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Development of an IoT-based temperature and humidity prediction system for baby incubators using solar panels

Radian Indra Mukromin[1], Fachruddin Ari Setiawan[2], Dio Alif Pradana[3], Agoes Santika Hyperastuty[4], Yanuar Mukhammad[5]
[1,2,3,4,5]Department of Electro-Medical Engineering, Universitas Kadiri, Indonesia

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ABSTRACT

Baby incubators are crucial medical devices to maintain environmental stability for babies born prematurely or have health problems. This research aims to develop a prediction system for temperature and humidity variables in baby incubators by utilizing Internet of Things (IoT) technology and solar panels as the main energy source. Despite advancements in IoT-based incubator systems, existing solutions often rely on reactive approaches, making them less effective in preventing harmful environmental fluctuations. Addressing this gap, this study focuses on optimizing temperature and humidity predictions using artificial intelligence (AI) for proactive control. Using a DHT22 sensor to measure temperature and humidity, as well as a 1 Wp solar panel, the system is designed to operate autonomously in areas with limited access to electricity. The methods used include data collection, data processing to calculate correlation coefficients, and selection of linear regression models for the analysis of relationships between variables. The results showed that the linear regression model applied had a good temperature and humidity prediction with a Mean Squared Error (MSE) value of 0.45 for the training data and 7.32 for the test data.

Corresponding Author:

Radian Indra Mukromin,
Department of Electrical and Computer Engineering,
Universitas Kadiri,
Road Selomangleng Number. 01, Vilage Pojok, District Mojoroto, East Java 64115, Indonesia.
Email: radian.i.mukromin@unik-kediri.ac.id
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1. INTRODUCTION

Baby incubators are a very important medical device to maintain environmental stability for babies born prematurely or have health problems [1]. The temperature and humidity in the incubator must be controlled very carefully to ensure optimal conditions for the baby's development [2], [3]. However, in its operation, baby incubators require a reliable supply of energy to maintain the stability of these environmental variables. In remote areas or areas with limited access to electricity, this challenge becomes even more significant [4], [5].

One solution that can be implemented is the use of renewable energy sources, such as solar panels, as the main power provider of incubators [6], [7]. Solar panels are able to provide more sustainable and environmentally friendly energy, as well as provide autonomy to incubators in locations with minimal access to the power grid [8]–[10]. However, the use of solar panels also presents challenges in maintaining temperature and humidity stability, especially under fluctuating environmental conditions [11], [12].

In this modern era, Internet of Things (IoT) technology offers an innovative approach to monitoring and controlling environmental variables in real-time. IoT allows the integration of various sensors to collect temperature, humidity, and other variable data on an ongoing basis, which is then sent to the control system for analysis and processing [13], [14]. With IoT, monitoring the condition of incubators can be carried out remotely, improving energy management efficiency and providing rapid response to environmental changes.

To overcome the challenge of environmental stability in solar panel-based baby incubators, it is necessary to develop an IoT-based prediction system that can monitor and predict temperature and humidity variables with high accuracy [15]. The linear regression model is one approach that can be used to analyze the relationship between different environmental variables and optimize the setting of the infant's incubator. With this model, prediction of temperature and humidity changes based on inputs from various IoT sensors can provide accurate information to automatically adjust control parameters, thus maintaining optimal conditions for the baby in the incubator.

This study aims to design and implement a temperature and humidity prediction model in infant incubator plants using linear regression, with the use of solar panels. This research is expected to contribute to the development of a more independent and efficient incubator system, especially in supporting baby care in areas with limited access to electricity.

2. METHOD

This research consists of several stages carried out to achieve the objectives of this research, namely the preparation of tools and materials, data collection, data processing, model selection, and model testing. The stages of the research are shown in Figure 1.

2.1. Preparation of Tools and Materials

The tools and materials from this study consist of a solar panel with a capacity of 1 Wp (Watt peak, maximum power conditions generated by solar panels) DHT22 as a sensor to measure temperature and humidity variables in the incubator room, and a multimeter as a measuring device for the output voltage of solar panels. The specifications of the solar panels and the specifications of the measuring instruments are shown in Table 1 and Table 2 respectively.

