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# IoT-Based Solar Dehydration Tunnel: Controlling and Monitoring Units

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## ABSTRACT

***This project presents the design and implementation of an IoT-based solar dehydration tunnel system aimed at enhancing the efficiency and control of food dehydration processes. The system integrates solar energy as the primary heat source with smart sensors and microcontrollers to monitor critical environmental parameters such as temperature, humidity, and airflow within the dehydration chamber. Real-time data acquisition and transmission are enabled through Internet of Things (IoT) technologies, allowing remote access and control via web or mobile interfaces. The control unit dynamically adjusts fan speeds and ventilation based on sensor feedback to maintain optimal drying conditions, improving energy efficiency and product quality. The proposed system contributes to sustainable food processing by reducing dependency on conventional energy sources and enabling precision drying through intelligent automation.***

***Keywords: IoT, Solar Dehydration, ESP32, DHT11, LDR, Arduino, Smart Agriculture, Renewable Energy***

## 1. INTRODUCTION

A Solar Dehydration Tunnel is a sustainable solution for drying agricultural products like fruits, vegetables, and herbs. Integrating IoT (Internet of Things) into this system allows for real-time monitoring and control, enhancing efficiency and product quality. Solar dehydration is a widely used method for preserving food, especially in agricultural regions. However, traditional solar dryers lack precise control, leading to inconsistent drying and potential product loss. The integration of IoT technology overcomes these limitations by providing real-time monitoring and automated adjustments based on environmental conditions. In this project, sensors collect data on temperature, humidity, and moisture levels inside the drying chamber. This data is transmitted to a microcontroller, which processes the information and adjusts parameters such as fan speed and vent openings. A mobile or web-based application allows users to monitor the drying process remotely. The system not only improves efficiency but also reduces manual intervention, making it an ideal solution for farmers and small-scale food processors. By leveraging renewable energy and smart automation, the IoT-based solar dehydration system offers a sustainable, cost effective, and efficient method for food preservation, reducing post- harvest losses and improving food security

## 2. MOTIVATION

An IoT-based solar dehydration system is a smart and sustainable solution for drying agricultural products (like fruits, vegetables, herbs) using solar energy, enhanced with Internet of Things (IoT) technology for monitoring and control.

## 3. OBJECTIVES

The objective of this project is to design and develop a smart solar dehydration system integrated with IoT technology to efficiently monitor and control the drying process of agricultural products. The system aims to optimize drying conditions using real-time data on temperature, humidity, and moisture levels, thereby enhancing drying efficiency, reducing energy consumption, and minimizing post-harvest losses. It also enables remote monitoring and automation, making it suitable for use in rural and off-grid agricultural environments.

## 4. BRIEF DESCRIPTION OF THE PROJECT WORK

The project work involved the design and development of a smart solar dehydration system using IoT technology to improve the efficiency of drying agricultural products. The work began with identifying the need for an affordable, eco-friendly, and automated drying solution. A solar drying chamber was constructed using insulated materials to retain heat, and sensors like DHT11 (temperature and humidity), LDR (light intensity), and a load cell (for weight loss) were installed. These components were connected to an ESP32 microcontroller, which controlled fans and vents based on sensor readings. A solar panel with a battery backup was used to power the system. Real-time data was monitored through a mobile/web app using platforms like ThingSpeak. The system was tested with various crops to ensure effective dehydration and optimized control. This project demonstrated how renewable energy and IoT can be combined for smarter, more sustainable agricultural practices.

