Automatic baby incubator system with fuzzy-PID controller

Satryo Budi Utomo1*, Januar Fery Irawan2, Arizal Mujibtamala1, Mochamad Irwan Nari3, Rosida Amalia1
1 Electrical Engineering Department, Jember University
Kalimantan No 37 Jember 68121 East Java Indonesia
*Email: satryo@unej.ac.id
2 Mining Engineering Department, Jember University
Kalimantan No 37 Jember 68121 East Java Indonesia
3 Engineering Department, Politeknik Negeri Jember
Mastrip Kotak Pos 164, Jember 68101, Indonesia

Abstract. Deaths due to temperature instability often occur in premature babies. Negligent handling of new-borns can pose a risk of temperature instability as well. Therefore, interventions to keep the baby’s body temperature warm can reduce the risk of infant death. An incubator is a box equipped with a temperature controller to maintain a baby's average body temperature. The faster nursery controlled the heat, the quicker the handling of the baby from the risk of temperature instability. This research aims to design a baby incubator that has an automatic control system for working temperatures quickly. The method to be used is Fuzzy-PID control, which functions to maintain temperature stability and accelerate the system's response to the incubator. The temperature in the nursery is measured using a DHT22 sensor. The temperature measured from the sensor use error and delta error as input parameters in the design of the fuzzy membership set. The heater used in this study is an incandescent lamp to produce heat that is safe for babies. An experiment was carried out by comparing the PID control to determine the speed of the system response. Besides, measurements to assess the stability of the controller are also carried out by analyzing the effect of the load on temperature variations. The test results show a faster system response compared to the PID control and stability at a temperature set point of 32 °C, 33 °C, 34 °C and 35 °C. The time needed to achieve balance at the highest temperature of set points is 205 seconds with a max overshoot of 0.5%. With the max overshoot, the incubator can still work at a temperature that is safe for babies.

Keywords: incubator, baby, premature, controller, system, fuzzy-PID, design

1. Introduction
Based on the 2016 Central Bureau of Statistics data, the infant mortality rate (IMR) reaches 25 deaths per 1,000 babies. Then on January 1, 2018, according to the UN, which takes care of the problems of children, namely UNICEF, the birth of premature babies in Indonesia is still in fifth place, with 13,370 premature babies born. There is a lot of evidence that shows that babies born
prematurely have weak postnatal growth, and the earlier the baby, the higher the disturbance that may occur, and the longer it will last [1]. Therefore, babies born prematurely need intensive care, care can imitate by way of mother Kangaroo care, and using an incubator [2].

Premature babies need incubators to keep their bodies warm, so temperature controller is required. Incubators work to increase the survival of babies by providing a friendly environment [3]. The problem now is that the price of imported incubators with the technology needed to care for premature babies has a relatively high cost of around Rp 16 million - Rp 118 million. Nevertheless, there are also locally-made incubators that have more affordable prices, ranging from Rp. 1 million to Rp. 3 million, but with inadequate technology, many local products of nursery are still controlled manually. Therefore this research aims to design an economical baby incubator but has an automatic controller system.

The method to be used is the Fuzzy-PID controller, a combination of conventional PID with logic fuzzy, maintains the same linear structure of proportional, integral, and derivative parts but has constant coefficients and self-controller advantages. This controller presents better and effective responses [4-6]. PID controller is the most popular controller used in the industry due to its extraordinary effectiveness, simplicity of implementation, and broad application. Still, it is not easy to determine a good and suitable regulatory value [7-9]. Logic Fuzzy adds human reasoning to the inferential mechanism [10]. Later the stability of the temperature and speed of the system response to the incubator will be regulated using the controller Fuzzy-PID. The combination of the PID controller and the controller Fuzzy can further improve the transient and response performance steady state [11]. The parameters in the PID required to adjust by the reasoning algorithm fuzzy, so they have the ability to self-adapting [12].

The difficulty in using logic controllers fuzzy is in designing the membership function correctly, and the rule base [13]. To develop a system fuzzy-PID, the first thing to do is to choose the controller type fuzzy-PID from fuzzy-PI [14], PD [15], fuzzy PI + D [16] or fuzzy PD + I [17]. The type of controller fuzzy must match the controller led plan. Controllers Fuzzy-PID can be expressed as shear mode controllers, which have two nonlinear terms, the first acting as equivalent controller and the other acting as switching controller [18].

