Implementation of IoT-Based Batik Fabric Dryer to Preserve Color and Fabric Quality (Case Study: Batik Puspayindra, Blitar)

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Abstract— **Batik Puspayindra MSME in Blitar City still relies on manual drying methods that depend on sunlight and wind. This traditional approach often creates challenges such as unpredictable drying time, risk of color fading, fabric shrinkage, and mold growth due to uncontrolled humidity. This study aims to develop a batik fabric drying system based on the Internet of Things (IoT) with a Proportional Integral Derivative (PID) control method. The research employed a Research and Development (R&D) approach by designing hardware components, including ESP32, DHT11 sensor, DC fan, heater, and exhaust fan, along with software using Arduino IDE integrated with the Blynk application for remote monitoring. Experimental results indicate that the system can maintain temperature within 25–35°C and humidity at 52% in a stable manner, performing more effectively than the manual method. The implementation of this system enhances production efficiency, preserves fabric quality, and provides convenience for MSME owners by enabling real-time monitoring of the drying process via smartphone.**

Keywords: Batik, Drying System, IoT, MSME, PID.

I. INTRODUCTION

Indonesia has a wide variety of cultural heritage with high artistic value that deserves to be preserved, one of which is batik. Batik is part of Indonesian culture inherited from the ancestors of the Indonesian people since ancient times [1]. On October 2, 2009, in Abu Dhabi, UAE, batik was designated by UNESCO as a *Masterpiece of the Oral and Intangible Heritage of Humanity* (UNESCO, 2009), making it an icon, symbol, and integral part of Indonesian cultural life [2]. The production process of batik involves several stages, one of the most crucial being the drying of fabric after the dyeing stage. Improper drying can lead to color changes, reduced fabric quality, and an increased risk of defects in batik motifs. Traditional drying methods, such as sun-drying, remain widely used but pose several challenges, including weather dependency, inconsistent drying times, and the risk of contamination from dust and environmental pollution.

One of the regions that continues to preserve batik culture is Blitar City. In this city, there are many batik SMEs (Small and Medium Enterprises), one of the most well-known being Batik Puspayindra. This SME produces various types of batik, including stamped batik, written batik, and brush batik. In its production process, Batik Puspayindra pays close attention to motifs, colors, and patterns to maintain its distinct characteristics. Among the production stages, the drying process is crucial, as it significantly affects the quality of batik in terms of color, durability, and overall fabric condition. Improper drying may cause damage such as fabric shrinkage and fading of colors. Currently, the drying process is still performed manually by exposing the fabric to sunlight or air, a method highly dependent on weather conditions. When the weather is cloudy, rainy, or highly humid, the fabric may not dry properly, or in some cases, may even become damp again. Air temperature and humidity levels greatly affect the drying rate: on hot days, the fabric may dry quickly, whereas on cold or humid days, the drying process takes considerably longer. This dependency on weather makes the drying duration unpredictable, which can disrupt production schedules, especially when SMEs need to fulfill bulk orders with timely delivery. Excessive direct sun exposure may also cause color fading, particularly for bright-colored fabrics or those made of sensitive materials. Additionally, dust, dirt, and air pollution can easily adhere to fabric dried outdoors. If drying is incomplete before nightfall or if humidity increases, there is a high risk of mold growth or unpleasant odors in the fabric.

