International Journal of Technology 14(4) 811-822 (2023)
Received May 2022 / Revised August 2022 / Accepted December 2022

International Journal of Technology

http://ijtech.eng.ui.ac.id

Baby Incubator with Overshoot Reduction System using PID Control Equipped with Heart Rate Monitoring Based on the Internet of Things

Bambang Guruh Irianto[1], Anita Miftahul Maghfiroh[1*], Moh Sofie[2] , Abd Kholiq[1]

[1]*Departement of Electromedical Enginering, Politeknik Kesehatan Kemenkes Surabaya, Jalan Pucang Jajar Tengah No.56, Surabaya 60282, Indonesia*
[2]*STIKES Semarang, Jalan kolonel warsito sugiarto km 2,5 Sadeng GunungPati, Semarang 50222, Indonesia*

Abstract. Factors causing premature infant mortality include the lack of simple care and inadequate equipment such as a baby incubator. Premature babies are very susceptible to heart disorders, including congenital heart defects. Congenital heart defects can cause a fetus to be born prematurely. The current research related to this matter was further conducted, aiming to develop a baby incubator with an overshoot reduction system specifically for babies with heart defects that can be monitored remotely using an IoT system. In this study, the AHT 10 sensor was used for room temperature sensing in the baby incubator. Temperature control was achieved using a closed-loop PID system. In this case, the monitoring of the baby's heart rate employed leads II to tap the heart's electrical signal. Data transmission consisted of temperature readings, ECG signals, and heart rate. The microdata was processed into digital data, which were then sent via the Raspberry Pi, then sent via the internet to access the cloud firebase. After that, the firebase data were downloaded from an Android system. The performance results showed that in the temperature test, the error value was below 5%, and the PID control made can reduce the overshoot temperature by no more than 5%. In addition, it was also determined that the steady-state error value was 2%. T-Test statistical test on the ECG signal further obtained a p-value > 0.05. Furthermore, the data transmission test using IoT did not find data loss when sending the data, and the minimum speed required for data transmission was 5 kbps. This research further implied that the user or the patient's family could easily monitor the baby's development anywhere and anytime.

Keywords: Baby incubator; ECG signal; Heart rate; IoT; Temperature

1. Introduction

Approximately 15 million and one million premature babies died yearly (Lawn *et al.*, 2013) because of the gap in survival between high and low-income countries. In this case, premature babies are born before 34 weeks of gestation (Kvalvik *et al.*, 2020). According to UNICEF, premature births in Indonesia ranked fifth with 13,370 premature babies on January 18, 2018 (Utomo *et al.*, 2021). Many premature babies died due to a lack of simple care and adequate equipment, such as incubators (Shaib, Hamawy, and Majzoub, 2017). The incubator is a medical treatment tool for premature babies that provides warmth, humidity, and oxygen as newborns require in controlled conditions (Janney *et al.* 2018). In addition, premature babies are also very susceptible to heart disorders, and even

*Corresponding author's email: anitamiftah@poltekkesdepkes-sby.ac.id, Tel.:085649131053
doi: 10.14716/ijtech.v14i4.5678

congenital heart defects can cause the fetus to be born prematurely (Kanáliková 1990).

The heart condition of premature babies has also been studied by several researchers, as described previously (Hubsher, 1961). Stoermer found that the interval for various components of the ECG time is somewhat shorter, and the P waves are higher and sharper. In this case, the frequently small waves and deviations were from the S-T segment. This explanation indicates that premature babies do not only need a controlled room but also need monitoring of heart conditions to detect congenital abnormalities or not (Sattar and Lovely, 2021). Therefore, there is a great need for equipment that can treat premature babies and those with heart defects efficiently and non-invasively. Premature babies are placed in a special room called the Neonatal Intensive Care Unit (NICU). The treatment provided in the NICU room is adjusted to the needs of the baby, including the need for incubators, blue light therapy, infusions, and heart and lung monitors.

In addition, the room temperature in the baby incubator must be controlled according to the specified standard so that the baby still gets warmth, moisture, and oxygen as what they get in the womb. Several researchers have made a temperature control system for baby incubators using PID control (Maghfiroh *et al.*, 2022; Kirana et al, 2021; Theopaga, Rizal, and Susanto, 2014). This system is considered to control the temperature well and suppress excessive temperature overshoot levels so that premature babies get warm according to standards. Widhiada *et al.* (2019a) made a baby incubator using a fuzzy logic control system with two measurement conditions. The first measurement is without load, and the second measurement uses a baby simulation with a load of 2 kg. The resulting overshoot value was less than 5% (Widhiada *et al.*, 2019a). However, in using this fuzzy system, the variables entered were only based on the researcher's experience, so further system testing is necessary. (Sinuraya and Pamungkas, 2019) further used the DHT11 sensor for sensing elements using a fuzzy-PI adaptive control system, resulting in its ability to suppress overshoot according to the setpoint within 200 seconds with an error of 5% (Sinuraya and Pamungkas, 2019). However, the computation of this system was quite heavy. A closed-loop control system was further designed and implemented by Mathew and Gupta *et al*. to regulate temperature, humidity, light level, and oxygen in infant incubators (Mathew and Gupta, 2015). This system was quite effective in maintaining the temperature from the threshold value limit. However, the threshold value was still set manually using the potentiometer.

