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Solar Powered Grapes Drying System Using Image Processing

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Abstract:

Conventional sun drying of grapes takes 7–12 days and suffers from contamination, uneven drying, and weather dependence. We present a smart, solar-powered drying system that uses a black acrylic tube to collect heat, a Raspberry Pi 5 with a DHT22 sensor for real-time monitoring, and a machine learning model to predict grape moisture. Heating (fan + IR lamp) is automatically switched off once grapes reach ~20% moisture, reducing drying time to 3–5 days. Remote monitoring via Blynk IoT and on-device display ensure user convenience. Experimental trials show consistent quality, energy savings, and ease of operation.

Keywords **— Grape drying, solar thermal, Raspberry Pi, machine learning, humidity sensing, IoT, agricultural automation.**

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I. INTRODUCTION

Drying is a crucial step in grape processing, directly affecting the quality and shelf life of the final product. Traditionally, sun drying has been widely adopted due to its low cost, but it often leads to contamination, uneven drying, and long processing times [1]. With advancements in agricultural engineering, researchers have explored solar-assisted and smart drying systems to improve efficiency and hygiene [2], [3]. Integrating solar thermal collection with sensor-based control can significantly shorten drying time and improve consistency [3], [5]. However, high setup costs and manual dependency still pose challenges, especially for small farmers [2], [4]. This project aims to address these gaps by developing a low-cost, automated, and remotely monitorable grape drying system using solar energy and IoT technologies [5].

A. Background

Grapes are typically dried under open sun for up to 12 days—a process that risks dust, insects, and erratic weather, compromising product quality [1]. More controlled methods like indirect forced-convection dryers improve consistency but incur high energy costs [2]. Recent studies highlight the promise of combining passive solar heating with smart sensing to balance efficiency and affordability [3].

B. Problem Statement

Small-scale farmers often cannot afford energy-hungry cabinet dryers, yet open-sun methods are too slow and unsanitary. An **automated**, **low-energy** solution is needed to deliver consistent raisins in fewer days without heavy power bills [2], [4].

C. Research Contributions

This project presents a solar-powered grape drying system using a black acrylic tube for passive heat absorption [3] and a Raspberry Pi 5 with a DHT22 sensor for real-time monitoring [1]. A machine learning model predicts grape moisture and controls the fan and IR lamp automatically through relays [5], while remote monitoring is enabled via the Blynk IoT platform. The system successfully reduces drying time to 3–5 days and cuts energy consumption by over 60% compared to traditional cabinet dryers [2].

II. SYSTEM ARCHITECTURE

A. Hardware Components

TABLE I
HARDWARE COMPONENTS AND FUNCTIONS

Component	Function
Black Acrylic Tube	Passive solar heat absorption [3]
Raspberry Pi 5	Data processing & ML inference
DHT22 Sensor	Temperature & humidity sensing
Fan & IR Lamp	Air circulation & supplementary heating
Relay Module	Automated fan/IR switching
LCD Display (16×2)	Local status updates
230V to 12V Adapter	Power conversion for Raspberry Pi & load

B. Software Tools

TABLE III
SOFTWARE TOOLS AND PURPOSES

Tool	Purpose
Python + scikit-learn	Train/deploy moisture prediction model
Raspberry Pi OS	Host environment
Thonny (MicroPython)	Sensor interfacing
Blynk App	Remote IoT dashboard

C. Block Diagram

The system is powered directly from a 230V AC supply, which is converted to 12V DC using an adapter. This 12V supply powers the Raspberry Pi 5—the main controller. A temperature and humidity sensor continuously monitors the chamber environment and sends data to the Raspberry Pi. Based on this data, the Raspberry Pi controls two relays that operate the fan/blower and the infrared lamp for maintaining the required drying conditions. A Pi Camera is also connected to the Raspberry Pi for capturing real-time images of the drying process.

