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Optimizing Battery Power Efficiency in Transport Baby Incubators Using PID-Fuzzy Control

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ABSTRACT Baby incubator transport plays an important role in maintaining a stable temperature to protect premature babies during transportation, especially in emergency situations. One of the main challenges with this device is the efficient use of battery power, which directly affects the duration of operation without recharging. A non-optimal temperature control system can accelerate power drain, thus jeopardizing the safety of the baby. This study aims to analyze the efficiency of battery power usage in baby incubator transport by applying PID-Fuzzy control method. This method was chosen to control temperature stability while minimizing power consumption during operation. The main contribution of this research is to improve battery power efficiency and extend battery life, thereby reducing the frequency of battery replacement and saving operational costs. In addition, this research integrates the PID-Fuzzy control concept into medical devices such as a baby incubator transport. The results show that the application of the PID-Fuzzy method is able to reduce power consumption by 70%, with better temperature stability and smaller deviation than conventional methods. The system is also able to respond quickly to temperature changes and reduce overloads on the power system, thus providing more safety during the baby transportation process. For future research, it is recommended to replace the battery with a Lithium-polymer (Lipo) battery, adjust the power consumption and heating power, and use a larger blower chamber size. In addition, additional testing is needed to evaluate the durability of the system in more extreme environmental conditions and transportation simulations with a longer duration. This research is expected to be a reference in developing a more efficient and safe temperature control technology in baby incubator transport devices.

INDEX TERMS Baby incubator Transport, PID-Fuzzy control, Battery, temperature

I. INTRODUCTION

Babies who have been born prematurely are usually immature in a system of maintaining their body to adjust to the surrounding environment. Due to the type of subcutaneous fat, low birth weight babies gradually become hypothermic and are more easily affected by environmental factors[1]. Sick or very premature babies (under 32 weeks gestation) often require intensive attention and support during the crucial adaptation period after birth[2],[3],[4] ,[5],[6].Premature and low birth weight infants should usually be handled in an incubator. Normal infant body temperature ranges from 36.5 to 37.5°C [7]. An infant's body temperature below 36℃ is called hypothermia, while an infant's body temperature above 38℃ is called hyperthermia [8],[9], ,[11].

Baby Incubator transport is a place designed to help newborns or premature babies to stay warm at a certain temperature and humidity when moving babies from one room to another that require intensive care in the hospital.[12],[13],[14],[15]. Baby incubator transport utilizes a power source or

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DC battery that is portable and can be used anywhere without the need to be in an area or location that has access to electrical energy [16],[17],[18],[19]. The battery also has a battery that can be discharged and can no longer be used if the energy source is exhausted. Once fully charged, the charger is used at the workplace using an AC source so that the battery can turn on again.[20],[21] ,[22]. Discharge period In general, a low battery reduces power consumption in all portable system [23],[24],[25],[26] ,[27]. Batteries will inevitably run out of power when used continuously. Because of this, recharging is required to generate energy from the battery.[28],[29],[30] ,[31],[32]. The battery of a baby incubator is the main power source, but limitations in the power system are a frequent problem. If there is a fault in the system or battery, the lack of power may cause the baby to suffer. Therefore, a reliable and durable power system is essential for baby incubator transportation. Rosida Amalia Nurul Qoyima, in her research used the Fuzzy-PID control method to design a premature baby incubator system with an automatic control system and a fast and stable response. this research uses the Fuzzy-PID control method which can provide a better and stable system response in regulating the temperature in premature baby incubators. PID and fuzzy controllers, this research can improve the transient and steady state performance response of the incubator system. Wisnu Kusuma Wardana et al (2019) This research was conducted to ensure that the baby's condition is stable and in accordance with the desired temperature and humidity during the transfer process. From previous research, the modifications made to the baby incubator transport this time include the use of a 12 volt DC 80 Ah battery as a power source, the estimated battery power usage time is around 160-180 minutes.

From the above identification results, the author will develop Optimization of Battery Power Efficiency in Baby Incubator Transport Through PID-Fuzzy Control Therefore, this research will make a significant contribution, namely:

1.Improve battery power efficiency and extend battery life thereby reducing the need for battery replacement and saving operational costs.

2.A more energy efficient device will be more reliable in transportation situations that may require a long time, thus ensuring stable and continuous care for premature or sick babies.

3.Energy efficient devices will help maintain optimal environmental conditions in the incubator, thus supporting better infant recovery and development.

