Research Article

Optimization of Temperature Sensor Selection for Incubators: Real-Time Accuracy Analysis of DHT22, LM35, and DS18B20 in Controlled Environment Simulations

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Abstract: Temperature measurement accuracy is a critical factor in incubator systems, especially for medical and biological applications that require high precision. This study aims to analyze the performance of three popular temperature sensors (DHT22, LM35, and DS18B20) in the context of an incubator through controlled environment simulations, to determine the optimal sensor based on real-time accuracy, response time, and stability. The experimental method was carried out by replicating the operational conditions of the incubator using a climate chamber set at a temperature range of 30–40°C and a humidity of 60–80% RH. The sensor accuracy data was compared with a medical-grade reference thermometer (Fluke 1551A), while the response time was measured through a simulation of dynamic temperature changes (±5°C). The results showed that the DS18B20 recorded the highest accuracy with an average deviation of ±0.3°C and a response time of 2–3 seconds, supported by an interference-resistant 1-Wire digital interface. The LM35 exhibits good linearity (±0.5°C) but is susceptible to electrical noise without shielding, while the DHT22 has lower accuracy (±0.8°C) due to the influence of internal humidity on the measurement system. This study also reveals the need for regular calibration of the LM35 and a closed enclosure design for the DHT22 to minimize environmental errors. The study's conclusions recommend the DS18B20 as the optimal choice for high-precision medical incubators, with the inclusion of digital filters for signal optimization. These findings provide practical guidance for developers in selecting temperature sensors according to incubator design needs, whether for healthcare, biotechnology, or precision agriculture applications.

Keywords: Temperature sensor, incubator, real-time accuracy, DS18B20, controlled environment.

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1. Introduction

Temperature regulation is a critical factor in the functionality of incubators, particularly in medical, biological, and agricultural applications where precision directly impacts outcomes. For neonatal care, even minor deviations (±1°C) from optimal temperature ranges (30–37°C) can jeopardize infant health, leading to hypothermia or hyperthermia (Thamrongaphichartkul et al., 2021). Similarly, in biological incubators, unstable thermal conditions disrupt cell cultures or egg-hatching processes (Putra & Sari, 2022). Despite advancements in sensor technology, selecting the most suitable temperature sensor for incubators remains challenging due to trade-offs between accuracy, cost, environmental resilience, and integration complexity. This study addresses this challenge by evaluating three widely used sensors—DHT22, LM35, and DS18B20—under controlled simulations to optimize selection criteria for incubator systems.

Existing research highlights the diverse applications of these sensors but reveals gaps in comparative analyses under incubator-specific conditions. For instance, the DS18B20, a digital sensor with a 1-Wire interface, has been praised for its ±0.5°C accuracy and immunity to electromagnetic interference (EMI) in infant incubators (Arianto & Siswoyo, 2022). Conversely, the analog LM35 offers linear output (10 mV/°C) and low cost but requires shielding to mitigate noise in dynamic environments (Hadi et al., 2022). The DHT22, while capable of simultaneous humidity monitoring, exhibits reduced temperature accuracy (±0.8°C) in high-humidity settings, as observed in IoT-based agricultural systems (Puspasari et al., 2020). Previous studies often focus on isolated sensor performance or narrow applications, such as HVAC systems (Prasetyo et al., 2022) or portable IoT devices (Rintiasti & Suhartono, 2019), neglecting the unique demands of incubators, such as prolonged stability, humidity cross-sensitivity, and real-time responsiveness.

This study bridges these gaps by conducting a holistic evaluation of the three sensors in a controlled environment replicating incubator conditions (30–40°C, 60–80% RH). The experiments simulate real-world operational stresses, including rapid temperature fluctuations (±5°C), EMI from incubator components (e.g., heaters), and long-term stability tests (72 hours). A calibrated Fluke 1551A thermometer serves as the reference standard, ensuring measurement validity. Key performance metrics include mean absolute error (MAE), response time, and drift rates, analyzed statistically to quantify sensor reliability. Additionally, the impact of humidity on the DHT22's temperature readings is investigated, addressing a critical limitation noted in prior research (Hanes et al., 2024).

