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A Fuzzy Logic-Based Temperature Control System for Baby Incubators

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ABSTRACT A The purpose of a baby incubator is to help preterm infants whose bodies cannot adapt to their new surroundings by providing them with artificial heat. The goal of this research was to develop a method of applying fuzzy control in conjunction with the DS18B20 sensor for analyzing the response points involved in the construction of a baby incubator. For this experiment, researchers employed conditions of 32 ˚C, 35 ˚C, and 36 ˚C. The Incu analyzer is utilized as the industry standard reference instrument. Fuzzy control on a microcontroller involves a few steps, including fuzzification, which involves inputting the value of the membership function, where this member is a collection of error and feedback values, in this case 0.5; this member is then processed further in fuzzification, which involves transforming raw crisp calculations into membership values via the function membership. A rule base is a set of rules developed to achieve a goal by specifying the appropriate control action in response to a particular input value using linguistic rules. Defuzzification performs calculations of changing fuzzy quantities presented in the form of variable values from the rule base with output values to set an output value that we need in the system. This fuzzy system produces an average rise point of 200 seconds and an overshoot value in the range of +0.50 C. Stability can be achieved within 8 to 10 minutes.

INDEX TERMS Baby Incubator, DS18B20, Fuzzy Logic, Response Poin

I. INTRODUCTION

Premature infants are one group of newborns whose conditions warrant special attention, as they experience the instability of birth for the first time when they put their feet down in their new environment. Babies born prematurely are said to be born into abnormal circumstances. This is due to a number of factors, including an incorrect birth date and an early gestational age. Extreme preterm birth occurs before 28 weeks of pregnancy, very preterm birth occurs between 28 and 32 weeks, and moderate to late preterm birth occurs between 32 and 37 weeks of pregnancy [1][2],if nothing is done to treat the baby's condition, the infant will die. An incubator is a special room where infants can be closely monitored and where the temperature and humidity can be adjusted to meet their specific needs. A baby incubator is a sealed container with adjustable environmental controls [3] that can be set to provide the optimal conditions for the development of the infant within.Fuzzy logic will be employed for dynamic measurements with complex values in direct temperature changes [4] in order to set the temperature in the incubator to meet the needs of the baby. According to Garima Mathur's study, "Fuzzy Logic Control for Infants," this type of control outperforms others because of its gradual temperature increase, slows to steady state, and relatively small overshoot. With fuzzy control[5], the temperature rise is gradual and minimal when the skin sensor is not present [4]. If the skin sensor attached to the baby comes off, this is a great way to deal with a situation outside of the technician's or nurse's control.

The FLC (Fuzzy Logic Controller) section takes 171.5 seconds to reach a steady state condition without disturbance, according to research conducted by Noor Yulita and Alif Catur. It takes 159.5 seconds to return to a steady state from a state of minor disturbance [3], and 660.5 seconds from a state of major disturbance. It's safe to say that settling into a steady state with the help of FLC is a breeze. It's excellent news if the incubator can maintain a constant temperature and humidity without adjusting any of the other variables.Authors Satriyo Prasojo and Bambang Suprianto found that while testing on fuzzy controls resulted in a higher error but a stable light in their study titled Design and Build of a Temperature Control System in a Baby Incubator Based on Fuzzy Logic Controller. The constant dimming of the lights upon the release of this control can be detrimental to the baby's comfort; however, some of the errors caused by this control can be reduced even further with the use of better components, and the baby's exposure to the dry air outside the incubator can be mitigated through the use of these controls.W. Widhiada, T.G.T. Nindhia, and IN Gantara conducted research on the temperature and humidity stability of infant incubators, and found that when Fuzzy Control Logic is combined with Arduino, the incubator can withstand an overshoot value of less than 5% during no-load or baby tests, and 1.3241 when subjected to a baby load of roughly 2 kg. When using fuzzy logic, the minimum percentage of signal error increases to 0.0185% when working with a load of 2 kg, and to 0.0086% when working without a load. Therefore[6], it can be concluded that the minimum error signal value can be reduced below 5%[7] and the error rate at the overshoot temperature can be reduced by 5%[8] when fuzzy logic is added.

Several studies on fuzzy logic have found that it functions adequately with some mathematical error introduced when translating the logic into a programming language and implementing it in integrated components; this error can be mitigated by switching to higher-quality parts. Humidity levels in the incubator, for example, will shift if the temperature suddenly rises or falls[9][10]. There must be a corresponding adjustment in temperature with changes in humidity in the incubator so that the environment created is optimal for the baby's condition at the time. Poor airflow in the incubator can have a detrimental effect on a baby's recovery,[11] so it's important to keep that in mind.

The authors intend to develop research on "Temperature and Humidity Control Systems Using Fuzzi Logic in Baby Incubators (Temperature Control)" in response to the issues mentioned above. The purpose of this research is to assess the efficacy of Fuzzy temperature control in a baby incubator, with temperature being monitored by a DS18B2 sensor.

II. MATERIALS AND METHODS

A. EXPERIMENTAL SETUP

In this experiment, a regular baby incubator box is used, and fuzzy logic is used to regulate the temperature and humidity. Here, we looked at how long it took for temperatures to stabilize after being rapidly changed between 32˚C, 35˚C, and 36˚C [12][13]. The module's temperature reading is then compared with an Incu Analyzer, a precision instrument.

1) MATERIALS AND TOOL

This study uses the DS18B20 sensor as a temperature sensor, the DHT11 sensor as a humidity sensor, and the second DS18B20 sensor as a skin sensor. A microcontroller with FLC (Fuzzy Logic Controller) control is used to process data using the Arduino Mega 2560[14]. Stepper motor to open and close the airflow door. L298N driver as a driver to drive stepper motors. Also, send the data to the Nextion Enhance 7-inch TFT LCD display to display graphs and values for chamber temperature, skin temperature, and humidity.