Another research project applied the principle method of natural circulation and natural convection in the baby incubator, whose main components were a lamp as a heater and a digital thermostat as a temperature control (Zaelani *et al.*, 2019). This system was quite good and stable only if the baby incubator was at ambient temperature. Along with the needs of premature babies, several researchers have also developed a baby incubator design with several functions. Fadilla *et al*. (2020) has made a baby incubator with a multi-function system that could warm and treat jaundiced babies and can soothe crying babies, and could be reached remotely using the IoT system (Fadilla *et al.*, 2020; Agresara, Vyas and Bhensdadiya, 2017). Luthfiyah *et al.* (2021) also applied the telemedicine system to monitor the temperature of the baby incubator using a WiFi network (Luthfiyah *et al.*, 2021). In addition, the IoT system has also been created by several researchers to monitor babies remotely (Muosa, 2017; Nachabe *et al.*, 2015). The use of the IoT system for nurses makes it easier to monitor the temperature of the baby incubator (Koli *et al.*, 2018). However, in this study, the temperature sensor used was less accurate, so it needed a more accurate sensor for sensing heat in the baby incubator room.

Based on several previous studies that have been mentioned, researchers have not found the development of a baby incubator specifically for babies who have heart defects and an overshoot reduction system at the temperature of the baby incubator. Therefore, this study aimed to meet the needs of premature babies with heart problems by combining several systems with lower costs and more efficiency. The system worked on in this research was temperature control with a PID control using an AHT10 sensor. This PID control was chosen because it was considered capable of suppressing the temperature overshoot value of less than 5% (Widhiada *et al.*, 2019b). Several researchers have also tried another several control methods (Abdurrakhman *et al.*, 2020), and the test results obtained could also be used as a reference for the researcher to develop a control method (Rahman, Ihsan, and Hassan, 2022). The designed baby incubator was also equipped with baby heart rate monitoring with a telemedicine system using the internet of things. It was expected that by combining the system, the costs incurred by patients would be lower because the baby incubator used was equipped with a premature baby heart rate monitoring system. The IoT system used was also expected to monitor the baby's condition anywhere and anytime. So that doctors, nurses, and parents of patients were easier and more efficient in finding out the baby's condition and the temperature in the baby incubator in real-time (Ashish, 2017).

2. Methods

2.1. System Design and System Control

The overall system is described in Figure 1. In this study, the AHT 10 sensor was used for room temperature sensing in the baby incubator. The temperature control used a PID control with a closed loop that was given interference in the baby incubator, which was likened to when the temperature of the incubator room was stable. In this case, the new baby was put by the nurse, so the door of the baby incubator box opened for a few minutes which resulted in a disturbance in temperature reading.

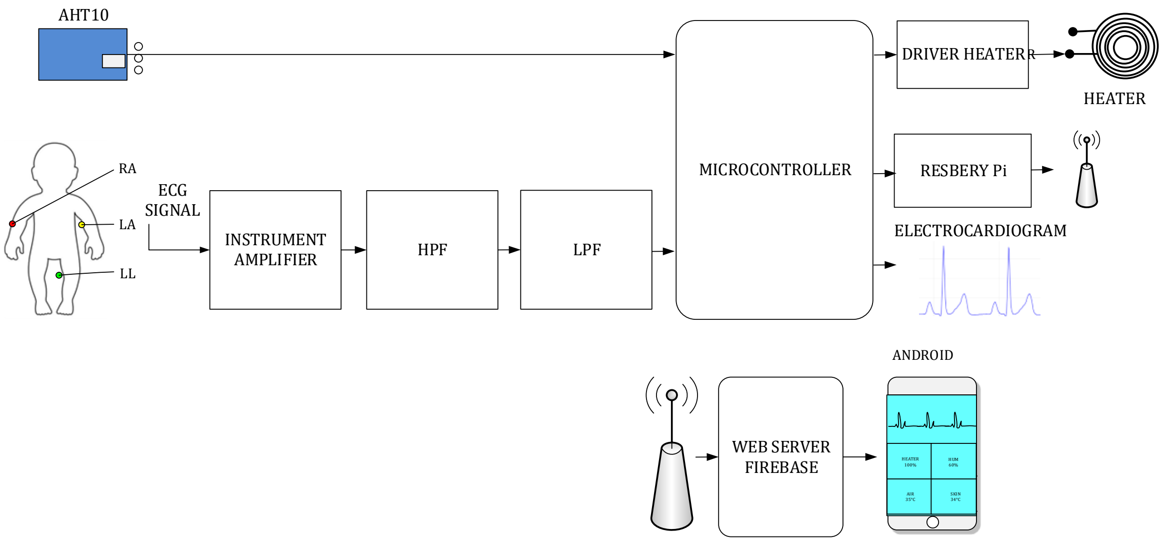


Figure 1 The design of baby incubator. The input ECG signal is amplified by an instrument amplifier circuit so that it can be read by the microcontroller, the instrument output is filtered with HPF and LPF filters with a bandwidth frequency of 0.05 Hz-100Hz. The signal output will be displayed on the LCD display and sent via android