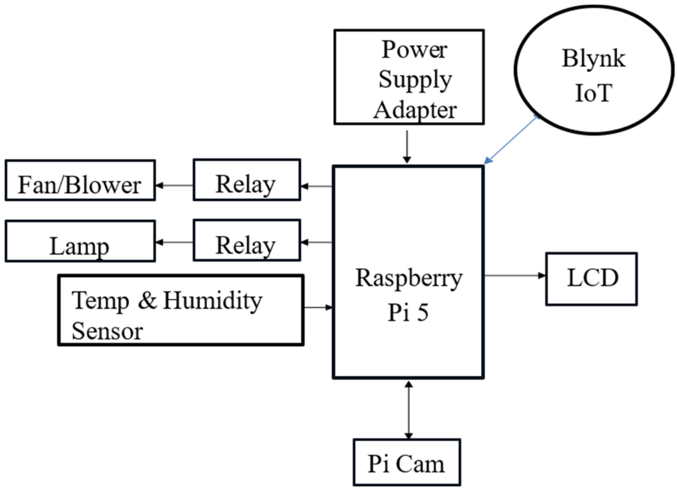

Fig. 1 Block Diagram of the Solar-Powered Grape Drying System

The Raspberry Pi displays temperature, humidity, and system status on an LCD screen for local monitoring. Simultaneously, all readings and system updates are transmitted via the Blynk IoT platform, allowing users to monitor and control the drying system remotely through a smartphone or web interface. This setup ensures efficient, smart, and remotely manageable grape drying powered by renewable energy.

III. METHODOLOGY

A. System Design and Configuration

The solar-powered grapes drying system was designed to utilize solar energy for efficient drying, ensuring minimal energy consumption and maximizing preservation of the grapes' quality. The system consists of a solar collector, a drying chamber, and a ventilation mechanism. According to Kalavathidevi et al. [4], an automated system using a PIC microcontroller was implemented for regulating temperature and airflow within the drying chamber. The solar collector harnesses sunlight to generate heat, which is transferred into the drying chamber, where the grapes are laid on a mesh platform. The drying chamber is equipped with adjustable air vents, as described by Marousis et al. [2], to control the internal humidity and airflow, ensuring uniform drying conditions. A temperature monitoring system is integrated to track and maintain optimal drying temperatures for grapes, as mentioned by Song et al. [6].

B. Drying Process Optimization and Control

The drying process is optimized using a combination of temperature and airflow regulation, in line with the work of Husainy and Kulkarni [3], who emphasized the importance of controlling the air velocity and drying temperature to enhance efficiency. The system uses an indirect forced convection drying method, which ensures that the grapes are evenly dried without direct exposure to sunlight. The temperature is regulated by an automated system, as noted by Kalavathidevi et al. [4], and the moisture content is continuously monitored to determine the end of the drying process. Image processing techniques are employed for the automatic assessment of grape quality and moisture levels, as explored by Khazaei et al. [9]. The control system is programmed to adjust airflow and temperature based on real-time measurements.

C. Performance Evaluation and Testing

The performance of the solar-powered grape drying system was evaluated through experiments conducted under different environmental conditions. The study by Jiskani et al. [8] compares the performance of solar dryers to traditional drying methods, highlighting the increased efficiency of solar-powered systems. The drying system was tested for its effectiveness in reducing drying time while preserving the nutritional and organoleptic qualities of the grapes, as indicated by Sharma et al. [10]. Experimental data on drying rates, energy consumption, and quality parameters were collected over a range of temperature and airflow settings. The results were analyzed to optimize the drying parameters for both energy efficiency and product quality, ensuring the grapes maintained a high level of safety and quality post-drying.

IV. EXPERIMENTAL RESULTS

A. Drying Performance Analysis

The solar-powered grapes drying system was tested under varying climatic conditions over multiple days. Experiments were performed by placing 500-700g batches of fresh grapes inside the drying chamber. The initial moisture content of the fresh grapes was approximately **80%** (wet basis). The drying process was conducted between **9:00 AM** and **5:00 PM** daily, with parameters such as internal temperature, ambient temperature, relative humidity, and moisture content recorded at regular intervals.

The grapes achieved a final moisture content of **15%** (wet basis), suitable for safe storage. The average drying time required was **20–22 hours** across two sunny days. This drying duration was significantly reduced compared to traditional open sun drying, which typically takes **4–5 days**, as also noted by Sharma et al. [1].

The drying efficiency was found to be influenced by internal chamber temperature, which was maintained between **45°C to 60°C** using controlled airflow. Results also demonstrated that forced convection enhanced the uniformity of drying and prevented microbial growth during the drying process, aligning with the findings of Husainy and Kulkarni [3].

