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JITK (JURNAL ILMU PENGETAHUAN DAN TEKNOLOGI KOMPUTER)

DESIGN OF CONTROL SYSTEM AND TEMPERATURE IN COFFEE DRYER ARDUINO BASED AUTOMATIC USING FUZZY

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Abstract—*The coffee bean drying process is a crucial stage in ensuring the final quality of coffee products. Conventional drying methods, which rely on sunlight, face several challenges, such as dependence on weather conditions and prolonged drying times. This study proposes the design of a control and temperature system for an automatic coffee dryer based on the Arduino Mega 2560, aimed at enhancing the efficiency and consistency of the drying process. The system utilizes a semi-enclosed drying technology equipped with DHT22 temperature and humidity sensors, controlled by Arduino-Uno and Fuzzy Logic. This control system monitors temperature and humidity in real-time, maintaining the drying conditions at 55°C and 15% RH. If the temperature or humidity exceeds the set limits, the system activates an LED and buzzer alarm, indicating that the drying process has reached optimal conditions. The prototype was tested under various conditions, and the results demonstrate that the system has a high accuracy level in controlling temperature and humidity, significantly accelerating the drying process compared to traditional methods. By implementing this technology, the coffee industry in Indonesia is expected to achieve the Coffee Drying Operational Standards in accordance with SNI, maintain flavor quality, optimize the use of drying land, and reduce drying duration. This development offers an innovative solution that can enhance the quality and productivity of coffee processing, providing significant economic benefits to farmers and coffee industry stakeholders.*

Keywords: *arduino, coffee beans, coffee beans dryer, fuzzy.*

Intisari— *Proses pengeringan biji kopi merupakan salah satu tahapan krusial dalam memastikan kualitas akhir produk kopi. Pengeringan konvensional yang mengandalkan sinar matahari memiliki beberapa kendala, seperti ketergantungan pada kondisi cuaca dan durasi pengeringan yang panjang. Penelitian ini mengusulkan perancangan sistem kendali dan suhu pada pengering kopi otomatis berbasis Arduino Mega 2560, yang dirancang untuk meningkatkan efisiensi dan konsistensi proses pengeringan. Sistem ini menggunakan teknologi pengeringan semi-tertutup yang dilengkapi dengan sensor suhu dan kelembaban DHT22 yang dikendalikan oleh Arduino dan metode Fuzzy Logic. Sistem kontrol ini memantau suhu dan kelembaban secara real-time, menjaga suhu pengeringan pada 50 - 55°C dan kelembaban pada 12-15% RH. Apabila suhu atau kelembaban melebihi batas yang telah ditetapkan, sistem akan mengaktifkan LED dan buzzer alarm sebagai indikator bahwa proses pengeringan telah mencapai kondisi optimal. Prototipe alat diuji untuk menilai performa dalam berbagai kondisi, dan hasilnya menunjukkan bahwa sistem memiliki tingkat akurasi yang tinggi dalam pengendalian suhu dan kelembaban, serta mampu mempercepat proses pengeringan secara signifikan dibandingkan dengan metode tradisional. Dengan penerapan teknologi ini, diharapkan industri kopi di Indonesia dapat mencapai Standar Operasional Pengeringan Kopi sesuai SNI, menjaga mutu cita rasa, mengoptimalkan penggunaan lahan penjemuran, serta mengurangi durasi pengeringan. Pengembangan ini*

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menawarkan solusi inovatif yang dapat meningkatkan kualitas dan produktivitas dalam pengolahan biji kopi, memberikan manfaat ekonomi yang signifikan bagi petani dan pelaku industri kopi.

Kata Kunci*: arduino, biji kopi, pengering biji kopi, fuzzy.*

INTRODUCTION

The advancement of technology in agriculture, particularly in post-harvest processing, has experienced significant progress. One of the agricultural commodities that requires special attention during its processing is coffee. Coffee is one of Indonesia's leading export commodities with high economic value. However, the quality of coffee is highly influenced by the post-harvest processing, especially during the drying stage. The coffee drying process is a critical phase that determines the final product quality, including its taste, aroma, and color. Uncontrolled drying can lead to a decrease in coffee quality, such as undesirable changes in taste, aroma, and color [1]. Therefore, a control system is needed to maintain optimal temperature and humidity during the drying process.

