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# Automation and Performance Evaluation of a Solar Tunnel Dryer Using Arduino UNO

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## ABSTRACT

The study on automation of an existing solar tunnel dryer was done using the Arduino UNO and DHT11 sensor during 2020–2021 at the Research Farm, Department of Farm Machinery and Power Engineering, Sam Higginbottom University of Agriculture, Science, and Technology, Allahabad, Uttar Pradesh, India. To ensure optimal drying conditions, the Arduino UNO was employed to regulate the operation of an exhaust fan. This control system was activated whenever the humidity level inside the dryer reached a specific threshold. The system was configured to operate at three different humidity levels-35%, 30% and 25% for three weeks of five working days each. Potatoes weighing 5000 g were sliced and spread inside the dryer daily between 9:30 am to 5:30 pm, ensuring consistent and regular activity within the specified timeframe. It was found that the moisture removal rate and the successive drying time were fastest when the exhaust fan was operated to remove 25% humidity, followed by 30% and 35%. During the third week, the drying time was two hours less than the first week and one hour less than the second. These results demonstrate that removing humidity at lower levels significantly contributed to faster drying. Therefore, it can be inferred that automating the solar tunnel dryer and maintaining a lower humidity threshold can significantly enhance the efficiency of the drying process.

**KEYWORDS:** Arduino, automation, DHT11 sensor, IoT, solar tunnel dryer

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***Data Availability Statement:*** Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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## 1. INTRODUCTION

Food is a basic necessity for all human beings. With an ever-increasing population, balancing food production and consumption is becoming increasingly difficult (Bahadur et al., 2018, Nukulwar and Tungikar, 2021). By 2050, the global population is expected to surpass nine billion people (Tripathi et al., 2018, Bahar et al., 2020). In addition, it is estimated that 852 million people worldwide don't have enough food to eat, which is likely to rise as the world's population grows (Khalid et al., 2019, Gopakumar, 2022). Many developing countries suffer significant post-harvest losses because of spoilage, microbiological contamination, insects, birds, and rodents, and storage deterioration (Atungulu et al., 2018, Sawicka and Egbuna, 2020). Given the growing food demand, post-harvest losses are becoming a significant concern (Porat et al., 2018, Raut et al., 2018). Agricultural products stored for extended periods are prone to degradation depending on their moisture level. When agricultural products are harvested, they typically have a high moisture content, leading to fungal and bacterial growth. Storing agricultural products at a safe moisture content eliminates the risk of spoiling under storage conditions (Gilmore et al., 2019).

Agricultural products can be preserved in a variety of ways for future consumption. Drying is an excellent method for preserving agricultural products. Drying helps remove excess moisture and is crucial for extending the shelf life of agricultural products (Green and Schwarz, 2001, He et al., 2013, De Corato, 2020, Lingayat et al., 2020). Using solar radiation for drying is one of the earliest applications of solar energy (Belessiotis and Delyannis, 2011, Kumar et al., 2016, Kesavan et al., 2019). Solar drying is an appropriate preservation technology for a sustainable world (Kamarulzaman et al., 2021). Open sun drying is an ancient method for drying crops that have been in use since ancient times. It is still used in rural areas since it is easy and inexpensive. However, wind, rain, birds, and animals can degrade quality when using open sun drying (Lingayat et al., 2018, Nukulwar and Tungikar, 2021). The challenges associated with open sun drying can be solved by solar dryers (Godireddy et al., 2018, Kumar and Singh, 2020).

Solar dryers use solar energy for the drying of agricultural products. Studies have shown that solar drying costs only one-third of conventional dryers using fossil fuels (Hadibi et al., 2021). Solar dryers using natural circulation are preferred for domestic applications as they demand no electric energy and can be operated in rural and remote areas (Singh et al., 2006, Ndukwu et al., 2018). Natural circulation dryers have a severe shortcoming in that moisture must be eliminated to prevent agricultural products from deteriorating because of condensation in the drying chamber (Tomar et al., 2017). In modified solar dryers, ventilation systems circulate heated air within the chamber. For ventilation, blowers or fans are used. The electric energy for the devices is harnessed from photovoltaic (P.V.) modules (Tiwari et al., 2016). To achieve high drying efficiencies and product qualities, the optimal temperature and air mass flow rate must be maintained (Ghatrehsamani et al., 2012, Rani and Tripathy, 2021).