Research related to the implementation of IoT-based drying systems has been widely conducted. One such study was carried out by Meilia Indriati Putri in 2019, entitled *"Rancang Bangun Alat Pengering Pakaian Otomatis Berbasis Arduino"* (Design and Development of an Automatic Clothes Dryer Based on Arduino). This research developed a control system for an automatic clothes dryer using Arduino as the controller, a humidity sensor to detect whether the clothes were dry or still damp, and a Bluetooth module as an interface with an Android application [3]. Another study by Herendra Priyandha in 2023, entitled *"Perancangan Prototipe Sistem Kendali Otomatis Pada Pengering Pakaian Berbasis Air Heater"* (Prototype Design of an Automatic Control System in an Air Heater-Based Clothes Dryer), focused on designing a control system for a drying device aimed at accelerating drying time while maintaining fabric quality. This prototype consisted of an air heater, temperature and humidity sensors, Arduino, and a user interface built in LabView, where the user could input parameters such as clothing type and quantity [4]. Furthermore, research conducted by Catur Wardana, Santi Rahayu, and Arvieka Gusta Pramudya in 2022, entitled *"Penerapan Alat Pengering Batik dengan Memanfaatkan Kalor Tungku Pelorotan guna Meningkatkan Efisiensi Produksi sebagai Antisipasi Cuaca yang Tidak Menentu"* (Application of a Batik Drying Tool Using Waste Heat from Batik Processing Furnaces to Increase Production Efficiency as Anticipation for Uncertain Weather Conditions), proposed a batik drying device utilizing waste heat from the pelorotan furnace. The heat was transferred using water as a medium to a heat exchanger and distributed into the drying chamber with seven heat-exchanger fans, thereby increasing the chamber temperature. The system was equipped with automation based on sensor readings of air temperature, humidity, and water temperature in the heating drum. The results showed that the drying process could be completed in just 50 minutes [2].

Therefore, to facilitate SMEs such as Batik Puspayindra in conducting a more controlled drying process, it is necessary to develop a drying device that can simplify and optimize the batik drying stage. In this study, the drying system was designed using an ESP32 microcontroller[3]-[5], implementing the Proportional Integral Derivative (PID) method[6], and connected to an IoT application for monitoring, controlling[7], and storing data[8] related to temperature[9] and humidity [10]during the drying process. The ESP32 acts as the main controller of the IoT-based batik drying system, enabling real-time monitoring and control of temperature and humidity. With Wi-Fi connectivity, the ESP32 can also transmit sensor data to the database [11]. The PID method plays an essential role in regulating both temperature and humidity by adjusting the heater and fan operations according to the setpoints. By applying PID control, the system can maintain stable environmental conditions in the drying chamber, reducing risks of excessive temperature, unsuitable humidity, and subsequent fabric damage. The PID algorithm is also adaptive to environmental changes, such as fluctuations in ambient temperature or humidity, ensuring that the drying process remains efficient under varying conditions. Furthermore, the integration of PID with the IoT platform allows real-time data collection and remote monitoring via a smartphone application.

II. METHOD

This research employed a Research and Development (R&D) approach by designing and implementing an Internet of Things (IoT)-based batik drying system using the Proportional Integral Derivative (PID) control method. The study consisted of three main stages: system design, hardware and software integration, and system testing at UMKM Batik Puspayindra in Blitar City.

In this study, the PID method was employed to automatically regulate temperature and humidity in the batik fabric dryer. The PID controller adjusts the power of the heater and fan based on the difference between the actual values and the desired setpoints. When the temperature falls below the setpoint, the heater output increases, whereas when the temperature exceeds the threshold, the fan operates more actively to reduce it. The application of the PID method ensures a more stable drying process while preserving the quality of the fabric and its colors.

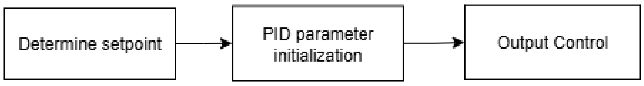

Figure 1. PID Method

Figure 1 illustrates the working principle of the Proportional Integral Derivative (PID) method applied in the batik drying system. The process begins with defining the setpoint, which represents the target temperature to be achieved. The system then initializes the PID parameters, consisting of three main components:

- Proportional (Kp): regulates the system response to the present error. A higher Kp value accelerates the response but may cause overshoot when excessive.
- Integral (Ki): accounts for the accumulated error over time to eliminate steady-state error. However, excessive Ki may increase the risk of overshoot.
- Derivative (Kd): responds to the rate of change of the error, helping to minimize overshoot and improve stabilization, although overly large values can lead to system instability.

These three components are combined to generate the control output, which adjusts the heater power to achieve the desired drying temperature. The control Equation 1 can be expressed as:

$$u(t) = k_p(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \qquad (1)$$

The drying system was designed with three operational stages: input, process, and output. Four DHT11 sensors were used to measure temperature and humidity inside the drying chamber. The sensor data were processed by an ESP32 microcontroller programmed with a PID algorithm as the main controller. Based on the processed data, the ESP32 regulated relays that controlled the heater and fans. The temperature and humidity readings were displayed through an I2C LCD and transmitted in real time to the Blynk application via Wi-Fi connectivity.