Post-harvest processing of coffee beans is a crucial stage in the coffee production chain that determines the final product quality. The drying stage is vital to reduce the moisture content of coffee beans to an optimal level, usually in the range of 11-12.5%. Properly controlled humidity during the drying process can preserve the distinctive flavor of the coffee beans, prevent mold growth, and improve the product's shelf life. According to research by Fatkhurrozi & Setiawan (2024), the optimal temperature for coffee bean drying is 24-37°C with a relative humidity below 11%. However, this process often faces challenges such as temperature instability, especially when manually controlled, which is prone to errors caused by human factors (human error) [2].

Based on recent research, conventional drying systems still have several shortcomings, such as inaccuracies in controlling temperature and humidity, as well as reliance on weather conditions and human labor [3]. These issues lead to inefficiencies in the drying process and may result in economic losses for coffee farmers. Furthermore, manual drying systems often require longer processing times and lack consistency in producing high-quality products [4]. For example, during the rainy season, the coffee drying process is frequently disrupted due to high air humidity, which can cause the coffee to become moldy or spoiled. Therefore, a technological solution is necessary to address these challenges. A study conducted by Adrian et al. (2023) demonstrated the potential of fuzzy logic-based control systems to stabilize humidity levels within drying chambers. However, the primary limitation of their research was the lack of focus on responding to external environmental changes, such as temperature fluctuations caused by changing weather conditions [5].

One potential solution is the implementation of an automated control system based on the Arduino microcontroller with a fuzzy logic approach. Fuzzy logic is chosen for its ability to handle systems with uncertainties and nonlinearities, such as the coffee drying process [6]. This system is expected to automatically regulate temperature and humidity, making the drying process more efficient and consistent. Additionally, Arduino is selected as the main microcontroller due to its ease of programming, flexibility, and relatively low cost [7]. Arduino also has a large developer community, which facilitates development and troubleshooting of technical issues.

Although several previous studies have developed microcontroller-based drying systems, there are still research gaps that need to be addressed. For instance, the study by Hardiansyah et al. (2021) focused solely on temperature control without considering humidity factors [8], while Handoko et al. (2022) did not integrate fuzzy logic into their control system [9]. Additionally, these studies have not fully optimized the use of sensors and actuators to achieve more precise control.

Thus, this research aims to design a temperature and humidity control system for an automatic coffee dryer based on Arduino using fuzzy logic. This study seeks to fill the existing research gaps by providing a more comprehensive and accurate solution.

The results of this study are expected to produce a prototype of an automatic coffee drying system capable of optimally controlling temperature and humidity, thereby improving the efficiency and quality of the coffee drying process. Moreover, this research is expected to contribute to the development of environmentally friendly and sustainable IoT (Internet of Things)-based agricultural technologies. By implementing this system, coffee farmers can reduce their dependence on weather conditions and manual labor while increasing productivity and the quality of the coffee produced.

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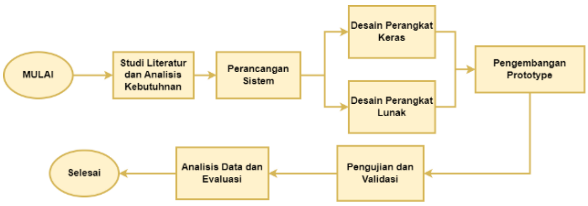
METHODS

The research implementation method used is to design a coffee dryer for coffee beans. By designing this coffee bean dryer, it can overcome problems in the fields of production and marketing. In the field of production, the tool made can be the answer to the dependence on the coffee drying process which has so far been manual, in line with that the quality of the coffee will be maintained, this is the impact of the production process which is monitored accurately with the help of the intelligent dryer that is made [10]. So that it will cause a domino effect between production, marketing and quality. The production process that has implemented artificial intelligence has an impact on the quality of coffee that is maintained, so that the selling value will remain with the stock that remains available. The following in Figure 1 will explain the research flow used.



