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AI-Enhanced Optimization of Solar Drying System for Agricultural Produce: A Sustainable Approach

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Abstract: The present emphasis in technology revolves around tapping into the abundant energy resources at our disposal. Numerous approaches have been introduced to harness this energy, one notable application being the solar drying of crops. The drying of crops plays a crucial role in augmenting crop quality and safeguarding against issues such as moisture, pest and insect attacks, as well as interference from birds and animals.

To achieve precise and efficient automation, artificial intelligence methods are deployed to calculate optimized values for parameters like dryer efficiency and drying time. This software system incorporates machine learning techniques to enhance the efficiency and effectiveness of solar drying. It utilizes real-time data from a variety of sensors, including those measuring temperature, humidity, solar radiation, and wind speed. These sensors continuously monitor and control the drying process.

The AI algorithm processes this data, making intelligent decisions that contribute to improved drying efficiency and product quality. This comprehensive approach, integrating technology and artificial intelligence, signifies a noteworthy advancement in agricultural practices.

Keywords—Regression, ANN, Drying Efficiency, Drying Rate, Solar Drying System

INTRODUCTION :

Utilizing solar energy for the dehydration of agricultural produce emerges as a sustainable and energy-efficient strategy, addressing the need to mitigate post-harvest losses and secure food supplies. Solar drying systems capitalize on solar energy to diminish moisture levels in diverse agricultural products, thereby extending their shelf life. However, the efficacy of these systems hinges on factors such as solar irradiance, ambient conditions, system design, and operational parameters. In this context, the integration of Artificial Intelligence (AI) techniques holds promise in revolutionizing the design, control, and optimization of solar drying systems.

AI, encompassing machine learning, deep learning, and data-driven algorithms, offers an opportunity to autonomously comprehend and adapt, presenting a dynamic approach to tackle the complex and nonlinear interactions inherent in solar drying. This study focuses on the development and application of AI-based software to simulate, control, and optimize solar drying systems, aiming to enhance their energy efficiency, product quality, and overall sustainability.

AI-driven software not only facilitates precise modeling of intricate thermal and environmental interactions within the solar drying system but also enables real-time monitoring and adaptive control. Machine learning algorithms have the capability to predict system behavior under diverse conditions, optimizing the drying process for various agricultural products. Additionally, the integration of AI empowers autonomous decision-making, leading to maximized energy savings and minimized drying time.

The incorporation of Artificial Intelligence (AI) into solar drying systems signifies an innovative approach to enhance efficiency, optimization, and predictive capabilities. This advanced AI-based software employs models such as regression and Artificial Neural Networks (ANN) to achieve optimal performance in the solar drying process.

Solar drying systems, crafted to reduce moisture content in agricultural products and extend shelf life, grapple with challenges related to changing environmental conditions, system parameters, and the intricate nature of thermal interactions. AI, particularly through regression models, serves as a valuable tool for comprehending and optimizing these complex relationships. Regression analysis aids in identifying key factors that influence the drying process, facilitating the development of predictive models.

In tandem with regression models, the inclusion of ANN augments the capabilities of AI in solar drying systems. Inspired by the neural networks of the human brain, ANN excels at learning intricate patterns and nonlinear relationships within data. This makes it well-suited for predicting and optimizing the behavior of solar drying systems under diverse conditions.

The AI-based software, incorporating regression and ANN models, enables a comprehensive approach to simulating, controlling, and optimizing solar drying. Through regression, it can discern and quantify the impact of various parameters on the drying process, while ANN allows for dynamic adaptation and accurate prediction in real-time scenarios. This integration not only improves the overall efficiency of solar drying but also contributes to sustainability by minimizing energy consumption and optimizing resource utilization.

