PROJECT NAME: IOT APPLICATIONS IN SOLAR DRYING

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Abstract:

In a developing country like India, agriculture plays a major role in the economy and is very much needed for increasing population. Although India is the top producer of food like cereals, fruits and vegetables, India is still facing food shortage due to food wastage and post - harvest loss. Before food reaches the plate, it travels from the farmer to wholesalers, retailers, and sometimes processors. At every stage, some proportion of crop production is lost. Most of the food is being wasted when there is more supply and less demand for a particular crop. In agriculture, the major problems are post-harvest loss and storage loss.

Most of the food is being wasted when there is more supply and less demand for a particular crop. These issues need to be addressed with utmost importance. Traditional methods like open sun drying were used in the past for preservation and to increase the shelf life of a crop. And we all know solar energy is sustainable energy and should be used the most to conserve fossil fuels. Open sun drying has disadvantages like food contamination, unpredictable weather changes, etc. These can be overcome by using solar drying. Solar dryer usage guarantees the retaining of nutrients, taste, color, odor and prevents contamination.

We have designed a prototype of an indirect solar dryer to dry food. We used an Arduino uno as a microcontroller and dht11 temperature and humidity sensors inside both collector and drying chamber to monitor the temperature and humidity inside the solar dryer. The values of temperature and humidity are constantly displayed in the lcd 16*2 (ic2) display. Optimum amount of temperature and humidity are always maintained inside the solar dryer. Our prototype can work 24 hrs even in windy or rainy conditions when required amount of solar energy is sufficient, we use UV lights and fans to provide temperature inside the dryer. The dryer consists of solar collector, a drying chamber, fans and UV lights to regulate air flow and temperature inside the dryer.

The principle we use inside our solar dryer is that if the temperature inside the solar dryer is less than required temperature then fans are turned off and UV lights are turned on. Similarly, if the temperature is more than required temperature, fans are turned on to increase air flow and UV lights are turned off. This helps us maintain optimum temperature inside the dryer so that food inside the dryer is not contaminated or result in decreased quality of the food kept inside the solar dryer.

We considered banana for our project as sample food, the optimum temperature levels for drying banana inside the solar dryer is 35 degrees centigrade to 60 degrees centigrade. The initial moisture level of banana is 75-77 percent. This moisture levels can be reduced to 16.8 to 27 % after drying with solar dryer. Banana dried at 1 m/s air flow rate was of the best quality in terms of colour, taste and shape when compared to drying at 0.5 and 2 m/s air flow rate.

The use of IOT applications in solar dryer enables better management and control over the drying process. The farmer or food processing companies can remotely monitor the temperature and humidity levels using thingspeak server and ESP32 wifi module. Data is visually represented via graphs for better understanding. Better drying conditions promote better drying quality of food in return helping farmers and food processing industries build exposure to new markets and increased prices for product due to prolonged shelf-life.

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Background:

Related work:

Fruits and vegetables are exposed to a gradual decomposition process after harvesting. So, it is important to increase the life span of fruits and veggies. We can use the general method i.e, Cold storage for preserving them, but this requires electricity and is not very efficient. Here Solar drying system comes into play. Many problems arise when following traditional drying techniques like dirt, dust, rains, birds, and other pet animals. As a result 40-65% of the outcome is wasted [9]. So Indirect solar drying is better than traditional drying. With the help of a microcontroller (Arduino/Raspberry pi) we can offer an efficient indirect solar dryer which can manage temperature and moisture content of a given fruit/vegetable.

Different published papers have classified solar dryers into several categories based on their functionality [1]. They are classified into direct, indirect and hybrid solar dryers. Here we used Indirect solar drying process. In Indirect solar drying, heat is first applied to the absorber plate from glass and then it is transferred to the drying chamber [6]. Also solar drying has a positive effect on the quality of the final food product as the moisture content is reduced to a certain level which is varying for one item to another [2].

The main components of a solar dryer are solar collector, drying chamber, axial fans, battery, automatic control devices etc. The factors like heat performance, end-product quality, economic aspect and dryer size are crucial when building a solar dryer[3]. There is a dryer called Natural convection solar dryer which is used for household purposes. This can store up to 10-15 kgs of food. But there are some limitations to this dryer when compared to indirect solar dryer, they are availability of solar radiation intensity, Quantity of the raw product used for drying, surface area of the absorber plate, Latitude and longitude angles of the solar dryer, air circulation inside the drying chamber, heat transfer losses [8].