Source: (Research Results, 2024)

Figure 1. Smart Dryer Machine Research Flow

The flowchart that has been created illustrates the flow of the research methodology used in the design and development of the control and temperature system on an automatic coffee dryer based on Arduino Mega 2560. Each stage in the flowchart shows the steps taken from needs analysis to data analysis and evaluation.

System Requirements Analysis

In addition to technical aspects such as hardware and software, system requirements analysis must also consider other important factors that affect the effectiveness of coffee bean drying. In this study, the type of coffee used is Arabica coffee which is known to have a higher water content compared to other types of coffee [11]. Arabica coffee requires careful drying treatment to maintain its taste and quality. The temperature and humidity settings on the automatic coffee dryer are adjusted to the specific needs of Arabica coffee, with an optimal drying temperature range of 55°C. Freshly picked coffee beans have a water content of around 60-70%. Coffee beans in this condition require a longer and more consistent drying time to achieve the ideal water content of around 12-15%. The use of an automatic drying system helps control temperature and humidity to avoid uneven drying. The general coffee bean drying process involves several important stages that require adjustments to the automatic drying system, namely:

a. Initial Sorting and Cleaning
b. Initial drying stage
c. Main drying stage
d. Final stage and monitoring of water content

System Design

This automatic coffee drying system is designed with the aim of increasing efficiency and quality in the coffee bean drying process. The design begins by selecting the main components that will support the system, namely the Arduino Mega 2560 microcontroller as the control center, which will manage the connected sensors and actuators. This microcontroller was chosen because of its memory capacity and the number of I/O pins that are sufficient to accommodate the various components needed [12].

To monitor the temperature and humidity in the drying chamber, a DHT22 sensor is used which has a high level of accuracy in measuring temperature and humidity in real-time. Data from this sensor will be sent to the Arduino, where the Fuzzy Logic algorithm is used to automatically regulate the operation of the heater, ensuring that the temperature and humidity remain within the optimal range for drying coffee beans, namely 55°C and 15% RH [13].

The system is equipped with LEDs and buzzers as visual and audio indicators that signal if the temperature or humidity has reached the desired limit. In addition, this system uses electricity as a power source.

The drying process is controlled automatically by the system, which continuously monitors conditions in the drying chamber and adjusts the temperature or humidity as needed. The device is also designed to cope with various environmental conditions and allows the drying process to continue even if external conditions change.

Hardware Design

The hardware design of this automatic coffee dryer system involves several main components that are integrated with each other. The Arduino Mega 2560 microcontroller is used as the control center, regulating sensors and actuators according to the needs of the drying process. This system is also supported by several sensor, actuator, and power source components, which are described as follows:

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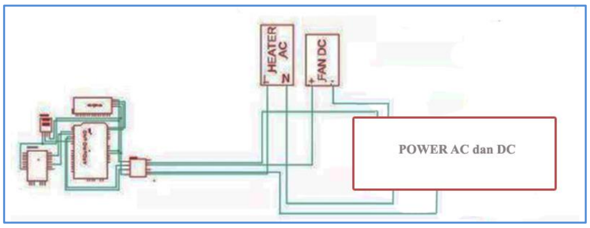
1. Arduino Mega 2560 microcontroller
2. DHT22 Temperature and Humidity Sensor
3. Electric Heater
4. Electrical Energy Source
5. LED Indicator and Buzzer

The automatic coffee dryer hardware system circuit can be seen in Figure 2.



Source: (Research Results, 2024)
Figure 2. Automatic Coffee Drying System Circuit Based on Arduino Mega 2560

Figure 2 shows how the DHT22 sensor, electric heater, solar panel, and LED and buzzer are connected to the Arduino Mega 2560. Each component is positioned to interact well with each other, ensuring the system runs automatically with optimal efficiency.

Software Design

The software design for this automatic coffee drying system was developed using the Arduino IDE platform, written in the C programming language. This software is tasked with controlling the entire system automatically, starting from collecting sensor data, processing data, to activating actuators based on the detected temperature and humidity conditions [14].