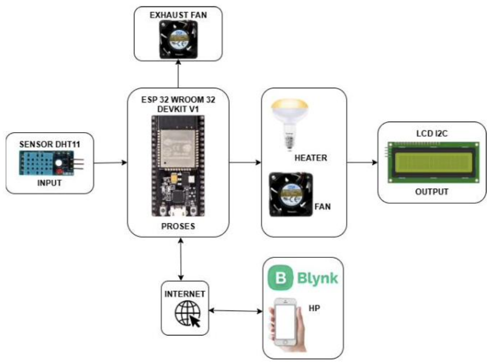

Figure 2. System Block Diagram

The hardware components included an ESP32 microcontroller, DHT11 sensors [12][13], two DC fans for drying, an exhaust fan for air circulation, a heating lamp as the heat source, relays as electronic switches, an I2C LCD for local display, and a switch mode power supply (SMPS) as the power source. On the software side, the system was developed using Arduino IDE [14][15]and integrated with the Blynk application as the user interface. The Blynk platform provided real-time monitoring, data visualization, and an emergency stop button to shut down the system in case of malfunction or unsafe conditions.

The PID method was applied to maintain stable temperature and humidity at the desired setpoints of 35°C and 52%, respectively. The proportional (P) component controlled the initial response, the integral (I) component reduced long-term error, and the derivative (D) component stabilized the system by minimizing overshoot. This combination ensured that the drying process remained efficient and consistent compared to traditional manual methods. As for the calculation formula for components, equation 2, 3 and 4.

- Proportional $K_P\, e(t)$ (2)
- Integral $K_i \int e(t)$ (3)
- Derivative $K_d \frac{de(t)}{dt}$ (4)

System testing was conducted in the working environment of UMKM Batik Puspayindra. The evaluation focused on sensor accuracy, system stability in maintaining temperature and humidity, the effectiveness of the PID control compared to manual drying, drying time, and the quality of the batik fabric after the drying process.

The IoT-based batik drying system was designed to operate automatically by monitoring and controlling the temperature and humidity inside the drying chamber. The primary objective of this system is to preserve the color quality and texture of batik fabric during the drying process. Four DHT11 sensors were installed inside the chamber to measure environmental parameters and transmit the data in real time to the ESP32 microcontroller. The data were then processed using a Proportional-Integral-Derivative (PID) control algorithm to determine the required adjustments. When the measured temperature dropped below the setpoint of 30°C, the relay activated the heater to raise the temperature to the optimal level. Conversely, when the humidity exceeded the threshold of 52%, the fan was switched on to reduce the humidity level in the chamber.

The monitoring and control processes were performed automatically and repeated every second. The ESP32 microcontroller was also connected to the Blynk application via Wi-Fi, serving as a user interface to allow real-time monitoring of temperature and humidity from a smartphone, as well as manual system control when needed. An Emergency button was integrated into the application to immediately shut down the system in case of malfunction or emergency conditions. Additionally, an I2C LCD was installed to display real-time temperature and humidity locally. The system was powered by a 5V supply for the ESP32, with a step-down converter used to regulate the voltage for peripheral devices such as relays. Figure 3 illustrates the system workflow of the proposed design.