2) EXPERIMENT

The decision-making process with fuzzy control has different stages, one of which is the formation of membership, which will be interfered with at the stage of forming the rule base and the defuzzification process.This fuzzy method uses an error or feedback[15] value of 0.5 with linguistic variable input and 7 design tables.

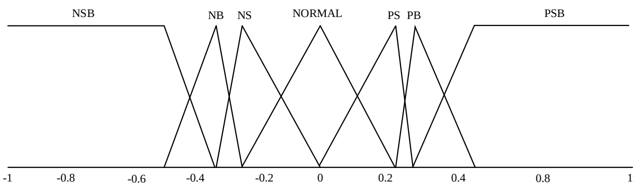


FIGURE 1 Membership Function from Fuzzy logic with ±0.5 tolerance

FIGURE 1 is a variable graph with 7 labels with a maximum error or feedback of 0.5. In the temperature control study, a tolerance value of 0.5˚C was used, with an error equal to the tolerance value, it is hoped that the output of this fuzzy control will maintain the temperature value within the tolerance value range.

The output of the 7 labels will be entered into the heater output value can be seen in TABLE 1:

The following is the calculation of the output from the control when the error value is -0.2 dan 0.2:

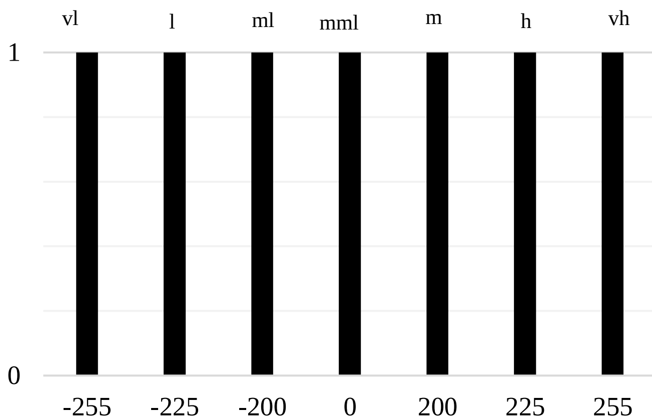


FIGURE 2 Output for Heater

when the value of NSB= -0.5, NB= -0.35, NS= -0.25, Z=0, PS=0.25, PB=0.35, PSB=0.5

Fuzzification is the process of changing non-fuzzy variables (numerical variables) into fuzzy variables (linguistic variables). Numerical variables in this case are error values that have been initialized with a, b, c, d, e, f, and g. The following is an illustration in FIGURE 2 of the calculation of fuzzy logic.

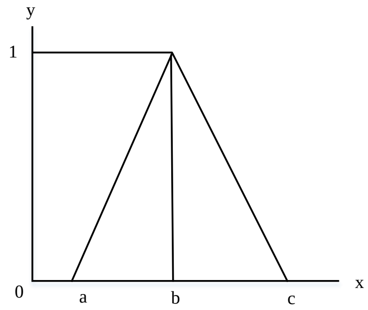


FIGURE 3 Isosceles triangle for fuzzy membership

Below is an example of the formula to define the fuzzy logic membership from the triangle of the same leg above Eq. (1) after sorting the membership, that value will inserted in rule base that would define how will fuzzy working or make the heater ON state or OFF state.

$$\text{Segitiga}(x; a,b,c) = \begin{cases} 0, & x \le a \\ \frac{x-b}{a-b}, & a \le x \le b \\ \frac{a-x}{a-b}, & b \le x \le c \\ 0, & c \le x \end{cases} \tag{1}$$

When a is lower limit or first limit that we meet in a triangle, b is a middle limit or second limit for dividing a and c, for the last is c for upper limit or last limit we found in a triangle equation.

So then, else if (error >= a && error <= b)
{
nb = (error - a) / (b - a);
nsb = 1 - nb;
inputing error value -0,2 dan 0,2 so then the calculation is

TABLE 2 Calculation of rule base as value for fuzzy logic

$\mu ns[-0.2] = \frac{((error)-ns)}{z-ns}$ $= \frac{(-0.2)-(-0)}{(-0.25)-0}$ $= \frac{-0.2}{-0.25}$ $= 0.8$	$\mu ps[0.2] = \frac{((error)-ps)}{z-ps}$ $= \frac{0.2-0.25}{0-(-0.25)}$ $= \frac{0.05}{0.25}$ $= 0.2$
$\mu z[-0.2] = \frac{(ns-(error))}{ns-z}$ $= \frac{(-0.25)-(-0.2)}{(-0.25)-0}$ $= -\frac{-0.05}{-0.25}$ $= 0.2$	$\mu z[0.2] = \frac{((error)-z}{ps-z}$ $= \frac{0.2-0}{0.25-0}$ $= \frac{0.2}{0.25}$ $= 0.8$ then $\mu ps' = 1$

In TABLE 2 Fuzzyfication this value must be 1 (one) when doing some calculation, so for value ns,z,ps,pb,psb is a 0. The fuzzy output is found by finding the highest rule strength value for each output label, which is a relative calculation made possible by rule evaluation. Fuzzy's guidelines are laid out as a series of if/then statements. The criteria for this analysis areIn this analysis, we follow these guidelines:

If (ERROR is nsb), then (PWM is vh).
If (ERROR is nb), then (PWM is h)
.If (ERROR is ns), then (PWM is m).
If (ERROR is z), then (PWM is mml).
If (ERROR is ps), then (PWM is ml).
If (ERROR is pb), then (PWM is l).
If (ERROR is psb), then (PWM is vl).