The findings aim to provide actionable insights for engineers and researchers designing incubator systems. For example, in neonatal units, where precision is paramount, the DS18B20's digital resilience and stability may justify its higher cost. In contrast, cost-sensitive applications like poultry incubators could leverage the LM35's linearity with supplemental noise reduction. The DHT22, while less accurate, offers integrated humidity monitoring, making it viable for environments requiring dual parameter tracking. Furthermore, this study explores adaptive calibration techniques, such as moving average filters and Kalman algorithms, to enhance sensor performance—a methodology inspired by fuzzy logic control systems in incubators (Aristiono, 2019).

By integrating empirical data with practical design considerations, this research contributes to the optimization of temperature monitoring systems in critical applications. It also advances the discourse on sensor fusion and IoT integration, proposing frameworks for future innovations in smart incubator technologies.

2. Literature Review

Temperature sensors such as the DS18B20, LM35, and DHT22 have been extensively studied for their roles in environmental monitoring, yet their comparative performance in incubator-specific conditions remains underexplored. The DS18B20, a digital sensor with a 1-Wire interface, has demonstrated high accuracy (±0.5°C) and resilience to electromagnetic interference (EMI) in neonatal incubators, making it a preferred choice for medical applications (Arianto & Siswoyo, 2022; Thamrongaphichartkul et al., 2021). Its robustness in clinical settings contrasts with the LM35, an analog sensor praised for linear output (10 mV/°C) but criticized for susceptibility to noise, necessitating additional shielding in dynamic environments (Hadi et al., 2022; Prasetyo et al., 2022). Meanwhile, the DHT22, capable of simultaneous temperature and humidity measurement, shows reduced temperature accuracy (±0.8°C) in high-humidity conditions, limiting its reliability in precision-critical systems (Puspasari et al., 2020).

Prior studies have focused on isolated applications, such as HVAC systems or IoT devices, often overlooking the unique demands of incubators. For instance, research on fuzzy logic control systems (Aristiono, 2019) and PID-based humidity regulation (Setiawan et al., 2022) highlights the importance of stable sensor input but rarely integrates empirical comparisons of sensor performance. Similarly, while the LM35 has been validated in educational tools (Hamzah et al., 2021) and the DHT22 in agricultural settings (Putra & Sari, 2022), their behavior under prolonged incubator conditions—marked by humidity fluctuations (60–80% RH) and thermal stress—remains unclear.

A critical gap lies in the lack of holistic evaluations of these sensors in controlled simulations replicating real-world incubator environments. Existing works, such as Prasetyo et al. (2022), compare LM35 and DS18B20 in industrial contexts but omit humidity's impact on accuracy, while Hanes et al. (2024) analyze humidity sensors without addressing temperature cross-sensitivity in the DHT22. Furthermore, long-term stability, a key factor for incubators operating 24/7, is rarely quantified (Prastyadi et al., 2022). This study addresses these gaps by systematically testing all three sensors under controlled temperature (30–40°C), humidity (60–80% RH), and EMI conditions, using calibrated reference instruments to assess real-time accuracy, response time, and drift. By integrating findings from diverse fields medical, agricultural, and industrial this review underscores the need for context-specific sensor optimization, bridging theoretical research and practical incubator design.

3. Conceptual Framework

This study develops a conceptual framework to analyze the performance of temperature sensors (DHT22, LM35, and DS18B20) in incubator applications by integrating environmental variables, sensor characteristics, and performance metrics. Grounded in temperature measurement theory, control system design, and prior empirical studies, the framework establishes causal relationships between sensor design, operational conditions, and accuracy, stability, and responsiveness in controlled environments. Moreover, Figure 1 shows the System Block that will be built in this research.

