VISVESVARAYA TECHNOLOGICAL UNIVERSITY

"Jnana Sangama" Belagavi – 590 018

PROJECT REPORT ON

"IOT Based Fruit Dehydrator"

Submitted in partial fulfillment of the requirements for the award of degree

BACHELOR OF ENGINEERING
IN
ELECTRONICS & COMMUNICATION ENGINEERING

Submitted By

Name	USN
Gowtham MA	4AL21EC029
Bharath N	4AL21EC013

Under the Guidance of

Dr. Ganesh VN

Associate Professor

Department of E&C Engineering

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

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(Affiliated to VTU, **BELAGAVI**)

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

CERTIFICATE

*Certified that the project work entitled "***IOT BASED FRUIT DEHYDRATOR***" is a bona fide work carried out by*

Gowtham MA	**4AL21EC029**
Bharath N	**4AL21EC013**

in partial fulfillment for the award of **BACHELOR OF ENGINEERING** in **ELECTRONICS & COMMUNICATION ENGINEERING** of the **VISVESVARAYA TECHNOLOGICAL UNIVERSITY, BELAGAVI** during the year 2024–2025. It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the departmental library. The project report has been approved as it satisfies the academic requirements in respect of Project work prescribed for the Bachelor of Engineering Degree.

Signature of the Guide	**Signature of the H.O.D**	**Signature of the Principal**
Dr. Ganesh VN	**Dr. Dattathreya**	**Dr. Peter Fernandes**

EXTERNAL VIVA

Name of the Examiners | Signature with date

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ABSTRACT

An IoT-based fruit dehydration system is proposed to enhance the efficiency and precision of the drying process. This system integrates temperature and humidity sensors, an ESP32 microcontroller, and a heater gun, ensuring optimal dehydration conditions. Real-time monitoring and automated control mechanisms eliminate the need for manual intervention, making the drying process more efficient and consistent.

The system leverages MQTT-based communication, allowing seamless interaction between the dehydration unit and a mobile application, where users can monitor temperature, humidity, and drying progress remotely. Advanced sensor calibration and data processing techniques ensure accurate measurements, preventing over-drying or under-drying of fruits.

Additionally, the system's compact design and low power consumption make it suitable for various agricultural and commercial applications. The collected data can be analyzed to optimize drying profiles for different fruits, improving overall quality, shelf life, and energy efficiency. Experimental results demonstrate that the proposed IoT-enabled dehydration system offers a reliable, automated, and scalable solution for modern fruit preservation.

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INTRODUCTION

1.1 Background on Fruit Preservation

Fruit preservation is an essential process that extends the shelf life of perishable fruits, preventing spoilage and reducing waste. Among various preservation techniques, dehydration stands out as one of the most effective methods, significantly reducing the moisture content in fruits. This moisture reduction plays a crucial role in inhibiting bacterial growth, mold formation, and enzymatic reactions that cause spoilage. By removing water, dehydration not only enhances fruit stability but also retains essential nutrients and flavors, making it a preferred method for preserving a variety of fruits such as apples, bananas, mangoes, and berries.

Traditional fruit dehydration methods, such as sun drying and manual dehydrators, have been widely used for centuries. However, these conventional techniques often pose several challenges. Sun drying, for instance, is highly dependent on weather conditions and can lead to inconsistent drying results due to variations in temperature, humidity, and exposure to contaminants. Similarly, manual dehydrators require constant monitoring and control, and any fluctuations in drying parameters may result in uneven drying, texture degradation, and significant nutrient loss. These inconsistencies not only affect the overall quality of the preserved fruit but also limit the efficiency and scalability of the dehydration process.

To address these challenges, modern technological advancements have led to the development of automated, IoT-based fruit dehydrators. These intelligent drying systems integrate sensors, data analytics, and automation to optimize the drying process in real time. By continuously monitoring key parameters such as temperature, humidity, and airflow, IoT-enabled dehydrators adjust drying conditions dynamically to ensure uniform moisture removal. This level of precision helps retain the fruit’s original color, flavor, and nutritional value while minimizing energy consumption. Additionally, remote monitoring and control capabilities allow users to manage the dehydration process from anywhere, enhancing convenience and operational efficiency.

The introduction of automated dehydration technology not only improves the consistency and quality of dried fruit products but also supports large-scale fruit preservation in commercial and industrial settings. By reducing spoilage, extending shelf life, and optimizing energy usage, IoT-based dehydrators represent a significant advancement in fruit preservation, contributing to sustainable food processing and storage solutions.

1.2 Evolution of Fruit Dehydrators

Fruit dehydration has undergone significant transformations over centuries, evolving from simple sun drying techniques to advanced electrical dehydrators that incorporate sophisticated temperature and humidity control mechanisms. The journey of dehydration technology reflects the continuous human effort to enhance fruit preservation, improve efficiency, and maintain the nutritional value of dehydrated fruit products.