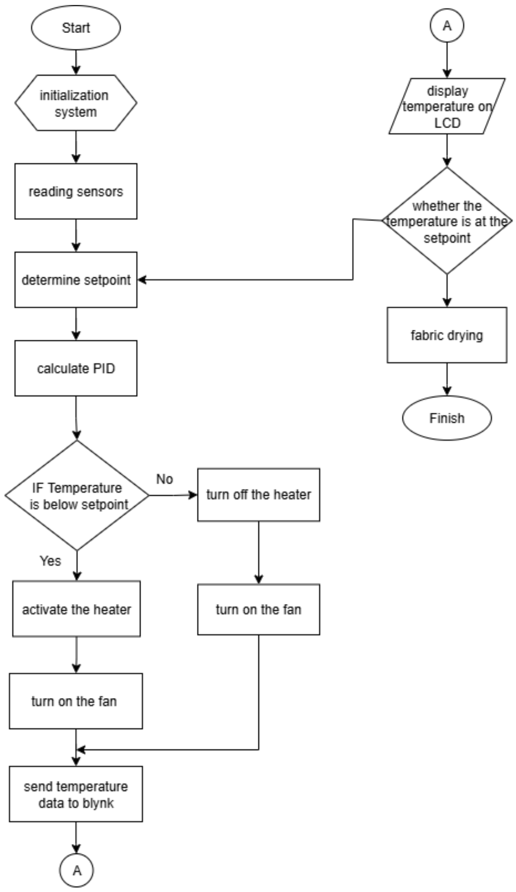

Figure 3. Flowchart System

The workflow of the IoT-based batik drying system is illustrated in Figure 3.6. The process begins with system initialization to prepare for temperature and humidity measurement. The ESP32 microcontroller subsequently reads data from the DHT11 sensors to obtain the actual conditions within the drying chamber. The system then defines a temperature setpoint as the target value. The difference between the measured temperature and the setpoint is calculated as the error, which is further processed by the PID control algorithm to regulate the heater output.

In addition, an LDR sensor is employed to monitor the intensity of the heating lamp. When the detected light intensity falls below the required setpoint, the relay automatically activates both the heating lamp and the fan. Conversely, if the temperature exceeds the setpoint, the lamp is switched off while the fan remains active to maintain airflow circulation. The measured temperature and humidity data are transmitted to the Blynk application, enabling real-time monitoring via a smartphone. The output is also displayed locally through an LCD module. This process is repeated continuously until the drying temperature reaches the defined setpoint. Once the target condition is achieved, the drying process is considered complete.

III. RESULTS AND DISCUSSION

The Internet of Things (IoT)-based batik fabric drying system was successfully implemented according to the design. The system uses an ESP32 microcontroller as the main controller, connected to four DHT22 sensors to detect temperature and humidity inside the drying chamber. The data obtained from the sensors is then processed by the ESP32 and used to control actuators such as a heater, drying fan, and exhaust fan, which are controlled via a relay module.

Temperature and humidity information is displayed locally via an I2C LCD, allowing users to directly monitor the drying chamber's condition. Furthermore, the system is equipped with Wi-Fi connectivity, allowing data to be sent in real time to the Blynk app. Through this app, users can monitor, control, and shut down the system remotely. An additional feature, an emergency stop button, is also provided in the app to shut down the entire system in the event of an emergency. With this integration of hardware and software, the batik drying system can operate automatically, simplifying the production process for users.

A. Accuracy test of DHT11 Sensor

The accuracy test of the DHT11 sensor was carried out by comparing its temperature and humidity readings with a reference digital hygrometer. The test was conducted repeatedly under the same environmental conditions to obtain the average measurement difference.

In this study, the DHT11 sensor was used in an Internet of Things-based batik fabric drying system. To ensure the sensor's accuracy and reliability during the drying process, an initial calibration process was performed by comparing the sensor's readings to a digital hygrometer. Testing was conducted inside a drying cabinet. The DHT11 sensor was placed close to the hygrometer to ensure more accurate temperature and humidity readings, and the readings were recorded several times for comparison. The calibration test table performed 10 trials, then calculated the average difference in temperature and humidity. The average difference (error) was calculated using the formula:

TABLE I
COMPARISON OF TEMPERATURE AND HUMIDITY MEASUREMENTS BETWEEN DHT11 AND HYGROMETER

No	DHT11 Temperature (°C)	Hygrometer Temperature (°C)	DHT11 Humidity (%)	Hygrometer Humidity (%)	Temperature Difference (°C)	Humidity Difference (%)
1	27.0	27.3	71.2	67	0.3	4.2
2	27.1	27.8	70.8	67	0.7	3.8
3	27.2	27.6	70.2	67	0.4	3.2
4	27.3	27.5	69.5	68	0.2	1.5
5	27.4	27.6	73.3	66	0.4	7.3
6	27.5	27.6	73.3	66	0.1	7.3
7	27.5	27.5	68.9	68	0.0	0.1
8	27.6	27.6	67.9	68	0.0	0.1
9	27.7	27.6	72.4	67	0.1	5.4
10	27.9	27.8	71.5	67	0.1	4.5
Average					0.23	3.74

The average difference (error) was calculated using the formula 5.

$$\mu = \frac{total\ difference}{number\ of\ trials} \quad (5)$$

The results showed that the DHT11 sensor had an average deviation of 0.23°C for temperature and 3.74% for humidity compared to the hygrometer. These differences are still within an acceptable tolerance range for batik drying applications. Therefore, the DHT11 sensor is considered reliable as an input device in the system, as it provides relatively accurate and stable readings of temperature and humidity. The reliability of this sensor is crucial since the collected data serve as the primary input for the PID algorithm in controlling the drying process.