## 5. LITERATURE SURVEY

In recent years, the integration of renewable energy and IoT technology in agriculture has gained significant attention. Several studies and innovations have been explored to improve food preservation through solar drying systems and smart monitoring techniques. 1. Traditional Solar Drying Techniques: Conventional solar dryers are widely used in rural areas for preserving agricultural produce. These systems rely on passive solar energy but lack control over drying parameters such as temperature and humidity, often leading to inconsistent results 2. Improved Solar Dryers with Thermal Control: Research has shown that adding basic sensors and temperature regulators enhances the drying process. Some systems integrate heating coils or improved airflow mechanisms for uniform drying 3. IoT-Based Agricultural Monitoring: IoT technology has been successfully applied in precision agriculture, enabling remote monitoring of soil moisture, temperature, and other environmental factors. Platforms like ThingSpeak, Blynk, and Firebase have made it easier to visualize real-time data from sensors 4. Smart Solar Dryers with Sensors: Recent papers have proposed smart solar dryers using DHT11/DHT22 sensors and microcontrollers (Arduino/ESP8266). These systems automate fan control based on humidity levels and provide alerts through IoT dashboards or mobile apps, improving efficiency and reducing manual effort [5][6]. 5. Gap Identified: Most existing systems are either manual or lack real-time monitoring capabilities. There is a need for an integrated system that is low-cost, solar-powered, and IoT-enabled for use in remote areas.

## 6. SUMMARY AND DISCUSSION

This project presents an innovative solution for reducing post-harvest losses by designing an IoT-based solar dehydration system. The system leverages solar energy as a sustainable heat source to dehydrate agricultural products and integrates IoT technology for real-time monitoring and automation. Core components include a solar drying chamber, ESP32 microcontroller, temperature and humidity sensors (DHT11), light sensors (LDR), a load cell, fans, and vents. The setup is powered by a solar panel and a rechargeable battery, making it highly suitable for rural or off-grid environments. Through cloud platforms like ThingSpeak, users can access live environmental data and control system functions remotely. This improves efficiency, reduces manual labor, and ensures consistent drying conditions.

The integration of IoT into solar dehydration addresses several key challenges in traditional drying methods. Manual sun-drying is often inconsistent, weather-dependent, and prone to contamination. In contrast, this system provides controlled, hygienic, and efficient drying using clean energy. The automation of fans and vents based on sensor data ensures the drying process is optimized, while real-time updates allow users to monitor progress remotely. During testing, the system demonstrated effective dehydration for a variety of crops, including fruits, vegetables, and herbs. Challenges such as fluctuating sunlight and sensor calibration were addressed by using insulated chambers and backup batteries. The modular design allows for scalability, and the open-source nature of the hardware/software ensures cost-effective implementation and further development. This project not only enhances agricultural productivity but also supports environmental sustainability and digital transformation in farming practices. With further advancements like AI integration and enhanced data analytics, the system has the potential for broader adoption in both small-scale and commercial farming sectors.

## 7. SCOPE OF THE SOLAR DEHYDRATION SYSTEM

The scope of this project encompasses the design, development, and testing of an intelligent solar-powered dehydration system equipped with IoT capabilities to improve the efficiency of drying agricultural products. This system aims to serve small to medium-scale farmers, especially in rural or off-grid areas, by providing a cost-effective, eco-friendly alternative to conventional drying methods. It allows real-time monitoring and control of key parameters like temperature, humidity, sunlight, and product weight, ensuring consistent and high-quality drying results. The system is scalable and can be adapted for various crops such as fruits, vegetables, herbs, and spices. Its IoT-based features enable remote access via smartphones or computers, making it user-friendly and reducing the need for constant physical supervision. Additionally, the project contributes to reducing post-harvest losses, improving product shelf life, and increasing farmer income by adding value to agricultural produce. facilitate market access. The scope is comprehensive, covering various aspects of farm management to address the diverse needs and challenges faced by modern farmers. .

## 8. METHODOLOGY

### 8.1 Designing Phase:

The designing phase of the IoT-based solar dehydration system plays a critical role in establishing a well-structured, intelligent, and energy-efficient setup for the effective dehydration of agricultural products. This stage involves thorough planning of both the physical structure and the embedded electronic systems to ensure smooth integration of solar energy with IoT technologies. The primary aim of this phase is to create a sustainable and automated system that not only harnesses solar power for drying but also allows real-time monitoring and smart control to enhance the overall efficiency and quality of the drying process.

