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# Design And Development Of A Smart Ventilated Onion Storage System With Humidity Controlled Window Automation

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**ABSTRACT:** Onions are grown and consumed on a large scale all around the world and are an important crop in many agricultural countries. Good postharvest storage conditions are vital to retaining their quality and preventing loss, yet traditional storage methods do not accurately manage one or more of the three major environmental contributors (i.e., ventilation, humidity, temperature) to postharvest losses. As a result, onions are often spoiled due to fungal decay, sprouting, or rot, which diminishes the shelf life of the crop as well as its market value. The high humidity level and inconsistent air circulation in onion storage as well as poor insulation (i.e., allowing outside ambient conditions to affect inside conditions) are major factors resulting in loss of onions after harvest. In order to overcome these challenges, this research proposes a Smart Ventilative Onion Storage System that utilizes automated humidity-controlled vent openings and insulated walls. Environmental temperature and humidity sensors are used with microcontrollers to activate exhaust fans and Pnuematic window openers based on environmental conditions. When the temperature or humidity exceeds the specified threshold levels, then the Smart Ventilation System will automatically ventilate the storage area. This will continue until the environmental conditions stabilize, resulting in reduced spoilage due to environmental factors, extended shelf life and quality of onions.

## 1. INTRODUCTION

Onions are widely cultivated around the world and play a vital role in the agricultural economy. They are an essential ingredient in many culinary dishes and serve as a significant source of income for numerous farmers. After harvest, improper storage conditions—such as uncontrolled temperature, humidity, and ventilation—can lead to a decline in onion quality, reducing the portion of the crop that meets market standards and resulting in financial losses for growers. As a result, farmers have limited information about the actual storage conditions, leaving onions vulnerable to spoilage caused by unfavorable environmental factors. Conventional indoor onion storage systems often fail to maintain critical environmental parameters. Ventilation is usually passive or manually operated, and monitoring of temperature and humidity is infrequent. Inadequate storage can lead to excessive moisture, poor airflow, and insufficient insulation. These conditions promote fungal infections, sprouting, and general spoilage, significantly reducing the shelf life of onions and decreasing their market value. The lack of continuous monitoring and automation in traditional storage systems makes it difficult to maintain stable conditions over time.

Farmers continue to experience major difficulties caused by losses after they harvest onions. The use of smart automated storage solutions can resolve these problems. If the storage of onions is combined with sensor-monitoring systems and active ventilation, the storage conditions will be optimal to help prevent spoilage and also provide the optimum quality throughout the storage period. The Smart Ventilated Onion Storage System is a storage structure that incorporates an automated method of controlling humidity by using window automation and insulated walls. The internal environment is monitored continuously to be thermally stable and controlled using a temperature and relative humidity sensor connected to a NodeMCU microcontroller that will process this information and automatically operate the exhaust fans and servo-driven windows to provide the idealized internal environment desired for the storage of onions, regardless of the external conditions. When the temperature or relative humidity exceeds the predetermined thresholds, the automated system will activate the ventilation system to remove excess moisture from the storage environment while maintaining sufficient air movement.

The insulated walls minimize the effect of changing external temperatures and humidities; thus, stabilizing the internal environment. Overall Benefits and Impact of the Automated Onion Storage System The creation of an ideal environment for storing onions will minimize post-harvest losses, provide a longer shelf life for onions, and increase their market value. With controlled storage environments, farmers will have improved methods for managing the storage of onions.

## 2. LITERATURE REVIEW

The growing awareness and concern to focus on post-harvest losses of agricultural products has led to developing automated and intelligent storage methods. Many of the studies conducted have described the benefits of using Internet of Things (IoT) and sensor-controlled systems for monitoring the conditions of storage facilities to preserve the quality of agricultural products. Kumar et al. (2021) and Patel et al. (2020) investigated the use of smart agricultural storage monitoring systems that combine temperature and humidity sensors with microcontrollers to automate environmental regulation and thus minimize post-harvest losses significantly.

Similarly, Mehta et al. (2019) and Sharma & Gupta (2020) examined how automatic ventilation systems affect agricultural storage. Their studies indicated that controlling the airflow using sensors in storage facilities would eliminate moisture accumulation and subsequently preclude fungal growth and sprouting, thereby extending shelf-life for crops such as onions.