B. PID System Perfomance Test

The performance test was conducted to evaluate the effectiveness of the Proportional Integral Derivative (PID) method in maintaining stable temperature and humidity during the batik drying process. The system was configured with a temperature setpoint of 35°C and a humidity setpoint of 52%. The test results showed that the heater was activated when the temperature dropped below the setpoint and automatically turned off when the temperature approached the desired value. Conversely, the drying fans and exhaust fan were activated when the humidity exceeded 52% and stopped once the humidity returned to the stable range.

The PID method successfully adjusted the system conditions dynamically, preventing extreme fluctuations. The proportional (P) component provided a rapid response to sudden changes in temperature or humidity, the integral (I) component corrected long-term errors, and the derivative (D) component stabilized the system to minimize overshoot. The results demonstrated that the drying system was able to maintain temperature and humidity close to the target values consistently, thereby preserving fabric quality and reducing the risk of damage caused by unstable drying conditions.

C. Comparison with Manual Drying

The traditional method of drying batik fabric generally relies on sunlight and natural airflow. This approach is highly dependent on weather conditions, making the drying process less effective during cloudy, rainy, or high-humidity days, and in some cases, the fabric may even become damp again. Moreover, the drying time using the manual method is unpredictable, which often disrupts the production schedule, especially when batik SMEs must meet large orders with tight deadlines. Other risks include exposure to dust, air pollution, and the potential growth of mold if the fabric is not fully dried.

In contrast, the IoT-based drying system with PID control is able to maintain a stable temperature at 35°C and humidity at around 52% consistently. The drying process becomes shorter and is no longer dependent on external weather conditions. Furthermore, temperature and humidity data can be monitored in real time through the Blynk application, allowing users to oversee the process remotely. With this stability, the risks of fabric damage such as color fading, shrinkage, or mold growth can be minimized. These results demonstrate that the IoT system with PID control not only improves efficiency but also preserves fabric quality and enhances SME productivity in meeting production targets.

D. Implementation Hardware

At this stage, all components are connected and arranged according to the schematic. The goal of this assembly is to create an automated system capable of controlling temperature and humidity using the PID method during the batik drying process to maintain fabric quality and color.

The specifications of the batik drying cabinet in the image are explained as follows:

• The cabinet frame is made of wood

• The cabinet lid is made of plywood with a melamine coating

E. Implementation Software

The batik drying system uses the Blynk platform as an app-based user interface. Connecting the ESP32 to a WiFi network, data from the DHT11 sensor is periodically sent to the Blynk app via an internet connection. The Blynk dashboard displays temperature and humidity using widgets. The Blynk app is used to monitor and control the batik drying system. Furthermore, the app also includes an emergency button for emergency use, as shown in Fig. 4.

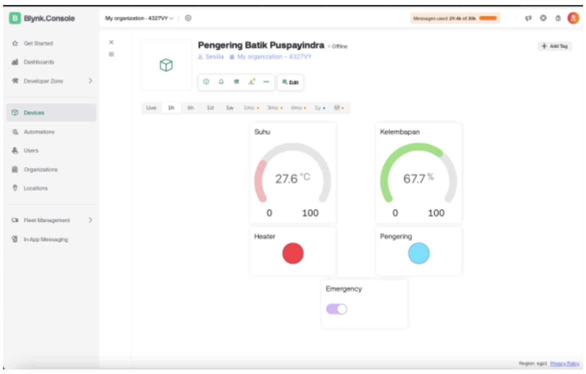

Figure 4. Blynk Aplication

F. Test Result Data

TABLE II
CONVERSION POTENTIAL OF SOME RADIONUCLIDES

Time (minute)	Room Tempertaure (°C) (Manual Method)	Drying Temperature (°C) (PID Method)
0	24,0	27,6
5	24,2	27,0
10	24,7	27,0
15	24,5	26,7
20	24,6	26,5
30	24,4	26,1
40	24,2	25,4
50	24.3	25,2