This study was undertaken to simplify the process of drying agricultural products, such as potato chips, safely and efficiently to ensure a high-quality dried product. This was accomplished with the use of an automated solar tunnel dryer. An automatic solar tunnel dryer was used to control the temperature and humidity within the dryer by operating the ventilation systems using pre-set parameters. Automation was carried out using the microcontroller Arduino U.N.O., which controlled an exhaust fan based on the temperature and humidity inputs received from the DHT11 sensor.

## 2. MATERIALS AND METHODS

The experiment was conducted during 2020–2021 at the Research Farm, Department of Farm Machinery and Power Engineering, Sam Higginbottom University of Agriculture, Science and Technology, Allahabad, Uttar Pradesh, India. The present investigation was undertaken to automate a solar tunnel dryer using sensors (DHT11) and a microcontroller (Arduino U.N.O.) and evaluate the developed system's performance.

Arduino U.N.O. is a mega 328 P microchip-based open-source microcontroller board. The board has digital and log input/output (I/O) pins interfaced with multiple expansion boards (shields) and additional circuits (Badamasi, 2014). It features 14 digital I/O pins, including six PWM outputs and six analog I/O pins, and can be programmed using the Arduino IDE (Integrated Development Environment) and a type-B USB connector. A 9 V battery or a USB cable with a 7–20 V voltage range provides power. The hardware design is governed by a Creative Commons Attribution Share-Alike license.

The DHT11 is a humidity and temperature sensor that produces a calibrated digital output (Gay, 2018). It is an inexpensive humidity and temperature sensor with high reliability and long-term stability. The DHT11 sensor is an analog sensor that detects physical changes in temperature and humidity when exposed to air when adequately connected and programmed. Its temperature range is between 0°C–50°C, and its humidity range is 20%–90%. Its small size, low cost, low power consumption, and fast response time make it the best choice for many consumers. DHT11 sensor detects humidity in the air by measuring the electrical resistance between the electrodes. When the substrate absorbs moisture, ionization occurs, and the electrode conductivity increases. The relative humidity is proportional to the change in resistance between the electrodes when water vapor is absorbed (Xiao and Li, 2020).

The arrangement of the various components in the automation system is shown in Figure 1. The power input for working the various components was provided by using a P.V. module. A battery was also provided as a backup when adequate sunlight was unavailable. The solar panel and battery provide power to the Arduino UNO, which provides power to all the other components. The connections between the various components were made using jumper wires. DHT11 sensor was connected to the microcontroller and placed inside the solar dryer to get the temperature and humidity at a particular instant. The time between successive readings was kept at 5 s.

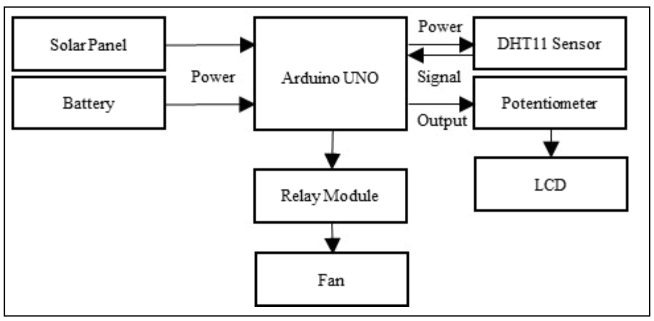


Figure 1: Block diagram of the automatic control system

An LCD screen was connected to the system that displayed instant readings recorded by the DHT11 sensor. A potentiometer was used to control the voltage of the LCD module. The exhaust fan of the solar dryer was controlled using a relay module as per the program of the Arduino U.N.O. A relay is an electromechanical device that uses an electric current to open or close a switch contact. It contains components that make switching and connecting easy and indicate whether the module is receiving power and whether the relay is active (Figure 2).