1. DHT22 Sensor Monitoring

The software starts by reading temperature and humidity data from the DHT22 sensor periodically. This data is taken every few seconds to monitor real-time conditions in the drying chamber. The temperature and humidity values are then sent to the Arduino Mega 2560 microcontroller for further processing.

2. Fuzzy Logic Temperature and Humidity Control

The control system uses Fuzzy Logic to automatically manage temperature and humidity. With Fuzzy Logic, the software is able to make more flexible settings compared to conventional control methods, which tend to be rigid. Fuzzy Logic allows the system to adjust the heater output based on the detected temperature conditions, keeping the dryer temperature at 55°C and humidity at 15% RH.

At this stage, the input variables obtained from the sensors, such as temperature and humidity, will be translated into Fuzzy membership functions to determine the appropriate output level. This Fuzzy algorithm combines several logic rules to produce accurate control [15] .

In the calculation of Fuzzy Logic, it requires the definition of Input and Output. The definition of Input 1 is Temperature which can be classified into cold, normal, hot. Input 2 is Humidity which can be classified into low, medium, and high. The definitions of Input 1 and 2 are taken from the DHT22 sensor. The definition of Output is in the form of actions for temperature control which can be classified into Low, Medium, and High.

Applying membership degrees. Fuzzy Logic works based on membership functions. For each input (temperature and humidity), there are several membership functions that indicate how far the input value falls into a certain category. For example:

Temperature Membership Function:

1) Cold: If the temperature is below 45°C
2) Normal: If the temperature is below 50°C - 60°C
3) Hot: If the temperature is above 65°C

$$\mu_{cold}(T) = \begin{cases} 1 & T \leq 45 \\ \frac{50-T}{5} & 45 < T \leq 50 \\ 0 & T > 50 \end{cases} \quad (1)$$

Membership Humidity Function:

1) Low: If below 10%
2) Medium: If below 15% to 20%
3) High: If above 25%

$$\mu_{low}(H) = \begin{cases} 1 & H \leq 10 \\ \frac{15-H}{5} & 10 < H \leq 15 \\ 0 & H > 15 \end{cases} \quad (2)$$

Fuzzy rules connect inputs to outputs based on linguistic logic. Some examples of Fuzzy rules for this temperature control system can be seen in Table 1.

Table 1. Fuzzy Rules

Temperature	Humidity		
	Low	Medium	High
Cold	High	High	High
Normal	Medium	Medium	High
Hot	Medium	Medium	Medium

Source: (Research Results, 2024)

For example, at a certain time, the DHT22 sensor gives a reading of Temperature (T) = 52°C and Humidity (H) = 18%.

a) Temperature 52˚C

$\mu_{cold}(52) = 0$
$\mu_{normal}(52) = \frac{60-52}{10} = 0.8$
$\mu_{hot}(52) = 0$

b) Humidity 18%

$\mu_{low}(18) = 0$
$\mu_{medium}(18) = \frac{20-18}{5} = 0.4$
$\mu_{high}(18) = 0$

Using Fuzzy rules, we perform inference based on membership values. For example, if Temperature is Normal and Humidity is Medium, then Output is Medium. The minimum value of μ_normal (52) and μ_medium (18) is min (0.8, 0.4) = 0.4. So the degree of output membership for the Medium condition is 0.4. The last step is to calculate the final output value using the Center of Gravity (CoG) method or weighted average. Assume that the output values for the Low, Medium, and High categories are 30%, 60%, and 90% respectively. Defuzzification is calculated using the following formula:

$$Output = \frac{\sum(membership\ degree \times output\ value}{\sum(membership\ degree)} \quad (3)$$

From the inference step, we only have output with a Medium membership degree of 0.4, so the calculation is: From the inference step, we only have output with a Medium membership degree of 0.4, so the calculation is:

$$Output = \frac{(0.4 \times 60)}{0.4} = 60$$

So, the temperature control output is 60%, which means the system will regulate the heater at 60% of its maximum capacity to keep the temperature stable.