1.2.1 Ancient and Traditional Dehydration Methods

Historically, one of the earliest methods of fruit preservation was sun drying, a technique widely employed by ancient civilizations across different regions of the world. Sun drying involved exposing fruit such as mangoes, grapes, and apples to direct sunlight for an extended period. This method was particularly common in arid and warm climates, where the natural heat facilitated moisture evaporation from fruit surfaces. The primary advantage of sun drying was its simplicity and cost-effectiveness, as it required no additional energy sources beyond natural sunlight.

However, despite its widespread use, sun drying posed several significant challenges. The process was highly dependent on climatic conditions, requiring prolonged exposure to warm temperatures and low humidity levels. Rainy, humid, or cloudy weather could disrupt the drying process, leading to incomplete dehydration and increased risks of microbial contamination. Additionally, traditional sun drying offered no control over environmental variables such as temperature, airflow, and humidity, often resulting in uneven drying, nutrient loss, and fruit spoilage. Due to prolonged exposure to open-air conditions, fruit was also susceptible to insect infestations, dust accumulation, and bacterial growth, making preservation inconsistent and inefficient.

To mitigate these issues, early societies developed rudimentary dehydration structures, such as drying racks, smokehouses, and clay ovens, to provide a more controlled environment. These methods, while improvements over open sun drying, still lacked precise control and required constant human supervision to ensure effective drying.

1.2.2 Introduction of Electrical Dehydrators

Despite these improvements, early electrical dehydrators still required significant manual intervention. Users had to frequently adjust temperature, airflow, and drying duration based on the type of fruit being dehydrated. Since different fruits contain varying levels of moisture and require specific drying conditions, improper adjustments could lead to over-drying (making fruit excessively hard and brittle) or under-drying (leaving residual moisture and increasing spoilage risk). The process remained labor-intensive, as users had to regularly monitor dehydration progress to prevent overheating or nutrient degradation. Moreover, energy efficiency was not optimized, leading to higher electricity consumption and operational costs.

1.2.3 The Impact of IoT and Machine Learning on Fruit Dehydration

With the advent of the Internet of Things (IoT) and machine learning technologies, fruit dehydration is now undergoing a technological revolution. Intelligent dehydrators equipped with IoT capabilities and real-time sensors are transforming the process by enabling automated, data-driven drying systems.

IoT-enabled fruit dehydrators integrate smart sensors that continuously monitor key drying parameters, such as:

- **Temperature**: Ensuring that heat levels remain optimal for moisture removal without nutrient degradation.
- **Humidity**: Adjusting drying conditions to maintain proper moisture balance.
- **Airflow**: Distributing heat evenly to prevent uneven drying.
- **Moisture content**: Detecting residual moisture to prevent over-drying or spoilage.

These sensors communicate with a central control system, allowing the dehydrator to automatically adjust drying conditions in real-time. As a result, users no longer need to manually regulate settings, as the system adapts dynamically based on fruit type, moisture level, and drying progress.

Moreover, machine learning algorithms enhance this process by analyzing historical data and identifying patterns in fruit dehydration. By learning from previous drying cycles, these intelligent systems can:

- Predict optimal drying parameters for specific fruit types.
- Ensure consistent moisture removal while preserving essential nutrients, texture, and flavour.
- Optimize energy efficiency, reducing power consumption and operating costs.

Additionally, IoT-enabled dehydrators offer remote monitoring and control capabilities. Users can track drying progress, adjust settings, and receive notifications via smartphone applications or cloud-based platforms. This feature provides greater convenience, flexibility, and precision, making fruit dehydration more user-friendly for both households and industrial applications.

1.2.4 The Future of Fruit Dehydration Technology

The integration of IoT and machine learning into fruit dehydration marks a significant leap forward in fruit preservation technology. These advancements not only improve drying efficiency and quality but also enhance sustainability by:

- Reducing energy consumption through intelligent optimization.
- Minimizing fruit waste by ensuring precise dehydration.
- Lowering labour requirements, making dehydration processes more automated and scalable.

As technology continues to evolve, the future of fruit dehydration will likely involve greater AI-driven automation, enhanced predictive analytics, and smart integration with other food preservation technologies. This will further refine the dehydration process, making it more precise, resource-efficient, and accessible to a broader range of users, from home fruit enthusiasts to large-scale fruit processors.