4.This research will also contribute to the development of health technology by integrating PID-Fuzzy control concepts in medical devices such as baby incubator transport.

II. MATERIAL AND METHOD

The location of the research or the place for collecting research data is the Department of Electromedical Technology, Health Polytechnic, Ministry of Health Surabaya. The sample or research subject used is a dry battery with 24V 28Ah specifications. The tools and materials used in this study are: Multimeter, Tespen, solder, tool set, cutter, PCB Board, Tin, Connector, push button, switch, TFT LCD.

A. FUZZY-PID

Fuzzy-PID Controller is a combination of Fuzzy Logic Controller (FLC) and PID (Proportional-Integral-Derivative) Controller which aims to optimize the performance of the control system. This combination utilizes the advantages of each method.

In Fuzzy-PID Controller, FLC is used to dynamically adjust PID parameters based on system conditions. Fuzzy logic helps make the PID more adaptive, for example, in non-linear systems or when changes in operating conditions occur. Overall, the Fuzzy-PID controller combines the stability and accuracy of PID with the flexibility of Fuzzy Logic to improve control performance over a wide range of scenarios.

The Fuzzy program for PID control tuning consists of several stages, namely fuzzification, rule evaluation, decision-making mechanism, and defuzzification. The final result of the defuzzification process is a summary of the entire fuzzy system. The fuzzy-PID controller is designed by following the standards.

In the PID-Fuzzy method, the parameters Kp, Ki, and Kd can be adjusted in a fuzzy way, namely by creating a fuzzy set for each parameter based on error and error change. The formula is as follows Eq. (1):

$$\mu(\mathrm{t}) = K_p(\mathrm{e}, \Delta\mathrm{e}).\mathrm{e}(\mathrm{t}) + K_i(\mathrm{e}, \Delta\mathrm{e}).\int e(t)dt +$$

$$K_d\ (e, \Delta e).\frac{de(t)}{dt} \quad (1)$$

Where, µ(t) is control signal, this formula shows that the parameters $K_p, K_i K_d$ dynamically adjusted based on error values and changes in error using fuzzy logic, rather than a fixed value as in classical PID, Δe is change in error (derivative of error over time), $e(t)$ is error signal (the difference between the desired value and the actual value).

From this explanation, it can be seen in Figure 1 which is a combination of PID-Fuzzy control.
1. Fuzzification
In this Fuzzification program, input membership function parameters are used to represent error and d_error. The membership degree range is between 0 and 1.
2. Rule evaluation
Rule evaluation is a process in which the membership degree of each fuzzy set membership function at the input is evaluated based on predetermined rules. Before performing the evaluation, a rule base is compiled. This rule base includes all possible combinations of two inputs. The fuzzy outputs are then used to determine the value of the PID constants.
3. Defuzzification
Defuzzification is the result of the Fuzzification process, which aims to convert fuzzy outputs into crisp outputs. This is necessary because the PID constant only considers temperature as a parameter.

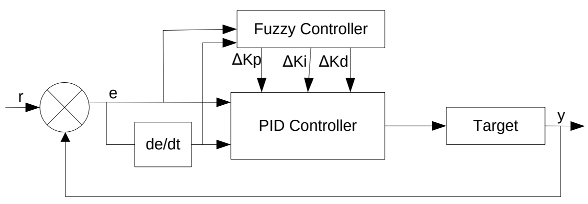

Figure 1 PID-Fuzzy Control

B. DATA COLLECTION

To check the functionality of the developed module, the author tested the module using a digital multimeter with the Sanwa brand type CD800A made in Japan. At the time of testing the module using a digital multimeter, data collection was carried out for 1 hour by taking 7 times the data at each measurement point according to the compliance test standard.

The results of the voltage sensor data readings are displayed on the computer.

In Figure 2, the battery functions as a power provider to the microcontroller. Before the battery power is flowed to the microcontroller, the power from the battery will be lowered using a step down. And the battery powers the heater and blower control circuits so that the Nexion TFT screen will display on the screen with several options, namely temperature settings and control settings.

