Temperature response analysis between PD and PI controls applied to infant incubators

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ABSTRACT

Premature infants, born with low birth weight, require specialized care and isolation due to their vulnerability to infections in public settings. Baby incubators, classified as life support equipment, play a crucial role in safeguarding these infants by maintaining a consistent temperature and humidity similar to the mother’s womb. This study compares the temperature control systems in baby incubators, specifically proportional and derivative (PD) control versus proportional and integral (PI) control. LM35 and DS18B20 sensors were employed in the study. Results from PD control using the LM35 sensor show a rise time of 5 min and 40 sec, a settling time of 25 min, and an overshoot of 2.2 °C. The DS18B20 digital sensor, under PD control, achieves a rise time in 6 min and 30 sec, a settling time of 23 min, with an overshoot of 1.2 °C. For PI control with the LM35 sensor, there’s a 3 °C overshoot, a 5-minute rise time, and a 30-minute settling time. The DS18B20 sensor under PI control exhibits a 2.7 °C overshoot, a 5-minute rise time, and a 29-minute settling time. PD control demonstrates lower overshoot and faster response but longer rise times than PI control. Future research explores fuzzy control systems and proportional integral derivative (PID)-fuzzy hybrid control.

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1. INTRODUCTION

According to the World Health Organization (WHO), premature newborns are those delivered before 37 weeks gestation, as estimated on the first day of the most recent menstrual cycle [1]. The American Academy of Pediatrics defines premature newborns as those who weigh less than 2,500 grams at 37 weeks of gestation. Because premature babies are more likely to get sick in public settings, they require extra attention and need to be kept entirely segregated [2]. Therefore, it is necessary to have an incubator. A baby incubator is a type of electromedical device classified as “life support equipment.” It plays a critical role in protecting infants born prematurely or with low birth weight by maintaining a stable temperature and humidity, mimicking the conditions of the mother’s womb [3]. Infants with unfinished organ development, malfunctioning biochemical or enzyme systems, or delayed prenatal growth need special care [4]. Some general practices (GP) in rural regions still use manual incubators, requiring nurses to maintain alertness and take regular temperature readings within the incubator [4]. Because manual incubators are more vulnerable to human error or carelessness and consequently have a lower standard of care, they are extremely harmful to premature babies [5]. To avoid hypothermia or hyperthermia in premature newborns, it is crucial to control the temperature within the neonatal incubator [1]. When the body temperature of a baby rises over normal, hyperthermia develops. Babies are not very large enough to act as heat sinks, limited thermal insulation, and a huge surface area. Due to their immature thermal regulation, newborns cannot control their environment's temperature or generate heat [5]. Their ability to retain heat is limited [6]. Therefore, the most important component of life that needs to be safeguarded is the baby's life. Organs may suffer injury, developmental delays, cold shock, and even death whether the temperature is excessively high or low. Therefore the temperature must be maintained [7]. Temperature regulation is done so that the baby's body temperature, the surrounding environment, and other factors remain constant [8], [9]. Research by [10], [11] used an on/off control system from the heating control system to reach 400 sec and the ambient temperature might be maintained by the incubator. To generate a steady temperature and accuracy. Typically, the baby incubator is built to help care for and monitor the infant by being transparent, clean (sterile), furnished with the necessary electronic tools, and soundproof [12]. In practice, all industrial manipulator laws frequently employ the dynamic technique known as proportional and derivative (PD) control. Ongoing research is being done on PD control [13]. The most widely utilized control algorithm in the automobile sector is PI control, which is also widely recognized in industrial control [14]. For many open-loop stable systems with dead time, the PI controllers generally exhibit acceptable control performance and are structurally appropriate [15]. The analog sensor's (LM35) output voltage is precisely proportionate to the temperature in degrees Celsius. Compared to linear temperature sensors calibrated in Kelvin, the analog sensor (LM35) has the benefit of directly providing output on a Celsius scale, removing the requirement for the user to deduct a sizable constant voltage from the output [16]. The Dallas Semiconductor DSl8B20 digital temperature sensor is used in temperature testers. The DS18B20's monolithic design makes it possible for it to take the place of analog temperature sensors and related signal processing equipment. Complete temperature monitoring and data processing can be accomplished rapidly by connecting the DSl8B20 and microcontroller. The only digital temperature sensor that uses a single bus to transmit data is the DSl8B20. The DS18B20 sensor uses a single line for both data input and output. A single connection line can be used for communication between the CPU processor and the DS18B20 digital temperature sensor because they can both send and receive data over the same interface. In total, nine more binary temperature indications are shown. Without an external power source, the DSl8B20 digital temperature sensor can supply the necessary electrical energy [17]. The ATMEGA 2560 serves as the foundation for the Arduino Mega microcontroller. This Arduino Mega is simply connected to a computer using a USB cable to get started. Arduino boards are used because they make it simple to communicate with the module's serial port and program the microcontroller in C [16].