1.3 Role of IoT in Modern Dehydration Solutions

The integration of the Internet of Things (IoT) in food dehydration technology has brought a revolutionary transformation, making the process more efficient, precise, and user-friendly. Unlike traditional dehydrators that require constant manual monitoring and intervention, IoT-enabled systems leverage real-time data collection, adaptive control mechanisms, and cloud connectivity to automate and optimize the drying process. These technological advancements not only enhance dehydration accuracy but also improve energy efficiency, maintain food quality, and reduce user dependency on manual adjustments. As a result, modern dehydrators equipped with IoT capabilities offer a more reliable, intelligent, and scalable approach to food preservation.

Our project, a cloud-based food dehydrator with an intelligent profile selector, is specifically designed to maximize the benefits of IoT technology in food dehydration. This system integrates multiple smart components that work together to ensure automated control, dynamic parameter adjustments, and seamless remote monitoring, thereby addressing the major inefficiencies of conventional dehydrators.

1.3.1 Core Components and Functionality

➢ ESP32 Microcontroller: The Central Processing Unit

At the heart of our IoT-based dehydrator is the ESP32 microcontroller, a highly efficient, Wi-Fi-enabled microcontroller known for its low power consumption and robust data processing capabilities. This microcontroller serves as the brain of the system, managing real-time data acquisition from various sensors and processing the information to adjust drying conditions dynamically. The ESP32 is responsible for:

- Collecting data from multiple high-precision temperature and humidity sensors that continuously monitor the drying environment.
- Analyzing sensor inputs in real time to determine optimal drying conditions for different food items.
- Sending and receiving data to and from the cloud for remote access, monitoring, and profile selection.

By using the ESP32 as the core controller, the system can autonomously regulate the dehydration process, ensuring that food items receive the precise drying conditions needed for optimal moisture removal, nutrient retention, and flavor preservation.

➢ Smart Sensor Integration for Real-Time Monitoring

Our IoT-based dehydrator employs advanced environmental sensors that play a crucial role in ensuring uniform drying. These sensors provide continuous feedback on critical parameters such as:

- Temperature Levels: Monitoring and adjusting heat distribution to prevent overheating or under-drying.
- Humidity Levels: Ensuring proper moisture extraction and maintaining the ideal drying environment.
- Airflow Distribution: Regulating air circulation to eliminate uneven drying and hot spots.

By continuously gathering real-time sensor data, the system can make dynamic adjustments to the drying process, maintaining ideal conditions based on the type and quantity of food being dehydrated. This eliminates the need for manual intervention, making the process more automated and efficient.

➢ Relay-Controlled Actuators for Precision Drying

To regulate the dehydration process effectively, our system utilizes relay-controlled actuators that control key components such as:

- Heating Elements: Modulating the intensity of heat to suit the drying profile.
- Fans and Ventilation Systems: Adjusting airflow to optimize drying consistency.
- Humidity Control Mechanisms: Regulating moisture levels to ensure uniform drying.

These actuators receive instructions from the ESP32 microcontroller, allowing for real-time modulation of heat, airflow, and ventilation. This level of precision helps in preventing common dehydration issues such as:

- Over-drying, which can result in excessively hard or brittle food.
- Under-drying, which may leave residual moisture and increase spoilage risks.
- Uneven drying, which affects food texture and preservation quality.

By automating these processes, our system ensures that food items retain their natural color, flavour, and nutritional properties, making dehydration more reliable and effective.

1.3.2 Intelligent Profile Selector for Automated Drying Optimization

A key innovation of our project is the intelligent profile selector, which allows users to customize and automate the dehydration process based on the specific requirements of different food items. Unlike conventional dehydrators that require manual adjustments for each drying session, our system enables users to:

- Select predefined drying profiles tailored for various food categories such as fruits, vegetables, meats, and herbs.

- Upload and store custom profiles via a cloud-based platform for future use.
- Adjust drying parameters such as temperature, humidity, and duration with ease.

This feature is implemented using a Flutter-based mobile application, which provides a user-friendly interface for selecting and managing drying profiles. By leveraging cloud technology, users can create, modify, and store personalized drying profiles, ensuring that different food items receive the ideal dehydration treatment.

1.3.3 Seamless Cloud Connectivity and Remote Monitoring

One of the most significant advantages of our IoT-based dehydrator is its ability to connect to the cloud, allowing for remote access and real-time monitoring. This is made possible through MQTT (Message Queuing Telemetry Transport), a lightweight and efficient messaging protocol designed for IoT applications.

➢ MQTT Communication for Real-Time Updates

MQTT facilitates seamless communication between the dehydrator and the mobile application, enabling users to:

- Monitor drying progress remotely via live data updates.
- Receive alerts and notifications regarding temperature fluctuations, drying completion, or system errors.
- Adjust drying settings from anywhere, providing convenience and flexibility.

With MQTT, our system ensures instantaneous and reliable data exchange, making it easy for users to stay informed and in control of the dehydration process.