In addition, several studies set out to integrate insulation and temperature regulation into smart storage designs. Singh et al. (2022) and Gupta et al. (2023) highlighted the incorporation of insulated building materials with control devices that automate the operation of fans and window mechanisms working together to maintain a stable internal storage environment, regardless of weather conditions outside. By utilizing these techniques, the amount of post-harvest losses can be reduced significantly and at the same time, increase sales potential or marketability of stored products.

Moreover, IoT monitoring systems can increase operational efficiency through continuous environmental tracking. Automated monitoring systems using NodeMCUs or equivalent microcontrollers were demonstrated to collect real-time temperature and humidity data and subsequently, operate exhaust fan and servo-controlled windows automatically (Singh and Patel, 2021; Reddy and Naidu, 2020; Mishra and Gupta, 2020). There is therefore reduced reliance on manual monitoring and improved conditions for stored products at all times.

Remote storage facility monitoring could be achieved through the integration of IoT and automatically controlled environmental systems (Patel and Shah, 2021; Mehta et al., 2019), allowing farmers and warehouse managers to anticipate adverse conditions and reduce labor requirements, while helping promote sustainable agricultural practices.

The literature reviewed in this report indicates that the combined use of IoT, sensor-based monitoring, and automated ventilation systems is an effective strategy to minimize post-harvest losses of onions in storage. Although, extensive use of these systems will need to overcome challenges in regards to initial cost and complexity in order to be quickly adopted by most farmers and processors.

## 3. METHODOLOGY

1. Temperature and Humidity Monitoring: Within the onion storage facility, sensors monitor both temperature and humidity levels 24/7. Data from these sensors is sent to a microcontroller (NodeMCU) that tracks the data in real time to ensure that both are maintained at their optimum levels for the preservation of onions.

2. Using Humidity to Operate Windows: To control humidity, servo motors operate storage area windows automatically when the humidity exceeds a pre-defined threshold; opening windows to the outside environment helps to release excess moisture from the storage area to prevent spoilage and fungus.

3. Automatically energize exhaust fan: Exhaust fans will automatically turn on when the humidity or temperature within the storage area exceeds the pre-defined thresholds, improving air circulation and reducing moisture accumulation; maintaining optimum temperature and humidity for onion storage.

4. Using insulated walls: The structure is built with insulated walls to minimize the impact of outside temperature and humidity on the inside of the storage area. This helps to keep onions at the same temperature and humidity level regardless of the outside temperature and humidity level.

5. Using Predefined Thresholds to Operate Systems Automatically: All automatic operation is based on predefined temperature and/or humidity thresholds; thus, the ventilation, fan, and window systems are only activated when necessary to reduce excessive energy consumption.

6. Real-Time Data Processing: The NodeMCU microcontroller processes real-time sensor data that oversees all systems for the optimum storage of onions without manual intervention.

7. Remote Monitoring: Sensor data from cloud platforms or mobile interfaces can be sent to allow farmers to monitor temperature and/or humidity levels in their storage areas.

## 4. EXISTING SYSTEM

The existing onion storage methods used in rural and semi-urban agricultural areas mainly rely on traditional techniques. In most cases, onions are stored in open sheds, warehouses, or temporary storage structures made from locally available materials such as bamboo, wood, or metal sheets. These structures mainly depend on natural air circulation and manual observation rather than controlled environmental conditions. However, these traditional storage methods do not continuously monitor important factors such as humidity, temperature, and ventilation. As a result, maintaining proper storage conditions becomes difficult, especially during rainy seasons and periods of high humidity.

One major limitation of the existing onion storage system is the lack of proper humidity control. In traditional storage structures, ventilation openings are usually fixed and manually operated. These openings are not adjusted according to changing humidity levels inside the storage area. When humidity increases beyond safe levels, moisture accumulates inside the storage space. This leads to fungal growth, sprouting, and rotting of onions, which reduces their shelf life and quality. Over time, this spoilage causes financial losses for farmers and reduces the market value of stored onions.

Another drawback of the existing system is the absence of real-time monitoring and automation. Farmers usually inspect storage conditions manually, which is time-consuming and sometimes inaccurate. There are no sensors available to provide real-time information about temperature and humidity levels inside the storage structure. Due to this delay in identifying unfavorable conditions, necessary corrective actions are not taken at the right time. This results in partial or complete damage to stored onions, especially when environmental conditions change suddenly.