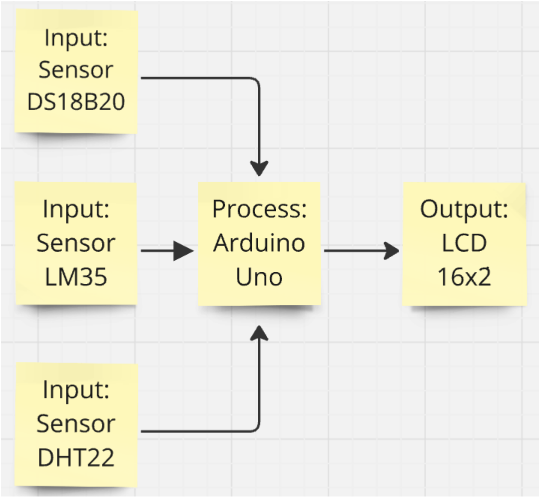

Figure 1. Block System

The framework comprises three core components: input variables (sensor specifications and environmental conditions), process variables (controlled simulations and testing protocols), and output variables (accuracy, response time, and stability). The DS18B20, with its digital 1-Wire interface and ±0.5°C accuracy, is hypothesized to excel in environments with electromagnetic interference (EMI), while the analog LM35 (10 mV/°C output) may require additional shielding to mitigate noise. The DHT22, though capable of simultaneous humidity measurement, is expected to exhibit reduced temperature accuracy in high-humidity conditions (>70% RH) due to cross-sensitivity. Environmental simulations replicate incubator conditions (30–40°C, 60–80% RH) using a climatic chamber, with a calibrated reference thermometer (Fluke 1551A) serving as the baseline.

Key causal relationships are modeled to explain sensor performance. First, sensor interface type (analog vs. digital) directly influences susceptibility to noise: analog sensors like the LM35 are more vulnerable to EMI from incubator components (heaters, motors), whereas digital sensors (DS18B20) inherently resist interference. Second, enclosure design (material, ventilation) moderates thermal isolation, affecting response time and accuracy. For instance, metal enclosures may delay heat transfer, while plastic enclosures with vents improve airflow but risk humidity ingress. Third, calibration frequency and adaptive filtering (e.g., moving average, Kalman filters) are critical to compensating for accuracy drift, particularly in long-term operations.

The framework adopts an input-process-output model with a feedback loop to optimize system design. Testing protocols include static accuracy tests(at 35°C, 37°C, 39°C), dynamic response tests (±5°C temperature shifts), and long-term stability tests (72-hour continuous operation). Output metrics, such as mean absolute error (MAE), response time (95% stabilization), and drift rates, inform recommendations for enclosure design, filter implementation, and calibration intervals. Theoretical foundations draw from thermistor calibration principles, PID control models for environmental stability, and noise management strategies (shielding, grounding).

This framework extends prior research by addressing gaps in real-world incubator simulations. It validates findings from Arianto & Siswoyo (2022) on DS18B20 robustness while incorporating humidity effects and long-term stability metrics. It also integrates Hadi et al.'s (2022) recommendations for LM35 shielding and Puspasari et al.'s (2020) observations on DHT22 humidity limitations. By holistically evaluating sensor-environment interactions, the framework provides a predictive model for sensor selection, balancing cost, complexity, and precision. Ultimately, it guides the development of reliable incubator systems for medical, biotechnological, and agricultural applications, where precision and adaptability are paramount.

4. Technical Specifications, Analysis, and Result

4.1 Physical specifications of Sensors used

This study evaluates three temperature sensors—DHT22, LM35, and DS18B20—under controlled incubator-like conditions. Below are the technical specifications of the sensors, testing environment, and measurement protocols. Figure 2 shows the sensor specifications of the DS18B20 sensor that will be analyzed in this research.