The block diagram of the PID control is described in Figure 2. In this case, monitoring the baby's heart rate used lead II as the heart's electrical signal tapping (Utomo, Nuryani, and Darmanto, 2017). The electrode output from lead II was amplified with an instrument amplifier with a gain of 100 times to eliminate noise interference or other artifacts. A filter was made according to the heart signal frequency, namely 0.05Hz-100Hz. The microcontroller output in the form of an electrocardiogram signal and the room temperature of the baby incubator sent via Resbery Pi from Resbery Pi will be received by the web server using a firebase. Furthermore, the data were sent to the Android phone. In this case, the Android display used the MIT App application, which must be installed first on a cellphone with an android system.

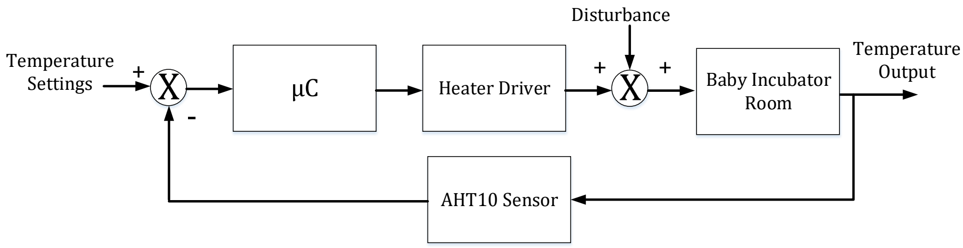


Figure 2 The design of PID control, setting the temperature as an input to the microcontroller then a closed loop system is used in this method to control the room temperature on the baby incubator by using the AHT10 sensor to sense the room

The PID control is based on Equation 1 and Equation 2 (Ang, Chong, and Li, 2005):

$$G(s) = K_P + K_I \frac{1}{s} + K_D s \tag{1}$$

$$= K_P + \left(1 + \frac{1}{T_I s} + T_D s\right) \tag{2}$$

Where Kp is the proportional gain, Ki is the integral gain and Kd is the derivative gain, Ti is the integral time constant, and Td is the derivative time constant.
For a PID control with disturbances described in Equation 3 (Ogata, 2005).

$$\frac{C_D(s)}{D(s)} = \frac{G_2(s)}{1+G_1(s)G_2(s)H(s)} \tag{3}$$

Where $C_D(s)$ is the response to disturbance, D(s) is the interference effect test.
The response to the reference input R(s) was assumed to be a zero disturbance. Then the response CR(s) to the reference input R(s) was obtained based on Equation 4 (Ogata, 2005).

$$\frac{C_R(s)}{R(s)} = \frac{G_1(s)G_2(s)}{1+G_1(s)G_2(s)H(s)} \tag{4}$$

Simultaneous application of the responses of the reference and perturbation inputs was obtained by adding up the two individual responses. Due to the application of the simultaneous C(s) response of the reference input R(s) and the disturbance D(s), it was obtained according to Equation 5 (Ogata, 2005).

$$C(s) = CR(s) + CD(s) \tag{5}$$

$$= \frac{G_2(s)}{1+G_1(s)G_2(s)H(s)}[G_1(s)R(s) + D(s)]$$

In the PID system, the control system control process applied the appropriate selection of Kp, Ki, and Kd in order to provide satisfying closed-loop performance. These parameters must be chosen properly so that the system's stability is satisfactory, including the response speed and the right level of overshoot. The system's transfer function was based on Equation 6 (Nayak and Singh, 2015).

$$G_{PID}(s) = K_p + \frac{K_p}{s} + K_D S = \frac{K_D S^2 + K_p + K_I}{S} \quad (6)$$

Where the selection of Kp, Ki, and Kd was applied to the proper control for closed-loop performance.

2.2. Data Acquisition ECG Signal

The ECG signal was obtained from the heart's electrical leads on Lead II. In this study, an ECG instrument was designed with a filter that was adjusted to the frequency of the heart signal, namely 0.05 Hz - 100 Hz. The designed ECG instrument is described in Figure 3. The amplitude of the ECG signal at the electrode output was still very small, namely 0.1 mV – 0.3 mV, so an instrument amplifier was needed. In this study, ICAD620 was used with 100 times the gain based on Equation 7 (Maghfiroh, Arifin, and Sardjono, 2019).