3. Alarm Indicator
After the temperature and humidity settings are made, the software will activate the LED and buzzer when the optimal conditions are reached. The LED will light up and the buzzer will sound as a sign that the drying process is complete or when the temperature and humidity exceed the set limits.

Prototype Development

The development of the automatic coffee dryer prototype was carried out by designing hardware and software. The hardware includes components such as Arduino Mega 2560, DHT22 temperature and humidity sensors, and a control system. The software design includes fuzzy logic to control temperature and humidity automatically. The purpose of this development is to ensure that each component functions according to the design to produce effective drying. This automatic coffee dryer prototype was designed using Arduino Mega 2560 as the control center. The DHT22 temperature and humidity sensor is used to monitor environmental conditions in the drying room in real time. The relay component is connected to control the heating element that maintains the drying temperature at the desired level. The system is also equipped with LEDs and buzzers as indicators when the temperature or humidity has reached the optimal limit. The power source is used directly using a stable power source. In the software, fuzzy logic is applied to regulate temperature and humidity based on input from the sensor. When the temperature or humidity is outside the set range, the system will give a signal via LED or buzzer to indicate that the drying process is complete or requires adjustment.

Testing and Validation

After the prototype was completed, testing was conducted to measure the performance of the system under real conditions. This process included temperature and humidity testing in various environmental conditions as well as comparison with traditional drying methods. Validation was conducted by evaluating whether the prototype met the standards for coffee drying, such as maintaining a temperature of 55°C and humidity of 15% RH.

Data Analysis and Evaluation

The results of the testing were recorded and analyzed. Data included drying time, accuracy of temperature and humidity control, and the quality of the coffee beans produced. Evaluation was conducted to determine how efficient the system was in reducing drying time and improving product quality compared to conventional methods.

RESULTS AND DISCUSSION

The design process of the automatic coffee dryer begins with designing an Arduino Mega 2560-based system that integrates DHT22 temperature and humidity sensors, relays, heating elements, fans, and LEDs and Alarm Buzzers. These components are connected to form an automatic control system that functions to maintain the temperature and humidity in the coffee drying room as needed. The design circuit can be seen in Figure 3.

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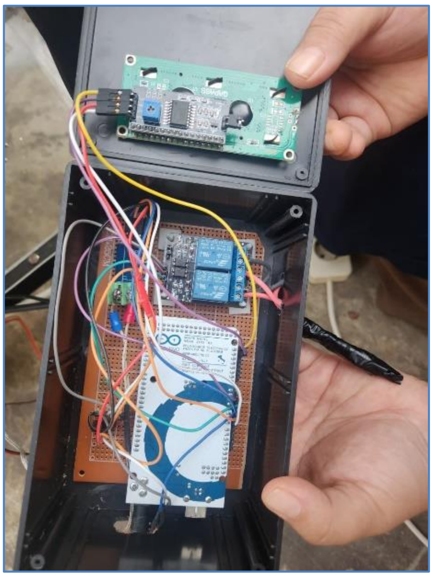

Source: (Research Results, 2024)
Figure 3. Automatic Coffee Bean Dryer Circuit

The coffee drying placement room is made using an iron frame coated with thick UV plastic so that the temperature and humidity in the room do not change. The room model is made like a house that has a large room so that it can accommodate 5 Kg of coffee. The design model for the coffee bean drying room is seen in Figure 4.

Source: (Research Results, 2024)
Figure 4. Coffee Bean Room Design

The coffee bean material used is the Arabica Coffee model type that has been washed clean and then weighed so that the weight does not exceed the sample. The sample used is 5 Kg. Before being put into the drying room, the temperature and humidity are measured to determine the previous values. The Arabica coffee beans used and weighed can be seen in Figure 5.

Source: (Research Results, 2024)
Figure 5. 5 Kg of Fresh Arabica Coffee Beans

The initial humidity measurement is 41% humidity and is classified as High so that the coffee beans still have a high water content. The following is the percentage of humidity in Figure 6 which is measured using a tool called "Grain Moisture Meter".

