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Design and Construction of a Multi-Channel Temperature Calibrator for a Blanket Warmer with Thermal Printer Integration

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ABSTRAK

Selimut penghangat merupakan perangkat medis esensial untuk mencegah hipotermia selama pembedahan maupun perawatan kritis, namun akurasi sensor suhunya cenderung menurun seiring waktu sehingga diperlukan kalibrasi berkala. Metode kalibrasi manual menggunakan termometer eksternal tidak lagi efisien untuk blanket warmer modern yang memiliki sistem multi-channel karena rentan kesalahan operator, memakan waktu lama, dan tidak menyediakan dokumentasi fisik secara instan. Solusi yang ada sebelumnya—seperti DHT22 dengan SD card (hanya monitoring lokal), LM35 4-channel (akurasi belum memenuhi standar medis), serta sistem termokopel K-type berbasis IoT (kompleks dan bergantung internet)—belum mampu menyediakan kalibrator portabel multi-channel yang dilengkapi pencetakan otomatis. Penelitian ini mengatasi kesenjangan tersebut dengan merancang dan memvalidasi kalibrator suhu portabel 4-channel untuk blanket warmer menggunakan sensor DS18B20 (−55°C hingga +125°C, akurasi ±0,5°C, 12-bit, 1-Wire), dilengkapi sensor DHT11 (akurasi ±5% RH) untuk memantau kelembapan ruang, Arduino Uno R3 (ATmega328P, 16 MHz) sebagai pengendali, LCD 20×4 I2C untuk tampilan real-time, serta printer termal 58 mm (9600 baud) untuk dokumentasi hasil kalibrasi secara otomatis. Perangkat dirakit dalam enclosure akrilik berukuran 20×15×10 cm. Pengujian dilakukan pada suhu target 38°C dengan 10 pengulangan per kanal (T1–T4 ditempatkan merata di permukaan blanket warmer), waktu stabilisasi 5 menit, kelembapan lingkungan 40–60% tanpa aliran udara, dan dibandingkan dengan termokopel referensi HT-9815. Hasil menunjukkan bahwa perangkat menghasilkan error rata-rata 0,28–0,78°C (terendah pada T3: 0,28°C), seluruhnya di bawah 1°C dan sebanding bahkan lebih akurat dibandingkan instrumen referensi (0,39–0,89°C). Kontribusi utama penelitian ini mencakup: (1) integrasi pertama sensor DS18B20 multi-channel dengan printer termal otomatis dalam kalibrator portabel, (2) akurasi yang lebih unggul pada beberapa titik pengukuran, dan (3) dokumentasi kalibrasi instan yang meningkatkan efisiensi kerja, keselamatan pasien, dan kepatuhan rumah sakit terhadap standar regulasi.

Kata Kunci: Selimut Penghangat, Pengukuran Suhu, Sensor DS18B20, Mikrokontroler, Printer Termal

ABSTRACT

Warming blankets are essential medical devices for preventing hypothermia during surgery and critical care, yet their built-in temperature sensors degrade over time, necessitating regular calibration. Conventional manual calibration using external thermometers is inefficient for modern multi-channel blanket warmers, as it is prone to operator error, time-consuming, and lacks instant physical documentation. Existing solutions—such as DHT22 with an SD card (local monitoring only), 4-channel LM35 systems (insufficient medical-grade accuracy), and IoT-based K-type thermocouples (complex and internet-dependent)—have not provided a portable multi-channel calibrator with automatic printing capability. This study addresses that gap by designing and validating a 4-channel portable temperature calibrator for blanket warmers based on DS18B20 sensors (−55°C to +125°C, ±0.5°C accuracy, 12-bit, 1-Wire), complemented by a DHT11 sensor (±5% RH) for ambient humidity monitoring, an Arduino Uno R3 (ATmega328P, 16 MHz) as the controller, a 20×4 I2C LCD for real-time display, and a 58-mm thermal printer (9600 baud) for automatic hard-copy documentation in an acrylic enclosure of 20×15×10 cm. Performance was tested at a target temperature of 38°C with ten repetitions per channel (T1–T4 placed uniformly on the blanket surface), a stabilization time of 5 minutes, and controlled environmental conditions (40–60% RH, no airflow), using an HT-9815 thermocouple thermometer as the reference. The proposed device achieved mean errors of 0.28–0.78°C (lowest at T3: 0.28°C), all below 1°C and comparable to or better than the reference instrument (0.39–0.89°C). The main contributions are: (i) the first integration of multi-channel DS18B20 sensors with an automatic thermal printer in a portable calibrator, (ii) demonstrated superior accuracy at several points relative to the reference device, and (iii) instant calibration documentation that improves workflow efficiency, patient safety, and hospital regulatory compliance.