In the fuzzification error of -0.2 above, the rule is obtained as below

TABLE 3
Calculating rule strenght

Rule Strenght	Rule
Rule 1: IF Error ns (-0.2) Then PWM ml	**0.8**
Rule 2: IF Error z (-0.2) Then PWM mml	**0.2**

For TABLE 3 we got fuzzification error 0,2 on above, we got a rule like this below.

TABLE 4
Calculating rule strength

Rule Strenght	Rule
Rule 1 : IF Error ps (0.2) Then PWM m	**0.2**
Rule 2 : IF Error z (0.2) Then PWM mml	**0.8**

So the fuzzy output for TABLE 4 output at error -0.2 is 0.8 for PWM ml and 0.2 for PWM mml. Meanwhile, the output error is 0.2 for PWM m and 0.8 for PWM mml. After getting the fuzzy output value for each label, the next step is defuzzification to determine the crisp output value (numeric output). Defuzzification is the process of calculating all fuzzy outputs for a given output variable to determine the crisp output action. Here is the output error: -0.2.

TABLE 5
Output Defuzzyfication with error -0.2

Vh	H	M	Mml	Ml	L	Vl
0	0	0.8	0.2	0	0	0

here is Eq. (2) for calculating the output when the error reaching or around -0.2.

TABLE 6
Output Defuzzification with error 0.2

Vh	H	M	Mml	Ml	L	Vl
0	0	0.2	0.8	0	0	0

Here is Eq.(3) for calculating the output when the error reaching or around 0.2. This Accordingly, the PWM that the SSR will receive is 36 for an error of -0.2 and 114 for an error of 0.2, and this PWM can vary depending on the error value that will be processed by the fuzzy system. The magnitude of the PWM output is proportional to the value of the error. To control the temperature, a wire from the Arduino's PWM output on a digital pin is connected to the SSR input pin.

After the design was finished, tests were performed on the DS18B20 sensor to determine the response point level of the sensor at 32˚C, 35˚C, and 36˚C, respectively, to see differences in the response points in the baby incubator. Once the DS18B20 has detected the temperature, the microcontroller can make the necessary adjustments to the incubator's heating system with the help of fuzzy logic. If the temperature is below the set point by 0.5˚C or more, the heater will receive full voltage to bring it up to that point. Once it reaches that point, however, the heater will pulse, meaning it will turn on and off repeatedly to keep the temperature from fluctuating too much around the set point. When the heater's temperature rises above 0.50˚C, the unit will power down entirely before powering back up once the temperature reaches the desired level. The data gathered by this incubator module will be analyzed based on the response points (rise time, overshoot time, and stabilize time) the heater power being graphically displayed on a TFT LCD by a bar which its showing the power of heater.

B. THE DIAGRAM BLOCK

For FIGURE 4 As can be seen, the DS18B20 sensor is used to monitor the temperature of the room, the LM35 is used to monitor the baby's skin, and the DHT11 is used to monitor the humidity of the room. Configurable Fuzzy Logic temperature and humidity settings A target setpoint temperature of 32˚C, 35˚C, or 36˚C can be selected in the temperature setting. The DS18B20 is employed as the sensor; it converts temperature into a voltage that can be controlled and processed by the microcontroller. The second DS18B20 is placed in a skin sensor to read the baby's temperature. Meanwhile, the DHT11 sensor will provide feedback on the relative humidity within the incubator, allowing the parents to make informed decisions about whether or not to move the baby.TFT displays the microcontroller's processed output, the heater warms the water, and the motor regulates the water's flow. The screen is used as an output display in the Baby Incubator, displaying graphs of environmental conditions like temperature, skin temperature, and humidity. During this time, the motor and heater output will be controlled. The author uses a program for the heater in which the heating power gradually decreases if the temperature in the baby's incubator is near the set temperature, decreases and increases to adjust to the same temperature as the set points, and increases gradually if the temperature in the baby's incubator is below the set temperature. Meanwhile, the motor program employs a program where the motor works to close the water chamber flow if the humidity is above 60% and works to open the water chamber flow if the humidity is below 40%.

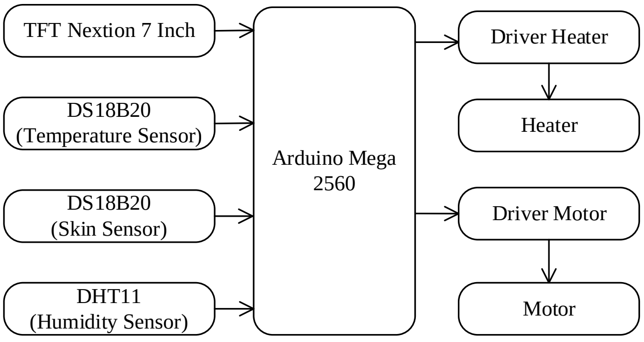


FIGURE 4 Block Diagram of baby incubator with Arduino mega as microcontrol for fuzzy logic processing.