1. The first step in the designing phase is the construction planning of the solar drying chamber. This chamber serves as the core of the system, where the actual dehydration process takes place. It is designed to capture solar radiation efficiently and convert it into heat energy, which increases the internal temperature to a level suitable for drying agricultural products such as fruits, vegetables, herbs, and spices. The chamber is constructed using materials that provide good thermal insulation, thereby preventing heat loss and maintaining a consistent internal temperature. Additionally, the structure is carefully designed to allow optimal airflow, either through natural convection or assisted by fans, to ensure even drying and prevent the growth of mold or bacteria.
2. Next, the focus shifts to the integration of IoT components, which make the system intelligent and responsive. Various sensors are strategically placed within the drying chamber to monitor environmental conditions and the status of the products being dried. The DHT11 sensor is chosen to measure temperature and humidity, which are crucial parameters in any drying process. A Light Dependent Resistor (LDR) is added to monitor the intensity of sunlight, which helps in evaluating the energy input and adjusting system behavior accordingly. Additionally, a load cell is incorporated to measure the weight of the products placed in the drying chamber. As the moisture content in the products decreases during the drying process, the weight reduces, providing an indirect yet accurate indication of the drying progress.
3. All sensor data is collected and processed by a microcontroller, such as the ESP32, which is selected due to its powerful processing capability, built-in Wi-Fi functionality, and energy efficiency. The microcontroller acts as the central control unit of the system, continuously gathering data from the sensors and making decisions based on pre programmed logic. For example, if the internal temperature drops below the desired range, the system can trigger a fan to enhance air circulation or adjust a vent to improve airflow. These actions are performed using relay modules that interface the microcontroller with electrical components like fans, motorized vents, or heaters (if used).
4. To make the system self-sufficient in terms of power, a solar panel is incorporated, along with a battery storage system. The solar panel harvests solar energy during the day, which powers the system and charges the battery. The battery ensures uninterrupted operation during periods of low sunlight or at night, making the system highly suitable for remote and off-grid agricultural regions, where access to reliable electricity may be limited.
5. The next critical element of the designing phase is cloud connectivity. The ESP32 microcontroller is programmed to send sensor data to an IoT platform such as Blynk, Thing Speak, or Firebase. These platforms act as intermediaries between the hardware and the user, storing data in the cloud and providing access through a mobile or web-based dashboard. This interface allows farmers or users to remotely monitor key parameters in real time, receive alerts if any parameter exceeds safe limits, and even control the system manually if required. This remote access reduces the need for constant physical supervision and ensures greater control over the drying process.
6. To further enhance functionality, control logic is implemented in the microcontroller code. This logic defines how the system should react under certain conditions—for example, turning on the fan if humidity is above a certain level or closing a vent when the temperature gets too high. By automating these responses, the system ensures that agricultural products are dried efficiently, with minimal energy consumption and reduced manual effort.

**8.2 Implementation Phase:** The implementation phase marks the transition from planning and designing to the actual construction and execution of the IoT-based solar dehydration system. During this phase, all the components outlined in the design are procured and assembled to build a functional prototype. The first step involves constructing the solar drying chamber, which serves as the core of the dehydration system. This chamber is built using locally available, cost-effective materials to make the solution affordable and sustainable, especially for rural and remote applications. The structure is carefully designed to maximize solar heat absorption while maintaining proper insulation to prevent heat loss. Strategic placement of air inlets and outlets ensures efficient airflow, which is essential for uniform drying of agricultural products.

Once the chamber is ready, IoT sensors are installed to enable real-time environmental monitoring. A DHT11 sensor is used to measure both temperature and humidity levels inside the chamber, providing crucial data for maintaining optimal drying conditions. An LDR (Light Dependent Resistor) is integrated to detect solar intensity, which helps in understanding the solar energy input and adjusting the operation accordingly. A load cell is also incorporated to measure the weight of the agricultural products, which indirectly indicates the moisture content — as the products lose water, their weight decreases, offering a way to track the drying progress.

These sensors are connected to a central microcontroller, typically an ESP32, which acts as the brain of the system. The ESP32 is selected due to its built-in Wi-Fi capabilities, low power consumption, and compatibility with various sensors. It is programmed to read the sensor data at regular intervals and process it to control other components, such as cooling fans and motorized vents. These actuators are connected via a relay module, allowing the system to respond automatically to changes in internal conditions — for example, activating a fan when the temperature exceeds a certain threshold or opening a vent if humidity becomes too high.