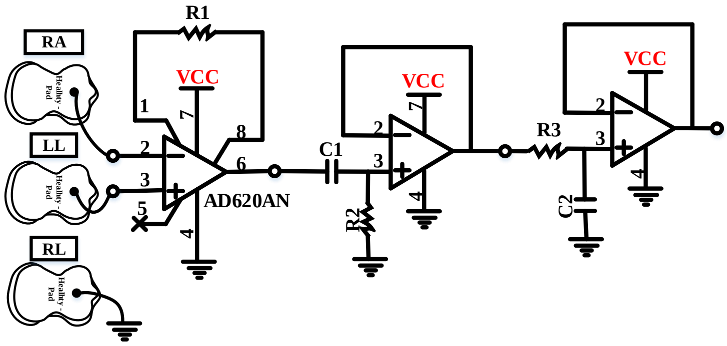


Figure 3 ECG instrumentation. Output electrode is amplified by instrument amplifier (100x) gain then filtered to remove noise with a bandwidth of 0.05-100Hz

$$G = \frac{49.4\,K\Omega}{R_G} + 1 \quad (7)$$

As for getting the ECG signal in this study, a filter was designed with an HPF cut-off frequency of 0.05Hz and an LPF cut-off frequency of 100Hz. As for getting the cut-off frequency bandwidth value for HPF was based on Equation 8 (Maghfiroh, Arifin, and Sardjono, 2019).

$$f_c = \frac{1}{2\pi RC} \quad (8)$$

The Sullen-Key topology method was used for order 2 LPF circuits. Value a1 = 1.8478; b1 = 1.0000; a2 = 0.7654; and b2 = 1.0000 were Butterworth coefficients for order 2. The first-order low pass filter can be calculated by Equations 9 and 10 with a value of C1 = 47 nF.

$$\text{R1, R2} = \frac{\left(a1*C2 \pm \sqrt{(a1^2*C2^2 - 4*b1*C1*C2)}\right)}{(4*Pi*Fo*C1*C2)} \quad (9)$$

$$C_2 \geq C_1 = \frac{4b_2}{a_1^2} \quad (10)$$

2.3. Data Collection

In this study, the temperature test process used the INCU analyzer INCU 2 of the Fluke brand as a comparison of temperature readings with five temperature measurement points placed at points T1, T2, T3, T4, and T5, as described in Figure 4. In this case, the measurements were taken at a temperature setting of 35°C, 36°C, and 37°C. Each point was measured 6 times so that the error value of the baby incubator was obtained. Meanwhile, to test the ECG signal in this study, the Fluke Phantom ECG brand was used as a simulation of the baby's heartbeat, as described in Figure 5.

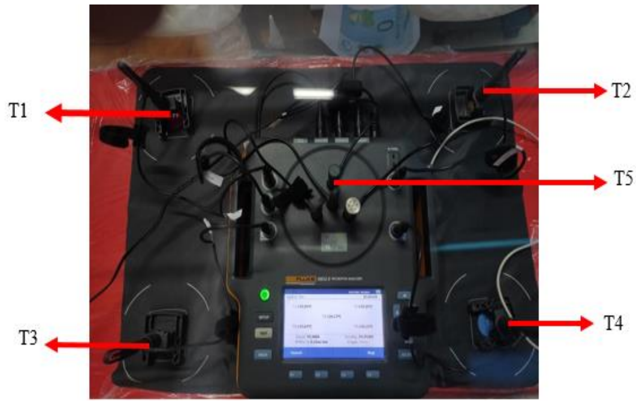


Figure 4 Temperature test using the Incu Analyzer type INCU 2 Brand Fluke, with five temperature parameters namely T1, T2, T3, T4 and T5 which are placed as shown in the picture

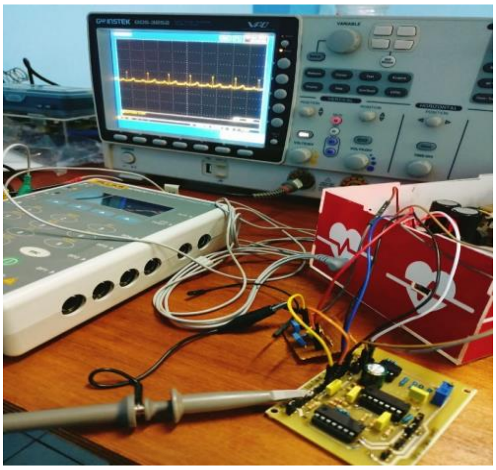


Figure 5 Electrocardiograph signal simulation with Phantom ECG using lead II displayed on the oscilloscope

2.4. *Data Transfer*

In this study, data transmission consisted of temperature readings, ECG signals, and heart rate. The microdata was processed into digital data, which were then sent via resbery pi. Resbery data were sent via the internet to access the cloud firebase, then from the firebase data was downloaded from the android system as described in Figure 6. In order to test the IoT system, the researcher set the speed of bps WiFi to determine the speed of data transmitted to android, with each speed measured 6 times.

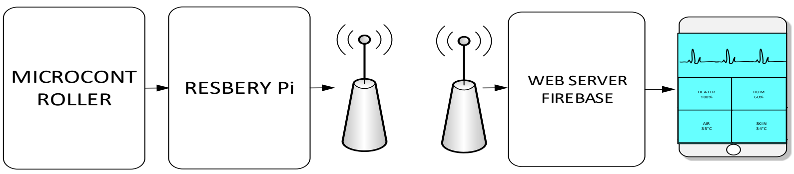


Figure 6 Data transfer method, data from microcontrollers sent via resbery pi then sent to over the internet and received web server which later data accessed by android.