In the study, Halder *et al.* [18] designed a closed loop temperature control system using proportional and integral (PI) control to sense the room temperature and maintain it to the desired value fixed, the results of this study are small overshoot, fast response, and high precision but respond a little slower. Ismail *et al.* [19] designed a water temperature controller heated by an oil-fuelled heater using a programmable logic controller (PLC) method in conjunction with a PI controller. Measured temperature but the high cost of the PLC system. Tisa *et al.* [20] developed a baby incubator temperature control system that uses basic ON-OFF control techniques and pulse width modulation (PWM). A neonatal incubator with On/Off control was developed by Widhiada *et al.* [5] to aid in the spread of temperature. The incubator has a 36°C temperature setting. Singh *et al.* [21] made an incubator using proportional integral derivative (PID). In study [21], the process of choosing controller settings to meet particular performance criteria is known as controller tuning Nicholas and Ziegler. Pinto *et al.* [22] designed a baby incubator with a digital PID temperature controller. The objective is to develop and implement the ESVIN newborn life support equipment prototype's cockpit temperature following the international standard IEC 60601-2-19 for the operation and safety of neonatal incubators. Theopaga *et al.* [23] designed a system using and controlling the temperature to effectively control PID for infant incubators. Because, according to the researchers, this technique maintains linearity in temperature regulation, allowing premature babies to be maintained at temperatures in the infant incubator.

Based on prior research evaluating the performance of two temperature sensors namely the analog LM35 and the digital DS18B20 utilizing PD control to achieve stable and precise temperature regulation, this study focuses on the development of a baby incubator. The incubator will implement PI control, to analyze key performance parameters such as rise time, settling time, and overshoot. The results we get will then be compared with the results of previous research using PD control. The sensors we use are the LM35 sensor and the DB18B20 sensor which are still in the incubators in the hospital. By comparing the two controls on these two sensors, it is hoped that PD and PI controls are suitable for controlling baby incubators or there is still a need for innovation in making temperature controls in baby incubators. The sensors used are still from previous research.

2. METHOD

2.1. Proportional and derivative-proportional and integral controller

The output of the proportional controller is determined by the magnitude of the error signal and the difference between the desired setpoint and the actual measured value. Put more simply, the proportional controller's output is the result of multiplying its input by the proportional six constants [24]. Integral: to produce a system response with a steady state error of zero is the aim of the integral controller. If a plant lacks an integrator element (1/s), the proportional controller alone cannot ensure a system output with zero steady-state error. The system's responsiveness can be improved with an integral controller because it has a zero stable state error [25]. Derivatives: derivative controllers are typically employed to accelerate a system's initial response, but they do not lower errors in the system's steady state. Work performed by a derivative controller is only useful in a limited context, particularly during the transition phase. Therefore the derivative controller is never utilized in conjunction with another controller of a system [26]. PID control is widely recognized for its simplicity, ease of implementation, and cost efficiency. Despite advancements in control technologies, PID controllers remain the most widely utilized in industrial control systems, with documented statistics indicating their application in over 95% of physical layer control loops. The term "PID" refers to the controller's three components: proportional, integral, and derivative. The behavior of a first-order delay system under PID control can be represented by (1):

$$P\tau(s) = \frac{K}{(1+Ts)}\, e^{-\tau s} \quad (1)$$

Here, K>0 represents the plant gain in the controlled process, $\tau \geq 0$ denotes the delay time, and $T \geq 0$ signifies the system's time constant. Typically, PID controllers are implemented by tuning parameters based on empirical approaches, such as the Ziegler-Nichols method and its variations [27]. This study uses PI control and then uses (2):

$$PI = Kp \times e(t) + Ki \times \int_0^t e(t)dt \quad (2)$$

This equation represents a PI controller, which is used in control systems to regulate processes such as temperature control. The goal of a PI controller is to minimize the error (e), This is the discrepancy between the actual process variable and the intended setpoint. where e is the error value of reading the set point value by reading temperature against time, Kp is a proportional constant, and Ki is an integral constant. Then compared with previous studies using PD controls using (3):

$$PD = Kp \times e(t) + Kd \times \frac{de}{dt} \quad (3)$$

This equation describes a PD controller, another common type of control system used to regulate dynamic processes. Such as temperature control, where the rate of change of the error is important. where e is the error value of reading the set point value using temperature observations versus time, Kp is a proportional constant, and Kd is a derivative constant.