The test was carried out 8 times with different times (Table II). Time 0 minutes temperature 27.6°C and humidity 70.6% with heater and fan status ON. Time 5 minutes temperature 27.0°C and humidity 70.4% with fan and heater status ON. Time 10 minutes temperature 27.0°C and humidity 69.7% with heater and fan status ON. Time 15 minutes temperature 26.7°C and humidity 65.3% with heater and fan status ON. Time 20 minutes temperature 26.7°C and humidity 63.2% with heater and fan status ON. Time 30 minutes temperature 26.1°C and humidity 58.9% with heater and fan status ON. Time 40 minutes temperature 25.4°C and humidity 56.4% with heater and fan status ON. At 50 minutes the temperature reached 25.2 °C and humidity 54.2 with the heater and fan status OFF. In this test result the initial temperature measured was 27 °C and did not experience a drastic temperature increase according to the specified setpoint of 35 °C. Drying of the batik cloth was completed in 50 minutes with a temperature of 25.2 and humidity 54.2%. For the system temperature threshold of 25 °C, the heater will automatically turn off if the temperature ≥ 35 °C and the fan will turn off when the humidity reaches 52%. Data will be displayed in real time on the Blynk application.

G. PID Method

In this study, the Proportional-Integral-Derivative (PID) method was implemented to control the temperature and humidity within the batik drying system. The PID control operates based on the calculation of error, defined as the difference between the desired value (setpoint) and the actual value measured by the sensors. In this system, the setpoints were determined as 35 °C for temperature and 52% for humidity, aiming to preserve the fabric quality and color of batik by preventing damage due to excessive heat or humidity. The input temperature values were obtained from the average readings of four DHT11 sensors installed inside the drying chamber.

The PID method consists of three fundamental components—proportional, integral, and derivative—that work together to minimize the error between the actual value and the setpoint. The proportional component generates a response proportional to the current error, scaled by the proportional constant (Kp). The integral component calculates the accumulated error over time to eliminate steady-state error, multiplied by the integral constant (Ki). Meanwhile, the derivative component predicts the rate of change of the error, providing a damping effect to reduce the likelihood of overshoot, and is scaled by the derivative constant (Kd). The combination of these three components allows the system to achieve stable conditions with the desired temperature and humidity. The PID constant values used for temperature and humidity testing are summarized in the table III.

TABLE III
PID CONSTANTA

Testing	**Kp**	**Ki**	**Kd**
Temperature	1,6	0,1	0,5
Humidity	1,3	0,8	0,4

The tuning of PID constants was carried out through a series of experiments to determine the most suitable parameters for maintaining temperature and humidity stability in the batik drying system. For the proportional component (Kp), the tested range for temperature was 1.0–2.0 . A Kp value of 1.0 resulted in a stable system without overshoot, while a value of 2.0 produced an overshoot of approximately 2 °C with a recovery time of around 40 seconds. Based on these results, the optimal Kp value for temperature was set at 1.6, providing a moderate response speed without excessive fluctuation. For humidity, the Kp range was 1.2–2.0, with 1.2 yielding stable performance and higher values causing fluctuations. Thus, the Kp value chosen for humidity control was 1.3, ensuring system stability.

The integral component (Ki) was kept lower than Kp since it continuously accumulates error correction to eliminate steady-state error. Experimental results showed that stable Ki values ranged between 0.08–0.12 for temperature and 0.05–0.12 for humidity, which successfully accelerated the system response while maintaining a low overshoot (around 1 °C).

The derivative constant (Kd) was applied to regulate the system's response to the rate of error change and to suppress overshoot. The selected Kd values were 0.5 for temperature and 0.4 for humidity. With this combination of Kp, Ki, and Kd, the system was able to achieve optimal stability in both temperature and humidity, ensuring that the fabric quality and batik color remain well preserved during the drying process.