3. Results and Discussion

In order to find out the performance of the baby incubator according to the standard, a calibration test was carried out. The parameters tested were the setting temperature of 35 ºC, 36 ºC, and 37 ºC using the INCU Analyzer, as described in Figure 4. Measurements were carried out 6 times, and then the average calculation was carried out, which later found the error from the temperature deviation of the baby incubator. The average calculation was obtained based on Equation 11 (Duvernoy, 2015).

$$\text{Mean} = \frac{\sum_{i=1}^{n} Xi}{n} = \frac{X1 + X2 + X3....Xn}{n} \tag{11}$$

Where x is the data retrieval to, and n is the number of data retrieval. While the temperature reading error value was based on Equation 12.

$$\text{Error} = \text{Mean} - \text{standard tool reading} \tag{12}$$

3.1. Temperature Testing and PID Control

The results of the comparison of temperature readings on the baby incubator with the INCU analyzer are described in Figure 7. Based on the description in Figure 7, it is explained that the average error of reading the temperature of the baby incubator was compared with the INCU analyzer at temperature settings of 35ºC, 36ºC, and 37ºC with 5 measurement sensor points with the maximum error value on the reading of the temperature point T2 which is 36ºC ± 0.7ºC, namely T1, T2, T3, T4 and T5 which are described in Figure 4 that is still within the threshold for use, namely the error value is still below 5% (Widhiada *et al.*, 2019b).

Meanwhile, the PID control overshoot reduction test with disturbance was carried out at a temperature setting of 37ºC, described in Figure 8.

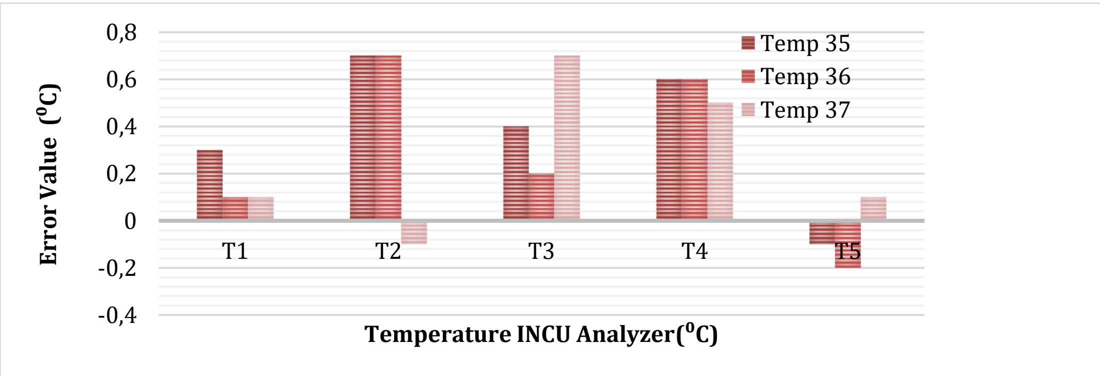


Figure 7 Graph of temperature measurement of baby incubator using INCU Analyzer

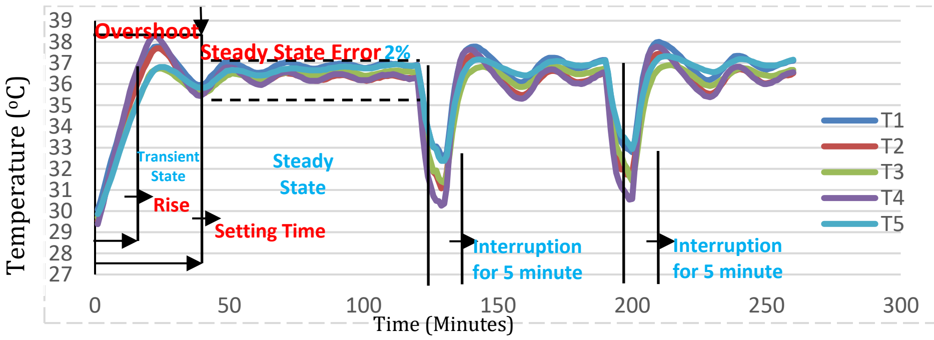


Figure 8 Temperature testing using PID control on the baby incubator and given a disturbance test which was carried out for 300 minutes

Based on the explanation in Figure 8, it took about 41 minutes to reach the 37°C setting temperature. Meanwhile, the readings at each sensor point T1, T2, T3, T4, and T5 on the INCU Analyzer showed an overshoot value of no more than 5%. From each sensor point, it was known that T4 had a higher overshoot value, namely at a temperature of 38.3°C ± 1.3°C, but this value is still within the tolerance threshold, so it is still safe and suitable for use. The performance of the PID control was also very good, and it is known that the steady-state error value was 2%. This shows that the PID control was able to reduce the overshoot temperature well, as evidenced in the 121st minute a disturbance experiment was carried out by opening the baby incubator door to give a baby simulation for 5 minutes, and the result was that the temperature dropped to 31°C and overshoot occurred at 145 minutes, it is known that the overshoot value was also still at the threshold and the steady state error value was still the same at 2%.