Keywords: *Blanket Warmer, Temperature Measurement, DS18B20 Sensor, Microcontroller, Thermal Printer*

Introduction

Blanket warmers are essential medical devices that maintain a patient's body temperature, especially during surgery or critical conditions [1]. Accurate temperature control is crucial for ensuring patient safety and comfort, preventing the risk of hypothermia, a condition where the body temperature drops below 35°C, and supporting the recovery process[2]. However, over time, the temperature sensor in blanket warmers can degrade in accuracy, leading to incorrect readings and potential deviations from medical temperature standards if not promptly detected and corrected. Most calibration procedures are still performed manually using an external thermometer[3]. This method is time-consuming, prone to human error, and requires experienced technicians. This is further complicated by the advent of modern blanket warmers equipped with multiple heating channels and temperature measurement points, making manual calibration less efficient and accurate, a method that is time-consuming, prone to human error, and dependent on experienced technicians. The emergence of modern blanket warmers with multiple heating channels and measurement points further complicates manual calibration, making it less efficient and potentially less reliable [4]. These conditions highlight the need for a portable, integrated, multi-channel temperature calibration tool that supports routine maintenance and ensures the reliability of blanket warmers in clinical settings [5].

Before designing and manufacturing a new calibrator, Several previous studies on temperature calibration systems provide useful references but also reveal significant limitations. Ahmad Dwiki Raharjo developed a temperature calibration tool using a DHT22 sensor, a thermo-hygrometer, and SD card storage, enabling automatic recording of temperature and humidity but limited to local monitoring without integration into a portable multi-channel calibrator [6]. Rismawati and Muhammad Sadli designed a four-input LM35-based temperature data system with a real-time LCD and computer-based graphs, which facilitate visualization but rely on a sensor whose accuracy and robustness are less optimal for medical-grade applications [7]. Nurhayati and Susanto proposed a K-type thermocouple calibrator with an IoT monitoring system that supports remote access, yet it requires a stable internet connection and a relatively complex configuration [8], [9]. These studies indicate that current temperature calibration solutions still lack a truly portable, multi-channel calibrator designed explicitly for blanket warmers, with integrated automatic printing of calibration results and simultaneous measurement of supporting environmental parameters, such as humidity [10]. Based on these conditions, the main problem addressed in this study is the lack of a portable multi-channel temperature calibrator that can be used directly on blanket warmers, while simultaneously providing medically acceptable accuracy and automatic hard-copy documentation of calibration results. Therefore, this research aims to develop and validate a four-channel portable temperature calibrator using DS18B20 digital temperature sensors integrated with an Arduino-based control system, LCD, and 58-mm thermal printer, targeting a measurement error of less than 1°C at a set temperature of 38°C. The scientific novelty of this work lies in the integration of multi-channel DS18B20 sensors and an on-board thermal printer within a compact, field-deployable enclosure, which has not been reported in previous designs using DHT22, LM35, or K-type thermocouples. This approach is expected to improve calibration efficiency, ensure traceability of results, and ensure compliance with hospital documentation requirements.