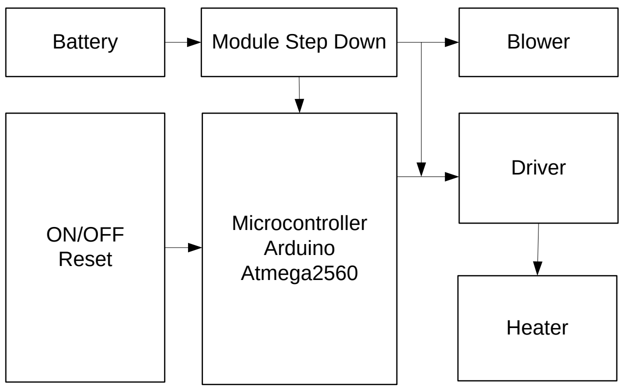

Figure 2 Block diagram structure of Battery

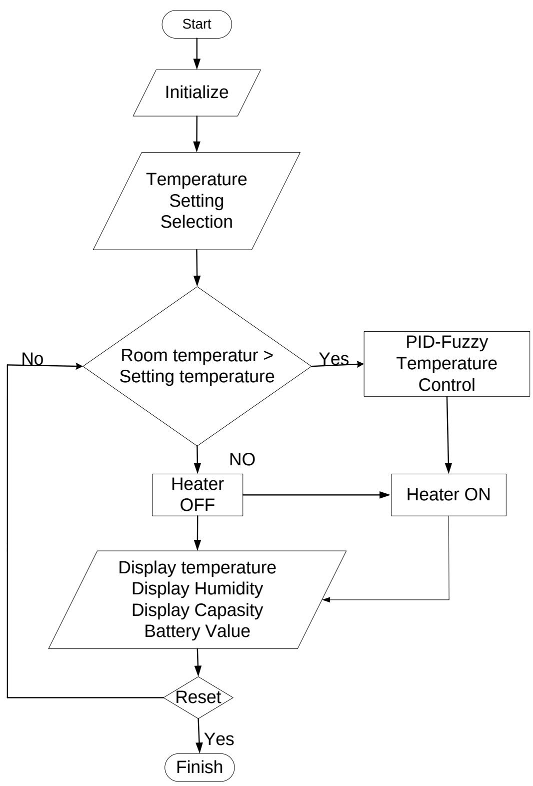

Figure 3 System Flowchart

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In Figure 3 explains that when the baby incubator is turned on, there is an initialization for the temperature sensor and which sends data in the form of an Arduino using a Nextion TFT. so that from the TFT an appearance appears and then will display the temperature setting options to control the operation of the heater. The temperature and humidity from inside the incubator and from the battery capacity will also be displayed on the TFT screen along with a graph. The temperature will turn on and off according to the settings as well as the humidity and will be controlled with PID-FUZZY.

Figure 4 Diagram of the Tool Mechanism Front View

Figure 4 is a mechanical diagram of the side of the baby incubator transport device.

C. DATA ANALYSIS

Measurements were taken for 1 hour for each temperature setting. The average measurement was determined with the Eq. (2):

$$\text{Average } (X') = \frac{X1+X2+\cdots+Xn}{n}$$

Where,
X' = average
X1, ..., Xn = data values
n = amount of data

The system error is displayed as (%) error.
The smaller the average difference of each data, the larger the error. The error indicates that the module may not fit or meet the criteria it is supposed to meet. the error formula is determined by the Eq. (3):

$$\% \; ERROR = \frac{X-X}{X} \text{ x } 100\%.$$

III. RESULT

This chapter presents the results of research that has been conducted in accordance with the methods described earlier. The data obtained is processed and analyzed to answer the problem formulation and prove the research hypothesis.

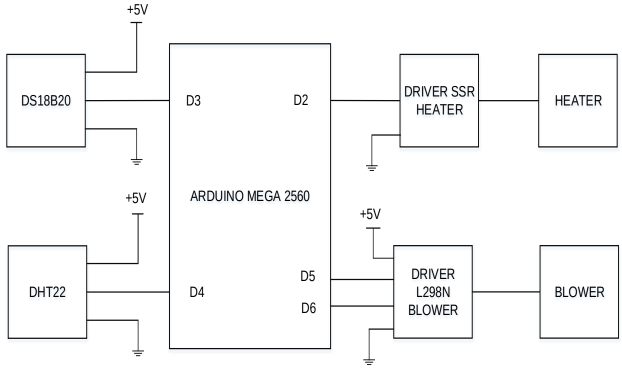

Figure 5 is the overall circuit.