3.2. Electrocardiograph (ECG) testing

This test was carried out using a Fluke Phantom ECG brand with BPM settings of 30, 60, 120, 180, and 240. Measurements were carried out for each BPM setting on the Phantom ECG, as described in Table 1. The heart rate value in this study using the adaptive threshold system (Köhler, Hennig, and Orglmeister, 2002). Meanwhile, to get the number of heartbeats was based on Equation 13.

Formulae should be numbered consecutively throughout the manuscript as Equation 1 and equation 2. In cases where the derivation of formulae has been abbreviated, it is of great help to the reviewers if the full derivation can be presented on a separate sheet (not to be published).

$$HR = \frac{60}{t_{n+1} - t_n} \tag{13}$$

Where HR is the heart rate (BPM), while tn+1 is the period time for the peak of R-peak (n+1), and tn is the period time for the peak of R tn. The results of the ECG heart rate test (BPM) with Phantom ECG are described in Table 1.

Table 1 Results of the ECG heart rate (BPM) test with Panthom ECG

BPM	MEAN (%)	SD (%)
30	30.16	0.37
60	60	0
120	120	0
180	180.16	0.40
240	239.66	1.36

Based on the calculation of the standard deviation in Table 1, the mean value and standard deviation of each BPM setting were obtained. At the BPM 30 setting, the standard deviation value was 0.3727%, while at BPM 60 and 120 settings, the standard deviation was 0%. Furthermore, the BPM 180 setting obtained a standard deviation of 0.4082%, while the BPM 240 setting obtained a standard deviation of 1.3662%. From the average values that have been explained, it is known that the highest average error value is produced by the BPM 240 value with an average value of 239.66 BPM ± 1.36 BPM. It can be concluded that the higher the BPM value, the higher the error value obtained. However, the value generated in this assessment is that this tool is suitable for use according to medical standards [32]. Meanwhile, to find out whether there is a significant difference in the heart rate (BPM) ECG calculation with the BPM setting on the Phantom ECG, a statistical test was carried out using a T-Test with a p-Value > 0.05 indicator as described in Table 2.

Table 2 Testing the difference using the T-Test statistic

				Alpha	0.05
	std err	*t-stat*	*df*	*p-value*	*t-crit*
One Tail	54.73431	0.000761	6	0.499708708	1.94318
Two Tail	54.73431	0.000761	6	0.999417415	2.446912

The results of the T-Test statistical test in Table 2 showed that there was a one-tail T-Test result with p-Value = 0.499708708, while in two tails, the p-value was 0.999417415, which means that there was no significant difference because the p-Value > 0.05 and the error rate was still within the appropriate level for medical purposes.

3.3. Data Transfer Test

Data transfer testing was carried out to test whether the sending data was missing data or there was a delay at the time of delivery. This system uses an IoT system by utilizing an API base to store data which later be downloaded via android. Therefore, this system was not affected by the distance that can be accessed from the feed and anywhere as long as the cellphone was in a WiFi network connection. In this test, the bps speed setting was conducted to find out the right bps speed for sending data via android based on IoT. The data transfer test is described in Figure 9.

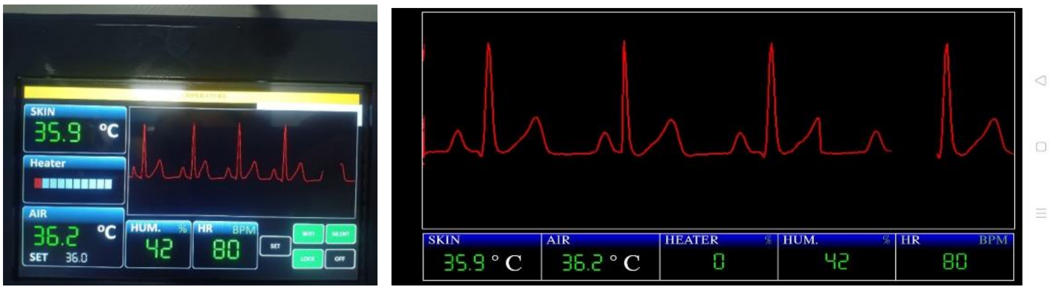
Figure 9 Testing the data transfer based on the IoT system displayed on the LCD display and the android system

Figure 9 above shows that the output of LCD display and Android display is the same. In addition, the testing of the EKG signal was carried out using the oscilloscope. From the three displays, there was no difference in SCG signal presentation.

Data transmitted via android were temperature data, humidity monitoring, ECG signal, and BPM heart rate. The comparison of readings between the LCD on the baby incubator and the display on the android system is described in Figure 10.

Meanwhile, for the data transmission test, 6 measurements were made at a temperature setting of 36^{o}C, and a setting of 80 BPM on the Phantom ECG with internet speed settings ranging from 5 kbps, 10 kbps, 20 kbps, 30 kbps, 40 kbps, and 50 kbps was used. Based on this internet speed setting, it was known that there was no difference in data reading on the LCD display on the baby incubator with the data sent to the android. However, there was a delay in the data transmission process. The test results are described in Table 3.