The Ziegler-Nichols tuning method is one of the most popular and widely used approaches for tuning PID controller parameters. Ziegler and Nichols proposed two popular methods for tuning parameters in PID controllers (including PI and PD), which are often used to optimize the response of control systems. Both methods aim to help determine the right values for Kp, Ki, and Kd to obtain a stable and fast response [28]. The Ziegler Nichols arrangement is proposed in Table 1.

Table 1. Determination of parameters

Controller	Kp	Ti	TD
Proportional	$1/a$	-	-
PI	$0.9/a$	3.33	-
PID	$1.2/a$	2	0.5

Based on a fictitious controller, the Ziegler and Nichols approach was the first PID tuning mat to be developed. Therefore, additional adjustments are always required; because the control is rather strong and causes overshoot and excessive oscillation. It is a little challenging to estimate the parameters for the first approach in the environment. This behavior can be highly harmful to the system when the second method uses the unstable side to determine the settings [26].

To find errors, we use (4):

$$Error(\%) = \frac{(Setting\ Data - Average\ Data)}{Setting\ Data} \times 100\% \quad (4)$$

We took data for each temperature 20 times, each data was taken within 45 min at a room temperature of 27 °C. Then we take the average of each temperature and sensor that we include in the results, and to make reading easier we also include a box plot. The series of baby incubators made in this study used a PI control system which was made digitally using an Arduino Mega microcontroller. The workflow of the PI control can be seen in Figure 1.

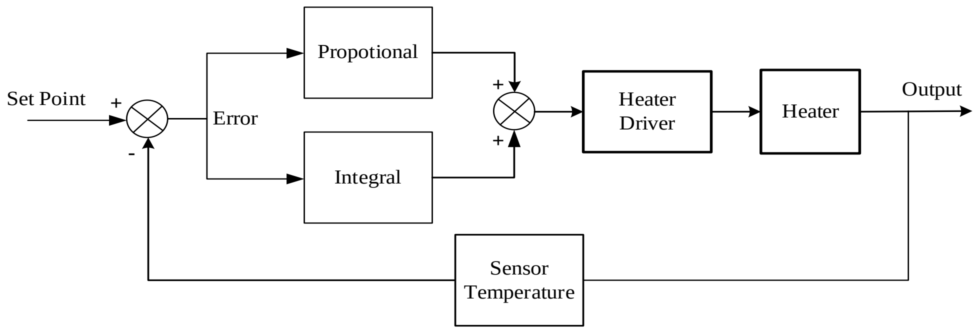


Figure 1. The control system used in this study uses PI control where the diagram for the closed system

Figure 1 presents a simple block diagram of the system used in the baby incubator research. The temperature sensor that has been selected will read the room temperature, and then be processed by Arduino Mega for later comparison with the predetermined temperature setting. The proceeds of the comparison of the temp sensor value and the temp setting will produce an error value. This error value is then processed by the PI control that has been made on the Arduino Mega microcontroller. The output of this PI will control the performance of the heater through the heater driver first. When the heater heats up, the temperature sensor will read the temperature inside the baby incubator again after it has been changed or raised.

2.2. Material and device

The temperature sensor used in this research is LM35 [29], the digital sensor (DS18B20) can read 9–12 bits of digital data, which is more than traditional thermistors can do. The 12-bit digital quantity can be finished in 750 millisec [30]. The LM35 sensor offers an advantage over linear temperature sensors calibrated in Kelvin, as it reliably provides temperature readings in Celsius without the need to subtract a significant constant voltage from the output [31]. This instrument is used to measure the temperature in the infant incubator. Data processing is carried out by a microcontroller (Atmega 2560). TFT is used for temperature readings and graphs. The heater is utilized to warm the interior of the baby incubator and assist in achieving the desired temperature [32].

2.3. Data acquisition

In the block diagram, the temperature sensor serves as the incubator input. The newborn incubator system uses the analog sensor (LM35) and the digital sensor (DS18B20), two different types of sensors that can be used interchangeably. The CPU converts the temperature measurements to voltage. The TFT display in this experiment is also used to choose the sensor, temperature, and control settings, and it also generates output in the form of graphs and an incubator temp readout.