Table 1. Solar Panel Specifications

Description	Monocrystalline
Size	60 × 110 × 1,5 mm
Output Voltage	6 V
Output Current	200 mA
Maximum Power	1 watt

From Table 1, it is known that the specifications of the solar panel used are solar panels with a length of 60 mm, a width of 110 mm, and a thickness of 1.5 mm. while the output of the solar panel is 6 V for voltage output and 200 mA for current output.

Table 2. Sensor and Measuring Device Specifications

	Temperature Sensor	Multimeter
Type	DHT22	Sanwa
Range	-40°C to 80°C / 0% to 100%	4mV-600V
Accuracy	±0,5% and ±0,1%	±0,7%

Table 2 explains the specifications of the sensors and measuring instruments used. The brand or type of measuring instrument is Sanwa with an accuracy of ±0.7%. While the sensor used is DHT22 with a temperature measurement range of -40°C to 80°C and 0 to 100% for the humidity variable measurement range.

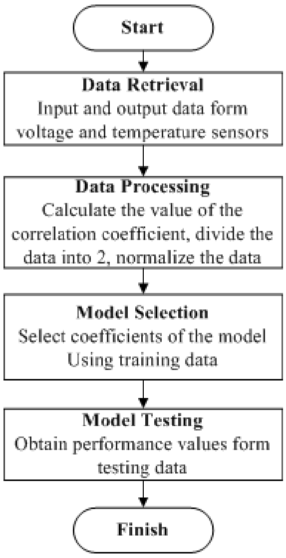


Figure 1. Research Methods

Figure 1 explains the research method used. It begins with taking input output data from the voltage measuring instrument and temperature sensor. Then enter the data processing stage to calculate the correlation coefficient value. The next stage is the model selection stage using training data. And the last stage is model testing to get the performance value from the testing data.

The placement of solar panels is on the side of the crib in the incubator. The location of this panel allows the energy collection of the light intensity of the heating lamp installed in the incubator room [16]. These panels serve as an energy source to support the operation of connected IoT devices. The position of the solar panel and DHT sensor is shown in Figure 2. Meanwhile, the integration of hardware and IoT is shown in Figure 3.

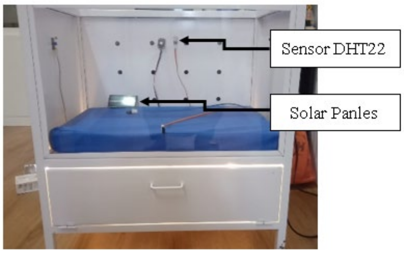


Figure 2. Solar Panel and DHT Sensor Placement Position

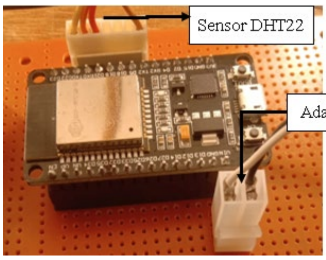
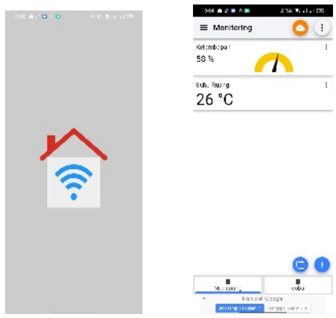


Figure 3. Hardware Integration monitoring IoT

2.2. Data Retrieval

Data collection is carried out by direct measurement for measuring the output voltage of solar panels and using IoT for measuring temperature and humidity variables. Data collection for temperature and humidity variables is shown in Figure 4 while the solar panel output voltage scheme is shown in Figure 5.

The method is applied to solve problems including procedures, measuring and analytical methods. Methods should make the reader able to reproduce your experiment. Provide enough detail to allow the work to be reproduced. The published method should be indicated by reference: only relevant modifications should be explained. Do not repeat details of existing methods, just refer it from the literature.