Based on the results of the table above, there was no data loss during the data transmission process, starting from the speed setting of 5 kbps to 50 kbps, because the researcher utilized the firebase web server function, which could accommodate data according to the data sent. In addition, the data were downloaded by the android system, so no data was lost. However, the weakness of this system is that there was a delay with an average time of 3.67 seconds, and it can be concluded that the minimum bps speed required for data transmission is 5 kbps. The advantage of this system is that data can be accessed anywhere and anytime without any minimum distance.



(a) (b)

Figure 10 (a) LCD display reading display on baby incubator (b) Android display reading

Table 3 Testing data transmission with Internet speed settings

BPS Speed (kbps)	Mean Temperature Reading (°C)	Mean Heartbeat Reading (BPM)	Transmission Data Delay (Second)
5	36.2	80	3.65
10	36.2	80	3.53
20	36.2	80	3.79
30	36.2	80	3.65
40	36.2	80	3.74
50	36.2	80	3.71

4. Conclusions

The research aims to reduce overshoot in baby incubators using the PID method, specifically for babies with heart defects, which can be monitored remotely using the IoT system. After investigating the performance of the PID method for an infant incubator temperature control system, it was found that the steady-state error value was 2%. While the results of measurements using the INCU Analyzer obtained the highest overshoot value at T4 with temperatures reaching 38 ^{0}C ± 1.3 ^{0}C. It can be concluded that the performance of the PID control system is very good for reducing temperature overshoot in baby incubators and is suitable for medical purposes. Then testing was also carried out on the ECG for heart rate (BPM) on the ECG signal using the T-Test statistical test, and the results obtained were p-Value > 0.05. From this value, it shows that this system is feasible to be used for medical purposes because there is no significant difference in value. Data transmission using IoT is also tested by changing several bps speeds with a speed setting of 5 kbps – 50 kbps. The results obtained are that there is no data loss when sending data, and the minimum speed required for data transmission is 5 kbps. However, there is a delay with an average time of 3.67 seconds in the data transmission process. From the overall results of measurements and tests carried out, it can be concluded that the method used is suitable for use according to medical standards. For further research development, researchers want to develop central monitoring of baby incubators so that nurses or users can easily monitor several baby incubators in the NICU room.

Acknowledgments

Appreciation is given to the Department of Electromedical Engineering and Research Management & Innovation Centre, Poltekkes Kemenkes Surabaya, for supporting this research work.

References

Abdurrakhman, A., Soehartanto, T., Hadi, H.S., Toriki, M.B., Widjiantoro, B.L., Sampurno, B., 2020. Design of Output Power Control Systems Based on Mass Flow Rate Comparison of Air-Fuel Ratio (AFR) on Dual Fuel Generator Set by Using the PID Control Method. *International Journal of Technology*, Volume 11(3), pp. 574–586

Ang, K.H., Chong, G., Li, Y., 2005. PID Control System Analysis, Design, and Technology. *IEEE Transactions on Control Systems Technology*, Volume 13(4), pp. 559–576

Agresara, M.N., Vyas, D.D., Bhensdadiya, B.S., 2017. System for Remote Monitoring and Control of Baby Incubator and Warmer. *International Journal of Futuristic Trends in Engineering and Technology*, Volume 3(6), pp.1–6

Ashish, B. 2017. Temperature Monitored IoT Based Smart Incubator. *Proceedings of the International Conference on IoT in Social, Mobile, Analytics and Cloud, I-SMAC 2017*, pp. 497–501

Duvernoy, J., 2015. World Meteorological Organization (WMO). *Guidance on the Computation of Calibration Uncertainties*

Fadilla, R., Idhil, A.N.I.I., Anggraini, M.A.P., Dewi, A.K., Sanjaya, M.R., Nurrohman, M.Y., 2020. A Multifunction Infant Incubator Monitoring System with Phototherapy and ESP-32 Based Mechanical Swing. *International Journal of Science, Technology & Management,* Volume 1(4), pp. 371–381

Hubsher, J.A., 1961. The Electrocardiogram of the Premature Infant. *American Heart Journal* 61(4), pp. 467–475

Janney, B.J., Krishnakumar, S., Anushree, P.B., Rayshma, V., Suresh, S., 2018. Deisgn of Mobile Infant Incubator with Comforting Pillow. *International Journal of Engineering and Technology(UAE)*, Volume 7(2), pp. 6–9

Kanáliková, K., 1990. Diagnosis of Congenital Heart Defects in Childhood. *Bratislavské lekárske listy*, Volume 91(12), pp. 868–873

Kirana, V.C., Andayani, D.H., Pudji, A., 2021. "Effect of Closed and Opened the Door to Temperature on PID-Based Baby Incubator with Kangaroo Mode. *Indonesian Journal of Electronics, Electromedical Engineering, And Medical Informatics*, Volume 3(3), pp. 121–127

Köhler, B.U., Hennig, C., Orglmeister, R., 2002. The Principles of Software QRS Detection. *IEEE Engineering in Medicine and biology Magazine*, Volume 21, pp. 42–57