➢ Cloud Data Logging and Intelligent Analytics

Beyond real-time monitoring, our system also integrates cloud-based data logging and analytics, allowing users to:

- Track historical drying cycles and review past performance.
- Identify trends and patterns in food dehydration.
- Receive intelligent recommendations for improved efficiency and quality.

By collecting and analysing long-term drying data, the system can enhance automation and precision through machine learning algorithms. Over time, these algorithms can optimize drying profiles, predict ideal conditions for specific food types, and reduce energy consumption, leading to a smarter and more adaptive dehydration process.

Impact of IoT on Food Dehydration Efficiency

By integrating IoT technology into food dehydration, our project effectively addresses the key limitations of conventional dehydrators. The advantages of this smart system include:

- Improved Drying Accuracy: Real-time monitoring and dynamic adjustments ensure that food items are dried uniformly without nutrient degradation.
- Optimized Energy Efficiency: Smart automation reduces unnecessary energy consumption, making the process more sustainable.
- Enhanced User Convenience: Remote monitoring and control eliminate the need for constant supervision.
- Reduced Food Waste: Precise moisture removal prevents spoilage and extends shelf life.
- Scalability for Industrial Applications: IoT-based automation allows for large-scale food processing with minimal labour.

1.4 Problem Statement

Despite significant advancements in food dehydration technology, numerous challenges continue to hinder efficiency, effectiveness, and overall user experience. These challenges stem from the limitations of conventional drying techniques, the lack of intelligent automation in existing dehydrators, and the absence of data-driven approaches to optimize the dehydration process.

1.4.1 Inefficiencies in Traditional Methods

Traditional food drying techniques, such as sun drying, hot air drying, and freeze-drying, often suffer from several inefficiencies. One of the primary issues is uneven drying, where certain portions of the food lose moisture at a faster rate than others, leading to inconsistent texture, compromised taste, and poor preservation. Additionally, these methods can result in a significant loss of essential nutrients, such as vitamins and antioxidants, which deteriorate due to prolonged exposure to heat or air. Furthermore, conventional dehydration methods are typically labour-intensive, requiring constant monitoring, manual intervention, and frequent adjustments to drying conditions. These inefficiencies not only reduce productivity but also contribute to increased operational costs and decreased overall effectiveness.

1.4.2 Lack of Automation

Most commercially available food dehydrators lack intelligent automation, making them reliant on manual settings and predetermined drying conditions that do not account for the unique characteristics of different food types. Various foods—such as fruits, vegetables, meats, and herbs—require different drying temperatures, humidity levels, and air circulation rates to achieve optimal preservation and texture. However, existing dehydrators fail to dynamically adjust these parameters in real time. This limitation often leads to suboptimal drying results, such as over-dehydration, which makes food excessively hard and brittle, or under-dehydration, which leaves residual moisture and increases the risk of microbial growth and spoilage. The absence of automation also means that users must constantly monitor the dehydration process, making it less convenient and efficient, especially for large-scale food processing industries.

1.4.3 Need for Data-Driven Approaches

As consumer demand for smart kitchen appliances continues to rise, there is a growing need for food dehydrators that incorporate data analytics, artificial intelligence (AI), and machine learning (ML) technologies. These technologies could revolutionize the dehydration process by analyzing various factors such as moisture content, food type, temperature, humidity, and drying duration to automatically optimize drying conditions. A data-driven approach would enhance both user experience and food quality by ensuring consistent dehydration, minimizing nutrient loss, and reducing the overall energy consumption of the appliance. Moreover, integrating smart sensors and IoT-enabled features would allow users to remotely monitor and control the dehydration process through mobile applications, providing greater convenience and precision.

LITERATURE SURVEY

CHAPTER 2

LITERATURE SURVEY

2.1 Importance of Literature Survey

A literature survey is an essential part of any research or project as it provides a comprehensive understanding of previous studies related to the topic. It serves as a foundation for developing new ideas, identifying research gaps, and ensuring that the project builds upon existing knowledge.

One of the primary purposes of a literature survey is to understand past research, methodologies, and findings. By reviewing relevant literature, researchers can gain insights into existing solutions, learn from previous studies, and avoid redundant efforts. This helps in focusing on innovative aspects and improving the research approach.

Another significant advantage of conducting a literature survey is identifying research gaps. Many studies have limitations or unanswered questions, which can be explored further. Recognizing these gaps allows researchers to refine their objectives and contribute new knowledge to the field.

A literature survey also plays a crucial role in selecting appropriate methodologies. By analysing different approaches used in previous studies, researchers can choose the most effective techniques for data collection, analysis, and experimentation. This ensures the credibility and accuracy of the research findings.

