Enhancing Bamboo Dryer Using IOT Control

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Abstract. The ideal temperature and humidity levels for the drying process of bamboo vary depending on the species of bamboo and desired product. This system has been designed to create an optimal and controlled drying environment within the temperature range of 50°C to 52°C encompassing three integral subsystems. At the core of this innovation lies the Control Subsystem, a pivotal entity responsible for maintaining the precise drying conditions required for optimal results. This subsystem integrates a range of components, including the NodeMCU-ESP32 microcontroller, DHT22 temperature and humidity sensors, 2 Channel 5V relays, AC Heater, and AC Fan. These elements collaboratively function to dynamically regulate the temperature and humidity parameters essential for efficient bamboo drying. The Communication Subsystem, seamlessly interfaced with the Blynk cloud platform, bridging the gap between the IoT components and user interaction. Through this innovative feature, the drying process becomes accessible from remote locations, enabling real-time monitoring and control via the Blynk mobile application. The Monitoring Subsystem through the I2C LCD Display provides users with a localized display of critical drying such as average temperature and humidity. On the experimental results, a comparative analysis between the traditional sun-drying approach and the IoT-Based Dryer method elucidates significant differentials in weight loss and moisture reduction trends. The latter consistently showcases heightened efficiency by achieving higher average moisture loss percentages, signifying its ability to rapidly reduce moisture content within bamboo samples by 5%. Furthermore, the IoT-Based Dryer method demonstrates enhanced time efficiency, predictability, and consistency due to its controlled and optimized drying conditions.

Keywords: Bamboo dryer, IOT-based Controller, Temperature Control.

1 Introduction

1.1 Overview

The suitable temperature and humidity for different bamboo species can vary as different species may have different requirements for optimal growth and preservation. High temperatures and relative humidity above 70% facilitate mold growth in Tropical climate [1]. The challenge of effectively controlling the temperature in bamboo drying environments is essential to prevent plant damage and achieve optimal drying results. This is attainable through precise temperature control methods, including heating, ventilation, and insulation. Continuously monitoring temperature and humidity for both the bamboo species being dried and local climate conditions is crucial to maintaining bamboo quality throughout the drying process.

1.2 Issues with Bamboo Drying

Bamboo, a highly renewable resource, undergoes drying for processing, preservation, and use. Yet, inadequate temperature and humidity regulation during drying can lead to cracks, warping, and reduced quality. The aim is to design a temperature control system ensuring consistent and controlled drying conditions for optimal results and enhanced bamboo product quality.

Conventional bamboo drying lacks precision and reliability, often yielding inconsistent outcomes and defects. Manual adjustments of temperature and humidity are error-prone and time-consuming. Recent global events, like the COVID-19 pandemic, have underscored the importance of intelligent, eco-friendly bamboo drying development. Sun drying exposes bamboo to the vagaries of weather, resulting in varying temperature and humidity conditions. Therefore, the quality of dried bamboo can be inconsistent, leading to defects such as cracks and warping. Additionally, the extended duration of sun drying can contribute to prolonged exposure, potentially affecting the overall quality and durability of the final bamboo products.

2 Bamboo Drying

2.1 Background on Drying

In [2], it was reported that defects in the drying process were reduced by employing the circulation of air from many sources with forced convection through a heater. In order to determine the drying time, as the drying time increases, the final water content will reduce [3].

2.2 Types of Bamboo Drying Methods

In the past, air-drying has been the norm in rural locations and in bamboo companies with low production volumes, although it has significant drawbacks. Climate plays a significant role in the air-drying process. The term "air drying" refers to a drying method in which air itself serves as the drying medium, and in which many forms of heat are possible [4].

Drying under the sun is expanded into solar drying, which makes use of the sun's radiation energy. However, there are a few issues with solar drying that prevent it from being used for mass production which includes the high cost of space and labour and the imprecision of drying times. Solar drying systems are popular in many countries due to their low energy use and low cost [5].

Kiln drying is more effective than air drying comparatively. This is a faster way to dry bamboo to the proper moisture level. Since there is a significant demand for production and trade, kiln-drying is a viable option to air-drying that can guarantee premium-quality bamboo. To achieve the desired moisture content reduction in bamboo, kiln-drying entails stacked bamboo culms and bamboo splits in a chamber with controlled air circulation, temperature, and humidity [4].