The circuit shown in Figure 5 is the overall circuit. The circuit consists of an Arduino Mega 2560 operating at a voltage of 5 volts and a 5 Amp power supply. It uses a 28Ah battery as the main power supply connected to the switch. It is also connected to the Arduino's VDC input via a stepdown output, so that the Arduino receives the input voltage and turns on. Provides 5V DC and ground to the DS18B20 and DHT22 sensors. The Nextion LCD circuit takes input directly from the Arduino Mega. After selecting the available temperature settings (32ºC, 33ºC, 34°C, 35°C and 36ºC), the Arduino sources the voltage through the driver switch and controls the on/off of the DC heater according to the running PID-Fuzzy program. This circuit consists of DS18B20, DHT22 circuit, skin sensor circuit, Nextion LCD circuit, DC fan circuit, 28Ah DC battery circuit, and DC heater driver circuit.
The module measurements will be compared with a digital multimeter as a reference and comparison when determining the battery efficiency of the baby incubator transport module using the fuzzy logic method.

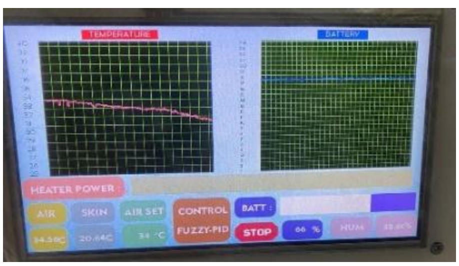

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Figure 6 TFT screen display on Baby incubator transport.

In figure 6, data, control system, temperature data, and battery capacity are displayed for each TFT device group.

Table 1
Results of Measurements Battery Voltage on Setting Temperature 32°C

Battery	Average Module (Volt)	Comparator (Volt)
Data 1	19.5	19.20
Data 2	21.8	21.30
Data 3	22.29	22.36
Data 4	23.25	23.28
Data 5	23.30	23.32
Data 6	24.15	24.16
Data 7	24.21	24.23

Table 1 is the result of measuring the battery voltage of the baby Incubator Transport after 1 hour of operation. The data was taken at a setting temperature of 32 °C. the measurement was carried out with a multimeter comparison tool.

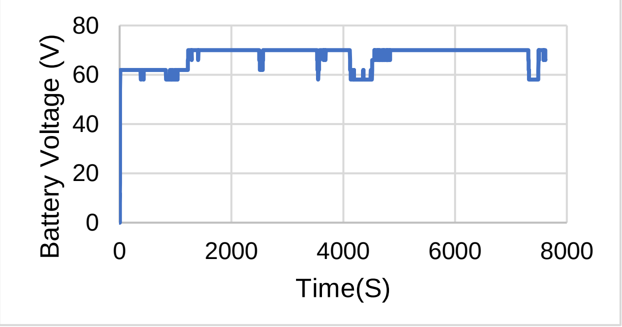

Figure 7 Battery Measurement Results at 32°C temperature setting

Figure 7 shows that when the incubator is turned on. the battery voltage drops as soon as the incubator heater starts.

As the battery optimizes its performance to reach its target temperature. the voltage on the battery continues to decrease. sometimes even drastically.

In the figure when the incubator is turned on. the voltage sensor has an effect when the temperature does not reach the setpoint. the battery is automatically forced to supply the heater so the voltage value will drop. As the battery optimizes performance to reach the target temperature. the voltage on the battery continues to decrease. After the temperature is determined to be sufficient and the temperature is stable according to the desired setpoint. the voltage sensor returns to normal as shown in the figure. In the graph. when the voltage rises. it shows that the heater is controlled with this PID-fuzzy method. A decrease in the voltage of the heater becomes smoldering and an increase in the voltage of the heater becomes dimming or lowering the voltage distribution to the heater to stabilize the temperature.

This will occur until the temperature inside the incubator is maintained according to the specified temperature setting.

Simply put. when the voltage rises. it means that the power supplied to the heater becomes less and when the voltage drops. the power supplied to the heater becomes more.

Table 2
Results of measurement current on setting temperature 32°C

Battery	Module (Ampere)
Data 1	3.8
Data 2	3.44
Data 3	3.37
Data 4	3.59
Data 5	4.5
Data 6	4.8
Data 7	4.10

Table 2 is the result of measuring the battery current of the baby Incubator Transport after 1 hour of operation. The data is taken at a temperature setting of 32 °C.