In addition, traditional storage systems depend heavily on manual labor for ventilation control and monitoring. Farmers must manually open or close ventilation windows based on their observation, which increases labor effort and reduces overall efficiency. Environmental factors such as rainfall, seasonal temperature changes, and poor insulation also affect storage conditions. External moisture and heat can easily enter the storage area, creating unsuitable conditions for onion preservation. These conditions may also attract pests and insects, which further damage the stored onions.

Overall, the existing onion storage system is less efficient, labor-intensive, and lacks intelligent monitoring and automated ventilation features. These limitations clearly highlight the need for a smart ventilated onion storage system that can automatically control humidity levels, improve air circulation, and maintain proper storage conditions to reduce onion spoilage and post-harvest losses.

## 5. PROPOSED SYSTEM

The proposed Smart Ventilated Onion Storage System with Humidity Controlled Window Automation is designed to overcome the limitations of traditional onion storage methods by integrating automation, environmental sensors, and intelligent ventilation control. This system helps in maintaining proper storage conditions by continuously monitoring environmental parameters such as humidity and temperature. By automatically controlling ventilation based on real-time conditions, the system improves storage efficiency and reduces onion spoilage.

The system uses temperature and humidity sensors such as DHT sensors to monitor the environmental conditions inside the storage structure. Once the humidity or temperature level exceeds the predefined threshold value, the microcontroller (such as NodeMCU or Arduino) processes the sensor data and activates the ventilation system. An exhaust fan is automatically turned on to remove moist air from the storage area. At the same time, a humidity-controlled window automation mechanism using a servo motor or pneumatic system is activated to open the ventilation window. This allows fresh air to circulate inside the storage space and helps maintain suitable storage conditions.

The proposed system also includes an automatic humidity-controlled window mechanism. When the humidity level rises beyond the safe limit, the microcontroller sends signals to the servo motor or pneumatic actuator to open the window gradually. Once the humidity level returns to the normal range, the window automatically closes. This continuous monitoring and automatic adjustment help maintain balanced airflow inside the storage area without the need for manual operation.

To further improve the storage conditions, the proposed system incorporates an insulation method in the storage structure. Insulated walls are designed using suitable materials such as thermocol sheets, foam boards, or other insulating materials. This insulation helps in reducing the effect of outside temperature and humidity variations on the internal environment of the storage system. By preventing the direct transfer of heat and moisture from outside, the insulation method supports stable internal conditions and enhances the effectiveness of the ventilation system.

In addition to this, the proposed system allows real-time monitoring of environmental conditions. Sensor data can be transmitted to an IoT platform such as ThingSpeak using wireless communication. This enables farmers or storage managers to observe temperature and humidity levels remotely through mobile devices or computers. Alerts can also be generated when environmental conditions exceed safe limits, allowing timely corrective actions to be taken.

Overall, the proposed Smart Ventilated Onion Storage System provides an efficient, automated, and reliable solution for maintaining proper storage conditions. The integration of humidity-controlled window automation, exhaust ventilation, insulation methods, and IoT-based monitoring helps in reducing post-harvest losses, improving onion quality, and increasing storage efficiency.