2.3 Proposed Modern Solutions for Bamboo Drying

By integrating wireless sensors, automated drying technology, and intelligent ventilation, bamboo drying can greatly improve. Shifting from manual data entry to IoT technology enhances material monitoring, temperature, and humidity regulation. Real-time adaptation and effective resource management through IoT, big data, and AI enable intelligent and efficient bamboo drying processes. These advances contribute to a data-driven bamboo drying system for sustainable practices.

IoT dryer's conditions are optimized for efficient and effective moisture removal. Moreover, the shorter drying time achievable with the IoT dryer contributes to preserving the inherent strength and quality of the bamboo, ensuring a reliable and superior product. The IoT dryer's capability to maintain consistent conditions translates to enhanced product quality, reduced waste, and improved resource efficiency. As the world moves towards sustainable and data-driven practices, the adoption of such advanced drying technologies holds the promise of elevating bamboo processing and utilization to new levels of reliability and excellence.

2.4 Types of Dryer Controller

Maintaining a desired value for a given variable or set of parameters is the goal of the control system. PID control technology is most effective when a clear mathematical model of the controlled object's structure and characteristics is either unavailable or impossible to get. Due to the large system controlling error that would be generated by using a typical PID controller to regulate a product drier, as well as the number of variables in play that might potentially alter the outcome of the process, it would be impossible to achieve desirable control. Using the PID approach, the dryer's temperature can be precisely adjusted, and the moisture content of grain can be tracked in real time [6].

Fuzzy controller has been widely adopted as controller for any system. It is reported in [7] that the drying chamber's temperature and humidity regulation mechanism formed the dual input of the Fuzzy controller. While the lower and upper ventilated doorway control signals form the output from the Fuzzy controller.

2.5 Internet of Things (IoT)

There are only four components in Internet of Things (IoT) namely sensing, connection, data, and user interface (UI) [8]. To regulate an IOT-based dryer, various sensors, including temperature and humidity moisture are used. IOT has eased users by way of automation and without using manual labour, it is simple to check the status of lights, buzzer, water pump, and fan in a dryer system. The Internet of Things (IoT) platform Blynk [9] allows users to remotely operate devices like Arduino, Raspberry Pi, and NodeMCU from their iOS or Android smartphones.

3 Development of the IOT-based Bamboo Dryer

3.1 The Controller System

In the flowchart shown in Fig. 1, the bamboo drying process begins with the collection of temperature and humidity data from the DHT22 sensors placed inside the dryer. These sensors continuously monitor the drying environment, sending real-time readings to the NodeMCU ESP32 microcontroller. The NodeMCU ESP32 serves as the brain of the operation, where it processes the incoming data and makes decisions based on the set parameters.

As the drying process progresses, the NodeMCU ESP32 assesses the temperature data. If the temperature falls below the lower limit of 50°C, the microcontroller activates the AC Heater. The heater generates warmth, gradually elevating the temperature inside the dryer. Simultaneously, the NodeMCU ESP32 evaluates the humidity level. Should the humidity exceed a predefined threshold which is 23%, the microcontroller triggers the AC Fan. The fan initiates, facilitating airflow that helps regulate humidity by expelling excess moisture from the drying environment.

Conversely, if the temperature climbs beyond the upper threshold of 52°C, the NodeMCU ESP32 promptly deactivates the AC Heater to prevent overheating. Similarly, when the humidity drops to an optimal level, the AC Fan is turned off, conserving energy while maintaining the desired humidity range. Throughout this process, the NodeMCU ESP32 continuously monitors and adjusts the drying conditions by intelligently toggling the heater and fan as required, ensuring the temperature remains within the 50°C to 52°C range. With reference to the study made in [10], this temperature ranged was selected in the developed dryer to avoid degradation to the bamboo during drying.