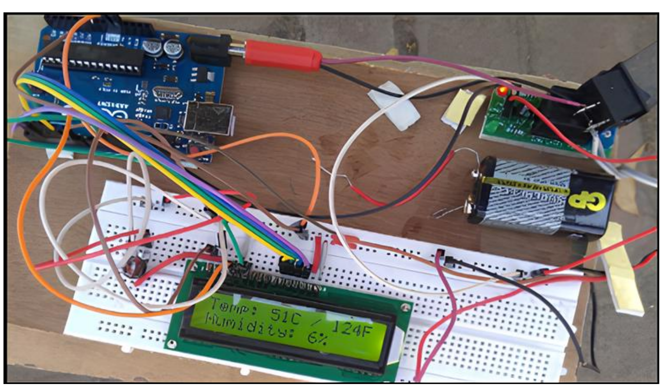


Figure 2: Layout of the automatic control system

Every day for three working weeks of five days each, 5000 g of potatoes were sliced and placed inside the solar dryer. The automatic control system was connected to the exhaust fan. The microcontroller was programmed to operate the exhaust fan at different humidity levels. The humidity values for operating the exhaust fan on different days are given in Table 1. The respective drying times and final weights were measured to determine the system's effectiveness for the different settings. The block diagram of the working of the control system is shown in Figure 3.

Table 1: Humidity levels for fan operation for different days

| Week | Configuration | Day | Humidity Level |
|---|---|---|---|
| 1 | $W_1$ | 1–5 | 35% |
| 2 | $W_2$ | 8–12 | 30% |
| 3 | $W_3$ | 15–19 | 25% |

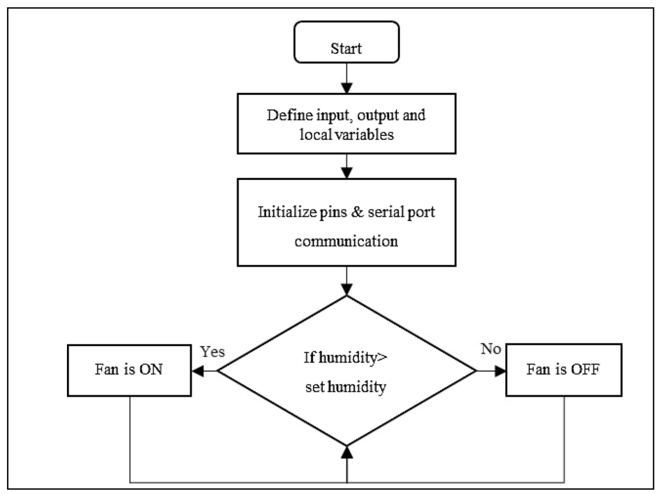


Figure 3: Block diagram of the exhaust fan control process

Observations of temperature, humidity inside the solar dryer, and potato slices weight were recorded at hourly intervals from 9:30 am–5:30 pm during the day. These observations were then analyzed to determine the best configuration from a list of configurations for the drying process. The moisture content was calculated according to the following equation:

$MC(\%)= (W_1-W_2)/W_1\times100\%$...............(1)

where,

MC (%)=moisture content (%),

$W_1$=weight before drying (g), and

$W_2$=weight after drying (g)

## 3. RESULTS AND DISCUSSION

The experiment was conducted during the second, third, and fourth week of April 2021. Data was collected in a day-to-day environment with changing air temperatures.

Air temperature varied between 27.1–43.6°C during the experimental period. Humidity varied between 16%–59% for the same period. The experiments began at 09:30 am and ended at 05:30 pm every day.

Temperature and humidity measurements were taken both inside and outside the dryer. A mercury thermometer was used to measure the temperature outside the dryer. Inside temperatures were measured with a mercury thermometer and the Arduino. Figure 4–6 shows the average outside, inside, and Arduino temperatures at various time intervals for weeks 1, 2, and 3.