Parameters	
W	Amount of moisture removed (kg)
h_{fg}	Latent heat of vaporization (kJ/kg)
P_t	Total input energy (W)
M_t	Moisture content at any time
dt	Time interval (s)
	Drying Efficiency
	Drying Rate

I. OBJECTIVE

The incorporation of AI into solar drying systems is primarily aimed at improving energy efficiency. AI assumes a pivotal role in scrutinizing weather forecasts, solar radiation data, and past drying performance to optimize the functioning of solar collectors, fans, and associated equipment. The overarching goal is to curtail operational expenses by leveraging AI for system optimization, encompassing the reduction of energy costs, prevention of product loss due to insufficient drying, and elongation of equipment lifespan.

A key focus is the incorporation of real-time weather data and forecasts through AI. This integration empowers the system to strategize drying cycles based on anticipated weather conditions. Another objective is to guarantee that products undergoing drying processes, such as fruits, vegetables, or grains, attain the desired moisture content while minimizing both drying time and energy consumption.

AI plays a crucial role in ensuring the system operates at peak efficiency, thereby diminishing reliance on fossil fuels and mitigating greenhouse gas emissions. An additional noteworthy objective is the development of a user-friendly interface for operators and farmers to interact seamlessly with the AI-based software. This approach facilitates the effective utilization of the system, promoting user engagement and understanding.

II. PROBLEMSTATEMENT

An AI-based software solution is designed to optimize agricultural solar drying systems by enhancing control, monitoring, and predictive capabilities. This software utilizes AI to enhance energy efficiency, effectively operate, and optimize solar drying systems. It aims to decrease energy costs, reduce drying time, enhance system efficiency, offer real-time data analysis for informed decision-making during solar drying processes, and minimize environmental impact.

III.METHODOLOGY

A. Performance Evaluation

Performance evaluation involves the methodical assessment of the predictive accuracy of AI algorithms and the responsiveness of the software in real-time, taking into account dynamic and variable environmental conditions. Key technical metrics for assessment include predictive accuracy, response time, and resource utilization. These metrics are essential in gauging the software's capacity to make timely adjustments to the drying process. The software's ability to adapt to changing conditions is critical, as it directly influences drying efficiency, energy consumption, and the overall quality of the dried products.

1) Drying Rate:
The drying rate is defined as the ratio of moisture evaporated during the drying process to the drying time (RP-1).

$$Drying\ rate = \frac{M_{t+dt} - M_t}{dt}$$

2)Dryer efficiency :
It is defined as the ratio of energy needed to evaporate the water present in cluster fig to the total energy input in the drying chamber (RP-1).

$$\eta_{dryer} = \frac{Wh_{fg}}{P_t}$$

B. Multiple Regression

Multiple regression, a statistical technique, explores the correlation between two or more independent variables and a dependent variable. In the context of AI-based software for a solar drying system, multiple regression can be utilized to model and predict drying performance based on various factors.

C. ANN

The implementation of AI-based software for a solar drying system involves several key steps. Initially, there is the pivotal stage of data collection, where pertinent information such as weather conditions, solar radiation, humidity levels, and temperature is gathered. Following this, data preprocessing is conducted to clean and refine the collected data, eliminating noise and ensuring its suitability for subsequent AI model development.

An integral step in the process is feature selection, where crucial features essential for making predictions, such as sunlight intensity and ambient temperature, are identified. Subsequently, the AI model undergoes training using historical data, employing machine learning algorithms to recognize patterns and relationships within the dataset.

Validation is then executed to assess the model's performance using a distinct set of data not utilized during the training phase, ensuring effective generalization to new inputs. The trained model is integrated into the software controlling the solar drying system, enabling real-time decision-making based on input data.

Continuous monitoring of the system's performance takes place, and if feasible, feedback mechanisms are incorporated to adapt the model over time for increased accuracy. Optimization follows, involving the fine-tuning of the AI model and system parameters to enhance efficiency and adapt to changing environmental conditions.

An essential facet of the process is the creation of a user interface (UI) that allows users to interact with the AI-based software. This interface empowers users to monitor and adjust system settings as necessary. Finally, the integrated AI-based software is deployed into the solar drying system, ensuring seamless and efficient operation.

