting of 35°C with an error of 0% [16]. Then another study also obtained a comparison of the DS18B20 sensor with a thermometer, the difference had an average of 0.3°C and 1% deviation. So that this is still within the standard limits [37]. Furthermore, infant warmers that used fuzzy logic obtained a level of precision for temperature monitors with a temperature difference with an average thermometer error of 1.07% with an accuracy rate of 98.93% [40].

TABLE I. OXYGEN SATURATION RESULTS

Oxygen Saturation Performance						
Parameters	Setting Standard	Average Tool Reading (%)	Correction	Relative Error (%)	Tolerance	Standard deviation
SpO_2 (%)	70	68	2	3	± 1% O_2	± 0.9
	75	73	2	3		± 0.6
	80	78	2	3		± 0.7
	85	84	1	1		± 0.6
	90	90	0	0		± 0.7
	95	95	0	0		± 0.6

TABLE II. PULSE RATE RESULTS

Oxygen Saturation Performance						
Parameters	Setting Standard	Average Tool Reading (BPM)	Correction	Relative Error (%)	Tolerance	Standard deviation
Pulse Rate (BPM)	30	30	0	0	± 5% ±5 BPM	± 0.6
	60	60	0	0		± 0.6
	120	120	0	0		± 0.6
	180	179	1	1		± 0.6

TABLE III. TEMPERATURE RESULTS

Temperature Performance						
Parameters	Setting Standard	Average Tool Reading (%)	Correction	Relative Error (%)	Tolerance	Standard deviation
Air Temperature	36	35.88	35.37	-0.51	≤ 2 (°C)	±0.49 (°C)
Skin Sensor Temperature	36	35.88	35.65	-0.23	±0.5 (°C)	±0.49 (°C)
	36	35.88	35.65	-0.23	±0.5 (°C)	±0.49 (°C)
	36	35.88	35.65	-0.23	±0.5 (°C)	±0.49 (°C)
	36	35.88	35.65	-0.23	±0.5 (°C)	±0.49 (°C)
	36	35.88	35.65	-0.23	±0.5 (°C)	±0.49 (°C)
	36	35.88	35.65	-0.23	±0.5 (°C)	±0.49 (°C)

Another similar infant warmer using fuzzy logic could provide a temperature with an error value of 1.36% with a tolerance limit of 0.1°C [41]. According to Shaib et al. [42], temperature monitoring still used a Wireless Computer Network where the tool is channeled through Xbee Pro. The weakness of this tool is that the data process and display process still use a computer. It was also made by Azkiyak et, al proposing a temperature and humidity monitoring with ATmega328 Microcontroller, the distribution process still used HC-12 wireless [43]. Then Hannouch et al. also proposed monitoring of temperature and humidity in infant warmers through wireless equipped nurse-call where the delivery process still used HC-11 and the results were displayed on a computer [44]. According to Shabaan, his research also used the internet, and the data was displayed through Character LCD for temperature and humidity monitoring [45].

According to Sendra et al. [46], An infant incubator was developed with DHT11, Wemos D1, Arduino Mega, and FSR-402 sensors. Then the device used a LoRa module and an NXP PN532. There was also an infant warmer developed with an Arduino Uno system, ESP8266 WIFI module, DHT11/DHT22 sensor, and Thingspeak Platform to store the data [47]. Furthermore, the development of an infant warmer used an alarm, SN-Pulse, and Arduino Uno system [48], while Ashish [49] only monitored the incubator temperature with an LM-35 sensor and Raspberry Pi 2+ ESP8266 WIFI module.

The development of Infant warmers had also been developed with the use of MQ5 to monitor temperature, humidity, and SpO_2 [50]. Furthermore, the development of the baby incubator had been improved its working system remotely via a web-based graphical user interface [51]. There was a similar development using a web application for remote monitoring and control with the inclusion of a DHT11 sensor, RTC DS130 module, and Arduino Mega 2560 [52]. The research also used a remote system through a web application by embedding the DHT22 sensor, DS18B20, and SIM900A GSM module [53]. Some infant warmer developments used a wireless system [54][55] for monitoring temperature, humidity, and SpO_2 with LabVIEW [56]–[58]. As well as infant warmers used Bluetooth communication systems through an Android smartphone [59].

The use of IoT technology allows medical consultations and follow-ups of its patients with the system in remote and isolated places, or with limited mobility [60]. Then, IoT technology provides real-time monitoring, cloud-related health analysis, and machine learning [61]. IoT has also increased global attention [62] IoT has become a key function for the prediction, prevention, and monitoring of infectious and communicable diseases [63]. IoT is one of the intelligent services and applications that can be linked, such as behavior recognition, disease diagnosis, and smart assistance [64]. Based on the explanation above, the implementation of IoT embedded in Infant Warmer is a smart assistance to help health workers in monitoring newborn patients.

V. CONCLUSION

The smart infant warmer is aimed to improve the accuracy of temperature monitoring, increase security, and enable remote monitoring. The infant warmer had earned to apply IoT Technology and the experiment also reached appropriate results. The skin temperature sensor obtained a standard deviation of around ±0.49, a tolerance value of ±0.5°C, and a correction value of -0.23 points. According to the SpO_2 sensor, the value reached a standard deviation around ±0.6-0.9 with a tolerance value of ±1%O_2 and a correction value of approximately 1-2 points. Then pulse rate value attained a standard deviation of ±0.6 with a tolerance value of ±5% and a correction value around 0-1 point. The calibration used an Incubator Analyzer and Thermo hygrometer for the temperature sensor, but Spotlight SpO2 Functional Tester was used by the SpO_2 sensor.

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