During Week 1, the minimum outside temperature was 31.9°C at 9:30 am. The inside thermometer and Arduino temperatures were 33.9° and 33.5°C. The maximum outside temperature was 41.4°C at 2:30 pm, with the inside thermometer and Arduino temperatures of 52.5°C and 51.9°C.

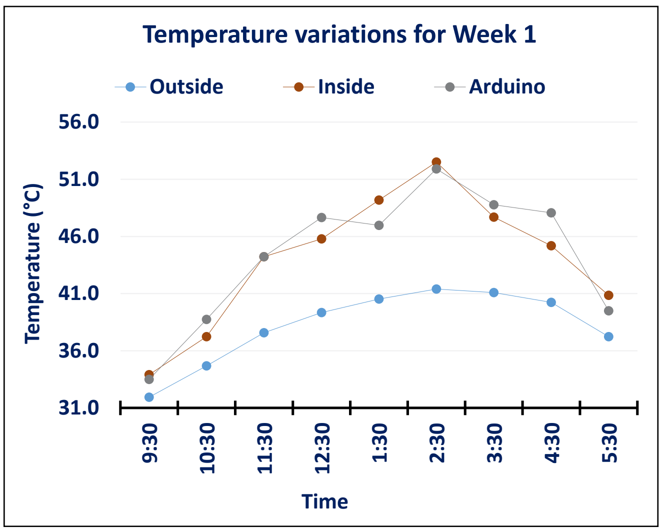


Figure 4: Variations of temperature at different time intervals for Week 1

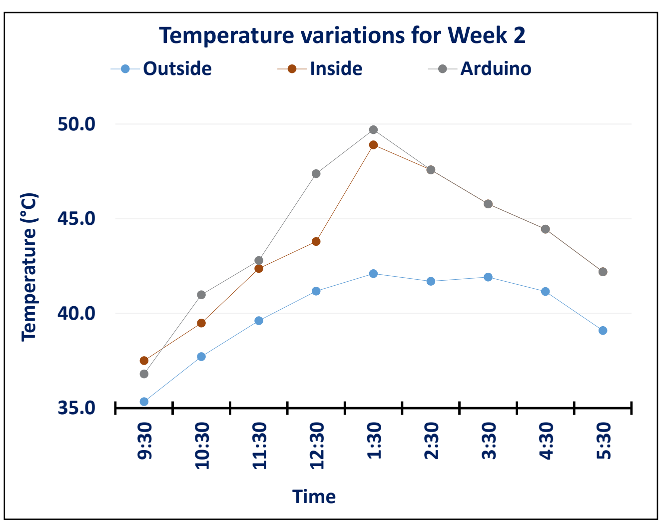


Figure 5: Variations in temperature at different time intervals for Week 2

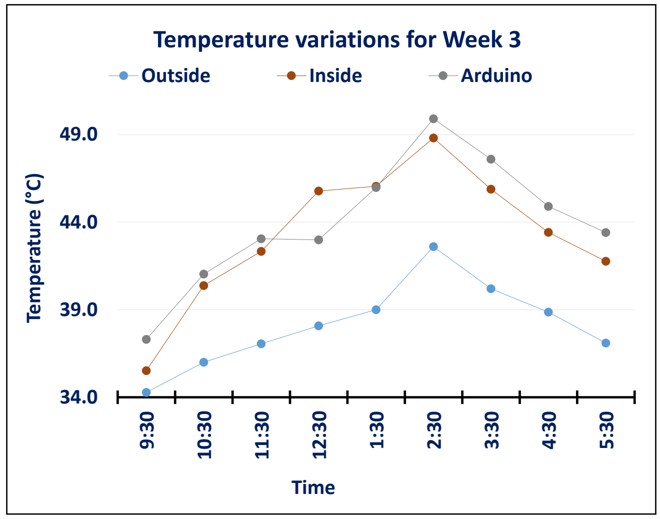


Figure 6: Variations in temperature at different time intervals for Week 3

During Week 2, the minimum outside temperature was 35.3°C at 9:30 am. The inside thermometer and Arduino temperatures were 37.5°C and 36.8°C. The maximum outside temperature was 42.1°C at 1:30 pm, with the inside thermometer and Arduino temperatures of 48.9°C and 49.7°C.