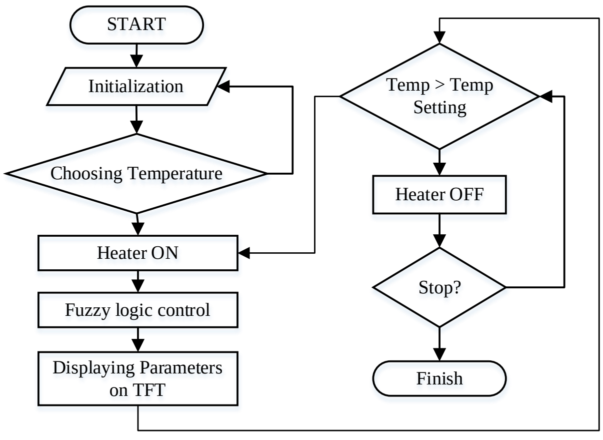


FIGURE 5 Program flow chart for baby incubator with fuzzy logic as control

C. THE FLOWCHART

For FIGURE 4 provides a diagram of the system's flow. As soon as you turn on the Baby Incubator, the temperature control, skin temperature, and data transmission from the Arduino with TFT will all be initialized. The TFT will then show a menu of temperature options from which to regulate the operation of the heater and the motor. In addition to the graph, the TFT will show the internal temperature, skin temperature, and humidity of the Baby Incubator. When the baby incubator's temperature gets close to the desired maintenance level, the heater turns off; when the temperature drops below the desired level, it turns back on.

D. SYSTEM CIRCUIT

FIGURE 5 explain that the DS18B20 sensor's circuit is built to identify both high and low temperature readings inside a chamber. To serve as an ON/OFF heating switch, a skin sensor will also be used, and its data will be analyzed using fuzzy logic. Three legs make up the DS18B20 sensor, and each one has a distinct function. Leg 1 functions as the VCC connection, supplying the required power. Leg 2 is used to transmit data for output, which will then be linked to a resistor before entering Arduino pin 35. Leg 3 is devoted to the ground connection and is the last leg. For temperature conversion (strong pull-up) on leg 2 of the sensor, the DS18B20 has a resistor to activate parasite mode, ensuring a sufficient power supply. When employing two DS18B20 sensors at once, the second DS18B20 will be wired in series with the first DS18B20's data output.

Moving on, the stepper motor driver circuit is in charge of directing the motion of the stepper motor. For the motor windings, this driver uses PIN 41–44 as a voltage distributor. The driver also shares the ground connection with the Arduino and gets a 5V voltage from it. Lastly the Nextion circuit, created to ease communication with the Nextion display, is the last component. The Nextion has four inputs: Pin 1 for 5VDC, Pin 2 for the TX input, Pin 3 for the RX input, Pin 4 for the ground connection from the Nextion, and Pin 2 for the TX input, which links to the Arduino's RX input.

III. RESULT

Module measurements will be compared with the Incubator Analyzer tool, as a reference and comparison in determining the correctness of the baby incubator.

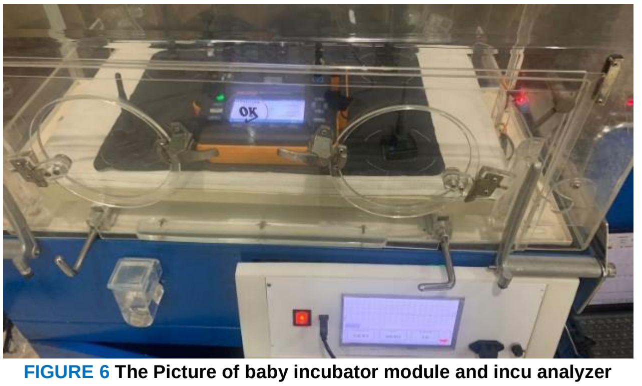


FIGURE 6 The Picture of baby incubator module and incu analyzer

FIGURE 6 this image showed us when we collecting data for baby incubator and will compared to incu analyzer. The DS18B20 and DHT11 sensors, as well as a second DS18B20 sensor, make up this module. Temperature readings are taken with a DS18B20 sensor, humidity readings are taken with a DHT11 sensor, and skin sensor readings are taken with a second DS18B20 sensor. The Mega 2560 Microcontroller is then linked to the three sensors. In this research, fuzzy controls are used to regulate the indoor climate via the Mega 2560 microcontroller. If the heater's temperature is below the set point or within a range of 0.5 C, the microcontroller will provide full voltage to the heater; if the heater's temperature is at or near the set point, the microcontroller will turn the heater on or off or pulse to stabilize the temperature at the set point; and if the heater's temperature is above the set point or within a range of 0.5˚C,[16] the microcontroller will turn the heater off. On the Nextion 7-inch TFT, you can view data collected by the second DHT11, third DS18B20, and fourth DS18B20 sensors.

In this experiment, temperature readings were taken at 32˚C, 35˚C, and 36˚C, each for 45 minutes. When the Incu analyzer has been properly calibrated, the retrieved moisture data will be compared to its actual value. In the Mega 2560 microcontroller used in this study, temperature and humidity were controlled using fuzzy controls. The results of humidity sensor readings will be read using the Nextion 7-inch TFT. Initialization of the temperature program contains the DS18B20 temperature sensor library, which is serial communication using one data line. Where the data/output leg of the DS18B20 temperature sensor pin 2 will be initialized on Arduino pin 3. The same goes for the 2nd DS18B20 sensor; the data leg will be connected in series, the same as leg 2 on the 1st DS18B20 sensor. The DS18B20 temperature sensor is a temperature sensor that has a 12-bit ADC and is very precise.