This design includes the interchangeable analog sensor (LM35) and the digital sensor (DS18B20) as inputs, and the power supply powers every component of the circuit. The baby incubator's working temperature setting provides details on the setting that may be altered to the temperature needed for the incubator to function. The LM35 and DS18B20 sensors are used to monitor the temperature, and the microcontroller can translate that data into voltage.

Then, the TFT (7 inches) will continue to display the sensor voltage after being set by the microcontroller. You may choose sensor settings, temperature settings, and control settings via the on-screen display. Additionally, a result is produced by the temperature and incubator temperature graph. The heater is used as a heater. When the baby incubator's temperature approaches the predetermined level, the author's program gradually lowers the heating power and turns off the heating when the temperature reaches the predetermined level. The heating capacity rises if the temperature goes below the permissible range Figure 2.

Figure 2. Baby incubator unit using PI control

The baby incubator box has been designed compactly to make it easier for users, as shown in Figure 2. On the right side, there are only 2 components, the power switch and the Nextion TFT LCD. The baby incubator box has been designed compactly to facilitate users, as shown in Figure 2. On the right side, there are only 2 components, namely the power switch and the Nextion TFT LCD. The power switch is used to turn the device on or off. Meanwhile, the TFT LCD is used for the temperature monitoring display in the baby incubator box.

2.4. Data processing

Using data for infant incubators, the author examines the overshoot, rising time, and settling time outcomes at temperatures of 32-37 °C with the same treatment. PI control utilizes a formula to determine the values of Kp and Ki, while PD control uses a formula to determine Kp and Kd. In this study, Borland Delphi 7 was employed to plot the data after obtaining the respective Kp, Ki, and Kd values. Both text and image formats can be used to store data. Temperature measurements are converted to voltage by the Arduino Atmega microcontroller, which also transforms analog data into digital data.

2.5. Experimental settings

A baby incubator box that is the same size as its original size is employed in this study. The Atmega 2560 microcontroller is used in the controller together with the analog sensor (LM35) and the digital sensor (DS18B20). In the system of the constructed baby incubator, both sensors are analyzed. For heaters used following the requirements, namely 1500 watts, a fan is also used to distribute the temperature evenly in the space. On a computer screen, temperature information is represented on a graph and transmitted via serial connections. The computer records the incubator's temperature monitoring data. Data was gathered in a climate-controlled room at 25 °C. The data retrieval process is shown in Figure 3.

Figure 3. 5 times at each temperature setting, this data was gathered at room temperature (25 °C), and the outcomes were compared using an incu analyzer

2.6. Data analysis

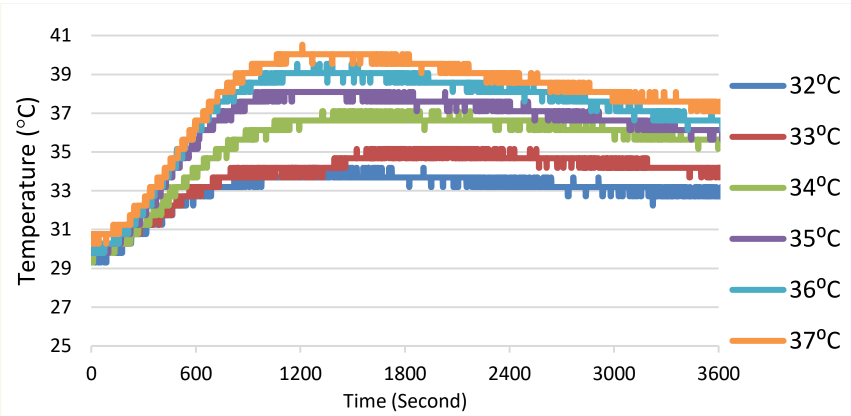
This research was conducted in a room with a temp of 27 °C for data collection and with the same treatment for each data collection at all temperature settings. The temperature settings to be taken care 32-37 °C, data retrieval is recorded for 1 hour using the Delphi application. The control system used is for PD control using Kp=60 and Kd=50, while for PI control using KP=60 and KI=7. To study the reaction of two types of temperature sensors while utilizing PD control and PI control, data collection is done alternately between two sensor types: the digital sensor (DS18B20) and the analog sensor (LM35). For data retrieval recorded using Borland Delphi7 to get the data. The average data to be analyzed include rise time, overshoot, and settling time, then the author will analyze the difference between the three things.