To power the entire setup sustainably, a solar panel system is installed. This includes photovoltaic panels to convert sunlight into electricity and a rechargeable battery that stores energy for use during cloudy periods or nighttime operation. This makes the system energy-efficient and independent of the electrical grid, which is especially beneficial in rural farming areas.

The next step involves setting up cloud connectivity. The ESP32 transmits real-time sensor data to an IoT platform such as Thing Speak, using Wi-Fi. These platforms serve as the backend for a mobile or web application, which is developed to visualize the data. Through this interface, users can monitor temperature, humidity, sunlight, and product weight remotely. Additionally, alerts can be set up to notify the user when specific thresholds are crossed or when the drying process is complete.

Finally, the fully assembled and programmed system is tested using various agricultural products such as chili, tomatoes, bananas, or herbs. These tests help in analyzing the performance of the system under different environmental conditions. Adjustments are made to the control logic or hardware as necessary to improve efficiency and reliability. The testing phase also includes comparing the system's drying time, product quality, and energy consumption against traditional drying methods. The results demonstrate the advantages of using a smart, IoT-enabled approach to agricultural dehydration, highlighting benefits such as better product preservation, reduced manual intervention, and energy savings.

**8.3Testing Phase:** The testing phase of the IoT-based solar dehydration system is essential to evaluate the functionality, performance, and reliability of the developed prototype. This phase begins with the calibration of all integrated sensors, including the DHT11 for temperature and humidity, the LDR for sunlight intensity, and the load cell for measuring weight. Each sensor is tested individually to ensure accurate data collection. After successful calibration, the system is operated under different environmental conditions using selected agricultural products such as tomatoes, chilies, or herbs. The drying process is carefully monitored in real-time through the connected IoT platform (e.g., Thing Speak), allowing the team to track changes in temperature, humidity, and weight throughout the dehydration cycle. During this phase, the automated functions—like fan activation and vent control—are observed to confirm they respond correctly to sensor input based on the programmed thresholds. Multiple test cycles are conducted to compare drying times, energy efficiency, and product quality against traditional drying methods. Based on test results, system parameters and control logic may be adjusted for better efficiency and reliability. This phase validates that the system performs as intended, offering a smart, sustainable, and user-friendly solution for dehydrating agricultural products.