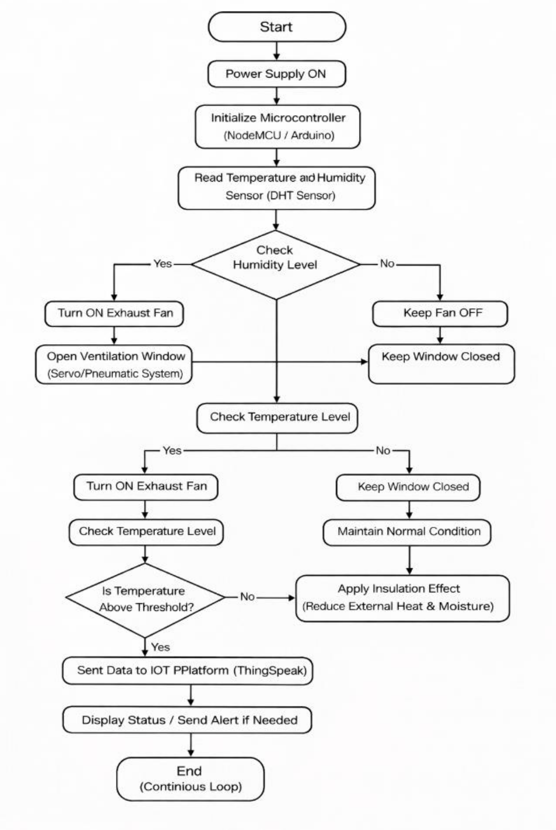


Fig1-Flow Chart

## 6. SYSTEM DESIGN

The system design for the Smart Ventilated Onion Storage System with Humidity Controlled Window Automation has been developed using a structured approach to create an efficient and reliable storage environment. The design integrates sensing, processing, actuation, insulation, and communication units to maintain suitable storage conditions for onions. The main objective of this design is to achieve automatic monitoring and control of environmental conditions such as humidity and temperature, thereby reducing post-harvest losses and improving storage efficiency. The system is divided into four major layers: input or sensing layer, processing or control layer, output or actuation layer, and communication layer. Each layer performs a specific function to ensure smooth operation of the overall system. The sensing layer consists of environmental sensors that continuously monitor the internal storage conditions. A temperature and humidity sensor, such as a DHT sensor, is used to measure the humidity and temperature levels inside the onion storage structure. These sensors help in detecting changes in environmental conditions that may affect the quality of stored onions.

In addition to the temperature and humidity sensor, the sensing layer may also include auxiliary components to improve system performance. These sensors provide continuous data to the controller, allowing timely actions to be taken when environmental conditions exceed safe limits. The sensing layer plays an important role in ensuring that the storage environment remains stable and suitable for onion preservation.

The processing layer consists of a microcontroller such as NodeMCU or Arduino, which acts as the brain of the system. The microcontroller receives signals from the sensors and processes the data using predefined threshold values. Based on the processed information, the microcontroller determines whether the humidity or temperature levels are within safe limits. If the environmental conditions exceed the set threshold values, the controller activates the required components to restore normal conditions. The microcontroller also coordinates the operation of different modules in the system, ensuring smooth communication between sensing and output components.

The actuation layer includes mechanical and electrical components that perform physical actions according to the instructions from the microcontroller. An exhaust fan is used to remove moist air from the storage area when humidity levels increase. A servo motor or pneumatic actuator is used to control the opening and closing of ventilation windows. When the humidity level rises above the predefined limit, the servo motor automatically opens the window to allow fresh air circulation. Once the humidity level returns to the normal range, the window closes automatically. This automated ventilation process helps maintain proper airflow inside the storage structure.

In addition to ventilation, the system design also incorporates an insulation method to maintain stable internal conditions. Insulated walls are designed using materials such as thermocol sheets, foam boards, or other suitable insulating materials. This insulation reduces the effect of external temperature changes and prevents a outside humidity from entering the storage area. By minimizing heat transfer and moisture entry, the insulation method supports efficient operation of the ventilation system and improves the overall storage performance.

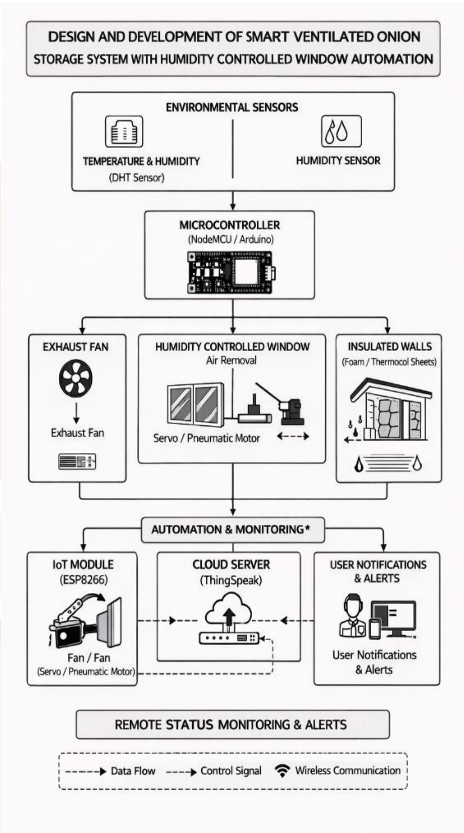


Fig2-Block Diagram

The communication layer is achieved by integrating an IoT module such as NodeMCU with wireless connectivity. In this system, environmental data collected from sensors is transmitted to a cloud platform such as ThingSpeak. This allows farmers or storage managers to monitor temperature and humidity levels remotely using a mobile phone or computer. Alerts can also be generated when environmental conditions exceed safe limits, enabling timely action to protect stored onions.