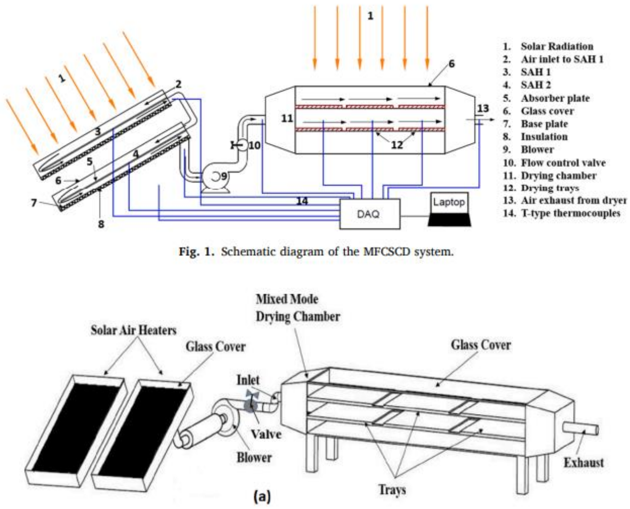

Fig 1. Solar Drying System (RP1)

The diagram illustrates a solar air heater (SAH) system, commonly employed for harnessing solar radiation to heat air in various applications, including space heating, crop drying, and industrial processes.

This SAH system consists of multiple components, such as solar radiation, air inlets to SAH 1 and SAH 2, absorber plates, glass covers, base plates, blowers, flow control valves, drying chambers, drying trays, air exhausts from the dryer, and T-type thermocouples.

Solar radiation initially interacts with the glass cover and is then conveyed to the absorber plates. SAH 1 and SAH 2 are flat plate collectors with black absorber plates that absorb solar radiation, consequently heating the air. The glass cover shields the absorber plates and retains heat, while the base plates offer support and insulation. An air circulation system facilitated by a blower, along with a flow control valve for regulating airflow, is integral to the setup.

In the drying chamber, equipped with drying trays, heated air is utilized for product drying. Air exhausts from the dryer allow the release of heated air, and T-type thermocouples measure air and absorber plate temperatures.

Operating in mixed mode, the SAH system employs both natural and forced convection. Natural convection arises from temperature differentials between the air inside and outside the SAH system, while the blower induces forced convection. This mixed mode proves more efficient than a purely natural convection system due to accelerated air circulation, resulting in heightened heat transfer rates and faster drying times.

Moreover, the SAH system incorporates a data acquisition (DAQ) system linked to T-type thermocouples, enabling real-time data collection for performance monitoring and optimization of the drying process.

In summary, the depicted SAH system stands as a well-designed solar energy-based drying system, offering versatility for various applications.

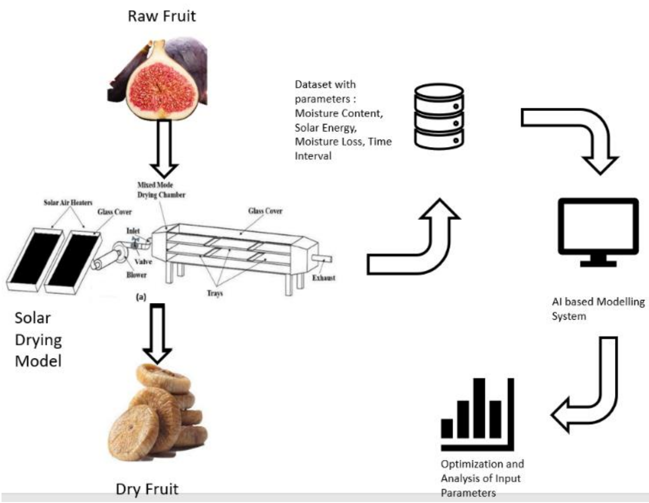

Fig 2.System Architecture

The solar drying model depicted in the provided image illustrates a hybrid approach that seamlessly integrates both direct and indirect solar drying methods.

Direct solar drying involves exposing products directly to sunlight, a widely used but relatively slow method that can result in quality issues like discoloration and nutrient loss. In contrast, indirect solar drying entails heating the product with air preheated by a solar collector, offering increased efficiency and greater control over the drying process.