The drying rate was found to increase when wooden skewers were used instead of conventional trays. At the end of the day, the total difference in moisture content is found to be 3.1 % which is considerable knowing that the rate of drying drastically decreases with time [10]. Whenever the moisture starts evaporating, enthalpy of water as vapor and enthalpy of water as liquid are obtained from steam tables [4], so using this information we can know the moisture content of the fruit/vegetable inside the dryer. The efficiency of the solar dryer can be calculated through thermal performance of two units or drying rate of the products [5]. Other type solar dryers like box type solar dryers for evaluating their energy performance are researched in [7].

Introduction:

Solar food processing unit mainly has two parts, one is a concentrator and the other is a dryer where the food is placed. Concentrators trap the sun's heat and transfer it to the drying chamber. Solar dryers are generally three types. Direct, indirect and hybrid solar dryers. Hybrid solar dryers are generally more efficient. In hybrid solar dryers, the hot air is circulated through forced convection. The process of drying is affected by hot air, the spreading density and initial and final moisture of food placed inside the drying chamber. The basic function of a solar dryer is to heat air to a constant temperature with solar energy, which facilitates extraction of humidity from crops inside a drying chamber.

The objective of a dryer is to supply the product with more heat than is available under ambient conditions, it is designed to dry farm products like mushrooms, tomatoes, onions etc.

The performance evaluation of solar dryers can be carried out via drying efficiency (η_d), which is the ratio of the evaporation energy to the received solar energy. where m_w denotes the water mass evaporated and L_w is the latent heat of water. It is worth mentioning that the fans' energy consumption can be added to the received solar energy in case of forced convection. The average efficiency of solar dryers is in the order of 20%, whereas values as high as 30% could be achieved by indirect solar dryers with efficient solar collectors and combined with thermal energy storage system.

Moreover, to assess the kinetic of the drying process, moisture ratio (MR) can be calculated, which is defined as the ratio of the contained moisture at a given instant to the initial moisture content. MR could achieve a value of 0.002 at the end of drying time which varies depending on the used technology, where the solar dryers with forced convection and enhanced efficiency, such as the integration of PCMs, have short drying time. Therefore, drying rate (DR) is a more significant indicator used to measure the evaporation rate of moisture content (*mc*) to surroundings.

The highest DR is usually achieved during the first hour of drying time, due to the high concentration of moisture, reaching a value of 0.2 kg h^{-1} for direct solar dryers that could be increased up to 2.5 kg h^{-1} for indirect solar dryers. Furthermore, a specific moisture extraction rate (SME) is employed to determine the rate of evaporated moisture with regards to the input energy, which could be in the range of 0.15–0.2 kg kWh^{-1}. However, the developed solar dryers integrating PCM could achieve an SME rate of 4 kg kWh^{-1}.

Solar dryers are more economically feasible compared to dryers that run on conventional fuel/electricity. The drying process is completed in the most hygienic and eco-friendly way, reducing post-harvest loss of food. Solar drying systems have low operation and maintenance costs. Solar dryers last longer. A typical dryer can last 15-20 years with minimum maintenance.

Internet of things (IoT) is really beneficial in food industry. For example, IoT in food processing allows food companies to achieve higher levels of traceability, food safety and accountability all throughout the supply chain. Additionally, the IoT network minimizes risk, costs and waste in all stages of the process.

Problem Definition:

Before food reaches the plate, it travels from the farmer to wholesalers, retailers, and sometimes processors. At every stage, some proportion of crop production is lost. Most of the food is being wasted when there is more supply and less demand for a particular crop. Solar drying is a sustainable and efficient method of food processing that utilizes the energy from the sun to remove moisture from food, preserving it for longer storage and consumption. Solar drying is a low-energy process since it primarily relies on sunlight, which is abundant and free. This is particularly important in regions with limited access to electricity or where energy costs are high. By using solar energy for drying, food producers can significantly reduce operational costs, especially when compared to traditional drying methods that require electricity or fossil fuels. Removing moisture from food inhibits the growth of spoilage microorganisms, reducing the risk of foodborne illnesses. Properly dried food can have an extended shelf life, which is essential in areas with limited access to refrigeration. It can preserve more nutrients in food compared to other drying methods that involve higher temperatures. This is crucial for maintaining the nutritional quality of the food being processed. Solar drying helps retain the natural flavors and aromas of the food, which can be lost in other drying processes that involve higher temperatures. Solar drying can be used for a wide range of food products, including fruits, vegetables, herbs, grains, meat, and fish, making it a versatile food processing technique. Solar drying can create opportunities for income generation, especially in rural areas where farmers can process excess produce and sell it during off-seasons or to distant markets. Implementing solar drying systems can enhance the resilience of communities, especially in areas prone to power outages, by providing a reliable method for food preservation.