3.2 The System Architecture

The system architecture in Fig. 2 consists of three subsystems as follows:
1. Control Subsystem (NodeMCU-ESP32, DHT22, Heater, Fan)
2. Communication Subsystem (Database)
3. Monitoring Subsystem (Blynk platform)

Subsystem No.1: The Control Subsystem is at the brain of the bamboo drying system, responsible for maintaining optimal drying conditions within the drying chamber. It encompasses essential components such as the NodeMCU-ESP32 microcontroller, DHT22 temperature and humidity sensors, 2 Channel 5V relays, AC Heater, and AC Fan.

- NodeMCU-ESP32: Serving as the central processing unit, the NodeMCU-ESP32 orchestrates the entire drying process. It collects real-time data from the DHT22 sensors, calculates the average temperature and humidity, and makes informed decisions based on predefined thresholds.
- DHT22 Sensors: These sensors play a pivotal role in monitoring the drying environment. They capture accurate temperature and humidity readings from within the drying chamber and transmit this data to the NodeMCU-ESP32.
- 2 Channel 5V Relays: The 2 Channel 5V relays serve as the control interface between the NodeMCU-ESP32 and the AC Heater and AC Fan. Based on the calculated average conditions, the NodeMCU-ESP32 activates or deactivates the corresponding relay to regulate the AC Heater and AC Fan.
- AC Heater and AC Fan: The AC Heater and AC Fan contribute to the controlled drying process. The AC Heater elevates the internal temperature when required, while the AC Fan ensures proper air circulation. The NodeMCU-ESP32 controls these components through the 2 Channel 5V relays.

Subsystem No.2: Communication Subsystem (Blynk): The Communication Subsystem facilitates seamless remote access and control of the drying process via the Blynk cloud platform.

- Blynk Cloud Platform: Blynk acts as the bridge between the IoT components and the user. It allows users to remotely monitor and control the drying process using the Blynk mobile application. Through the Blynk app, users can visualize real-time data, receive notifications, and adjust drying parameters.

Subsystem 3: The monitoring subsystem block is the last system directly connected to the user. The sensing data from the microcontroller will be presented in a dashboard containing data on temperature and humidity. The Monitoring Subsystem provides a local display of essential information about the drying process, enhancing user interaction and transparency.

- I2C LCD Display: The LiquidCrystal_I2C display presents vital data, including the average temperature and humidity, in a user-friendly manner. This local display provides quick insights to users without relying solely on the mobile application.

All the components of all the 3 subsystems are shown in Fig. 2 with 2 number of the temperature and humidity sensors formed the inputs to the ESP-32 microcontroller. As for the heater, fan and LCD display will be connected as output from the ESP-32. The ESP-32 is also connected to the Database in the Blynk Platform which enabled a Graphical User Interface (GUI) interface through apps and web.