H. Test Result Graph

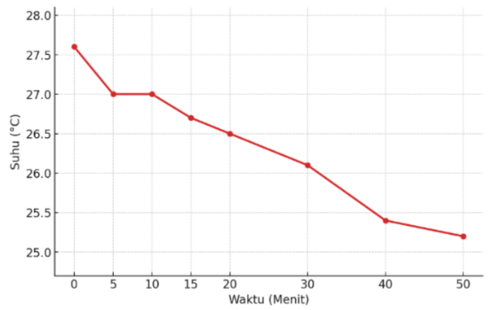

Figure 5. Temperature Variation Graph

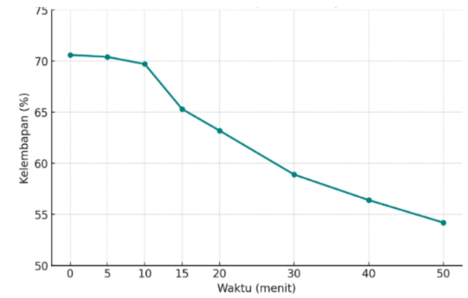

Figure 6. Humidity Variation Graph

The red line graph as shown in Figure 5 shows the minute-to-minute temperature change, while the blue line graph shows the decrease in humidity during the drying process. From 0-15 minutes, the temperature decreased slightly from 27.6°C to 26.7°C. This decrease was relatively slow because the system had just started operating and the process of water evaporation from the fabric was taking place. From 15-50 minutes, the temperature continued to decrease gradually until it reached 25.2°C. This indicates that the heater was working efficiently at the start, maintaining the temperature close to the setpoint of 35°C. The system began turning off the heater when it dropped sufficiently below the PID control threshold.

From 0-15 minutes in Fugure 6, the humidity decreased from 70.6% to 65.3%, indicating the drying process was beginning. From 15-50 minutes, the humidity decrease became more rapid and significant, reaching 54.2%, which is the system's target humidity of 52%. This indicates that the fan was working effectively to dry the cabinet and remove moisture from the cabinet. Heater and fan are ON until the 40th minute then turn off at the 50th minute according to logic.

I. System Response to Temperature and Humidity

This test aims to evaluate the system's ability to respond to changes in temperature and humidity within the batik drying chamber. The test was conducted by starting the system from its initial condition, automatically activating the heater and fan based on sensor readings, and recording how the system adjusted temperature and humidity until reaching the specified setpoints.

From the test results, when the system was first activated, the initial temperature was below 35 °C, causing the heater and fan relays to automatically switch ON. The system then gradually increased the temperature and approached the predefined setpoint within approximately 3–5 minutes. The PID method regulated the heater to prevent excessive temperature overshoot, which could potentially degrade the quality and color of the fabric. For humidity, the initial level was around 70%, thus the fan relay was automatically activated. The fan functioned to reduce humidity and accelerate air circulation gradually until stabilizing around 52%, with the resulting fabric humidity measured at 54.2%.

Regarding temperature response, the system exhibited a fast and stable adjustment with a well-controlled temperature rise. No significant overshoot or delay was observed, ensuring precise temperature control. The PID method also optimized heater activation duration to prevent excessive temperature increase. For humidity response, the reduction process was relatively slower but remained stable. The fan operated efficiently in reducing humidity without causing major temperature fluctuations inside the chamber. Consequently, both temperature and humidity in the chamber remained within safe ranges. The PID parameters were carefully tuned, enabling the system to dynamically adjust heater and fan outputs according to the error, defined as the difference between actual conditions and the setpoints.

The experimental results demonstrate that the IoT-based batik drying system is capable of providing a rapid and accurate response to changes in temperature and humidity. The system effectively maintained chamber conditions at the desired targets with stability through the implementation of the PID method. Furthermore, the Blynk application significantly enhanced usability by allowing real-time monitoring and control. The emergency button provided additional safety in the event of system malfunctions or emergency conditions.

J. Effectiveness of the PID Method

The PID method regulates the batik drying process by minimizing the error between actual sensor readings and setpoints (35 °C, 52% humidity). Using tuned parameters (Kp = 1.6, Ki = 0.1, Kd = 0.5 for temperature; Kp = 1.3, Ki = 0.8, Kd = 0.4 for humidity), the system achieved stable and efficient control without overshoot. Test results showed the chamber temperature and humidity reached targets smoothly, while the fan and heater operated only as needed, reducing energy consumption and extending component lifespan. Despite using simple ON/OFF relays, PID tuning allowed smooth, adaptive control. Overall, the method effectively ensured fabric quality, prevented color fading and shrinkage, and provided an energy-efficient solution for IoT-based batik drying.