In regions where post-harvest losses are a significant issue, solar drying can help reduce these losses by providing a reliable method for preserving excess produce. Solar drying can be used for a wide range of food products, including fruits, vegetables, herbs, grains, meat, and fish, making it a versatile food processing technique. Solar drying can create opportunities for income generation, especially in rural areas where farmers can process excess produce and sell it during off-seasons or to distant markets. Implementing solar drying systems can enhance the resilience of communities, especially in areas prone to power outages or with limited infrastructure, by providing a reliable method for food preservation.

Sensors can significantly help to perk up quality control, products tracking, workers' activities, and taking advantage of real-time analysis for production. Sensors persistently inspect the colour and specks throughout flour production, which helps to immediately rectify any inaccuracy. Moreover, sensors gauge the moisture content along with protein or cash content and allow real-time optimization of the production procedure.

The Internet of Things (IoT) has become increasingly important in various industries, including food processing, due to its ability to enhance efficiency, quality control, traceability, and safety. IoT devices can monitor various aspects of the food processing environment in real-time, such as temperature, humidity, and equipment performance. This ensures that food is processed under optimal conditions, reducing the risk of spoilage, contamination, or quality degradation.

IoT systems can track the movement of ingredients and products throughout the processing and supply chain. This is crucial for quickly identifying the source of contamination or other issues, enabling targeted recalls and enhancing overall food safety. IoT-enabled equipment can predict when maintenance is needed based on real-time data, reducing downtime and preventing costly breakdowns. This is particularly important in food processing where equipment failure can disrupt production and lead to product losses.

IoT systems can help food processors comply with various regulations and standards by providing detailed records of processing conditions and ingredient sources. IoT allows for remote monitoring and control of food processing facilities, which can be especially beneficial for companies with multiple locations or for addressing issues in real-time without physically being on-site. IoT generates a wealth of data that can be analyzed to identify trends, optimize processes, and make informed decisions to improve overall efficiency and profitability. IoT can enhance food safety by providing rapid and accurate information during recalls, reducing the potential health risks associated with contaminated or improperly processed food.

Objectives of the proposed work

The main objectives of the current project include:

1. Determine and display the temperature and humidity of solar dryer continuously.

2. Maintain the quality of food after being dried with solar dryer.

3. To monitor and control the temperature and humidity of solar dryer remotely through user interface.

Methodology/Procedure

Solar food processing is an efficient and sustainable way to dry the food and help farmers and food processing industries. Better drying conditions help farmers and solar food processing industries help them to expose to new markets, trade international markets with better quality dried food. The aim is to build a solar dryer that helps small-scale farmers and food processing industries. We constructed a solar dryer which consists of drying chamber, solar collector, sensors, fans and UV lights.

The collecting chamber contains glass to help with the green house effect inside the collecting chamber, when the sun rays fall on the glass the solar energy is trapped inside the collecting chamber. There is a metal plate absorber inside the collecting chamber, which helps with the absorption of solar energy to a greater extent. Collecting chamber is linked to the drying chamber, the heat absorbed inside the collecting chamber is forced into the drying chamber of the solar dryer. Fans are connected to the collector which helps with the air flow inside the solar dryer and to control the temperature and humidity levels inside the solar dryer.

The drying chamber consists of trays that are outlined with wood to increase the heat absorption and help with the better drying of the food kept on the trays. The drying chamber is coated with the black pain and inside layer is coated with aluminium foil to trap the heat inside the solar dryer and increase the heat absorption in return helping with the drying process. There are two dht11 sensors placed inside the solar dryer. One is placed inside the drying chamber and one is placed inside the collecting chamber, these sensors help measure the temperature and humidity inside both the drying chamber and collecting chamber. These measured sensor values of temperature and humidity are constantly displayed in the lcd display. The drying chamber also contains UV lights to maintain the temperature inside the solar dryer when the required amount of solar energy is not present outside due to bad weather conditions.