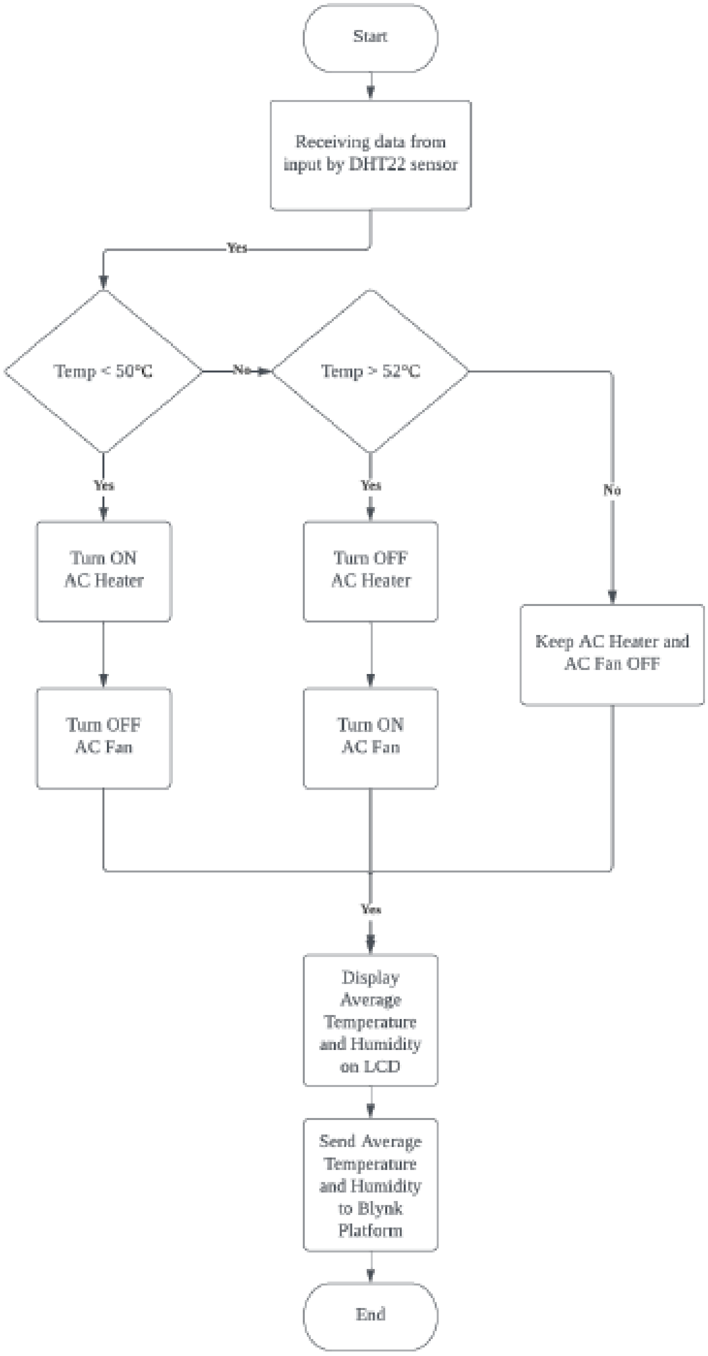

Fig. 1. Flowchart of the controller system

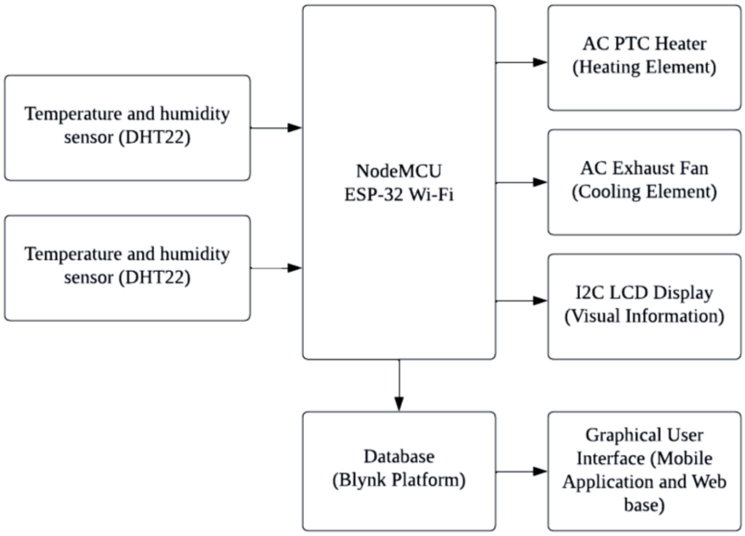

Fig. 2. Block Diagram of the control system

3.3 The Cubic Feet Calculation (CFM)

The aim is to maintain bamboo drying temperatures to within the range of 50°C to 52°C, therefore, the calculated CFM value becomes a foundational element for achieving this goal. By using the exhaust fan to circulate air and manage heat dispersion, it will create an environment conducive to controlled drying.

The CFM Calculation is as follows:
Given chamber volume: 3x3x3 feet drying chamber = 27 ft^3
Cubic feet desired air changes per hour: 8

$$\text{CFM} = (\text{Volume} \times \text{Desired Air Changes per Hour}) / 60 \text{ CFM} \quad (1)$$
$$= (27 \text{ ft}^3 \times 8) / 60 \text{ CFM} = 3.6 \text{ CFM}$$

The calculated CFM value of 3.6 CFM informs the choice of an appropriate 4-inch AC exhaust fan, ensuring effective ventilation and contributing to the controlled drying process of the bamboo. Within the dimensions of 3x3x3 feet drying chamber, calculating the required CFM assists in selecting the appropriate 4-inch AC exhaust fan.