In designing this incubator system, the fuzzy controller will later be adapted by PID as tuning. The design offset fuzzy membership adopted error and delta error of temperature as parameter input. There are several stages to design fuzzy logic, namely fuzzification, by forming the membership function. Then, the next step is the inference with the establishment of a rule base, and the last is defuzzification [19-24]. The fuzzy controller, consists of the fuzzification of the input and output using the membership function [13]. The temperature and humidity of the incubator are measured using a DHT22 sensor [13]. Then use the AC light dimmer to adjust the brightness of the lights, and the driver L298N to adjusts the fan [26-27]. The microcontroller used is Arduino Uno [28]. There are two analyses in testing in this study, namely the no-load analysis and the load analysis. The load applied is water, with a temperature of 36.5 °C-37.5 °C [29]. This temperature resembles the heat of a new-born.

2. Materials and methods
In designing tools, the incubator has two parts, namely the top and lower box. The bottom of the incubator box works as a place for electronic circuits, as described in figure 1. The head of the incubator box serves as a place to put the baby with a DHT22 sensor and 16x2 LCD.
2.1 Performance measurement method

2.1.1 PID Control Test
This test aims to set the control value on the PID parameters to produce the best system response by considering the output in the form of max overshoot, rise time, settling time, and steady-state error. This test carried out by tuning trial and error. Before testing with the PID control, several stages are carried out, the first being testing the P control by changing the value of the P parameter and using the zero value for Kp and Ki. The second stage is testing the PI control by changing the value of parameter I and using the best value for Kp based on the results of the previous test, while the benefit for Kd is zero. Then the third step is testing the PD control by changing the value of the parameter D and using the best value for Kp based on the previous test, while for the benefit of Ki is zero.

2.1.2 Control test of fuzzy-PID
This test aims to adapt the logic fuzzy as tuning PID to produces a faster system response and a stable temperature. The experiment requires the establishment of a membership function for input, as illustrated in Figure 2 and the formation of membership output, as seen in Figure 3. In the next step, the inference stage is where the formation of conditions for control output is called the rule base (Table 1 and Table 2). It is essential to apply the condition of the rule base for setting the value of the output PWM is used to control the heater in the events leading to reach the setpoint temperature.

Figure 2. a) Function input error temperature, b) Function input delta error temperature
Figure 3. (a) Function Output $K_p$, (b) Function Output $K_i$, (c) Function Output $K_d$

Table 1. Output rule $K_p$

| ErrorDelta | NE   | ZE   | PE   |
|------------|------|------|------|
| Nde        | SKp  | MKP  | BKP  |
| ZDE        | SKp  | SKp  | BKP  |
| PDE        | SKp  | MKP  | BKP  |

Table 2. Output rule $K_i$

| ErrorDelta | NE   | ZE   | PE   |
|------------|------|------|------|
| Nde        | SKi  | MKI  | BKI  |
| ZDE        | SKi  | MKI  | BKI  |
| PDE        | SKi  | MKI  | BKI  |

Table 3. Output rule $K_d$

| ErrorDelta | NE   | ZE   | PE   |
|------------|------|------|------|
| Nde        | SKD  | MKD  | BKP  |
| ZDE        | SKD  | SKD  | MKP  |
| PDE        | SKD  | MKD  | BKP  |
2.1.3 Stability test of fuzzy-PID
Water load test is carried out with four different set points to determine the response of the system. The water load used in testing has a temperature resembling a newborn baby, which is 36.5 °C to 37.5 °C. The ideal heat needed by premature babies based on the age and weight rules of the baby are applied as the set point in this test.

3. Results and discussion
It is necessary to perform serial experiments of the control system and the influence of the load to reveal the work of the system. Output testing on the control system is done at 35 °C set points to get the output chart pattern, settling time, rest time, and maximum overshoot on the both control systems. The stability of Fuzzy-PID control and PID control has the same performance at a temperature of 35°C, as seen in Figure 4. However, the test results show that Fuzzy-PID output has a faster response result than PID control, although the max overshoot of Fuzzy-PID is slightly higher compared to the PID control, as seen in table 4. The steady-state error value has the same amount, which is 0.085%. Overall fuzzy-PID control is better than PID control.