K. Response of the Emergency Button

The PID method effectively regulates the batik drying process by minimizing the error between sensor measurements and predefined setpoints (35 °C for temperature and 52% for humidity). With optimized tuning parameters (Kp = 1.6, Ki = 0.1, Kd = 0.5 for temperature; Kp = 1.3, Ki = 0.8, Kd = 0.4 for humidity), the system demonstrated stable and efficient control with negligible overshoot. Experimental results confirmed that both temperature and humidity reached their targets smoothly, while the heater and fan were activated only when necessary, thereby reducing energy consumption and extending component lifespan. Although the system employed simple ON/OFF relay switching, PID tuning enabled smooth and adaptive control. Overall, this approach not only ensured fabric quality by preventing color fading and shrinkage but also provided an energy-efficient and reliable solution for IoT-based batik drying systems.

L. Fabric and Color Quality Results

In the manual drying process, which relies solely on ambient room temperature, the quality of batik fabric is often affected by environmental conditions. Unstable temperature makes the drying duration inconsistent, and high humidity levels prolong the process, leaving the fabric at risk of mold growth or unpleasant odors. Excessive exposure to direct sunlight can also fade the malam (wax) layer, causing colors to bleed and mix, thereby damaging the distinct patterns of batik. At UMKM Batik Puspayindra, drying is conducted indoors by relying on natural air circulation, avoiding direct exposure to sunlight. This precaution is taken because direct sunlight can cause the wax layer to dissolve, leading to color blending during subsequent dyeing stages and ultimately reducing fabric quality. Furthermore, prolonged exposure to strong sunlight can result in faded or uneven colors, diminishing the aesthetic and commercial value of the fabric. Uneven sunlight intensity may also cause fabric shrinkage, making the fabric asymmetrical. In hand-drawn (batik tulis) designs, this can compromise motif precision and reduce artistic accuracy.

In contrast, the drying system using the PID method is capable of maintaining fabric quality consistently. The PID controller precisely regulates temperature and humidity within the drying chamber to remain within the optimal range required by batik fabric. This ensures drying at a stable temperature without sunlight exposure, thereby preserving the integrity of the wax layer and preventing color fading or mixing. Controlled humidity further prevents fibers from becoming stiff or brittle due to excessive drying. Moreover, the drying process is faster, as the chamber environment is optimized according to the required standard conditions.

Experimental results demonstrated that the PID-controlled dryer successfully preserved the fabric's texture and color quality. Batik dried with this method retained the softness of its fibers, exhibited no distortion in shape, and maintained sharp, vivid colors consistent with the original motif. In contrast, the manual method was more vulnerable to quality degradation due to its dependence on unpredictable external factors. Therefore, the application of PID-based drying not only improves time efficiency but also provides more consistent and reliable results in maintaining the aesthetic and commercial value of batik fabric.

IV. CONCLUSION

The This study successfully implemented an Internet of Things (IoT)-based batik fabric drying system using the *Proportional Integral Derivative* (PID) method to maintain fabric and color quality at UMKM Batik Puspayindra, Blitar. The system was able to automatically control temperature and humidity at setpoints of 35°C and 52% RH. The test results showed that the DHT11 sensor provided sufficient accuracy, with an average deviation of 0.23°C for temperature and 3.74% for humidity compared to a hygrometer, making it reliable as control input. The PID method proved effective in maintaining the stability of the drying chamber by minimizing fluctuations and preventing overshoot. This had a positive impact on batik quality, where the fabric color remained bright and consistent, while the texture and dimensions of the fabric were well-preserved. Compared to manual drying methods that are highly dependent on weather conditions, this system offered greater efficiency, consistency, and the advantage of real-time monitoring via the Blynk application. In conclusion, the implementation of an IoT-based drying system with PID control provides a practical solution for batik SMEs to improve production efficiency while ensuring product quality. Moreover, this research contributes to the preservation of batik as Indonesia's cultural heritage through the application of modern technology.

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