Research Methods

a) Design Wiring Diagram System

The multi-channel temperature calibrator is designed with several key components integrated into its system. The device utilizes DHT11 sensors and DS18B20 sensors for temperature and humidity measurement, with dedicated connectors for the DS18B20 sensors. DS18B20 digital temperature sensors were selected instead of K-type thermocouples or RTD sensors (e.g., PT100) for several reasons. First, DS18B20 provides a direct digital output via the 1-Wire protocol, eliminating the need for cold-junction compensation and precision analog amplification required by thermocouples, which simplifies the multi-channel hardware design. Second, the operating range of −55°C to +125°C with a typical accuracy of ±0.5°C at 12-bit resolution is sufficient for clinical blanket warmer applications, which generally operate in the 35–45°C range. Third, the multi-drop capability of the 1-Wire bus allows four DS18B20 sensors to be connected on a single data line, reducing wiring complexity, potential connection errors, and overall system cost, while still meeting medical temperature calibration requirements.[11][12]

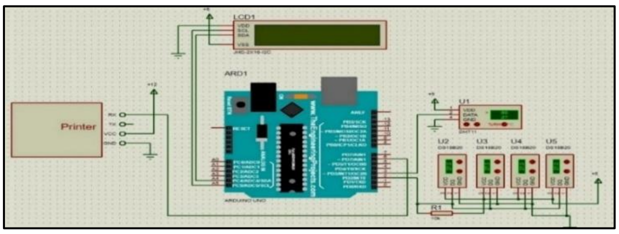

Figure 1. Design Wiring Diagram System

A Liquid Crystal Display (LCD) is prominently featured to show real-time data. User interaction is facilitated by three push buttons: a Reset button to clear data, a Hold button to freeze the current reading, and a Print button to send the displayed data to an integrated thermal printer. The system's power is managed by an ON/OFF switch connected via a dedicated power button connector. This layout ensures a user-friendly interface for measuring, displaying, and printing temperature readings from multiple channels.[13]

b) System Operations

The device's operation begins when a 220 VAC power source powers an adapter or a DC power supply. When the ON/OFF switch is turned on, the 220 VAC voltage is converted to 5 VDC, which then powers all the electronic components in the circuit. Temperature is first detected by four DS18B20 sensors, which convert the temperature readings into electrical signals. These signals are then amplified and converted into digital data before being sent to an Arduino microcontroller for processing. Simultaneously, a DHT11 sensor measures ambient room temperature and humidity. The processed temperature data from the DS18B20 sensors and humidity data from the DHT11 sensor are then displayed on a 20x4 LCD screen. For documentation purposes, this data is also printed using a thermal printer. To pause the sensor readings, the user can press the Hold & Run button; pressing it again resumes the readings.

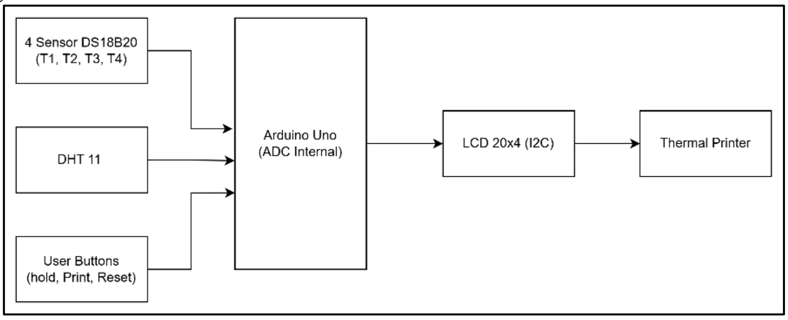

Figure 2. Real-level block diagram of the DS18B20-based multi-channel temperature calibrator

Figure 2. Real-level block diagram of the portable multi-channel blanket warmer temperature calibrator. Four DS18B20 temperature sensors (T1–T4) and one DHT11 humidity sensor send digital data to the Arduino Uno R3 microcontroller, which processes and displays the values on a 20×4 I2C LCD and sends formatted data to a 58-mm thermal printer for automatic hard-copy calibration records. A 220 VAC mains supply is converted to 5 V DC to power all modules, while user buttons (Hold, Print, Reset) provide control over measurement, data freezing, and printing.

The hardware of the proposed calibrator consists of a microcontroller board, digital temperature and humidity sensors, a character LCD, a thermal printer, and a regulated power supply integrated in a portable acrylic enclosure. The main hardware specifications are summarized in Table 1.