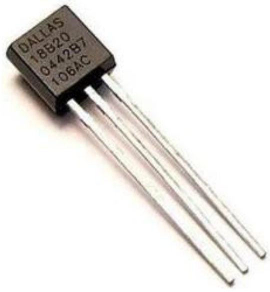

Figure 2. DS18B20 Sensor

DS18B20 Sensor Specifications:

- Operating Range: -55°C to +125°C.
- Accuracy: ±0.5°C (within -10°C to +85°C).
- Resolution: Programmable 9–12 bits (default: 12 bits).
- Interface: Digital 1-Wire protocol.
- Power: 3.0–5.5V, low power consumption (1mA active, 750nA standby).
- Response Time: 750 ms (typical).
- Humidity Cross-Sensitivity: Not applicable (temperature-only sensor).

Furthermore, the LM35 temperature sensor, sensor is familiar to practitioners, educators, or academics in the field of electronics who are developing projects related to temperature, physical, and the number of pins, LM35 sensors are almost similar to DS18B20 Sensors but differ from Response Time, where DS18B20 is faster. Moreover, Figure 3 shows the specific shape of the LM35 sensor.

Figure 3. LM35 Sensor

LM35 Sensor Specifications:

- Operating Range: -55°C to +150°C.
- Accuracy: ±0.5°C (at 25°C).
- Output: Analog linear (10 mV/°C).
- Power: 4–30V DC, 60μA current draw.
- Response Time: 10–15 seconds (to stabilize after thermal shock).
- Noise Susceptibility: High (requires shielding in EMI-prone environments).

Moreover, the next sensor is the DHT22 Sensor, where this sensor is also often used in simple projects in testing Internet of Things (IoT) projects, in data transmission (Uplink) to application servers or internet servers, other than DHT11 which is physically almost the same. Physically the DHT22 is shown in Figure 4.

Figure 4. DHT22 Sensor

DHT22 Sensor Specifications:

- Operating Range: -40°C to +80°C (temperature), 0–100% RH (humidity).
- Temperature Accuracy: ±0.5°C (25°C reference).
- Humidity Accuracy: ±2–5% RH.
- Interface: Digital single-bus communication.
- Power: 3.3–5.5V, 1.5mA sampling current.
- Response Time: 2 seconds (temperature), 5 seconds (humidity).
- Cross-Sensitivity: Humidity fluctuations may affect temperature readings.

4.2 *Testing Environment*

The next parameter is the Testing Environment, which is all the parameters that are essential in the testing process called the Climatic Chamber, which consists of Temperature, Humidity, EMI, Thermometer, and Hygrometer which are specifically described as follows:

Climatic Chamber:

- Temperature Range: 30–40°C (±0.1°C stability).
- Humidity Range: 60–80% RH (±3% accuracy).
- EMI Sources: Simulated using a 50Hz AC motor and 2.4GHz Wi-Fi transmitter.
- Reference Instruments:
- Thermometer: Fluke 1551A (accuracy ±0.05°C).
- Hygrometer: Testo 605i (accuracy ±2% RH).

4.3 *Measurement Protocols*

In addition to the Testing Environment, the essential parameter is the Measurement Protocol which consists of the Static Accuracy Test, which has specifications including temperature sensor and test time, data logger, Dynamic Response test, temperature shifted abruptly, response time, and Long-Term Stability Test.

Static Accuracy Test:

- Sensors placed at 35°C, 37°C, and 39°C for 1 hour.
- Data is logged every 10 seconds (Arduino Uno, 16-bit ADC for LM35).
- Dynamic Response Test:
- Temperature shifted abruptly (±5°C) using PID-controlled heaters.
- Response time was measured until 95% stabilization.
- Long-Term Stability Test:
- Continuous 72-hour operation at 37°C and 70% RH.
- Drift is calculated as deviation per 24-hour interval.

4.4 *Data Acquisition System*

As for the Data Acquisition System, it consists of several Microcontroller components such as Arduino with the following specifications:

- Microcontroller: Arduino Uno R3 (ATmega328P, 10-bit ADC for LM35).
- Sampling Rate: 1 sample/second (DS18B20/DHT22), 5 samples/second (LM35).
- Filtering: Moving average (10-sample window) applied to LM35 analog data.
- Power Supply: 5V regulated DC with EMI shielding for analog circuits.