(a) (b)

Figure 4. Iot Home Platform Display (a) Home, (b) Measurement Data

Figure 5. Schematic of Voltage Measurement at Solar Panel Output

Data collection began at 15.11 WIB until 15.37 WIB for the first day and 13.00 WIB until 13.21 WIB for the second day with an interval of 1 minute for each measurement. Data collection was carried out for two days, so there were two groups of data. The first data group is used to build the model and the second data group is used to test the model.

2.3. Data Processing

The incubator room temperature or humidity prediction system uses linear regression. This linear regression model has a number of independent variables (X) that affect the dependent variable (Y), which is the temperature and humidity in the incubator room. The general form of the model for linear regression is shown in equation (1) [17], [18].

$$\hat{Y} = a_0 + b_1 X_1 \tag{1}$$

a_0 is a constant and the coefficient can be determined based on the data unit X_1, and Y is obtained from the study. This study concerned the temperature or humidity of the incubator chamber (Y) in °C for temperature and % for the humidity variable associated with the output voltage of the solar panel (X_1). The coefficients a_0, and b_1, are calculated by the deviation equation method. This method is simpler when compared to the elimination method. The regression coefficient is calculated using equations (2) - (3).

$$a_0 = \bar{Y} - b_1 \bar{X}_1 \tag{2}$$

$$b_1 = \frac{n\sum x_i y_i - \left(\sum x_i\right)\left(\sum y_i\right)}{n\sum x_i^2 - \left(\sum x_i\right)^2} \tag{3}$$

The equation for the deviation value is shown in equations (4)-(7)

$$\sum y^2 = \sum Y^2 - \frac{\left(\sum Y\right)^2}{n} \tag{4}$$

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$$\sum x^2 = \sum X^2 - \frac{\left(\sum X\right)^2}{n} \quad (5)$$

$$\sum x_i y = \sum X_i Y - \frac{\left(\sum X_i\right)\left(\sum Y\right)}{n} \quad (6)$$

$$\sum x_i x_j = \sum X_i X_j - \frac{\left(\sum X_i\right)\left(\sum X_j\right)}{n} \quad (7)$$

$\bar{Y}$ is the average of the output data, $\bar{X}$ is the average of the data input, and n is the total amount of data.

2.4. Data Testing

Data testing consists of a correlation test and a linear regression significance test. The correlation test is used to show the direction and strength of the relationship between the independent variable and the dependent variable.

2.5. Correlation test

Calculation of linear correlation for one predictor r_{xy} is done after obtaining the regression coefficient with equation (8).

$$r_{xy} = \frac{\sum xy}{\sqrt{\left(\sum x^2 - y^2\right)}} \quad (8)$$

2.6. Regression significance test

Calculation of linear regression significance test can use variance table analysis with equation (9-17).

$$\text{sum of square } (reg) = b_1 \sum x_1 y \quad (9)$$

$$\text{sum of square } (T) = \sum y^2 \quad (10)$$

$$\text{sum of square } (res) = \sum y^2 - \left(b_1 \sum x_1 y\right) \quad (11)$$

$$\text{df } (reg) = k \quad (12)$$

$$\text{df } (res) = n - k - 1 \quad (13)$$

$$\text{df } (T) = n - 1 \quad (14)$$

$$\text{mean square } (reg) = \frac{\text{sum of square } (reg)}{\text{dk } (reg)} \quad (15)$$

$$\text{mean square } (res) = \frac{\text{sum of square } (res)}{\text{dk } (res)} \quad (16)$$

$$F = \frac{\text{mean square } (reg)}{\text{mean square } (res)} \quad (17)$$

The equations (9-19) explains the steps in the analysis of variance for linear regression, which aims to evaluate the ability of the model to explain the relationship between the independent variable (x) and the dependent variable (y). It starts by calculating the sum of squares of the regression (*SSreg*) as the variability explained by the model and the total sum of squares (*SST*) as the total variability of the data. The variability not explained by the model is calculated as the sum of squares of the residuals (*SSres*). The degrees of freedom (*df*) are calculated for the regression, residuals, and totals, which are then used to determine the average of the squares (*MSreg* and *MSres*) by dividing the sum of squares by the respective degrees of freedom. Finally, the statistical value *F* is calculated as the ratio between *MSreg* and *MSres* to test the significance of the regression model.