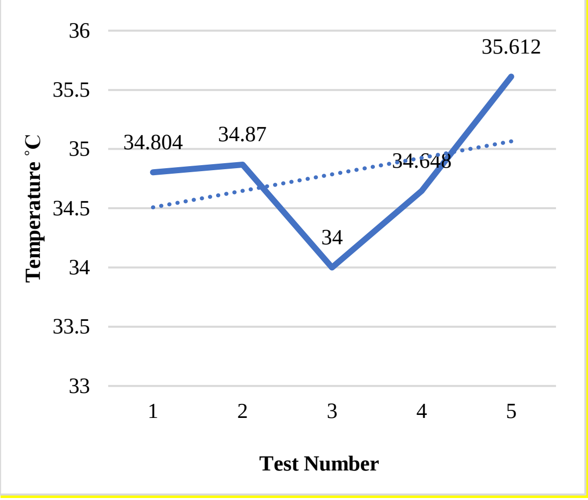
This sensor has a temperature range of -10 °C to +85 °C and an accuracy level of 0.5. The sensor calculates the temperature in Celsius and Fahrenheit, respectively. But actually, the sensor is calibrated to work in Celsius, so farenheit values are converted from Celsius by the library. Then the output results are sent to the serial monitor. In the first initialization, there is an initialization of the input to the fuzzy; in this case, the DS18B20 is used as input. The data that will be given by the sensor will be processed as an error value in the error formula above. Then there is the reading of the error values from the fuzzy input, where we can create a set based on these error values for the fuzzification process. This method uses the value of crisp and multiplies it based on the rules that have been fulfilled for the weight of the defuzzification. After completing the defuzzification, the PWM results for the controlled heater will appear according to the available rule base list.This program contains coding for calling data from Nextion to Arduino. If we take an action on Nextion, then Arduino will respond with the code provided above. In the first line, there are initializations of various buttons used in Nextion, which will be processed by Arduino when taking action on Nextion. Then there is initialization for calling some of the sensors used; there are DS18B20 sensors and DHT-11 sensors. Initialization of sensor readings is used according to the available library.

TABLE 7
The result of temperature from incu analyzer with setting 32°C

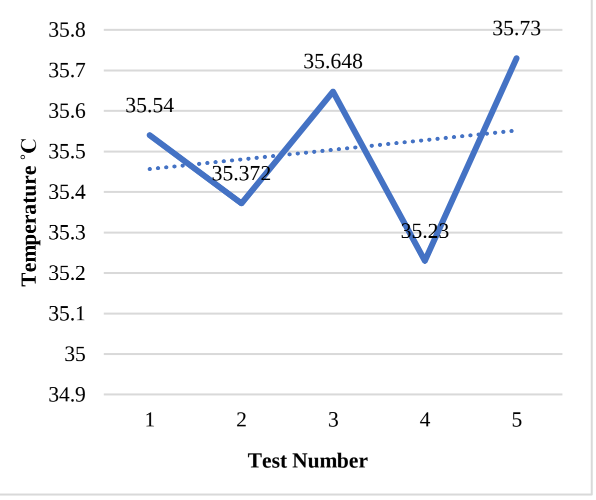
Test	Test Temperature on Incu Analyzer (˚C)					Average	Module
	T1	T2	T3	T4	T5		
1	31.93	31.62	31.71	31.75	31.58	31.718	31.92
2	31.53	31.37	31.49	31.49	31.67	31.51	32.2
3	31.5	31.45	31.47	31.37	31.7	31.498	32.13
4	31.87	31.54	32.05	31.8	32.1	31.872	32.14
5	31.58	31.34	31.81	31.67	32.04	31.688	32.01
Average	31.82316	31.464	31.706	31.616	31.818	31.6572	32.08
SD	0.237189	0.116748	0.240583	0.181052	0.235202		0.112916
Error	0.01%	0.01%	0.01%	0.01%	0.01%		0.05%

TABLE 8
The result of temperature from incu analyzer with setting 35ºC

Test	Test Temperature on Incu Analyzer (˚C)					Average	Design
	T1	T2	T3	T4	T5		
1	35.44	34.6	34.7	34.37	34.91	34.804	35.02
2	35.48	34.82	34.74	34.42	34.89	34.87	35.07
3	34.09	33.86	33.64	33.68	34.73	34	35.23
4	35.19	34.46	34.54	34.3	34.75	34.648	35.14
5	34.91	35.65	35.93	35.88	35.69	35.612	34.85
Average	34.04769	34.678	34.71	34.53	34.994	34.7868	35.062
SD	0.303231	0.649554	0.815966	0.811727	0.397341		0.142373
Error	0.01%	0.03%	0.04%	0.04%	0.02%		0.06%



(a)



(b)

FIGURE 7. **Graph for result and tren for data we got in temperature setting a) 35℃, b) 36ºC**

TABLE 9
Result of temperature from incu analyzer with setting 36ºC

Test	Test Temperature on Incu Analyzer (˚C)					Average	Module
	T1	T2	T3	T4	T5		
1	34.72	36.1	35.2	35.71	35.47	35.44	35.92
2	34.65	35.2	35.32	35.33	35.53	35.206	36.2
3	35.8	35.97	35.1	35.67	35.7	35.648	36.13
4	34.02	34.77	35.9	35.77	35.71	35.234	36.14
5	35.78	35.65	35.93	35.88	35.69	35.786	35.82
Average	35.55883	35.538	35.49	35.672	35.62	35.4628	36.042
SD	0.174653	0.55206	0.395854	0.20693	0.111803		0.163156
Error	0.01%	0.03%	0.02%	0.01%	0.01%		0.07%

TABLE 10
Measurement Results Error and uncertainty setting32ºC,35ºC,and 36ºC

Temp. Setting (˚C)	Average		Error (%)	Uncertainty	
	Module(˚C)	Calibrator(˚C)		Module	Calibrator
32	31.75	31.65	0.1	0.112	0.23
35	34.74	34.56	0.22	0.112	0.21
36	35.59	35.59	0	0.112	0.26

For data input baby incubators was using Incu Analyzer.