The air flow due to fans transfers this heat energy to the dryer which is completely coated with black paint and wrapped with aluminium foils inside to sustain the heat energy. The food (bananas) is placed inside the drying chamber on a wire mesh. The food gets dried according to the moisture content in it. The moisture level and the temperature inside the concentrator and the drying chamber are monitored using DH11 sensors and displayed through the LCD display. The data of temperature and humidity can be accessed anywhere using thingspeak and ESP module.

We control the temperature and humidity levels by using the algorithm mentioned below in the code section. We follow the principle that if the temperature inside the solar dryer is less than required temperature then fans are turned off and UV lights are put on. Similarly, if the temperature is more than required temperature, fans are turned on to increase air flow and UV lights are turned off. Alerts/ notifications are received by the farmer when temperature exceeds the optimal limit.

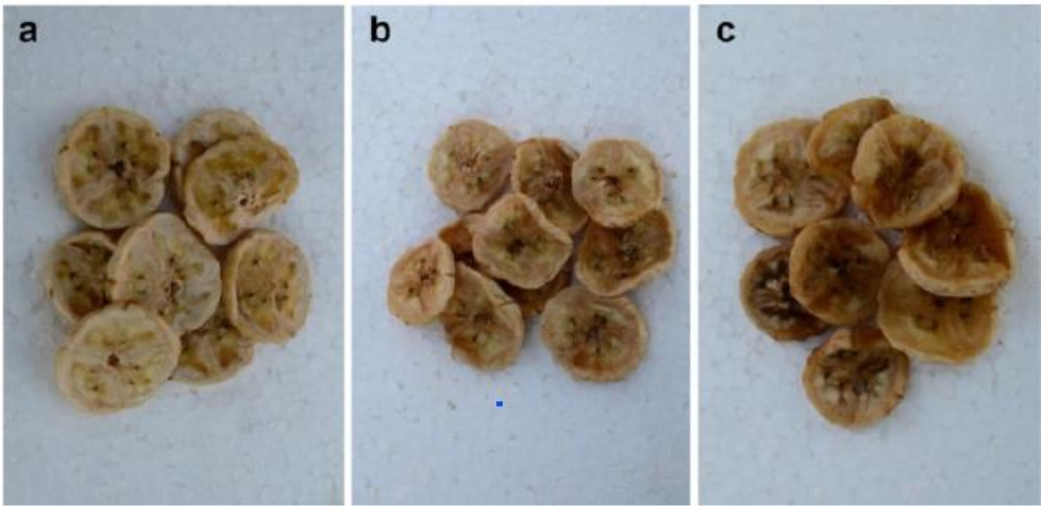
Results and Discussion

The table below shows the initial moisture content and obtained final moisture content, open sun drying time and time taken with solar dryer for some crops,

CROP	**INITIAL MOISTURE CONTENT**	**FINAL MOISTURE CONTENT**	**OPEN SUN DRYING TIME**	**SOLAR DRYING TIME**
Tomato	90 %	9 %	74 hrs	29 hrs
Red Chillies	63.8 %	8.01 %	3 weeks	48 hrs
Cabbage	91.2 %	8.63 %	48 hrs	7 hrs
Banana	75%	27%	2 days	10 hrs

In the top and bottom flow experiments, the bottom flow provided about 2.5 °C higher chamber temperatures than the top flow for the same solar energy input. The efficiency of top flow configuration was found to be 27.5 %, whereas the efficiency of bottom flow configuration was found to be higher at 38.21 %. The results also agree well with the theoretical calculations performed as 60 W of energy can be saved for the same energy input. The drying rate was found to increase when wooden skewers were used instead of conventional trays. At the end of the day, the total difference in moisture content is found to be 3.1 % which is considerable knowing that the rate of drying drastically decreases with time. Banana dried at 1 m/s air flow rate was of the best quality in terms of colour, taste and shape when compared to drying at 0.5 and 2 m/s air flow rate while the weather condition and ambient conditions were almost the same for all the cases with negligible difference.