During Week 3, the minimum outside temperature was 34.3°C at 9:30 am. The inside thermometer and Arduino temperatures were 35.5°C and 37.3°C. The maximum outside temperature was 42.6°C at 2:30 pm, with the inside thermometer and Arduino temperatures of 48.8°C and 49.9°C.

Throughout the weeks, the temperature inside the dryer increased in proportion to the outside temperature. The temperature peaked between 01:30 pm and 2:30 pm, after which it decreased. There were some variations between the temperatures recorded by the thermometer and the Arduino. This difference can be explained by Arduino's ability to record instant readings that a mercury thermometer cannot.

The variation of the tunnel temperature with changes in the outside temperature was not uniform. Figure 7 shows the relationship between the outside temperature and the inside temperature of the dryer measured using mercury thermometers. The linear trend line for the relationship was also obtained along with the equation and the $R^2$. The value of $R^2$ was 0.7933, which denotes a good relationship between the two temperatures. The following equation gives the variation of the inside temperature with changes in the outside temperature:

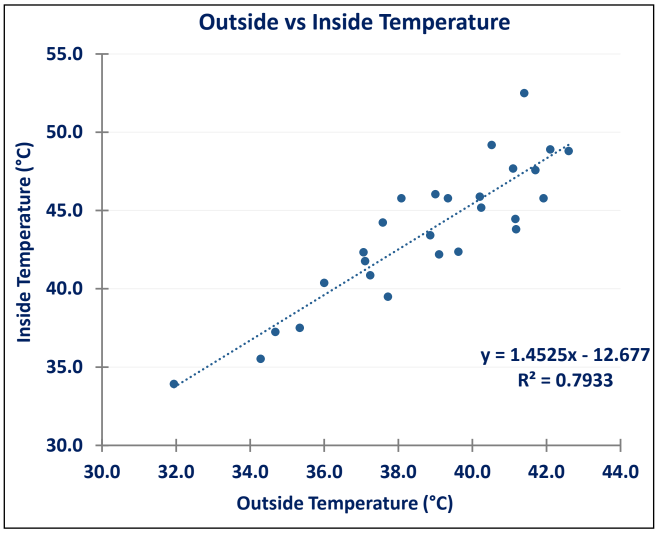


Figure 7: Relationship between the outside temperature and inside temperature of the dryer

y = 1.4525x - 12.677…………(2)

where,

y=Temperature inside the dryer, ˚C

x=Temperature outside the dryer, ˚C

The linear relationship between the temperature recorded by the Arduino and the mercury thermometer inside the dryer was also obtained (Figure 8). The $R^2$ value was 0.9007, indicating a good relationship between the recordings by both devices. The following equation gives the relationship:

y = 0.9565x - 2.439………………… (3)

where,

y=Temperature recorded by Arduino, ˚C

x=Temperature recorded by mercury thermometer, ˚C

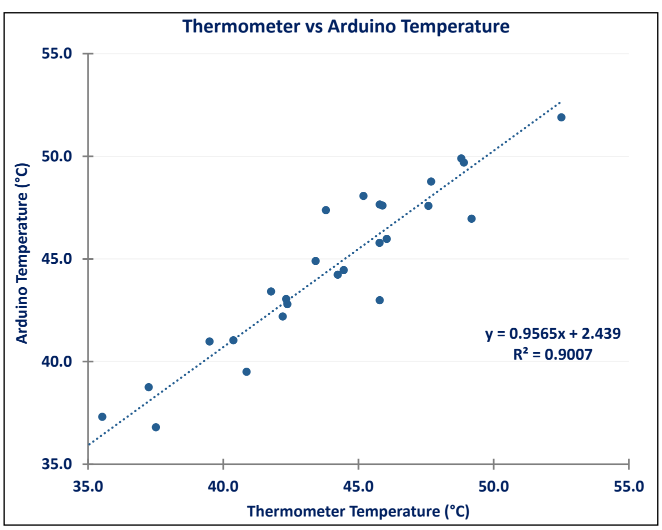


Figure 8: Relationship between the inside temperature recorded by the thermometer and Arduino