3. RESULTS AND DISCUSSION

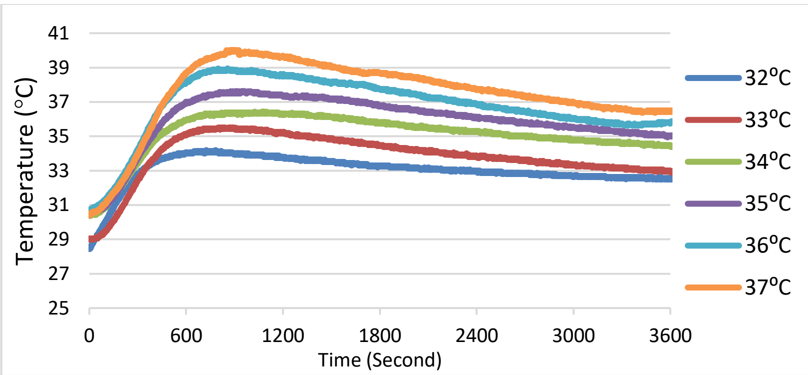
3.1. Result measurement

Figures 4 and 5 present the data collected from analog sensors (LM35) and digital sensors (DS18B20) under PI and PD control. Data collection was conducted over 1 hour with various temperature settings, all performed at a room temperature of 25 °C. The horizontal axis states the time of data collection, while the vertical axis states the setting temperature. The following are the results of the data collection:

In Figure 4(a), the performance of the PD control using the LM35 sensor shows that at 32 °C, the system has a rise time of 5 min, a settling time of 30 min, and an overshoot of 1.1 °C. When the temperature increases to 33 °C to 35 °C, the rise time is in the range of 5 min 40 sec to 6 min, the settling time remains 25 min, and the overshoot increases from 1.6 °C to 2.6 °C. At 36 °C and 37 °C, the rise time increases to 8 min with a settling time of 25 min, while the overshoot increases from 2.5 °C to 3 °C. Meanwhile, in Figure 4(b), the PD control using the DS18B20 sensor shows that at 32 °C, the system has a rise time of 3 min 20 sec, a settling time of 23 min, and an overshoot of 2 °C. At 33 °C to 36 °C, the rise time increases from 4 min to 7 min, with the settling time remaining 23 min and the overshoot increasing from 2.3 °C to 2.8 °C. At 37 °C, the rise time reached 8 min with a settling time of 23 min and an overshoot of 2.9 °C.



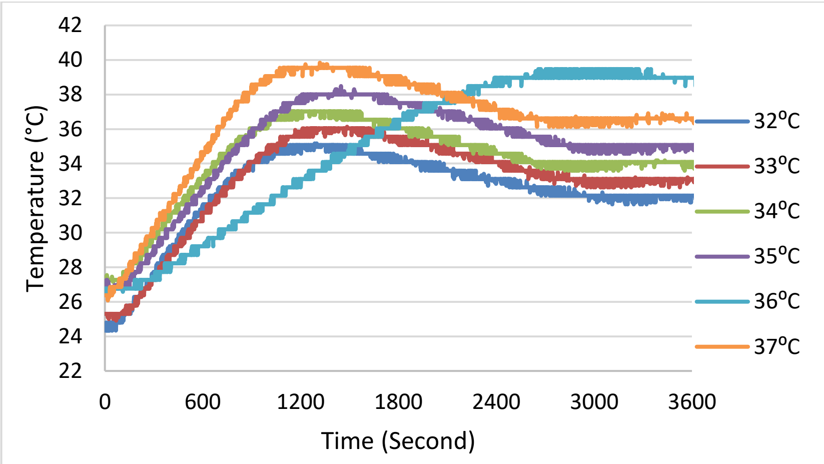
(a)



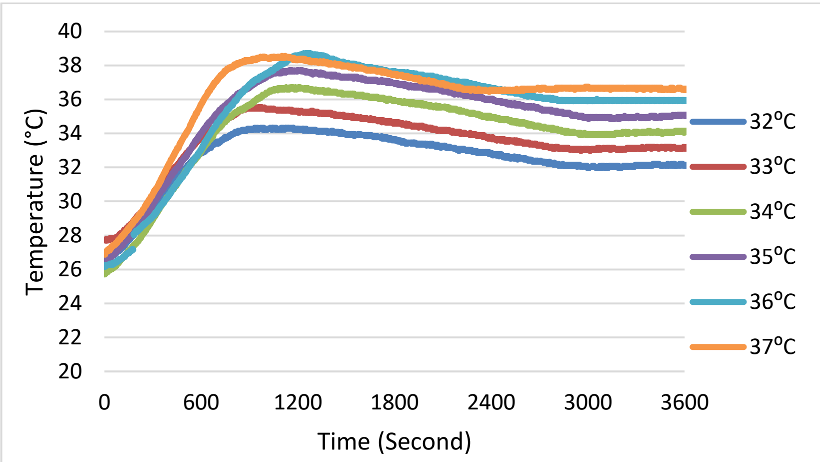
(b)