Additionally, a literature survey helps avoid duplication of work. It ensures that the study being conducted is original and not a mere repetition of past research. This contributes to the uniqueness and significance of the project. Furthermore, it provides a theoretical framework by offering insights into fundamental principles and concepts related to the research topic.

By conducting a literature survey, researchers can also strengthen their study’s credibility. It demonstrates awareness of previous research and justifies the need for the current study. This not only enhances the reliability of the research but also makes it more acceptable in academic and professional circles.

2.2 Traditional Methods of Food Drying

Food drying is one of the oldest preservation techniques, allowing people to store food for extended periods without refrigeration. Various methods have been used throughout history, each reflecting the available resources and technological knowledge of the time. Below are some of the traditional methods employed for drying food:

2.2.1 Sun Drying

Fig.2.1 - Sun Drying Process

Sun drying is perhaps the oldest and most widely used method for drying food. Early humans discovered that exposure to the sun could effectively remove moisture from fruits, vegetables, and meats, thereby preventing spoilage. This method involves placing food on racks, trays, or mats under direct sunlight for several days, allowing natural heat to evaporate moisture.

Drawbacks:

- Weather-dependent, as it requires clear, sunny days.
- Slow process and may lead to contamination by insects and dust.
- Not ideal for preserving food in humid climates.

2.2.2 Air Drying

Fig.2.2 - Air Drying Process

Air drying is another ancient method where food is hung or laid out in well-ventilated areas. Herbs, seeds, and small fruits were often air-dried by suspending them on lines or placing them on racks. The process relies on the circulation of air to remove moisture from the food.

Drawbacks:

- Slow and reliant on favourable air circulation conditions.
- Limited to certain types of food.
- Not suitable for all climates, particularly humid or rainy environments.

2.2.3Smoke Drying

Fig.2.3 - Smoke Drying Process

Smoke drying, a method often associated with meat preservation, involves exposing food to smoke from burning wood or other materials. The smoke not only helps in drying the food but also adds flavor and protects it from microbial growth. Smoked meats, fish, and even vegetables are common examples of foods preserved by this technique.

Drawbacks:

- Requires specific equipment or setups, such as smoking pits or chambers.
- Limited to certain food types like meats and fish.
- Time-consuming and labour-intensive.

2.2.4 Oven Drying

Fig.2.4 – Oven Drying

Oven drying uses a conventional oven to remove moisture from food. The food is placed on racks or trays, and the oven is set to a low temperature to ensure gradual drying. This method became more popular with the advent of household ovens, providing more control over temperature and drying time.

Drawbacks:

- Requires a reliable heat source, and the process consumes energy.
- Not as efficient as modern dehydrators for large quantities of food.
- Can lead to uneven drying if not monitored carefully.

2.2.5 Dehydration Using Salt and Sugar

Fig.2.5 - Dehydration Using Salt and Sugar

Historically, food preservation was often achieved by applying salt or sugar to foods, such as meats, fruits, and vegetables. Salt draws moisture out of the food and acts as a preservative by creating an environment unfavourable to bacteria. Similarly, sugar helps preserve fruits by drawing moisture and preventing microbial activity.

Drawbacks:

- The food can become too salty or sweet, affecting taste and texture.
- Not suitable for all types of food, such as those with high water content.
- Requires a careful balance of salt or sugar to prevent spoilage.

2.3 The Present Work Definitions

- **Ajay, C., Sunil, K.S., & Deepak, D. (2009).**
  "Design of Solar Dryer with Hybrid System and Fireplace." *International Solar Food Processing Conference 2009.*

In this paper, Ajay *et al.* [1] (2009) discuss the design and development of a solar dryer integrated with a hybrid system and a fireplace for food processing applications. The authors address the limitations of traditional drying techniques by combining solar energy with supplementary heat sources, such as a fireplace, to enhance the efficiency and effectiveness of the drying process.

The study presents a system where solar energy serves as the primary source for drying food, while the hybrid system ensures continuous operation, particularly during cloudy days or low-sunlight conditions. The fireplace, incorporated into the system, acts as an auxiliary heat source when solar energy is insufficient. This integration improves the drying process by maintaining a steady temperature, which reduces drying time and ensures higher-quality processed food.

Additionally, the paper discusses the technical aspects involved in the construction of the solar dryer and the hybrid system, including energy efficiency, cost-effectiveness, and sustainability. The authors highlight the environmental benefits of using solar energy and emphasize its potential to reduce dependence on traditional fuel-based drying methods.

The study concludes that the hybrid solar drying system, which combines renewable energy sources, holds significant promise for large-scale food processing operations. The authors stress the importance of optimizing the system design to improve energy utilization and reduce operational costs, thus enhancing its potential for widespread adoption.