TABLE 7 shows the results of temperature sensor measurements on the baby incubator and incubator analyzer modules as a comparison with a temperature setting of 32°C.While the Incu Analyzer reads the lowest value at 31.34˚C[17] and the highest value at 32.04˚C. From the table above, it can be seen the results of five temperature readings: the tool module reads the lowest value at 34.85 °C and the highest value at 35.23 °C. While the Incu Analyzer reads the lowest value at 34.3 °C[17] and the highest value at 35.19 °C. FIGURE 7 the result of incu analyzer with 35ºC as temperature setting.

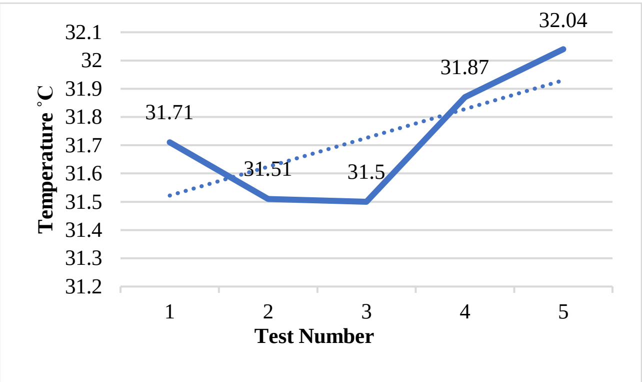
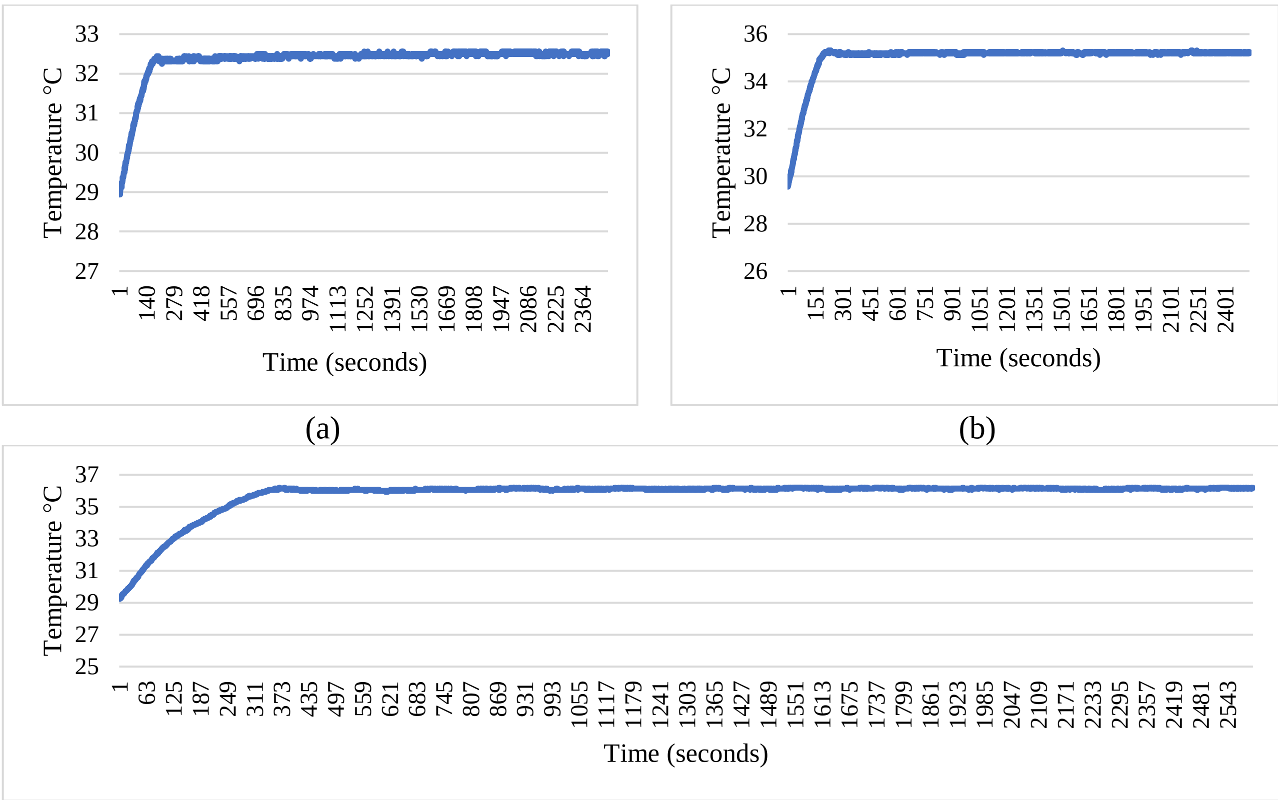


FIGURE 8 Graph for result and tren for data we got in temperature setting 32ºC.

FIGURE 8 the result of incu analyzer with 32ºC as setting. TABLE 8 shows the results of temperature measurements on the baby incubator and incubator analyzer modules as a comparison with a temperature setting of 35°C and measurements are carried out with 5x data collection.

TABLE 9 Using a temperature setting of 32°C, the results of temperature measurements on the baby incubator and incubator analyzer modules are displayed for comparison. The data collection time was increased by a factor of 5. The results of five temperature readings are shown in the table above; the lowest value is 35.92 °C,[17] and the highest is 36.14 °C, according to the tool module.The Incu Analyzer shows a range from 34.02 to 35.97 In this study, we examined the temperature measurements obtained from both the baby incubator and incubator analyzer modules. The data collection time was extended to provide a comprehensive set of readings for analysis. The results demonstrate that both modules are capable of maintaining temperatures within an acceptable range for neonatal care.