Table 4. Temperature Response in PID and Fuzzy-PID Controller

|       | Mv (%) | Tr (seconds) | Ts (seconds) | Ess (%) |
|-------|--------|--------------|--------------|---------|
| PID   | 0.31   | 217          | 233          | 0.085   |
| Fuzzy-PID | 0.42 | 205          | 227          | 0.085   |

![Figure 4. Output Fuzzy-PID Control and PID Control at C setpoint 35](image)

Test results show that both systems have the same stability, as shown in the same chart pattern in Figure 5. The rise time results are 92 seconds for load-free testing and 93 seconds for load testing. Meanwhile, settling time is 138 seconds for load-free testing and 149 seconds for load-testing. The Steady-State Error results even show the same value between the two systems. Overall, the test results with set point 32°C show that the results of the control response in the test with a load have effects that are not much different from those in the no-load test despite having differences in settling time and maximum overshoot, but not too large as seen in table 5.
Figure 5. Control Response without Load at Setpoint 32°C (a) without Load, (b) with Load

Table 5. Temperature responses at setpoint 32 ° C

| Conditions    | Mv (%) | Tr (seconds) | Ts (seconds) | Ess (%) |
|---------------|--------|--------------|--------------|---------|
| No Load       | 0.34   | 92           | 138          | 0.09    |
| With Loads    | 0.4    | 93           | 149          | 0.09    |

The stability of the two systems shows the same response pattern as Figure 6. Besides, the results of the temperature response at 33 °C setpoints also display results that are not much different and do not have a significant difference, as in table 6. The rise time test result is 137 seconds for testing no load and 129 seconds for load testing. The overall performance of the two systems shows the same performance.

Figure 6. Control Response without Load at Setpoint 33°C (a) without Load, (b) with Load.

Table 6. Temperature Responses at Setpoint 33 ° C

| Conditions    | Mv (%) | Tr (seconds) | Ts (seconds) | Ess (%) |
|---------------|--------|--------------|--------------|---------|
| No Load       | 0.45   | 137          | 159          | 0.09    |
| With Loads    | 0.5    | 129          | 163          | 0.15    |

The stability of the two systems at the 34 °C setpoint shows the same response pattern as Figure 7. Besides that, the temperature response results also display results that are not much different and do not have a significant difference, as in table 7. The rise time value is 179 seconds for testing without loads and 172 seconds for testing with loads, settling time of 241 seconds for
testing without loads, and 246 seconds for testing with loads. The overall performance of the two systems showed the same performance at 34°C.

![Figure 7. Control response without load at setpoint 34°C (a) without load, (b) with load](image)

**Table 7. Temperature responses at setpoint 34 °C**

| Conditions      | Mv (%) | Tr (seconds) | Ts (seconds) | Ess (%) |
|-----------------|--------|--------------|--------------|---------|
| No Load         | 0.38   | 179          | 241          | 0.14    |
| With a Load of  | 0.5    | 172          | 246          | 0.2     |

The stability of the two systems at the 35 °C setpoints also shows the same response pattern as Figure 8. Besides that, the temperature response results also display results that are not much different and do not have a significant difference, as in table 8. The results of the control responses in the test with a set point of 35 °C have a rise time result of 205 seconds for testing without bed and 223 seconds for testing with a load. The steady-state error results have the same value for no-load and load testing. Even though the amount of max overshoot without load testing is more significant than 0.05% compared to experiment with weight, overall, the two systems show the same performance.

![Figure 8. Control Response without Load at Setpoint 35°C (a) without Load, (b) with Load](image)

**Table 8. Temperature Responses at Setpoint 35 °C**

| Conditions      | Mv (%) | Tr (seconds) | Ts (seconds) | Ess (%) |
|-----------------|--------|--------------|--------------|---------|
| No Load         | 0.42   | 205          | 227          | 0.085   |
| With Loads      | 0.37   | 223          | 245          | 0.085   |
Of the four tests with different set points, the system response is not much different in the no-load analysis and the load analysis. It is caused by the fuzzy control, which plays a role as a tuning for the PID parameter. The results of the control output response have a max overshoot that is not too large, which only reaches 0.5% as the maximum value in the tests that have been performed. In the experiment with a temperature setpoint of 34 °C, it takes longer than in other test points to reach a steady-state, a 34 °C setpoint test requires 241 seconds to enter a steady state when no load and takes 246 seconds to achieve a constant state when with a charge.

4. Conclusions
A fuzzy-PID control has been proposed to build a quick and stable incubator. The use of a fuzzy-PID control system has demonstrated a more rapid rise time than the PID control system, which is 205 seconds. In addition to that, the fuzzy-PID control system also accelerates the temperature to a steady state. When a Load work on Fuzzy-PID control systems, it does not affect the work of the fuzzy-PID control system. The most significant max overshoot by experiment using the Fuzzy-PID control produced in this research was 0.5%. Therefore, the incubator is safe enough to keep the baby's temperature warm.

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6. Reference
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