The hybrid solar drying model showcased in the image intelligently combines both direct and indirect methods. Initially, the product undergoes direct exposure to sunlight in the drying chamber, rapidly increasing its temperature and initiating the drying process. Once a specific temperature is reached, the air inlet is closed, and the blower is activated. This compels the air through the solar collector and back into the drying chamber, where the preheated air contributes to further drying.

This hybrid model offers several advantages:

1. Efficiency: The use of preheated air enhances efficiency compared to direct solar drying.
2. Control: Improved control over the drying process results in enhanced product quality.
3. Versatility: The hybrid model can be applied to a broader range of products compared to direct solar drying.

The hybrid solar drying model holds promise for sustainable and efficient product drying. The operational steps are detailed as follows:

1. Placement of Raw Fruit: Raw fruit is positioned on drying trays within the drying chamber.
2. Air Inlet and Blower Activation: The air inlet is opened, and the blower is turned on.
3. Solar Collector: Air flows through the solar collector, where it gets preheated by solar energy.
4. Preheated Air Drying: The preheated air circulates into the drying chamber, facilitating the drying of the fruit.
5. Moisture Evaporation: Moisture from the fruit evaporates and is exhausted from the drying chamber through the air exhaust.
6. Drying Continues: The drying process persists until the fruit attains the desired moisture content.
7. Closing Inlet and Blower Deactivation: Once dry, the air inlet is closed, and the blower is turned off.
8. Removal of Dry Fruit: The dried fruit is then taken out from the drying chamber.

Optimizing the solar drying model involves adjusting parameters such as air flow rate, preheated air temperature, and drying time to tailor these variables to achieve the desired drying time and product quality.

IV. RESULTS AND DISCUSSION

Within the realm of solar drying systems, regression serves as a statistical methodology utilized to model the correlation between various parameters and the system's drying performance. This involves a thorough analysis of data derived from experiments or simulations to formulate mathematical equations capable of predicting drying behavior under diverse conditions.

Solar drying systems harness solar radiation to evaporate moisture from the material being dried. The effectiveness of this process relies on several crucial factors, including:

- Solar radiation intensity: The quantity of solar radiation directly affects the heat transfer rate to the drying material.
- Ambient temperature and humidity: Surrounding temperature and humidity impact the drying process by influencing moisture diffusion within the material and the evaporation rate.
- Airflow characteristics: The velocity and distribution of air within the drying chamber play a pivotal role in removing moisture from the material and maintaining a uniform drying temperature.
- Material properties: Physical and chemical attributes of the material, such as moisture content, shape, and porosity, influence its drying behavior.

Regression analysis serves to quantify the relationships between these factors and key drying performance metrics, such as drying time, moisture content, and product quality. By establishing these connections, researchers and engineers can optimize solar drying systems to achieve enhanced efficiency and improved product quality.

The role of regression analysis is crucial in the advancement and optimization of solar drying systems, providing valuable insights into factors influencing drying performance. This insight enables researchers and engineers to design more efficient systems suitable for various applications, including food preservation, agricultural processing, and industrial drying..

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In [25]: fig, axs = plt.subplots(2, figsize = (5,5))
         plt1 = sns.boxplot(df['DEWTS'], ax = axs[0])
         plt2 = sns.boxplot(df['DRS'], ax = axs[1])
         plt.tight_layout()
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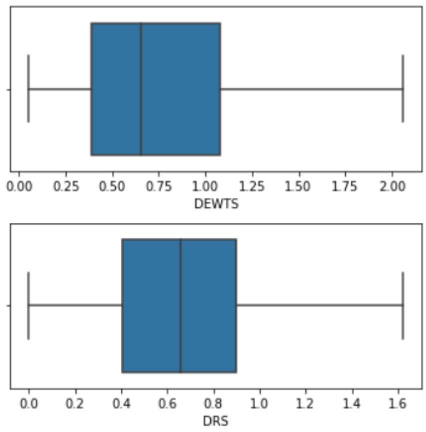