Dried banana over time period in solar dryer:



Conclusion and Future Scope:

IoT applications in solar dryers make the management and control of drying process easier and more efficient for farmers and solar food processing industries. Better drying of food helps them with exposure to new markets and improved prices the food due to increased shelf-life. One can be able to monitor and control the temperature and humidity levels of the solar dryer remotely using our project. With the help of an indirect solar dryer we can reduce the moisture content of the food and thus increase its shelf life by preserving the taste, color, odor and quality. The food dried using an indirect solar dryer not only has a long shelf-life but also has high demand in the market increasing income of small scale farmers.

To run the solar dryer 24 hours we can use UV lights to get the sunlight even at night time and we can use solar panels to store solar energy and use it to power the uv lights at night time. Ethylene sensors can be used to check if the food has ripen inside the drying chamber and we can give an alert using a buzzer if the food has ripen inside the drying chamber or if the temperature is too less inside the drying chamber for the food to dry. More heat regulation techniques need to be increased for effective drying of food in solar drying.

Awareness needs to be created among farmers regarding the benefits of solar dryers and their role in better drying process. It helps farmers to expose to new markets, better income and better quality in drying process.

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<u>Algorithm:</u>

1. Food is kept in trays inside the drying chamber. Temperature and humidity of solar dryer is monitored using dht11 sensors.

2. Temperature and humidity are continuously displayed on the lcd display.

3. If the temperature inside the solar dryer is less than required temperature then fans are turned off and UV lights are put on. Similarly, if the temperature is more than required temperature, fans are turned on to increase air flow and UV lights are turned off.

4. Alert/ notification is sent when the temperature exceeds the optimal limit.

5. Temperature and humidity is monitored remotely using ThingSpeak.

Code:

```
#include <DHT.h>
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
// Set the LCD address to 0x27 for a 16 chars and 2 line display
LiquidCrystal_I2C lcd(0x27, 16, 2);
#define DHTPIN1 2
#define DHTPIN2 5
// Uncomment whatever type you're using!
#define DHTTYPE DHT11   // DHT 11
//#define DHTTYPE DHT22   // DHT 22  (AM2302)
//#define DHTTYPE DHT21   // DHT 21 (AM2301)
// Initialize DHT sensor for normal 16mhz Arduino
DHT dht1(DHTPIN1, DHTTYPE);
DHT dht2(DHTPIN2, DHTTYPE);
byte celcius[] = {
  B11000,
  B11000,
  B00000,
  B00111,
  B01000,
  B01000,
  B00111,
  B00000
  };
void setup() {
  Serial.begin(9600);
  Serial.println("DHT11 test!");
  lcd.begin();
  dht1.begin();
```

```
  dht2.begin();
  lcd.createChar(0, celcius);
}
void loop() {
  // Reading temperature or humidity takes about 250 milliseconds!
  // Sensor readings may also be up to 2 seconds 'old' (its a very slow sensor)
  float h1 = dht1.readHumidity();
  float t1 = dht1.readTemperature();
  float h2 = dht2.readHumidity();
  float t2 = dht2.readTemperature();
  if (isnan(h1) || isnan(t1)) {
    Serial.println("Failed to read from DHT sensor 1!");
    return;
  }
 if (isnan(h2) || isnan(t2)) {
    Serial.println("Failed to read from DHT sensor 2!");
    return;
  }
 lcd.clear();
 lcd.setCursor(2,0);
 lcd.print("Temperature");
 lcd.setCursor(0,1);
 lcd.print(t1);
 lcd.write(0);
 lcd.setCursor(10,1);
 lcd.print(t2);
 lcd.write(0);
 lcd.print(t1);
 delay(1500);
 lcd.clear();
```

```
 lcd.setCursor(4,0);
 lcd.print("Humidity");
 lcd.setCursor(0,1);
 lcd.print(h1);
 lcd.print("%");
 lcd.setCursor(10,1);
 lcd.print(h2);
 lcd.print("%");
delay(1500);
  Serial.print("Humidity: ");
  Serial.print(h1);
  Serial.print(" & ");
  Serial.println(h2);
  Serial.print("Temperature: ");
  Serial.print(t1);
  Serial.print(" °C");
  Serial.print(t2);
  Serial.println(" °C");
  Serial.println();
//  Serial.print(f);
//  Serial.print(" *F\t");
//  Serial.print("Heat index: ");
// Serial.print(hi);
//  Serial.println(" *F");
}
```