The baby incubator module exhibited a slightly wider temperature range, with readings spanning from 35.92°C to 36.14°C. Despite the minor fluctuations, the recorded temperatures remained suitable for providing a conducive environment for newborns. The incubator analyzer module, on the other hand, displayed a narrower temperature range, indicating consistent and accurate temperature control. From the measurement data of the temperature sensor on the



(c)

FIGURE 10. **Temperature stability at a set temperature of a) 32ºC, b) 35ºC, and d) 36ºC**

module and incuanalizer in FIGURE 9 above, a comparison of the average values and errors is obtained, as shown in the following Table 10. TABLE 10 (a) The average value is calculated from the value attained after 45 minutes of stable temperature measurement, and errors (errors) are calculated from the difference between the values displayed by the module and the incuanalizer using a calibrated comparison[18]. The temperature readings from the module and incu analyzer are compared in Table 4.20. The error of 0.10 was calculated using the module uncertainty of 0.112 and the incu analyzer uncertainty of 0.023 at a temperature setting of 32˚C. With the temperature set to 35˚C, the error of 0.22 was calculated using the module's uncertainty value of 0.112 and the incu analyzer's uncertainty value of 0.021. In addition, at 36˚C, the incu analyzer's uncertainty is 0.26, the module's uncertainty is 0.112, and the error value is 0.The precision of a module is associated with this uncertainty value. The greater the uncertainty value, the more precise the module reading. FIGURE 10 (b) is a graph of the temperature sensor readings on the module when the temperature setting is 32ºC. We using delphi as a tool for recording the temperature condition, as we can see the table is displaying how temperature rising from room temperature to the setting that we want apply in baby incubator. The time we use to recording for temperature is seconds, from 1 second to approximately 1800 seconds for standard incubator but we use until 2364 seconds or 39.4 minutes for recording. Testing the limit of our module for recording the temperature is also important in this research. Table 11 is temperature sensor readings on the module when the temperature setting is 32ºC.

TABLE 11
Table of temperature sensor values at a set temperature of 32ºC

Experiment Setting temperature 32˚C (data1)				
Time	Average Tempt (˚C)	Standard deivasi	Error (%)	All Error (%)
Minute 1-10	31.92	0.883	0.036	0.012
Minute 10-20	32.43	0.035	0.001	
Minute 20-30	32.45	0.033	0.001	

On the TABLE 11, when the temperature setting is 32°C, the following data results are obtained:Indicates that the temperature has stabilized at a temperature setting of 32°C.It can be seen from the results of the setting temperature of 32°C that has been measured using the Delphi application that the average reading has reached the setting temperature with a tolerance value of 0.5°C.During the first minute to 10 minutes, it has a high standard deviation due to an increase in temperature from 0 seconds to 179 seconds to reach the set point. Then overshoot occurs at 180 to 220 seconds, and it takes 40 seconds to stabilize back to the set point. The stability time ranges from 250 seconds to 1800 seconds, or 30 minutes. It has an overall error value of 0.012, which means that every increase in temperature will have a 0.012% chance of changing. Below in FIGURE 11 (c) is a graph of the temperature sensor readings on the module when the temperature setting is 35ºC. TABLE 12 is temperature sensor readings on the module when the temperature setting is 35ºC.

TABLE 12
Table of temperature sensor values at a set temperature of 35ºC

Experiment Setting temperature 35˚C (data1)				
Time	Average Tempt (˚C)	Standard deivasi	Error (%)	All Error (%)
Minute 1-10	34.40	1.474	0.060	
Minute 10-20	35.20	0.031	0.001	
Minute 20-30	35.21	0.030	0.001	0.020

TABLE 12 is set at 35°C, the following data results are obtained:It can be seen from the results of the setting temperature of 35°C from the first data that has been measured using the Delphi application that the average reading has reached the setting temperature with a tolerance value of 0.5 C.During the first minute to 10 minutes, it has a standard deviation of 1,474 due to an increase in temperature from 0 seconds to 200 seconds to reach the set point. Following the overshoot and subsequent stabilization, the system demonstrates an impressive period of stability, lasting from 305 seconds to 1800 seconds (approximately 30 minutes). This sustained stability phase indicates that the temperature control system successfully maintains the desired temperature, minimizing fluctuations and deviations. This characteristic is particularly significant in scenarios where precise temperature control is critical.

TABLE 13
Table of temperature sensor values at a set temperature of 36ºC

Experiment Setting temperature 36˚C (data4)				
Time	Average Tempt (˚C)	Standard deivasi	Error	All Error
Minute 1-10	34.56	1.954	0.079	
Minute 10-20	36.09	0.049	0.002	
Minute 20-30	36.12	0.040	0.001	0.027

The stability time ranges from 305 seconds to 1800 seconds, or 30 minutes estimate. Has an overall error value of 0.02, which means that every increase in temperature will have a 0.02% chance of changing its value.The overall error assessment provides a quantitative measure of the system's performance. With an error value of 0.02, it is established that each incremental increase in temperature carries a mere 0.02% chance of inducing a change in the recorded value. This level of accuracy speaks to the robustness of the temperature control system in adhering to the intended set point, minimizing the risk of unintended temperature variations. FIGURE 13 is a graph of the temperature sensor readings on the module when the temperature setting is 36ºC. Table 13 is a temperature sensor reading on the module when the temperature setting is 36ºC. TABLE 13 It can be seen from the results of the setting temperature of 36°C from the 5th data set that has been measured using the Delphi application that the average reading has reached the setting temperature with a tolerance value of 0.5 C.During the first minute to 10 minutes, it has a standard deviation of 1,954 due to an increase in temperature from 0 seconds to 350 seconds to reach the set point. Then overshoot occurs at 350 to 450 seconds, and it takes 50 seconds to stabilize back to the set point. The stability time ranges from 460 seconds to 1800 seconds, or 30 minutes. It has an overall error value of 0.027, which means that every increase in temperature will have a 0.027% chance of changing.