## 9. DETAILS OF DESIGN WORKING AND PROCESS

### 1. System Design :-

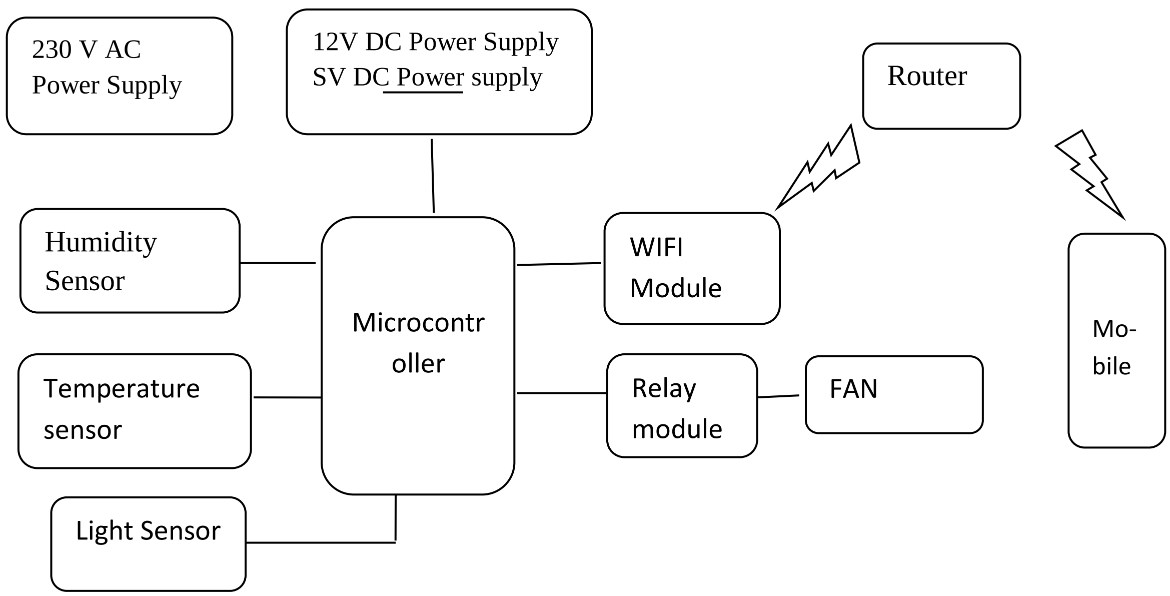


**Fig1: System design of solar dehydration**

The system is designed around three core elements: a solar-powered drying chamber, IoT-enabled monitoring and control, and renewable energy integration. The major design components include:

1. Solar Dehydration Tunnel:
   - Structure: A tunnel-like setup with a transparent cover (usually plastic) to allow sunlight in,
   - with racks inside to place the products.
   - Solar Panels: Power the system, particularly the fans and sensors.
   - Fans: Ensure proper air circulation inside the tunnel to facilitate even drying.
2. Sensors:
   - Temperature Sensors: Measure the temperature inside the tunnel to ensure it stays within the optimal range for dehydration.
   - Humidity Sensors: Monitor the humidity level inside the tunnel, crucial for preventing mold growth.
   - Light Intensity Sensors: Check the amount of sunlight entering the tunnel.
3. Microcontroller/Processing Unit:
   - Microcontroller (e.g., Raspberry Pi Pico W or Arduino): Acts as the central control unit, processing data from sensors and executing commands.
   - Connectivity Module: For wireless communication, a Wi-Fi module can be integrated to send data to a cloud server or mobile app.
4. Actuators:
   - Fans and Vents: Controlled by the microcontroller to maintain optimal temperature and humidity levels.
5. **Working Principle Heating:** Solar radiation heats up the air inside the chamber. Moisture Removal: Heated air absorbs moisture from the crops. Fans help circulate air and push out humid air through vents. Monitoring: Sensors continuously track chamber conditions (temperature, humidity, light). Control: If temperature or humidity exceeds set levels, the system automatically activates or deactivates fans to balance conditions. Power Management: The solar panel charges the battery during daylight and powers the

system continuously. IoT Integration: The ESP32 sends data to a cloud dashboard, allowing users to view real-time status and receive alerts or control the system remotely.

6. **Process Flow**
    - Setup: Fresh agricultural produce is placed inside the solar drying chamber.
    - Sensor Activation: Sensors begin monitoring environmental conditions.
    - Data Processing: Microcontroller processes the data and decides whether to turn on/off fans or adjust vents.
    - Drying: Moisture gradually leaves the produce; weight loss is tracked via the load cell.
    - User Monitoring: Real-time data is sent to the mobile/web dashboard.
    - Completion: Once the target dryness is reached (based on weight or time), the system notifies the user or automatically stops.

## 10. FUTURE SCOPE

The IoT-based solar dehydration system presents numerous opportunities for future development and large-scale application. As technology continues to advance and the need for sustainable agricultural practices grows. With advancements in AI and cloud computing, it can be upgraded to automatically control drying conditions based on crop type and weather. Enhancements in the mobile app and integration with smart farming systems will improve usability and efficiency. Its scalable and modular design makes it suitable for commercial and rural applications. Future collaboration with governments and NGOs can help deploy this system in remote areas, promoting sustainable agriculture and reducing post-harvest losses.

## 11. CONCLUSION

The IoT-based solar dehydration system offers a practical and sustainable solution to agricultural drying challenges. By combining renewable energy and IoT technology, the system provides efficient drying, minimizes manual intervention, and supports remote monitoring. This innovation contributes to smarter agriculture and reduced post-harvest waste, helping farmers increase profitability and reduce dependency on traditional drying methods.

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