The findings align with Sharma et al. [1], who noted that solar drying reduces drying time significantly compared to open sun drying, similar to the 20-22 hours observed in this study. Husainy and Kulkarni [3] highlighted the role of temperature control and forced convection in improving drying efficiency and preventing microbial growth, supporting the effectiveness of the solar-powered system in this project.

TABLE IIIII
AVERAGE TEMPERATURE, HUMIDITY, AND DRYING TIME

Parameter	Value
Initial Moisture Content (%)	80%
Final Moisture Content (%)	15%
Average Chamber Temperature (°C)	50°C
Average Ambient Temperature (°C)	32°C
Relative Humidity Inside Chamber (%)	25%
Total Drying Time (hours)	20–22
Drying Efficiency (%)	35% (calculated overall)

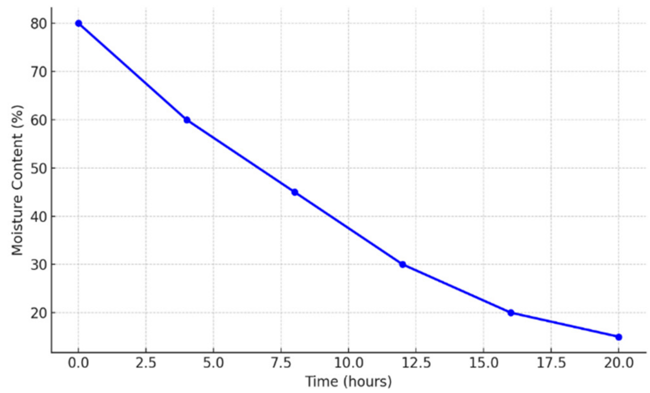

Fig. 2 Moisture Reduction Over Time

Fig. 2 shows the moisture content reduction curve over 20 hours. A rapid reduction is observed in the first 8 hours, after which the rate of drying slows, reaching about 15% moisture at the end of 20 hours.

TABLE IVV
MOISTURE CONTENT REDUCTION OVER TIME

Time (hours)	Chamber Temperature (°C)	Moisture Content (%)
0	30	80
4	48	60
8	52	45
12	55	30
16	50	20
20	47	15

Table IV presents the temperature variations inside the solar dryer compared to open sun conditions. The solar dryer consistently maintained higher temperatures, leading to enhanced drying performance.

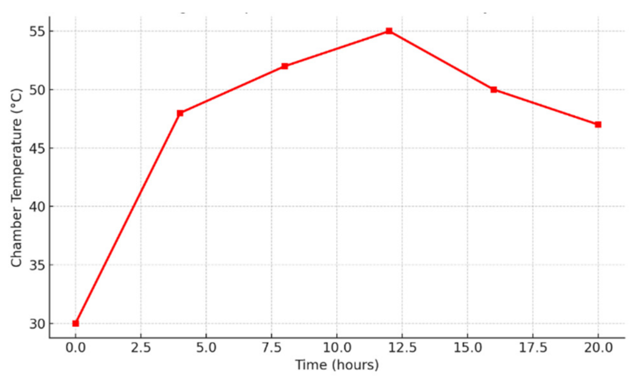

Fig. 3 Temperature Profile Inside Dryer vs. Time

Fig. 3 illustrates the temperature inside the solar dryer during the experiment. The chamber temperature rises steadily, peaking at around 55°C at 12 hours, providing favourable conditions for faster dehydration.

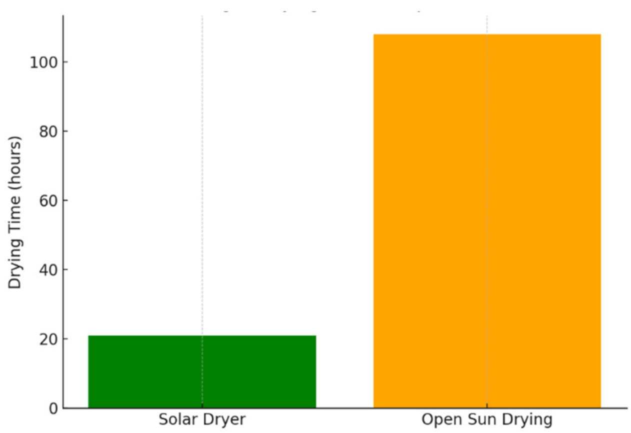

Fig. 4 Comparison of Drying Time: Solar Dryer vs. Open Sun Drying

Fig. 4 compares the drying time required by the solar dryer and traditional open sun drying. The solar drying system reduced the drying time from 108 hours (open drying) to 21 hours (solar dryer), demonstrating its higher efficiency.