In addition to the above layers, the system design also includes power management and reliability features. A stable power supply is provided to ensure proper functioning of sensors, microcontroller, and actuators. Energy efficiency is achieved by operating components only when required, such as activating the exhaust fan only during high humidity conditions. The modular design of the system makes it easy to maintain, expand, and upgrade in the future. Additional features such as data logging and advanced monitoring can also be included as extensions to improve system performance. Safety and protection measures such as proper wiring, secure mounting of components, and overload protection can also be included to prevent damage to the electronic parts and improve system durability.

In conclusion, the system design provides a complete solution by integrating sensing, control, ventilation, insulation, and communication components into a single automated system. The design ensures proper environmental control, reduces manual effort, and improves the storage life of onions. This makes the Smart Ventilated Onion Storage System an effective and reliable solution for modern agricultural storage applications.

## 7. COMPONENTS

1. Microcontroller (Arduino): The microcontroller acts as the main control unit of the system. It receives data from sensors, processes the information, and controls devices like the exhaust fan and window motor. It ensures smooth coordination between all parts of the system.

2. Temperature and Humidity Sensor (DHT Sensor): This sensor measures the temperature and humidity levels inside the storage unit. It continuously sends data to the microcontroller to maintain suitable storage conditions for onions.

3. Humidity Sensor (Moisture Monitoring): The humidity sensor detects excess moisture inside the storage area. When humidity increases beyond the safe level, it alerts the controller to activate ventilation.

4. Servo Motor (Window Control): The servo motor controls the opening and closing of the ventilation window. It automatically adjusts the window position based on humidity levels.

5. Exhaust Fan: The exhaust fan helps remove hot and moist air from the storage area. It improves air circulation and protects onions from spoilage.

6. Ventilation Window: The ventilation window allows fresh air to enter and moist air to exit. It works along with the servo motor to maintain proper airflow.

7. Insulated Walls (Thermocol/ Foam Sheets): Insulated walls help maintain stable temperature inside the storage structure. They reduce the effect of external heat and moisture.

8. IoT Module (ESP8266): The IoT module sends real-time sensor data to the cloud platform like ThingSpeak. This allows users to monitor the storage conditions remotely.

9. Power Supply Unit: The power supply provides the required voltage to all components. It ensures reliable and continuous system operation.

## 8. CONCLUSIONS

The Smart Ventilated Onion Storage System with Humidity Controlled Window Automation provides a practical solution to the limitations of traditional onion storage methods. By using humidity and temperature sensors along with automated control, the system maintains suitable environmental conditions inside the storage space. This helps reduce spoilage caused by excess moisture and poor ventilation, allowing onions to remain fresh for a longer period. The system also includes automatic ventilation windows and exhaust fans that improve air circulation without the need for constant manual monitoring. These features increase storage efficiency and reduce post-harvest losses, making the system more reliable for farmers and storage users. In addition, IoT-based monitoring allows users to check storage conditions in real time through cloud platforms such as ThingSpeak. This helps in taking timely action whenever unusual conditions occur. Overall, the proposed system offers an efficient and cost-effective method for improving onion storage and can be further developed for wider agricultural applications.

## 9. FUTURE SCOPE

1. Cloud Data Storage and Analysis: Integration with advanced cloud platforms can help store large amounts of environmental data and analyze patterns related to storage conditions.

2. Solar Power Integration: The system can be powered using solar panels to make it energy-efficient and suitable for rural areas with limited electricity supply.

3. The Mobile Application Development: A dedicated mobile application can be developed to allow users to monitor humidity and temperature levels easily from smartphones.

4. Automatic Cooling Mechanism: Additional cooling systems can be introduced to maintain optimal temperature levels during extreme weather conditions.

5. Smart Alert and Notification System: Future improvements can include advanced alert systems that send notifications through mobile apps, SMS, or email.

6. Improved Insulation Techniques: The use of advanced insulation materials can further enhance temperature stability and reduce external heat transfer.

7. Scalability and Large-Scale Deployment: The system can be expanded for use in large warehouses and commercial onion storage facilities.

8. AI-Based Predictive Monitoring: Artificial intelligence techniques can be used to predict environmental changes and automatically adjust ventilation before problems occur.

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