Koli, M., Ladge, P., Prasad, B., Boria, R., Balur, N.J., 2018. Intelligent Baby Incubator. *Proceedings of the 2nd International Conference on Electronics, Communication and Aerospace Technology, ICECA 2018*, pp. 1036–1042

Kvalvik, L.G., Wilcox, A.J., Skjærven, R., Østbye, T., Harmon, Q.E., 2020. Term Complications and Subsequent Risk of Preterm Birth: Registry Based Study. *The BMJ,* Volume 369

Lawn, J.E., Davidge, R., Paul, V., Von Xylander, S., De Graft Johnson, J., Costello, A., Kinney, M., Segre, J., Molyneux, E., 2013. Preterm Baby Survival and Care Round the World Born Too Soon: Care for the Preterm Baby. *Reproductive Health*, Volume 10(10), p. 5

Luthfiyah, S., Kristya, F., Wisana, I.D.G.H., Thaseen, M., 2021. Baby Incubator Monitoring Center for Temperature and Humidity Using WiFi Network. *Journal of Electronics, Electromedical Engineering, and Medical Informatics*, Volume 3(1), pp. 8–13

Maghfiroh, A.M., Amrinsani, F., Setiawan, S.Y., Firmansyah, R.M., Misra, S., 2022. Infant Warmer with Digital Scales for Auto Adjustment PID Control Parameters. *Jurnal Teknokes*, Volume 15(2), pp. 117–123

Maghfiroh, A.M., Arifin, A., Sardjono, T.A., 2019. Wavelet-Based Respiratory Rate Estimation Using Electrocardiogram. *Proceedings - 2019 International Seminar on Intelligent Technology and Its Application,* pp. 354–359

Mathew, H.B.D.L., Gupta, A., 2015. Controlling of Temperature and Humidity for an Infant Incubator Using Microcontroller. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Volume 4(6), pp. 4975–4982

Muosa, A.H., 2017. Wireless Controland Monitoring Systemfor Premature Infant IncubatorEnvironment. *Journal of College of Education For Pure Sciences (ICEPS)*, Volume 7(4), pp. 28–39

Nachabe, L., Girod-Genet, M., ElHassan, B., Jammas, J., 2015. M-Health Application for Neonatal Incubator Signals Monitoring through a CoAP-Based Multi-Agent System. *2015 International Conference on Advances in Biomedical Engineering,* pp. 170–173

Nayak, A., Singh, M., 2015. Study of Tuning of PID Controller By Using Particle Swarm Optimization. *International Journal of Advanced Engineering Research and Studies* IV(Jan.-March), Volume 346, p. 350

Ogata, K., 2005. Mathematical Modelling of Control Systems. *Modern control Engineering*, pp. 13–62

Rahman, A., Hassan, N., Ihsan, S.I., 2022. Fuzzy Logic Controlled Two Speed Electromagnetic Gearbox for Electric Vehicle. *International Journal of Technology* 13(2), pp. 297–309

Sattar, Y., Chhabra, L., 2021. *Electrocardiogram*. StatPearls Publishing

Shaib, M., Rashid, M., Hamawy, L., Arnout, M., El Majzoub, I., Zaylaa, A.J., 2017. Advanced Portable Preterm Baby Incubator. In *2017 Fourth International Conference on Advances in Biomedical Engineering (ICABME)*, pp. 1–4

Sinuraya, E.W., Pamungkas, 2019. Design of Temperature Control System for Infant Incubator Using Auto Tuning Fuzzy-PI Controller. *International Journal of Engineering and Information Systems (IJEAIS)*, Volume 3(1), pp. 33–41

Utomo, S.B., Irawan, J.F., Mujibtamala, A., Nari, M.I., Amalia, R., 2021. Automatic Baby Incubator System with Fuzzy-PID Controller. *IOP Conference Series: Materials Science and Engineering*, Volume 1034(1), p. 012023

Utomo, T.P., Nuryani, N., Darmanto, 2017. QRS Peak Detection for Heart Rate Monitoring on Android Smartphone. *Journal of Physics: Conference Series*, Volume 909(1), p. 012006

Widhiada, W., Nindhia, T.G.T., Gantara, I.N., Budarsa, I.N., Suarndwipa, I.N., 2019a. Temperature Stability and Humidity on Infant Incubator Based on Fuzzy Logic Control. *ACM International Conference Proceeding Series*, pp. 155–159

Widhiada, W., Antara, I.N.G., Budiarsa, I.N. and Karohika, I.M.G., 2019b. The Robust PID Control System of Temperature Stability and Humidity on Infant Incubator Based on Arduino at Mega 2560. *IOP Conference Series: Earth and Environmental Science*, Volume 248(1), p. 012046

Zaelani, A.V., Koestoer, R.A., Roihan, I., Harinaldi, 2019. Analysis of Temperature Stabilization in Grashof Incubator with Environment Variations Based on Indonesian National Standard (SNI). *AIP Conference Proceedings,* Volume 2062(1), p. 020003