2.7. Model Testing

Model testing is the final stage of the prediction system design process. The model is used to check the closeness between the model and the measurement data. This study uses the mean square error as a performance model criterion. MSE is shown in equation (18) [19]–[21].

$$MSE = \frac{1}{N}\sum_{t=1}^{N}\left(Y - \hat{Y}\right)^2 \tag{18}$$

Y is the output data, $\hat{Y}$ is the training output data, and N is the amount of data.

3. RESULTS AND DISCUSSIONS

3.1. Data Capture Results

The measurement results as training data and test data are shown in Figures 6-7. The temperature and humidity data in the incubator room have a pattern that matches the solar panel output voltage data. The relationship between input and output variables needs to be proven through correlation tests. The measurement results of the three variables show that there are variations in the input signals (voltage, temperature, and humidity) over different sample data. The downward trend in voltage and humidity, and the upward trend in temperature, the greater the temperature variable, the smaller the solar panel output voltage and humidity variables in the incubator.

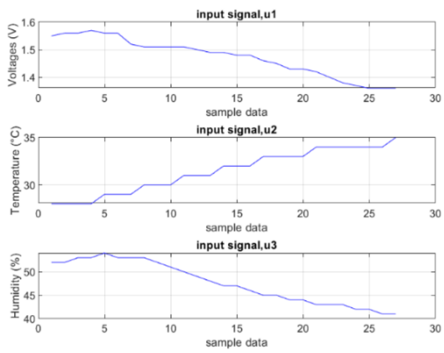

Figure 6. Training Data with Variables (a) Solar Panel Output Voltage, (b) Incubator Room Temperature, (c) Incubator Room Humidity.

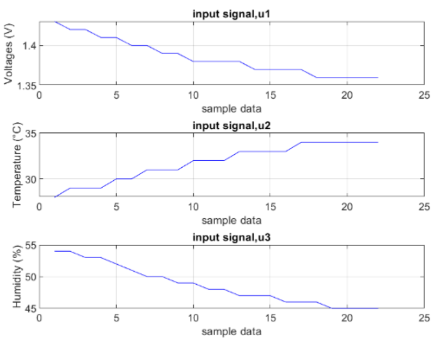

Figure 7. Test Data with Variables (a) Solar Panel Temperature, (b) Solar Irradiance, (c) Solar Panel Power.

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3.2. Correlation Analysis

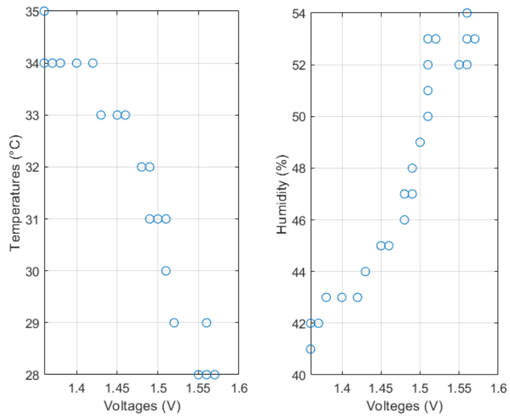

Figure 8. Scatter Plot of (a) Incubator Room Temperature against Solar Panel Output Voltage, (b) Incubator Room Humidity against Solar Panel Output Voltage

Figure 8 shows that there is a relationship between the temperature of the incubator room and the output voltage of the solar panel and the humidity of the incubator room and the output voltage of the solar panel. The correlation coefficient value is 0.909 for temperature and 0.913 for humidity in the incubator room. The values of 0.909 and 0.913 are included in the very strong correlation category so that both can be predicted using the input voltage value issued by the solar panel. The ditermination and correlation values are shown in Table 3-4.