3.4 The Final Prototype

Fig. 3 shows the implementation of the control panel utilizing the NodeMCU ESP32, I2C LCD Display, and 2 Channels 5V Relay module, securely stacked on an acrylic board with standoffs, introduces a well-organized and efficient control interface to your bamboo drying project. Referring to Fig. 4, with the door ajar, the internal sidewalls, meticulously shielded by robust aluminium foil, come into view, demonstrating a methodical approach to moisture management. Positioned at the centre-bottom is the AC PTC Heater, a pivotal apparatus in achieving the prescribed temperature range. Its strategic placement ensures a homogeneous dispersion of heat throughout the drying chamber. The incorporation of an iron grill serves as an integral framework for bamboo placement, optimizing airflow and promoting uniform drying. Fig. 5 shows the monitoring of temperature and humidity through the Blynk Platform mobile applications.

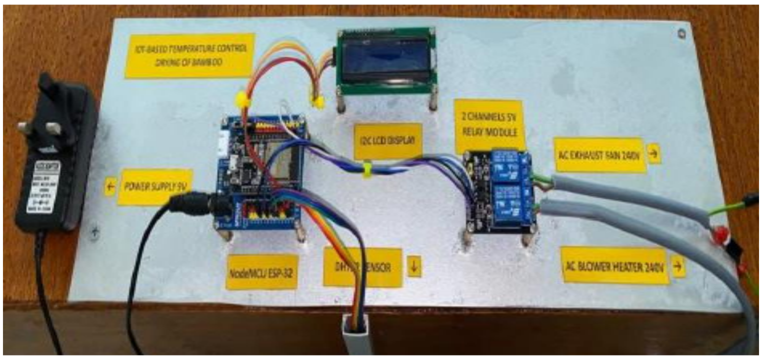

Fig. 3. Control Panel System

Fig. 4. Front and Inside View of the Dryer

Fig. 5. Monitoring temperature and humidity through Blynk Platform Mobile Application

4 Preliminary Results of the Prototype Testing

4.1 Experimental Results

A total of six bamboo samples having similar weights were tested by comparing the drying effect in direct sun drying and using the IOT-based Dryer prototype for seven hours. In the sun drying experiment, the initial temperature is noted as 33.5°C, reflecting the ambient drying conditions. Over the course of the drying process, temperature fluctuations are observed. In the 2nd hour, the temperature increases to 35.2°C, followed by a decrease to 33.8°C in the 4th hour, and a subsequent rise to 34.5°C in the 6th hour. The average temperature every 2 hours is determined to be 34.5°C. As shown in Table 1, Bamboo A, starting at 156g, loses 26g by the 7th hour. Bamboo B, with an initial weight of 153g, loses 25g, while Bamboo C, beginning at 163g, experiences a weight loss of 28g.

Table 1. Weight Loss Versus Time

(a) Sun Drying

TIME (h)	WEIGHT (g)		
	A	B	C
1	156	153	163
2	149	147	156
3	146	143	152
4	141	139	147
5	136	134	141
6	133	131	138
7	130	128	135

(b) IOT-based Dryer Prototype

TIME (h)	WEIGHT (g)		
	A	B	C
1	150	146	162
2	139	137	152
3	133	128	146
4	127	122	140
5	122	116	135
6	118	112	131
7	113	108	127

As for the IOT-based prototype, the initial temperature is noted as 33.5°C (same initial temperature was set as per the sun drying experiment), reflecting the starting point of the drying process. In the 2nd hour, the temperature rises significantly to 50.2°C, followed by a further increase to 52.3°C in the 4th hour, and a subsequent slight decrease to 51.8°C in the 6th hour. The average temperature every 2 hours is calculated as 51.4°C. As shown in Table 1, it is observed that, for the prototype drying experiment, Bamboo A, starting at 150g, experiences a weight loss of 37g by the 7th hour. Bamboo B, initially at 146g, undergoes a weight loss of 38g, and Bamboo C, with an initial weight of 162g, loses 35g.