Table 1. Testing System with Comparative Tools

Component	Specification
Microcontroller	Arduino Uno R3, 16 MHz, 5 V DC
Temperature sensor	DS18B20 digital, −55°C to +125°C, ±0.5°C accuracy at 12-bit, 1-Wire bus
Number of channels	4 temperature channels (T1–T4) with separate probe connectors
Humidity sensor	DHT11, relative humidity accuracy ±5% RH
Display	20×4 character LCD with I2C interface for real-time data display
Printer	58-mm thermal printer, 9600 baud serial interface
Power Supply	220 VAC mains input, converted to regulated 5 V DC for all electronic modules
Enclosure	Acrylic housing, 20 × 15 × 10 cm (length × width × height)
User interface	ON/OFF switch, Hold/Run, Print, and Reset push buttons

c) Flowchart System

This flowchart illustrates the process of a temperature calibrator system, starting with the initial initialization stage, where the device prepares itself for measurement [14][15]. After initialization, the system reads data from four DS18B20 temperature sensors and one DHT11 humidity sensor, then processes it to display it on the LCD screen [16]. The LCD screen displays the readings from all sensors, namely four temperature points and one humidity point in the room. In the next stage, the system checks whether the Hold button is pressed. If the Hold button is pressed, the system pauses the display of measurement results, showing the last read value without updating until the Hold button is rereleased. If the Hold button is not active, the system then checks whether the Print button is pressed. If so, the displayed temperature and humidity readings are printed as calibration output[17][18]. After printing is complete, or if the Print button is not pressed, the system then checks the Reset button. If the Reset button is pressed, the system restarts and returns to the initialization stage, starting a new measurement from the beginning. This process continues in a loop until the system is stopped, ensuring accurate temperature and humidity readings and controlling operational functions via the three buttons.

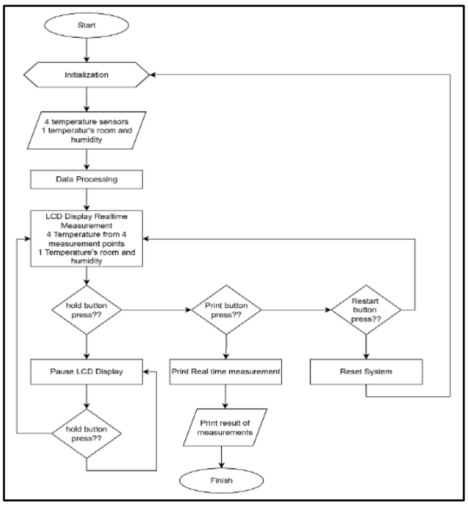

Figure 3. Flowchart System

Result and Discussion

This temperature calibrator operates automatically after being turned on using the ON/OFF switch. When the device is active, the 220V AC power supply circuit steps down the AC and rectifies it to 5V DC. This voltage powers all the main components, including the Arduino Uno microcontroller, DS18B20 and DHT11 sensors, LCD, and thermal printer. Once the system is active, the microcontroller initiates and measures the temperature from four DS18B20 sensors installed at various points on the blanket warmer. The DHT11 sensor also simultaneously measures room temperature and humidity, and this data is then processed by the microcontroller and displayed on a 20x4 LCD so users can monitor changes in temperature and humidity [19]. If users wish to pause data reading, they can press the HOLD button to freeze the data on the screen (unchanging). To resume reading, the HOLD button is pressed again. When users wish to print the calibration results, press the print button. The microcontroller will send the latest temperature and humidity data to the thermal printer, which then prints it as proof of the calibration results. This section presents the results of comprehensive testing of the multi-channel temperature calibrator system in the blanket warmer we designed.

Figure 4. Testing System

The image above illustrates the physical setup for testing the multi-channel temperature calibrator. The testing procedure was conducted on a blanket warmer, represented by the blue patterned surface, to validate the performance of the designed system.

The core of the experiment involves measuring temperature data at four distinct locations on the blanket warmer's surface. These four measurement points are crucial for assessing the device under test's temperature uniformity and accuracy. To achieve this, four temperature sensors, labeled as T1, T2, T3, and T4, are strategically placed across the blanket warmer. These sensors are likely the DS18B20 sensors mentioned in the device's operational description.