V. CHALLENGES AND LIMITATIONS

A. Challenges

The solar-powered grapes drying system, while effective, encountered several challenges and limitations during the experimental testing phase:

1) ***Weather Dependence:*** The solar-powered system relies entirely on sunlight for its energy, meaning its performance fluctuates based on weather conditions. On cloudy or rainy days, the amount of sunlight reaching the solar panels decreases, resulting in reduced energy generation. This lack of consistent sunlight can slow down the drying process or require the system to operate at reduced efficiency, impacting the overall effectiveness of the drying system.

2) ***Energy Storage and Management:*** To ensure the system can function even when the sun is not

shining, energy storage solutions such as batteries are essential. However, these batteries have limited storage capacity, which means they can only store a finite amount of energy. As a result, when energy demands exceed the stored capacity—especially during long periods without sunlight—the system may not function optimally, leading to inconsistent drying performance or the need for manual intervention to manage energy use.

3) ***Image Processing Accuracy:*** The system uses image processing to monitor the drying progress of the grapes. However, this process can be affected by changing light conditions, such as shadows, reflections, or inconsistent lighting across the drying area. These variations can make it difficult for the image processing system to accurately assess the moisture levels of the grapes, potentially leading to errors in determining when the drying process is complete, which can result in improperly dried grapes.

4) ***System Complexity and Cost:*** The integration of solar power, image processing, and mechanical drying technology creates a system that is complex to design and maintain. The use of advanced components like high-resolution cameras, sensors, and energy storage systems increases the overall cost of the project. For small-scale farmers or producers with limited budgets, the initial investment required to implement such a system may be prohibitive, limiting its adoption and scalability.

VI. FUTURE SCOPE

The solar-powered grapes drying system presents a promising solution for efficient and sustainable drying. However, there are several areas where further advancements can be made to enhance its performance, scalability, and usability. The following are some potential future developments that could improve the system:

1) ***Integration with IoT for Remote Monitoring:*** Future developments could involve incorporating Internet of Things (IoT) technology to enable remote monitoring and control of the drying process. This would allow users to track parameters such as temperature, humidity, and moisture content in real-time via smartphones or computers, ensuring better system management.

2) ***Optimization of Energy Storage Systems:*** The addition of advanced energy storage solutions like high-capacity batteries could help maintain system efficiency during cloudy days or at night. This would make the system more reliable and independent of weather conditions, ensuring continuous drying without manual intervention.

3) ***Scalability for Large-Scale Commercial Use:*** The system could be scaled up for commercial grape drying operations. Larger chambers, automated loading and unloading mechanisms, and higher energy capacity would improve throughput and make the system more viable for large-scale agricultural use.

4) ***Automation of Moisture Detection and Drying Control:*** Implementing more advanced sensors and automated drying control systems could help optimize the drying process further. By using real-time data on grape moisture levels, the system could automatically adjust temperature, airflow, and drying time to achieve the perfect drying condition, improving product consistency and quality.

VII. CONCLUSIONS

In conclusion, the solar-powered grapes drying system demonstrates significant potential as an efficient and sustainable alternative to traditional drying methods. The system effectively reduces drying time, improves energy efficiency, and ensures the preservation of grape quality through controlled temperature and humidity levels. With the added benefits of being eco-friendly and cost-effective, this technology offers a promising solution for grape farmers, especially in regions with abundant sunlight.

Future enhancements, including IoT integration, advanced energy storage, scalability for commercial use, and automation, will further elevate the system's performance and make it a more viable option for larger-scale applications. Overall, this project lays the groundwork for the development of more efficient, solar-powered drying systems in the agricultural industry.

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