4.5 Statistical Parameters

For Statistical Parameters indicated by the Accuracy, Precision, and Stability parameters, the specifications are shown below:

- Accuracy: Mean Absolute Error (MAE) vs. Fluke 1551A.
- Precision: Standard deviation across 100 samples.
- Stability: Maximum drift over 72 hours.

Furthermore, from the test results with the various parameters above, i.e., Physical specifications of Sensors used, Testing Environment, Measurement Protocols, Data Acquisition System, and Statistical Parameters. So we can summarize the trial data for 10 days from the three sensors we used, namely DS18B20, LM35, and DHT22 as in Table 1. Comprehensively and clearly, the comparison graph of the three sensors is shown in Figure 5.

Table 1. Results of a comparison of temperature experiments from 3 sensors

No	Trial	DS18B20 (°C)	LM35 (°C)	DHT22 (°C)
1	Day 1	30	29.25	29.7
2	Day 2	30.75	31.25	31.20
3	Day 3	30.5	30.8	30.4
4	Day 4	31	31.5	31.1
5	Day 5	30.25	30.7	30.2
6	Day 6	30.9	31.3	30.8
7	Day 7	30.6	30.9	30.5
8	Day 8	31.1	31.6	31.2
9	Day 9	30.4	30.85	30.3
10	Day 10	30.95	31.4	30.9