Figure 4. Results PD control of sensor: (a) PD control used LM35 sensor and (b) PD control used DS18B20 sensor

In Figure 5(a), the PI controller using the LM35 sensor shows a similar pattern at several temperatures. At 32 °C to 34 °C, the rise time is reached in 5 min, the settling time ranges from 28 to 30 min, and the overshoot exceeds 2.8 °C from the setpoint. At 35 °C to 36 °C, the rise time remains 5 min, settling time increases to 31 min, with the overshoot exceeding 3 °C. While at 37 °C, the rise time remains 5 min, the settling time is 29 min, but the overshoot decreases to 2.5 °C. In Figure 5(b), the PI controller using the DS18B20 sensor shows that at 32 °C to 35 °C, the rise time is reached in 4 min, the settling time is stable at 28 min, and the overshoot ranges from 2.5 °C to 2.7 °C. At 36 °C, the rise time increased to 8 min, the settling time remained at 28 min, and the overshoot decreased to 1.5 °C. While at 37 °C, the rise time returned to 4 min, the settling time decreased to 23 min, and the overshoot remained at 1.5 °C.



(a)



(b)

Figure 5. Result PI control of sensor: (a) PI control used LM35 sensor and (b) PI control used DS18B20 sensor

Figure 6, displays the infant incubator box’s temperature dispersion; at focal point 1, the temperature is 32.3 °C, at focus point 2 it is 30.6 °C, and at focus point 3 it is 30.4 °C. At each camera focus point, there is a difference due to the position of the heater located on the left. However, overall, the system operates according to the set point temperature. The following is a box plot analysis, where this section analyzes the comparison of LM35 and DS18B20 sensors using PD and PI control.

From Figure 7, it can be seen that the analog sensor (LM35) using PI control has a higher overshoot compared to the analog sensor (LM35) using PD control, where when using PD control the overshoot is 39.2 °C while PI control is 39.5 °C. Likewise, the digital sensor (DS18B20) using PI control has a higher overshoot compared to the digital sensor (DS18B20) using PD control, where when using PD control the overshoot is 38.2 °C while when using PI control, it is 38.5 °C. From Figure 8, it can be seen that the analog sensor (LM35) using PD control has a higher rise time than the analog sensor (LM35) using PI control, where if using PD control the rise time is 480 sec while using PI control it is 300 sec. Likewise, the digital sensor (DS18B20) uses PD control and has a higher rise time than the digital sensor (DS18B20) using PI control, where when using PD control the rise time is 240 sec while when using PI control, it is 480 sec.

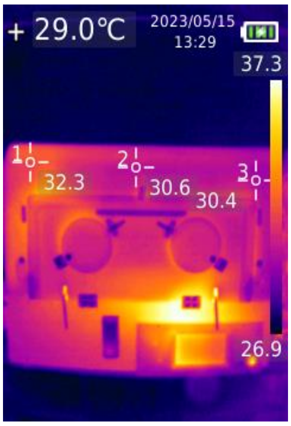


Figure 6. The thermal camera provides results to display the temperature in the baby incubator room

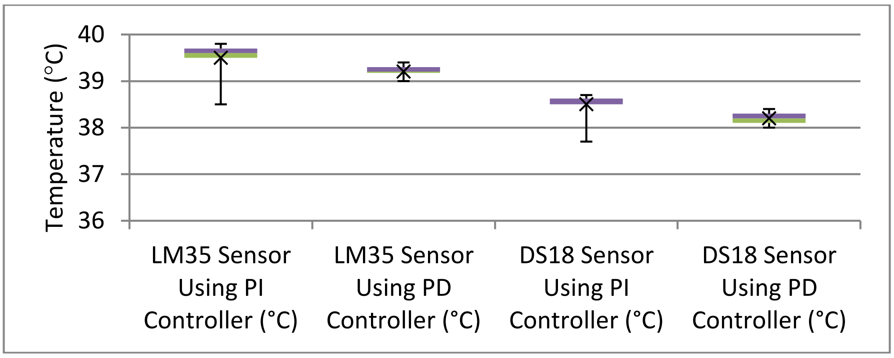


Figure 7. Comparison of PI and PD control using LM35 and DS18B20 sensors when experiencing overshoot