The weight loss of the sample with time at different configurations $W_1$, $W_2$, and $W_3$ (Table 1) of humidity settings inside the dryer is shown in Figure 9. W3 took the least time for drying, followed by $W_2$ and $W_1$, respectively. The rate of moisture loss (Figure 10) was highest in W3, followed by $W_2$ and $W_1$. This was because the humidity removal was faster in $W_3$ compared to the other two configurations. The lower the humidity levels, the higher the drying rate for the same temperatures (Algaithi et al., 2023; Chasiotis et al., 2023; Getahun et al., 2021; Marques et al., 2023; Rasooli et al., 2023, ). At the end of the drying process, the final weights of the potato chips for W1, W2, and W3 were 1557.0 g, 1531.5 g and 1502.5 g, respectively, and the moisture content was calculated as 68.9%, 69.4%, and 70.0%.

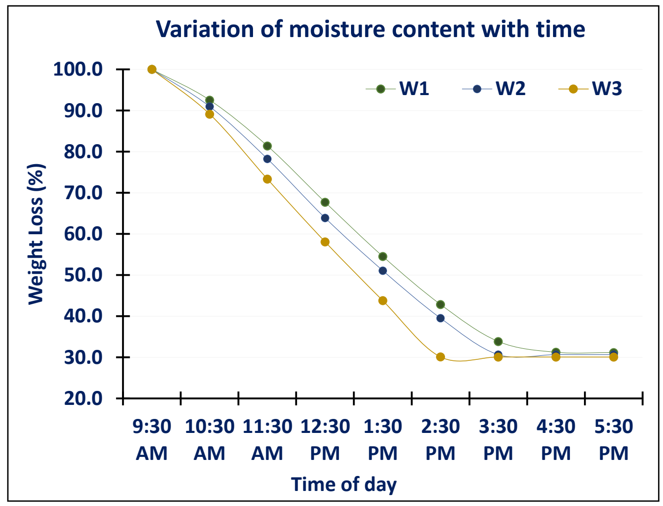


Figure 9: Variation of moisture content with time

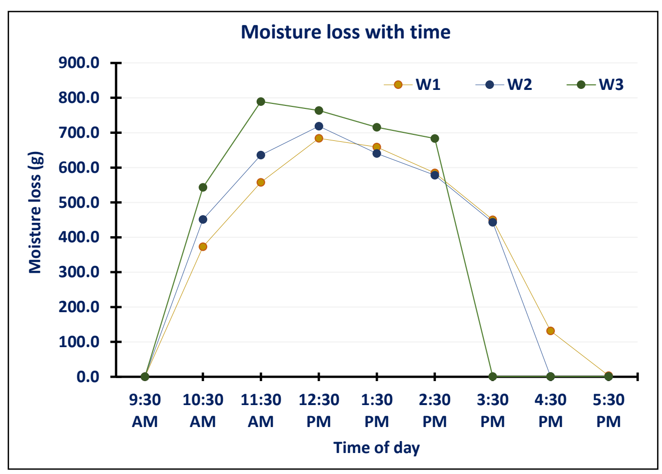


Figure 10: Loss of moisture with time

## 4. CONCLUSION

Arduino UNO and DHT11 sensors were used to automate a solar tunnel dryer for controlling an exhaust fan whenever the humidity inside the dryer reached a specific value. Potatoes weighing 5000 g were sliced and spread inside the dryer daily for three weeks at humidity levels of 35%, 30%, and 25%, respectively. It was found that the exhaust fan operation at lower humidity levels accelerated drying. It can therefore be concluded that automating the dryer reduced drying time.

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