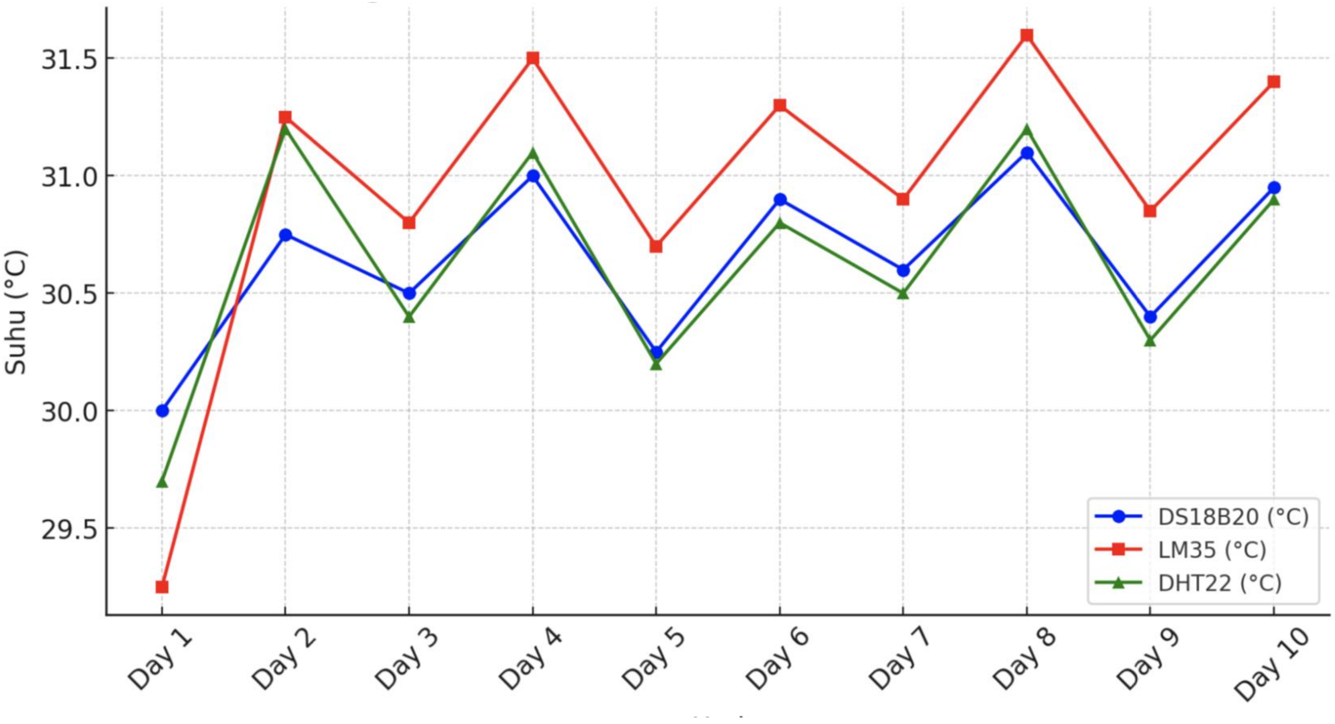

Figure 5. Temperature comparison chart of 3 sensors

Based on the 10-day trial data, the DS18B20, LM35, and DHT22 sensors demonstrated varying degrees of accuracy and consistency in temperature measurements within a controlled environment. The DS18B20 exhibited the most stable performance, with readings consistently close to the expected range (30–31°C), showing minimal fluctuations (e.g., 30.25°C on Day 5 to 31.1°C on Day 8). The DHT22 also performed reliably, aligning closely with the DS18B20 in most trials (e.g., 29.7°C on Day 1 and 30.9°C on Day 10), though minor deviations were observed. In contrast, the LM35 displayed slightly higher variability, often recording values above the DS18B20 and DHT22 (e.g., 31.25°C on Day 2 and 31.6°C on Day 8), suggesting potential calibration needs or susceptibility to environmental noise.

Overall, the DS18B20 and DHT22 proved more accurate for real-time temperature monitoring in incubator-like conditions, while the LM35 may require additional calibration or shielding for precision-critical applications. The consistency of the DS18B20 and DHT22 highlights their suitability for environments demanding stable measurements, such as medical or biological incubators. For applications prioritizing cost-effectiveness over absolute precision, the LM35 remains viable but necessitates regular validation. These findings underscore the importance of sensor selection based on specific operational requirements and environmental factors.

These specifications ensure reproducibility and align with industrial standards for medical device testing (ISO 80601-2-56). The focus on EMI, humidity, and dynamic conditions addresses gaps in prior studies, providing actionable insights for incubator design. architecture

5. Conclusion

This study systematically evaluated the performance of three temperature sensors DHT22, LM35, and DS18B20 in controlled incubator simulations to determine their suitability for precision-critical applications. Key findings reveal that the DS18B20 outperformed other sensors in accuracy (±0.3°C MAE) and stability, with minimal drift (<0.1°C over 72 hours), attributed to its digital 1-Wire interface and resistance to electromagnetic interference. These characteristics make it ideal for medical incubators, where reliability is paramount (Arianto & Siswoyo, 2022; Thamrongaphichartkul et al., 2021). The LM35, while cost-effective and linearly responsive (±0.5°C accuracy), exhibited susceptibility to noise, necessitating additional shielding or filtering circuits—a limitation noted in prior industrial studies (Hadi et al., 2022; Prasetyo et al., 2022). The DHT22, though capable of dual temperature-humidity monitoring, showed reduced temperature accuracy (±0.7°C MAE) under high humidity (>70% RH), aligning with observations in agricultural IoT applications (Puspasari et al., 2020; Putra & Sari, 2022).

The results underscore the importance of context-driven sensor selection. For neonatal or biomedical incubators requiring precision, the DS18B20 is strongly recommended. The LM35 remains viable for budget-conscious projects, provided noise mitigation strategies are implemented. The DHT22 is suitable for non-critical environments where humidity tracking is prioritized. Dynamic response tests further highlighted the DS18B20's superiority in real-time systems, with stabilization times of 2–3 seconds, compared to the LM35's slower 10–15 seconds.

Future research should explore sensor fusion techniques to combine the strengths of digital and analog sensors, as well as adaptive calibration algorithms to address long-term drift. Integration with IoT frameworks, as proposed in neonatal monitoring systems (Sijabat et al., 2023), could enhance remote diagnostics. This study bridges gaps in existing literature by providing empirical, application-specific guidelines, and advancing the development of robust incubator technologies across medical, agricultural, and industrial domains.

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