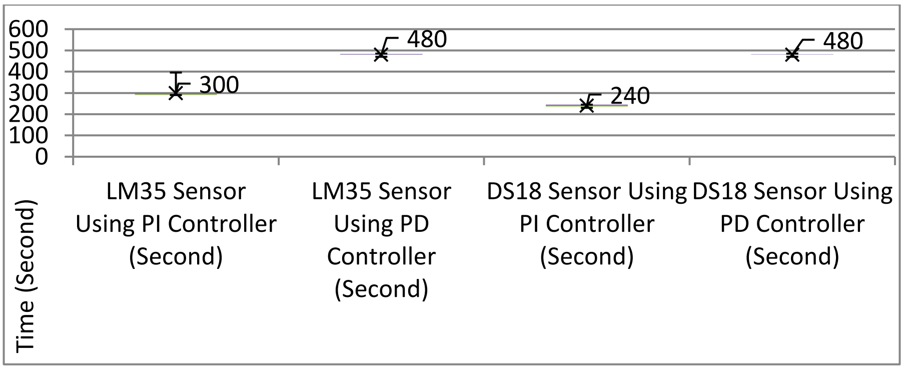


Figure 8. Comparison of PI and PD control using LM35 and DS18B20 sensors when experiencing rise time

From Figure 9, it can be seen that the analog sensor (LM35) using PI control has a longer settling time than the analog sensor (LM35) using PD control, where when using PD control the settling time is 1,500 sec while when using PI control, it is 1,740 sec. However, digital sensors (DS18B20) using PI control and digital sensors (DS18B20) using PD control on settling time are not much different from the difference, while when using PD control and PI control the settling time is 1,400 sec.

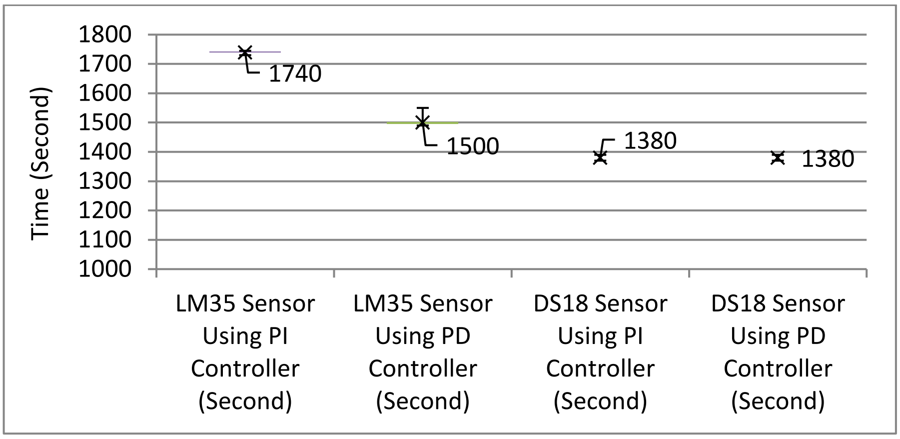


Figure 9. Comparison of PI and PD control using LM35 and DS18B20 sensors when experiencing settling time with a set point of 37 °C

In the context of control systems, the choice between PI and PD control depends on the specific priorities, whether it be minimizing overshoot, achieving faster rise times, or optimizing settling times. These observations highlight the trade-offs associated with each control strategy, and careful consideration is required when selecting the most suitable control approach for a given application. T-Test of two independent samples was used in analyzing the data of this study. T-Test of two independent samples was conducted to test the null hypothesis, which states that there is no significant difference between the LM35 sensor device and the DS18B20 sensor in PD control made when the resulting p-value is greater than alpha. Statistics were performed using the real statistics resource pack as presented in Tables 2 and 3.