IV. DISCUSSION

The research development plan encompasses several key improvements aimed at enhancing the experimental setup and achieving more precise and reliable results. These improvements are as follows like Heating Distribution System Enhancement The first step involves improving the heating distribution system within the tool chamber. By optimizing this system, we aim to achieve better control over the humidity levels. Properly controlled humidity is critical for maintaining an ideal environment for the experiments, ensuring accurate and consistent outcomes[19].

According to Tables 7–13, this fuzzy control system has an effect on the rise time. At a temperature of 32°C, the average time spent ascending is 177 seconds. The typical time for a chamber's temperature to increase by 35°C is 300.6 seconds. However, the second set of data shows a significant deviation, with the temperature rising too quickly by 580 seconds. Time to reach 36 °C takes around 376 seconds on average[20].

In certain studies, temperature will have some fluctuation in the range of +/- 0.31 °C and so on. My research has shown that temperature will fluctuate from ±0.30˚C until ±0.40˚C because of the fuzzy method that I use. With better methods or a mixing method like Sugeno and Mamdani, it can be much better at temperature. Mixing better methods than just sugeno may be better and can lower the fluctuation value [15].When it is far from the set point and has an error of -0.5°C, the heater will ON to maximum, when it is closer to the set point or below the error range of -0.5°C to 0°C, the heater condition will be dim, when it reaches the set point or has an error range of 0°C, the heater condition will pulsing, and when the error range reaches 0°C to + 0.5°C, the heater condition will OFF to continuously stabilize the temperature between the range that needed for baby [21].

Because we employ a fuzzy system, the rate of overshoot in this incubator is also significant; the data in Tables 7–13 suggest that overshoots occur infrequently and last for only brief periods of time. When 32 °C is chosen, the overshoot lasts an average of 42 seconds before the temperature returns to normal, and the temperature during the overshoot is 0.3°C. The average overshoot to recover time for the chosen 35°C temperatures is 263.8 seconds, and the highest temperature reached is 35.23°C. The average overshoot time before the temperature returns to the set point is 51.8 seconds when the temperature is set to 36°C. Overshoot is reduced by the fuzzy logic system we employ, as evidenced by the levels of overshoot resulting from 5x measurements on each set of points [22], but its possible to make the overshoot poin lower than 0.3°C by using better fuzzy methode like mixing mamdani-sugeno or hybrid fuzzy-pid[23]

According to certain study fuzzy had better response than PID, the PID steady state at 218 seconds while the fuzzy at 200 seconds it was moderate changing and then the stabilization time start at 325 seconds and the fuzzy is starting at 300 seconds with slowest on data, fastest is around 270 at 35°C[24], at concentrating on temperature is beneficial for quickly boosting the temperature but will upset the humidity balance. As the temperature climbed, it caused the humidity to decrease. Therefore, we take both into account and determine a suitable temperature while considering the importance of humidity[19]

Upgrade to a More Accurate Skin Sensor to enhance the accuracy of temperature measurements, we plan to replace the existing skin sensor with a more advanced and precise model for medical. The new sensor will provide more reliable and real-time temperature data, allowing for better adjustments to the heating distribution system and resulting in improved control over the chamber's conditions.

Fan Replacement with Enhanced Specifications Addressing the issue of noise interference during experiments, we will replace the current fan with a specially selected model that boasts superior specifications. This new fan will not only operate more quietly, reducing disturbance in the research environment, but it will also optimize airflow to achieve the desired maximum temperature distribution throughout the chamber.

Utilization of a Standardized Box To ensure consistency and reliability across experiments, we will utilize a standardized box for conducting our research. This standardized environment will eliminate variations that could potentially impact the results, allowing us to draw more accurate and reproducible conclusions.

Heater Replacement with Improved Specifications recognizing the crucial role of the incubator heater in maintaining a stable environment, we plan to replace it with a better or standard model that meets our specific requirements. The new heater will deliver more precise and controlled heating, providing the necessary conditions for our experiments to yield optimal and consistent results[25].

We have so many interconnected characteristics in a newborn incubator that we can't just disregard one and dismiss the others.

V. CONCLUSION

The findings of the investigation into the Temperature and Humidity Control System Employing Fuzzy Logic in Neonatal Isolation Units suggest that the DS18B20 sensor, a digital sensor employing 16-bit data processing, is the best option. Using a humidity sensor like the DHT11, which provides an analog voltage output and can be processed by a microcontroller.

Connecting the SSR input to an Arduino digital pin causes the fuzzy logic-generated PWM to either turn the heater on or off. From input to output, fuzzy logic uses a process called PWM (fuzzification, rule, defuzzification). When the temperature is set to 35˚C , the study found that the highest temperature error is up to 34˚C, where the error reaches 10˚C, when the temperature is set to 36˚, the study found that the highest temperature error is up to 34.02˚C, where the error reaches 20 ˚C due to external disturbances; and if it is not 35.22˚C, the error is 0.80 ˚C.

We expect these changes to have a major impact on increasing the quality and reliability of our research findings. Better humidity control will help us achieve our experimental goals, and the improved heating distribution system and accurate skin sensor will both contribute to this. Because of the new fan, the room will be much quieter, making it ideal for concentrated study. The standardized box will guarantee consistent conditions, removing any possible sources of bias and increasing the reliability of our results. Finally, the improved incubator heater will provide consistent and manageable warmth, which is ideal for our studies. For different control might have slight different in increasing temperature such as PID Control or different fuzzy control

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