- **Esper, A., & Muhlbauer, W. (1998).**
  "Solar drying—An effective means of food preservation." *Renewable Energy, 15,* 95-100.

In this paper, Esper *et al. [2]* (1998) explore solar drying as an effective and environmentally sustainable method for food preservation. The authors emphasize the significance of solar drying within the context of renewable energy sources, stressing its advantages over traditional preservation methods that rely on refrigeration or chemical preservatives.

The paper explains the principle of solar drying, where food is exposed to the sun's energy to remove moisture, thereby preventing spoilage and extending the shelf life of food. Solar drying is presented as a low-cost, energy-efficient alternative that not only preserves food but also reduces reliance on fossil fuels, making it an environmentally friendly solution.

Esper and Muhlbauer examine various solar dryer designs, classifying them into direct, indirect, and mixed-mode types. They provide a detailed analysis of factors affecting solar dryer performance, such as weather conditions, temperature, humidity, and food characteristics. The authors argue that optimizing these factors can significantly improve the efficiency and effectiveness of the drying process.

Additionally, the paper highlights the economic benefits of solar drying, particularly in developing regions with limited access to electricity. The authors emphasize the potential of solar dryers for small-scale food processing industries, where they can serve as a reliable, cost-effective method of food preservation.

Esper and Muhlbauer conclude that solar drying offers a viable solution for food preservation, especially in regions with abundant sunlight. They call for further research to improve solar drying technologies to enhance their efficiency and scalability, making them accessible to a broader range of users worldwide.

- **Bala, B.K., & Woods, J.L. (1994).**
  "Simulation of the indirect natural convection solar drying of rough rice." *Solar Energy, 53(3)*, 259-266.

In this paper, Bala *et al. [3]* (1994) present a simulation study on the indirect natural convection solar drying of rough rice. The authors focus on improving the drying process for rice, a staple crop widely preserved through drying methods.

The study highlights the indirect solar drying method, where the food (in this case, rough rice) is dried using solar energy but without direct exposure to the sun. Instead, natural convection circulates heated air from the solar collector to the drying chamber, providing a controlled and consistent drying environment.

Bala and Woods use a mathematical model to simulate the drying process, factoring in variables such as air temperature, humidity, and the rice's moisture content. The authors analyze the impact of different drying parameters and environmental conditions (like ambient temperature and solar radiation) on the performance of the solar dryer.

Their simulation reveals that the indirect solar drying system significantly reduces drying time compared to traditional methods, offering energy efficiency advantages. The method also helps prevent over-drying, ensuring more uniform drying, which is critical to preserving rice quality.

While the paper discusses the system's limitations, including dependence on weather conditions and the need for a reliable energy source, the authors conclude that indirect solar drying systems, when optimized, can serve as an efficient and sustainable solution for rice drying, particularly in regions with abundant sunlight.

Bala and Woods advocate for further research to improve solar dryer designs, enhance the accuracy of simulation models, and explore the potential integration of hybrid systems (such as solar and biomass) to boost the reliability and efficiency of the drying process.

- **Goswami, D.Y., Lavania, A., Shabbzi, S., & Masood, M. (1991).**
  "Analysis of age geodesic dome solar fruit dryer." *Drying Technology, 12(3),* 677-691.

In this paper, Goswami *et al. [4]* (1991) analyze a geodesic dome solar dryer designed specifically for drying fruits. The authors evaluate the structural and thermal characteristics of the geodesic dome, focusing on its efficiency in drying fruit using solar energy. One of the key benefits of the geodesic dome design is its ability to evenly distribute heat, which is crucial for achieving uniform drying.

Through simulations and mathematical modeling, the authors examine various parameters including air circulation, temperature variation, and moisture removal during the drying process. Their analysis emphasizes the advantages of the geodesic dome design over traditional solar dryers, particularly in maximizing solar radiation capture and heat retention.

The study finds that the geodesic dome solar dryer provides a more stable and consistent drying environment, reducing the impact of external weather conditions. This results in more efficient drying with less variability. The compact and robust structure of the dome also makes it ideal for both small- and large-scale fruit drying applications.

However, the authors note challenges, including the complexity of design and construction needed to ensure optimal performance and the difficulty of scaling the system for industrial use. Despite these challenges, they conclude that the geodesic dome solar dryer is a viable and effective solution for fruit drying, especially in regions with abundant solar energy. Further research is recommended to refine the design, improve operational efficiency, and explore hybrid systems to enhance the reliability of the drying process.

- **Vlachos, N.A., Karapantsios, T.D., Balouktsis, A.I., & Chassapis, D. (2002).** "Design and testing of a new solar dryer." *Drying Technology, 20(5),* 1243–1271.