Table 3. Coefficient of Determination

Single Correlation Analysis		
Variable	Room Temperature Incubator	Room Humidity Incubator
Solar Panel Output Voltage	0,909	0,913

Table 4. Correlation Coefficient

Single Correlation Analysis		
Variable	Room Temperature Incubator	Room Humidity Incubator
Solar Panel Output Voltage	0,909	0,913

The coefficient of determination for correlation analysis is 0.909 which shows that 90.9% of the incubator room temperature (Y) can be explained by the solar panel output voltage variable (X1). The correlation value has the highest value of 0.913 in the variable humidity of the incubator room to the output voltage of the solar panel. The results of the linear regression equation are shown in equations (19)-(20). The equation results are then compared with the training data and test data to calculate the MSE value. The results of the comparison graphs for the training and test data are shown in Figures 9-10.

$$Y = -31{,}33X + 77{,}604 \quad (19)$$

$$Y = 61{,}725X - 43{,}312 \quad (20)$$

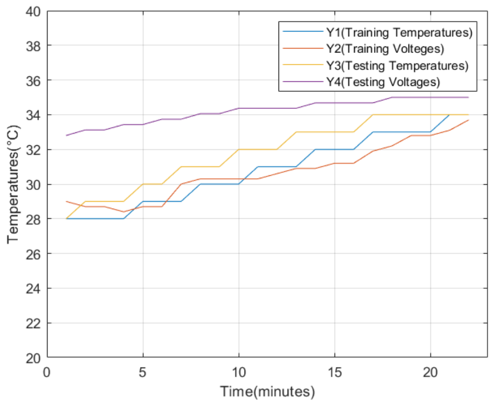

Figure 9. Comparison Chart of Training Data and Test Data on Temperature Variables

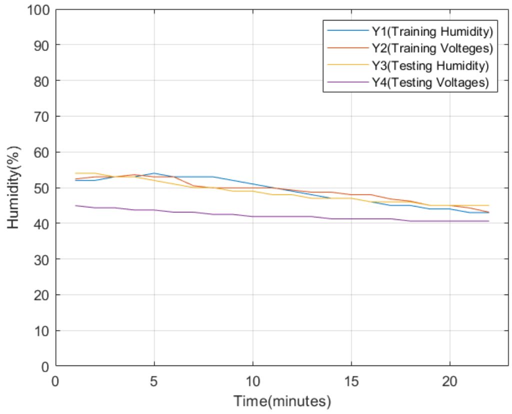

Figure 10. Comparison Chart of Training Data and Test Data on Humidity Variables

Table 5. MSE Result of Training Data

Input Variable	Output Variable	MSE
Solar Panel Output Voltage	Room Temperature Incubator	0,45
	Room Humidity Incubator	1,66

Table 6. MSE Results of Test Data

Input Variable	Output Variable	MSE
Solar Panel Output Voltage	Room Temperature Incubator	7,32
	Room Humidity Incubator	44,65

Table 5-6 explain that the smallest MSE value for training data is 0.45 which is found in the combination of incubator room temperature and solar panel output voltage as input variables. The smallest MSE value is also found in the combination of incubator room temperature and solar panel output voltage as input variables for test data with an MSE value of 7.32. Input variables in the form of solar panel voltage can be used to predict the value of the incubator room temperature.

4. CONCLUSION

Predictions of the temperature and humidity of the incubator room can be made using linear regression. The input variable of solar panel output voltage can predict the temperature and humidity value of the incubator room with a correlation coefficient of 0.909 and 0.913. The MSE value of 0.45 for training data and 7.32 for test data with incubator room temperature and solar panel output voltage as input variables. From those values, there is a possibility that an overfitting phenomenon occurs where the model obtained is only good for part of the data set. From these results, it would be great if further research tested the obtained model with more varied data.

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