4.2 Discussions on the Experimental Results

In both scenarios, the weight loss data reflects a consistent trend of decreasing weight over time for all bamboo samples. This weight reduction is indicative of successful moisture removal from the bamboo during the drying process. The contrasting temperature conditions significantly impact the rate of moisture evaporation and, consequently, the weight loss of the bamboo. In the IoT-Based Dryer scenario, where higher temperatures are maintained, the rate of moisture removal is accelerated due to increased thermal energy, resulting in a more substantial weight loss compared to the sun-drying scenario.

Additionally, variations in the bamboo's inherent moisture content could contribute to the observed differences. Bamboo A and Bamboo B might have started with relatively lower moisture content, leading to faster initial weight loss. Bamboo C, with a higher initial weight, could have contained more moisture, resulting in a slower weight loss rate to achieve the same level of dryness.

5 Conclusions

The IoT-Based Dryer demonstrated its effectiveness in maintaining precise and controlled drying conditions, leading to improved moisture loss rates compared to traditional sun-drying methods. The dynamic regulation of temperature and humidity using the AC Heater and AC Fan, guided by real-time sensor data from the DHT22, showcased the system's adaptability and responsiveness. The comparison of moisture loss profiles among different bamboo samples (A, B, and C) underscored the influence of varying bamboo attributes on drying behavior. This understanding highlights the importance of tailored drying approaches to accommodate different bamboo species and their inherent characteristics. The successful integration of the Blynk platform provided seamless remote monitoring and control capabilities, enhancing user convenience and system management. The visualization of real-time temperature and humidity data on the Blynk dashboard facilitated informed decision-making and the ability to make timely adjustments to drying parameters. Energy consumption optimization remains a key focus for future endeavors. Exploring strategies to minimize energy usage while upholding drying efficiency could involve the development of algorithms that factor in variables like time of day, ambient temperature, and humidity levels.

Acknowledgements

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References

1. Tang, TKH., O Schmidt, and W, Liese.: Protection of Bamboo Against Mould Using Environment-Friendly Chemicals. *Journal of Tropical Forest Science* 24(2), 285–90 (2012).
2. Atienza, A.H., Dela Peña, P., Eroles, R. and Fandiñola, E.: Multi-Directional Forced Convection Kiln Oven Drying System for Bamboo Culms. *IOP Conf. Ser.: Mater. Sci. Eng.* 739 (2020).
3. Saparudin, M.A., Setiawan, R.J., Budi, E., Puspito, A. and Fauzi, I.: Design and Manufacture of Bamboo Handicraft Dryer Machine Based on LPG Gas. *Tadulako Science and Technology Journal* 2, 01-09 (2021).
4. Liese, W., and Tang, T. K. H.: Preservation and Drying of Bamboo In: Liese, W., Köhl, M. (eds) *Bamboo*. Tropical Forestry, vol 10. Springer, Cham. 257–297 (2015).
5. Nguyen V.L.: Improvement of Conventional Solar Drying System. In: 2017 International Conference on System Science and Engineering (ICSSE), pp. 690-693, Ho Chi Minh City, Vietnam (2017).
6. Fahruzi, A., and Rhamdany, R.: An Automatic Grain Dryer Prototype Using the PID Method as Temperature Controller. *Jurnal INFORM*, 5(2) (2020).
7. Zhu, D. S., Shi, D. D., and Dang, Y.: Study on Corn Ear Drying System Based on Fuzzy Control. In: IEEE 5th International Conference on Electronics Technology (ICET 2022) pp. 601–605, Chengdu, China (2022).
8. Sunardi, Yudhana, A., and Furizal.: Tsukamoto Fuzzy Inference System on Internet of Things-Based for Room Temperature and Humidity Control. *IEEE Access*, 11, 6209–6227 (2023).
9. Media's, E.S. and Rif'an, M.: Internet of Things (IoT): BLYNK Framework for Smart Home. *KnE Social Sciences* 3, 579–586 (2019).
10. Tang, T.K., Welling, J., Ho, T., and Liese, W.: Investigation on optimisation of kiln drying for the bamboo species Bambusa stenostachya, Dendrocalamus asper and Thyrsostachys siamensis. *Bamboo Science and Culture: The Journal of the American Bamboo Society* 25(1), 27-35 (2012).