The cables from these four sensors are connected to the central control unit of the temperature calibrator, which is the white box with a blue LCD screen. This control unit houses the Arduino Uno microcontroller, which simultaneously acquires and processes data from all four sensors. The device's LCD screen displays real-time temperature readings, enabling live monitoring of the test.

A secondary device, a handheld thermometer (likely a commercial reference thermometer), is also included in the setup. This reference device is essential for validating the accuracy of the multi-channel calibrator. By comparing the temperature readings from the custom-built calibrator's sensors (T1-T4) with the reading from the reference thermometer, the calibration and precision of the designed device can be quantitatively evaluated.

This testing aims to ensure that the integration between components and subsystems runs synchronously and functions optimally under actual operational conditions [19]. System testing includes checking sensor functionality, inter-module communication, temperature and humidity reading accuracy, and data output via a thermal printer[20].

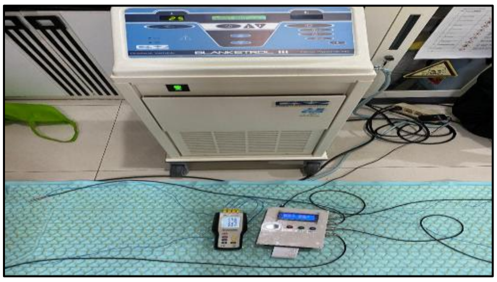

Figure 5. Testing System with Blanket Warmer set in 38°C

The measurement procedure of the multi-channel temperature calibrator was evaluated on a blanket warmer set to a target temperature of 38°C. Four DS18B20 probes (T1–T4) were placed evenly on the surface of the warming blanket to represent different measurement points across the heating area. For each channel, ten repeated measurements were recorded after an initial stabilization period of 5 minutes to allow the blanket warmer and sensors to reach steady-state temperature. All tests were conducted in a room with ambient relative humidity maintained between 40–60% RH and without forced airflow (no fan or air conditioning directed at the device), to minimize convective disturbances. The readings from the developed device were compared with those of an HT-9815 thermocouple thermometer used as a reference instrument. The mean temperature of each channel from the proposed system and from the reference thermometer was then used to calculate the measurement error at the 38°C set point.

The percentage error of the developed calibrator for each channel was calculated using:

$$\mathbf{Errordevice(\%)} = \frac{T_{device}-T_{set}}{T_{set}}\, x\ 100\ \% \quad \text{.....(1)}$$

where T_{device}Is the mean temperature measured by the proposed calibrator at a given channel and T_{set} is the blanket warmer set temperature (38°C).

Similarly, the percentage error of the reference thermometer was obtained as:

$$\boldsymbol{Error_{ref}}(\%) = \frac{T_{ref}-T_{set}}{T_{set}}\, x\ 100\ \% \quad \text{.....(2)}$$

where T_{ref}**Denotes** the mean temperature measured by the HT-9815 thermocouple thermometer at the corresponding channel position.

Each point was tested ten times to obtain representative data and measure the consistency and stability of the sensor across various positions. The measurement results were then compared with a thermocouple calibrator as a benchmark to evaluate the accuracy of the designed device. Furthermore, documentation of the testing process was included as proof that the device had been tested directly on the blanket warmer. The measurement data was used as the basis for evaluating the device's performance against actual temperature measurements and for final validation.

Table 2. Testing summarizes the mean temperatures and percentage errors computed using Formulas (1) and (2)

Blanket Warmer Temperature Set: 38°C								
Measurement	**Design System**				**Thermocouple Thermometers HT-9815**			
	T1	**T2**	**T3**	**T4**	**T1**	**T2**	**T3**	**T4**
1	38,1	38,6	38,2	38,9	38,4	37,8	38,5	38,5
2	38,1	38,2	38,1	38,4	38,2	38,3	38,5	38,4
3	38,2	38,1	37,9	38,2	38,3	38,2	38,0	38,4
4	38,9	38,1	38,3	38,1	37,9	38,1	38,3	38,5
5	38,6	37,9	38,1	38,0	37,7	37,9	38,2	38,1
6	37,6	38,1	37,7	38,3	37,9	38,0	37,8	38,2
7	37,2	38,6	38,5	38,7	38,7	38,6	38,4	38,7
8	38,9	38,7	38,4	38,2	38,8	38,5	38,4	38,3