Source: (Research Results, 2024)
Figure 6. Moisture Content of Coffee Beans Before Drying

Coffee beans are put into a previously designed room. Temperature and humidity are measured at the beginning using a “Temperature Humidity Meter” so that changes in temperature and humidity in the room can be known. The application of coffee beans can be seen in Figure 7 and Figure 8.

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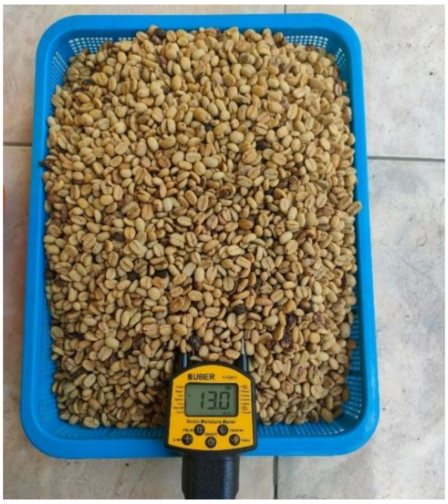
Source: (Research Results, 2024)
Figure 7. Coffee Bean Drying Process

Source: (Research Results, 2024)
Figure 8. Initial Temperature and Humidity of Coffee Beans Entered

Figure 7 shows the drying process of 5 kg of Arabica coffee beans. The temperature and humidity are continuously monitored and monitored by the Arduino sensor. If the sensor exceeds the specified limit, a sound will appear as an indicator and the blower fan will be active to reduce the temperature and humidity.

Source: (Research Results, 2024)
Figure 9. Second Process of Drying Coffee Beans

Figure 9 Arabica coffee beans that have been dried using an automatic dryer have successfully achieved the best coffee humidity standard, which is 13% RH, after going through a drying process for 6 hours. This condition meets the optimal drying standard to maintain the taste of coffee, according to industry standards. During drying, the coffee beans experience weight shrinkage from the initial 5 kg to 3 kg. This shrinkage is caused by the evaporation of water in the coffee beans, which is a natural result of the drying process. This process shows that the automatic dryer is able to optimize drying time, save energy, and maintain the quality of coffee beans. The results of humidity and changes in the weight of coffee beans can be seen in Figure 10 and Figure 11.



Source: (Research Results, 2024)
Figure 10. Results of Automatic Drying of Arabica Coffee Beans

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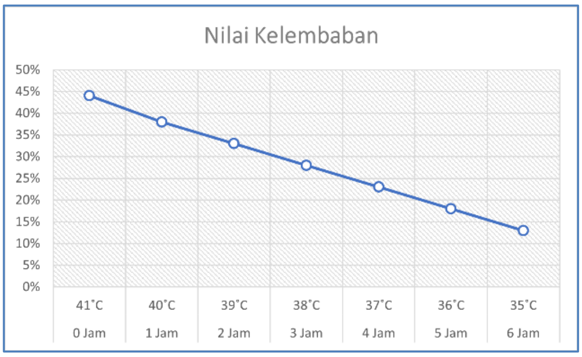
Source: (Research Results, 2024)
Figure 11. Results of Coffee Weight Size Reduction



Source: (Research Results, 2024)
Figure 12. Humidity and Temperature Value Graph

As shown in Figure 12, the developed drying system efficiently regulates temperature and humidity in the drying chamber. The system provides clear indicators when optimal drying conditions are reached. The faster process compared to conventional methods also has a positive impact on productivity.

CONCLUSION

The Arduino Mega 2560-based coffee bean drying system with the fuzzy logic method has been proven to be able to maintain temperature and humidity according to optimal standards, increase drying efficiency, and produce better quality coffee compared to conventional methods. The reduction in the weight of the coffee beans used from 5kg to 3kg is proof that the coffee dryer can reduce the amount of water in the coffee beans themselves, resulting in coffee beans with a quality taste. The solution offers innovation in the coffee drying process but also has a significant impact on the coffee industry in Indonesia, Especially in areas that rely on traditional methods.

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