Table 2. T-Test testing of two independent samples between LM35 sensor devices and DS18B20 sensors on PD control

T-Test: equal variances				Alpha	0.05				
	std err	t-stat	df	p-value	t-crit	lower	upper	sig	effect r
One tail	0.97689	0.31136	10	0.38095	1.81246			no	0.09798
Two tails	0.97689	0.31136	10	0.76191	2.22813	-1.8724	2.48082	no	0.09798

Table 3. T-Test testing of two independent samples between LM35 sensor devices and DS18B20 sensors on PI control

T-Test: equal variances				Alpha	0.05				
	std err	t-stat	df	p-value	t-crit	lower	upper	sig	effect r
One tail	0.98765	0.00895	10	0.496516	1.81246			no	0.00283
Two tails	0.98765	0.00895	10	0.993031	2.22819	-2.2094	2.19178	no	0.00283

Based on the results presented in Table 2, the p-value of 0.380958 exceeds the predetermined significance level of 0.05. This indicates that the null hypothesis (H_0) cannot be rejected. Therefore, there is no statistically significant difference between the temperature readings obtained from the baby incubator and the standard device. Similarly, no significant difference was observed between the LM35 and DS18B20 sensors when using PD control. These findings suggest that both sensor types provide reliable and accurate temperature measurements. A two-independent samples T-Test was conducted to test the null hypothesis, which posits that there is no significant difference between the LM35 sensor device and the DS18B20 sensor when implementing the PI control. The resulting p-value is compared to the alpha level, and if it is greater than alpha, the null hypothesis is retained.

As shown in Table 3, the p-value is 0.496516, which exceeds the predetermined significance level of 0.05. Consequently, the null hypothesis (H0) is accepted, indicating no significant difference between the performance of the baby incubator and the standard device. Similarly, the acceptance of H0 confirms that there is no significant difference in performance between the LM35 and DS18B20 sensors when used with PI control. Consequently, it can be concluded that temperature readings from these two sensors are both reliable and provide accurate measurements.

3.2. Discussion

Infant incubators are indispensable for the care of premature newborns, with the maintenance of stable incubator temperatures ranking among the utmost priorities. This study collected data from two distinct sensors, namely the LM35 and DS18B20 sensors, to analyze crucial parameters including rising time, overshoot, and settling time under both PI and PD control systems. The findings are summarized in Table 4, which represents the average results using PD control. In addition, Table 5 shows the average results using the PI control.

Table 4. Average results under the PD control

Sensor type (control)	Rise time	Settling time (min)	Overshoot
LM35 (PD)	5 min and 40 sec	25	2.2 °C above the set temperature
DS18B20 (PD)	6 min and 30 sec	23	1.2 °C above the set temperature

Table 5. Average results under the PI control

Sensor type (control)	Rise time time (min)	Settling time time (min)	Overshoot
LM35 (PI)	5	30	3 °C above the set temperature
DS18B20 (PI)	5	29	2.7 °C above the set temperature

The results demonstrate that the PD control system achieves a lower overshoot and a faster settling time compared to the PI control system. However, on average, PD control results in a longer rise time when compared to PI control. Building on these findings and previous research, the main objective is to design a baby incubator utilizing PI control and perform a comparative analysis. Subsequently, the results obtained from the DS18B20 sensor and the LM35 sensor are compared with previous research focusing on Incubator designs incorporating PD control [33]. This study places significant emphasis on the achievement and maintenance of the infant incubator temperature, with the ultimate goal of ensuring temperature stability within the incubator monitoring system to prevent adverse patient outcomes, including potential fatalities.

The study does not provide specific details about the sample size, data collection methods, or ethical considerations involved. Additionally, the lack of references to prior research makes it challenging to assess the context of the study and the significance of its findings. The findings indicate that while PD control provides benefits in reducing overshoot and achieving faster settling times, it comes at the expense of longer rise times. These insights could guide the design and implementation of infant incubator systems, aiming to enhance temperature stability and improve overall patient care. The comparative objectives of this study are to assess the performance of PI control against PD control and to compare the results obtained from different sensors (DS18B20 and LM35) with previous research involving PD control.

4. CONCLUSION

In this study, the temperature sensor on the baby incubator was checked for this study using PI control. The temperature sensor is placed inside a standard hospital baby incubator to ensure accurate and consistent temperature measurements. Based on the measurement results using PI control on the analog sensor (LM35), the overshoot is 3 °C from the set point, the sensor takes 5 min to reach the rise time, and the settling time lasts 30 min. Overshoot was 2.7 ºC from the set point while the digital sensor (DS18B20) took 5 min to reach the rise time and 29 min to reach the set time. The results of previous studies show that PD control has a lower overshoot than PI control and a faster settling time. But on average PD has a longer rise time than PI control. For further research, the 2 sensors will be compared using PID control.

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