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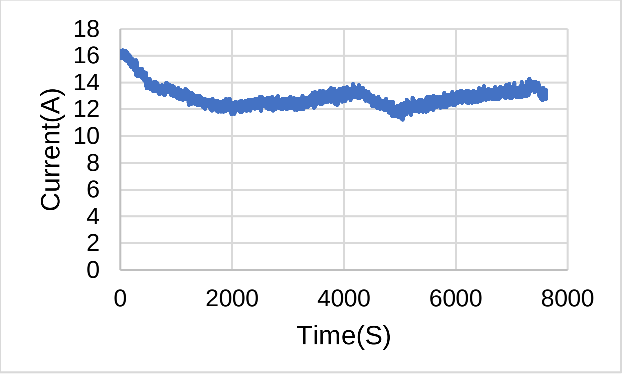

Figure 8 is a graph of current measurement

Observations after 1 hour of operation using the PID-Fuzzy method at a setting temperature of 32°C. Calculation of power consumption per hour can be done after the current and voltage values before and after heating are known. Thus. the estimated energy used can be calculated from the results of these calculations. Then the calculation at a setting temperature of 32ºC with a duration of data collection for 1 hour is:

$$\text{Wh heating} = 16 \times 13.37 \times 1.8 = 385.056$$

$$\text{Wh stable} = 12 \times 16.33 \times 0.08 = 15.67$$

Wh heating + Wh stable = Wh total

$$385.056 + 15.67 = 400.726$$

$$\frac{400.726}{672} \times 100\% = 59.631\%$$

IV. DISCUSSION

The implications of this research include improved infant health and safety. With higher battery power efficiency, the infant transport incubator can operate longer without the need for recharging, which directly improves infant safety, especially in emergency situations or during long-distance travel. In addition, better temperature stability reduces the risk of hypothermia or hyperthermia in premature infants, thereby supporting optimal infant recovery and development.

Operational efficiency is also one of the important implications of this research. Power savings of up to 70% enable a reduction in operational costs as the battery has a longer lifespan and the frequency of battery replacement is significantly reduced. In addition, the system allows hospitals to use resources more efficiently, especially on portable devices that are frequently moved, thus supporting effectiveness in medical services without compromising on quality.

In this study. only 62% of battery power was used. and battery life is affected by performance when more than 62% of battery power is used. In this module. the room temperature has a significant influence on the temperature in the room. Battery life is affected by performance at a battery voltage of 14.88 volts. Due to the age of the battery. the ambient temperature affects the battery power and when the battery is charged the battery suddenly experiences a voltage drop so the power used at this time is only 62%.

From previous research, showing that the fuzzy logic method can successfully adjust the temperature automatically based on existing environmental conditions. The use of fuzzy logic also provides an increase in battery power efficiency, so that battery life becomes more optimal during use. However, the performance of fuzzy logic temperature control tends to be affected by the external ambient temperature, especially if the temperature outside the incubator chamber is below 28°C. On the other hand, the PID control method proves to be faster in achieving the desired target temperature, but the power consumption required is relatively higher compared to fuzzy logic. Battery Power Usage, In the 1-hour test, it is shown that the PID control requires more power to maintain the temperature quickly and stably [31]. The fuzzy logic method has a longer rise time but only requires less power to heat the heater. Therefore, this fuzzy method is more battery-efficient than the PID method.

V. CONCLUSION

The use of temperature control method on Baby Incubator Transport tool with PID-Fuzzy method can improve the efficiency of battery power usage. This tool is able to operate for ± 3 hours, saving 70% battery usage and has been running well and according to its function. However, from the results of research on this Baby Incubator Transport tool, there are still some things that can be improved. Some suggested improvements include replacing the battery with a Lithium-Polymer (LiPo) battery for better performance, adjusting the heater for lower power consumption by lowering its wattage, and

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replacing the size of the Blower Chamber with a larger one for more optimal air circulation.

The use of the Baby Incubator transport device with the combined PID-Fuzzy method has great potential for future development, especially in improving temperature stability more precisely and adaptively. In the future, the combined use of the PID-Fuzzy method can be integrated with smart sensors and IoT systems for real-time remote monitoring, as well as an automatic alarm system when temperature deviations occur. This would be particularly useful in emergency conditions, in remote areas, or during medical transportation. With further development, this device will not only improve infant safety and comfort, but also support energy efficiency and operational effectiveness in neonatal healthcare.

VI. ADVICE

Some suggested improvements include replacing the battery with a Lithium-Polymer (LiPo) battery for better performance, adjusting the heater for lower power consumption by lowering its wattage, and replacing the size of the Blower Chamber with a larger one for more optimal air circulation.

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