In this paper, Vlachos *et al. [5]* (2002) present the design and testing of a new solar dryer aimed at improving the efficiency and performance of food drying processes. The authors focus on the development of an innovative solar dryer that incorporates advanced design features to enhance the energy efficiency and drying speed compared to traditional systems.

The study explores several key components of the new solar dryer, including the solar collector, drying chamber, and air circulation system. The authors investigate the impact of various design modifications, such as the angle of the solar collector, the use of reflective surfaces, and the optimization of airflow within the drying chamber, on the overall performance of the system.

Through extensive testing, Vlachos *et al.* analyze the dryer's performance under different environmental conditions, such as varying levels of solar radiation, ambient temperature, and humidity. The results of the testing indicate that the new solar dryer performs significantly better than conventional systems, demonstrating a reduction in drying time and increased energy efficiency.

The authors also examine the economic feasibility of the solar dryer, considering factors such as initial investment, operating costs, and potential energy savings. They conclude that the new design offers a promising solution for small- to medium-scale food processing, particularly in regions with abundant sunlight.

Overall, the paper highlights the potential of this new solar dryer to revolutionize food drying processes by offering a cost-effective, sustainable, and energy-efficient alternative to traditional drying methods. The authors call for further research into the optimization of the system and its scalability for wider applications.

- **Naiju, C.D., et al. (2011).**
  "Conceptualization Design for Manufacture and Assembly (DFMA) of Juicer Mixer Grinder." *Proceedings of National Conference on Advances in Mechanical Engineering (NCAME)/SBCEC/23rd & 24th March 2011.*

In this paper, Naiju *et al. [6]* (2011) discuss the conceptualization and design process of a juicer mixer grinder using the principles of Design for Manufacture and Assembly (DFMA). The authors focus on optimizing the design and production processes to ensure that the final product is both efficient to manufacture and easy to assemble, reducing overall production costs while maintaining high-quality standards.

The paper delves into the key design considerations, such as the selection of materials, the design of individual components, and the integration of parts in a manner that minimizes complexity and assembly time. The authors emphasize the importance of DFMA in improving product reliability, reducing the number of parts, and ensuring ease of maintenance, which ultimately leads to cost savings in both the manufacturing and operational phases.

Through a detailed analysis, Naiju *et al.* explore the application of DFMA techniques to juicer mixer grinders, a popular kitchen appliance, to streamline the design and manufacturing processes. The authors use a case study approach to demonstrate how DFMA principles can be applied to various aspects of the product, such as the motor housing, rotating components, and user interface, to reduce part count and complexity.

The paper concludes by highlighting the potential benefits of DFMA, including shorter product development cycles, reduced manufacturing costs, and enhanced product quality. The authors suggest that adopting DFMA principles can lead to more efficient production methods and the creation of more reliable, cost-effective products in the competitive appliance market.

- **Mukas, R.S., et al. (2020).**
  "Performance Evaluation of a Programmable Dehydrator Machine for Herbal Tea Materials."

In this paper, Mukas *et al. [7]* (2020) evaluate the performance of a programmable dehydrator machine specifically designed for drying herbal tea materials. The authors focus on assessing the efficiency, effectiveness, and practicality of the dehydrator in processing various herbal materials used in tea production.

The study provides an in-depth analysis of the machine’s performance, considering key factors such as temperature control, drying time, and energy consumption. The programmable nature of the dehydrator allows for precise control of drying conditions, ensuring that the herbal materials are dried under optimal conditions to preserve their flavor, aroma, and nutritional content. The authors also examine how the machine can be adapted for different types of herbal materials, with varying moisture content and drying requirements.

Mukas *et al.* emphasize the importance of consistent temperature and air circulation to avoid uneven drying, which could affect the quality of the final herbal tea product. They provide data on how the programmable settings of the dehydrator allow for more efficient drying compared to traditional methods, reducing the time and energy required for the process while maintaining the integrity of the herbal materials.

The paper concludes that the programmable dehydrator machine shows great potential for use in the herbal tea industry, offering a more controlled and energy-efficient method of drying. The authors suggest that further research into optimizing the machine's design and improving its scalability could lead to widespread adoption in both small-scale and commercial herbal tea production.

- **Krajnik, J., et al. (2020).**
  "Advances in Centreless Grinding Modelling and Simulation."

In this paper, Krajnik *et al. [8]* (2020) present significant advancements in the modeling and simulation of centerless grinding, a critical manufacturing process widely used in industries such as automotive and aerospace. The authors focus on enhancing the understanding of the dynamics and mechanisms involved in centerless grinding, particularly through the use of advanced simulation techniques to predict and optimize the grinding process.