Fig 3. Plotting of dependent variables separately

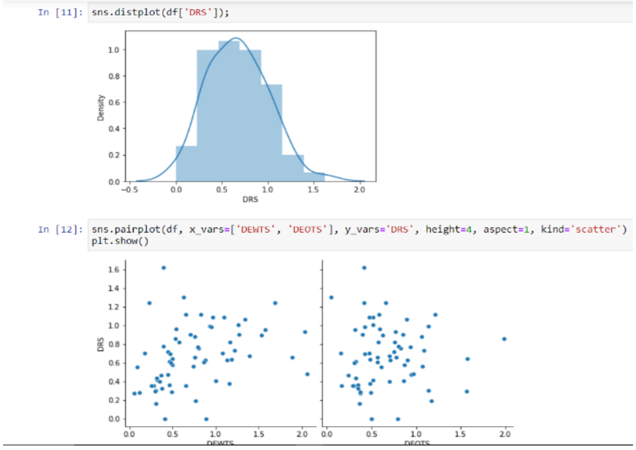

Fig 4. Plotting analysis of dependent and independent variables

	Actual value	Predicted value
41	0.579716	0.601090
32	1.246066	0.531529
12	0.189763	0.674071
56	0.400417	0.563117
57	0.321087	0.561733
25	0.633902	0.761808
33	0.351351	0.538087
5	0.558204	0.665461
11	0.673210	0.818538
64	0.000000	0.688984
0	0.820667	0.759948
18	0.603100	0.685825
6	0.700808	0.735733
49	0.898246	0.790371
40	0.410186	0.551675
26	1.242788	0.882720
21	0.769382	0.675098
47	0.954830	0.853264
20	1.118324	0.633577
42	1.623489	0.566490

Fig 5. Model Optimization

Artificial Neural Networks (ANNs) play a crucial role in elevating the efficiency and efficacy of solar drying systems. Modeled after the human brain's structure and functioning, ANNs significantly contribute to the modeling, prediction, and optimization aspects of solar drying processes.

1. Modeling Complex Relationships:
- ANNs excel in capturing intricate, non-linear relationships within data. In the context of solar drying systems, where multiple parameters influence the drying process, ANNs adeptly learn and model intricate patterns and correlations that may pose challenges for traditional modeling techniques.

2. Predictive Capabilities:
- By leveraging historical data from solar drying experiments, ANNs can be trained to comprehend the relationships between input factors (e.g., solar radiation, ambient conditions) and output variables (e.g., drying time, moisture content). Once trained, ANNs possess the capability to predict drying performance under varying conditions.

3. Adaptability to Dynamic Conditions:
- Solar drying systems often face dynamic environmental conditions. ANNs exhibit adaptability by adjusting their internal parameters based on new data, making them suitable for systems experiencing fluctuations in solar radiation, temperature, and humidity.

4. Optimization of System Parameters:
- ANNs can be utilized to optimize the parameters of a solar drying system. Analyzing historical data and considering various input factors, ANNs can suggest optimal settings for system parameters like airflow,

temperature, and drying time, contributing to improved efficiency and resource utilization.

5. Real-time Decision-Making:
 - Equipped with sensors, solar drying systems can benefit from ANNs processing real-time data from sources like temperature and humidity sensors. This enables the system to make intelligent decisions on-the-fly, adjusting operational parameters for optimal drying performance.

6. Handling Uncertainty and Noise:
 - ANNs demonstrate robustness in handling noisy data, a common challenge in solar drying systems. Their ability to generalize patterns from data aids in dealing with variations and uncertainties in the drying environment.

7. Improved Product Quality:
 - Through accurate prediction and control of the drying process, ANNs contribute to enhanced product quality. They play a crucial role in preventing over-drying or under-drying, leading to improved consistency in the final product.

In summary, ANNs offer a valuable set of tools for optimizing and controlling solar drying systems. Their proficiency in modeling complex relationships, predicting drying performance, adapting to changing conditions, and optimizing parameters makes them instrumental in enhancing the overall efficiency and effectiveness of solar drying processes.