9	38,6	38,0	37,9	38,3	38,1	38,1	38,0	38,4
10	38,4	37,8	38,0	37,9	38,1	38,0	38,0	37,9
Average	**38,26**	**38,21**	**38,11**	**38,3**	**38,21**	**38,15**	**38,21**	**38,34**
Error (%)	**0,68**	**0,55**	**0,28**	**0,78**	**0,55**	**0,39**	**0,55**	**0,89**

The performance of the designed system was evaluated by calculating the percentage error at each of the four measurement points on the blanket warmer using (1). For point 1, for example, the percentage error of the proposed device is obtained as

$$\mathbf{Errordevice}(\%) = \frac{|38{,}26 - 38|}{38} x\ 100\ \% = 0{,}68\ \%$$

Applying the same formula to all channels yields percentage errors of 0.68%, 0.55%, 0.28%, and 0.78% for points 1-4, respectively. All values are below 1%, indicating that the multi-channel temperature calibrator achieves high accuracy and is suitable for blanket warmer calibration.

Similarly, the error of the reference thermocouple thermometer (HT-9815) was calculated using (2). For point 1, the percentage error is

$$\boldsymbol{Error_{ref}}(\%) = \frac{|38{,}21 - 38|}{38} x\ 100\ \% = 0{,}55\ \%$$

Based on this comparison, the performance of the designed calibration tool is comparable to that of the reference instrument. In absolute temperature terms, the error margins of the proposed device range from 0.28 to 0.78°C, while those of the reference tool range from 0.39 to 0.89°C; both remain within 1°C of the set value. This provides strong evidence that the developed calibrator is valid and reliable for blanket warmer calibration tasks.

The image below presents direct visual evidence of the calibration process, showing the designed multi-channel temperature calibrator operating in parallel with the professional reference thermometer. The reference thermometer on the left displays four temperature readings from the blanket warmer, while the LCD screen of the proposed device on the right shows the corresponding measurements from its own sensors. With the “HOLD ACTIVE” function engaged, the system can freeze the displayed data to enable precise side-by-side comparison, which is essential for validating the accuracy and performance of the designed calibrator.

Figure 6. Result

One of the crucial features of the designed device is its ability to print calibration data automatically. The image below displays a sample printout from the thermal printer, which contains a summary of the temperature data from each channel (T1-T4) as well as environmental information from the DHT11 sensor.

Conclusion

This study has presented the design and implementation of a portable four-channel temperature calibrator specifically intended for blanket warmers, integrating multi-channel DS18B20 digital temperature sensors, ambient humidity monitoring, and an on-board 58-mm thermal printer within a compact 20 × 15 × 10 cm acrylic enclosure. Experimental evaluation at a 38°C set point shows that the proposed device achieves mean absolute temperature errors of 0.28-0.78°C across all channels, i.e., below 1°C and comparable to, or in some cases lower than, those of a commercial HT-9815 thermocouple calibrator (0.39–0.89°C). These results indicate that the system satisfies the accuracy requirements for medical temperature calibration and is suitable for routine blanket warmer verification.

The main contributions of this work are: (i) the first realization, to the best of our knowledge, of a multi-channel DS18B20-based calibrator with integrated automatic thermal printing for direct bedside use, and (ii) an efficient calibration workflow that produces immediate hard-copy documentation, thereby improving traceability, facilitating audits, and supporting regulatory compliance in hospital settings. In addition to validating the accuracy of the proposed design, the integration of real-time display, humidity monitoring, and instant printout functions makes the device practical and reliable for clinical engineering teams responsible for maintaining blanket warmers. Future work may include extending the calibration to multiple set points, adding digital data logging to external storage or hospital information systems, and performing broader clinical evaluations across different hospital environments.

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