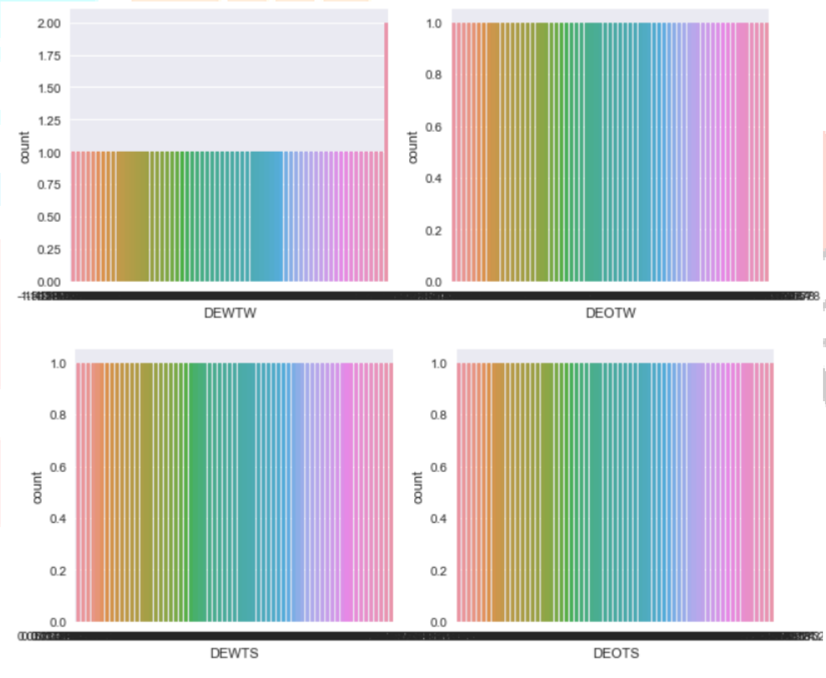

Fig 6 :Countplot

Fig 7 :HeatMap

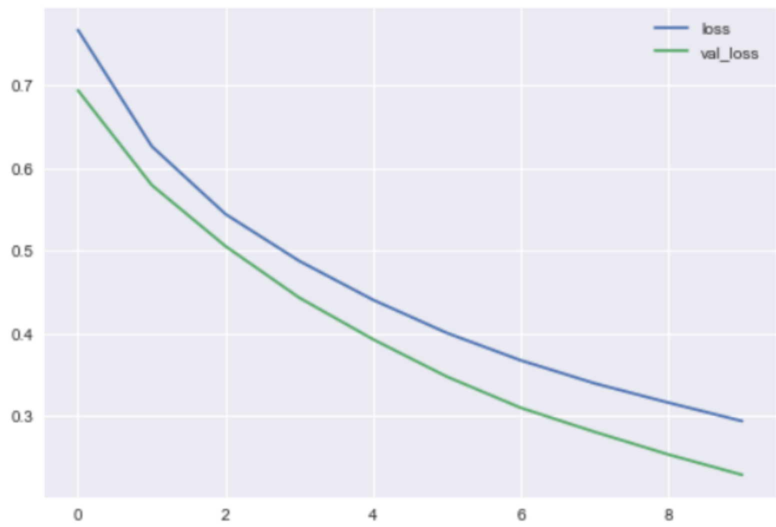

Fig 8 :AxesSubplot

V. CONCLUSION

The implementation of AI-based software for a solar drying system represents a promising advancement in the field of renewable energy and agricultural processing. This technology leverages machine learning algorithms and real-time data analysis to optimize the efficiency and performance of solar drying processes. The incorporation of AI enables the system to adapt to varying environmental conditions, ensuring consistent and precise control over drying parameters. the AI software can dynamically adjust parameters such as temperature, humidity, and airflow to maximize the drying rate and maintain product quality. the integration of AI into solar drying systems holds the potential to revolutionize the field by enhancing efficiency, sustainability, and overall product quality..

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