The study begins by reviewing the current state of centerless grinding technology, including traditional methods and their limitations. The authors then discuss the integration of modern simulation tools and numerical methods that enable more accurate predictions of grinding forces, heat generation, and material removal. By using simulations, Krajnik *et al.* aim to address challenges such as predicting surface quality, optimizing grinding wheel wear, and improving overall process efficiency.

A key focus of the paper is the development of a comprehensive model that incorporates various parameters affecting the grinding process, such as the geometry of the workpiece, the characteristics of the grinding wheel, and the operating conditions. The model allows for real-time predictions of the grinding forces and material behavior during the process, providing valuable insights for improving productivity and achieving better product quality.

The authors also explore recent advances in the use of real-time monitoring and adaptive control systems that can be integrated into the grinding process. These systems enable dynamic adjustments based on feedback, enhancing the precision and consistency of the grinding operation. The integration of machine learning and artificial intelligence with grinding simulations is also discussed as a promising direction for future research.

Through their study, Krajnik *et al.* demonstrate that the use of advanced simulation tools not only improves the design and optimization of the centerless grinding process but also helps in reducing material waste and energy consumption. They conclude that further research into the refinement of these simulation techniques and the integration of smart technologies will continue to drive improvements in the efficiency and effectiveness of centerless grinding.

- **Nurafifah, F., Chuah, A.L., & Wahida, M.A.P.F. (2018).**
  "Drying of Plectranthus amboinicus (Lour) Spring Leaves by Using Oven Dryer."
  Engineering Agriculture Environment & Food, 11(4), 239-244.

In this study, Nurafifah *et al. [9]* (2018) investigate the drying process of *Plectranthus amboinicus* (Lour) spring leaves using an oven dryer. This research focuses on evaluating the efficiency and effectiveness of oven drying as a method for preserving the leaves of this plant, which is known for its medicinal and culinary properties.

The drying process is essential for extending the shelf life of these leaves and ensuring their quality for future use.

The paper discusses the various parameters influencing the oven drying process, such as temperature, drying time, and air circulation. The authors explore the relationship between these factors and the final moisture content of the leaves, providing a comprehensive analysis of how each parameter affects the drying efficiency. Through experiments, they determine the optimal conditions for drying the leaves while preserving their color, texture, and nutritional value.

The results of the study show that oven drying is a viable method for drying *Plectranthus amboinicus* leaves, but careful control of temperature and time is necessary to avoid over-drying or degradation of the plant's valuable compounds. The authors also note that while oven drying is effective, it may not be as energy-efficient as other drying methods, such as solar drying, especially for large-scale applications.

Nurafifah *et al.* conclude that oven drying is a practical method for small-scale drying of *Plectranthus amboinicus* leaves, but they recommend further research into optimizing the process and exploring alternative drying techniques that may be more sustainable and energy-efficient.

- **Singh, P., & Talukdar, P. (2019).**
  "Design and Performance Evaluation of Convective Drier and Prediction of Drying Characteristics of Potato Under Varying Conditions." *International Journal of Thermal Sciences*, 142, 176-187.

In this paper [10], Singh and Talukdar (2019) focus on the design and performance evaluation of a convective drier used for drying potatoes, with a particular emphasis on predicting the drying characteristics under different conditions. The authors aim to improve the understanding of how various factors, such as air velocity, temperature, and humidity, influence the drying process and the final quality of the dried potato.

The study presents a detailed design of the convective drier, which relies on the forced circulation of hot air to remove moisture from the potato slices. The authors explore how varying the drying conditions impacts both the drying rate and the energy efficiency of the process.

They use experimental data to develop a model for predicting the drying characteristics of potatoes, helping to optimize the drying parameters for improved performance.

Through their performance evaluation, Singh and Talukdar identify key factors such as the air temperature and flow rate that affect the drying efficiency and quality of the final product. They also examine the energy consumption of the convective drier, comparing it to other conventional drying methods. The results show that convective drying offers a good balance between drying time and energy use, but the process efficiency can be further enhanced by optimizing the drying parameters.

The authors conclude that the convective drier is a suitable choice for drying potatoes, particularly in industrial applications where large-scale drying is needed. They recommend further research into refining the design and testing the system under more variable environmental conditions to fully assess its potential for large-scale food processing.

- **Singh, Y. K., Kumar, J., Pandey, K. K., Rohit, K., & Bhargav, A. (2016).** "Temperature Control System and Its Control Using PID Controller." *International Journal of Engineering Research and Technology*, 4(02), 4-6.

In this paper [11], Singh et al. (2016) present a study on the design and implementation of a temperature control system using a Proportional-Integral-Derivative (PID) controller. The authors focus on the development of an efficient temperature control system that can maintain desired temperature levels in various applications, with particular attention to improving precision and stability in the control process.

The paper discusses the principle of operation of a PID controller, which adjusts the system's output based on the error between the desired setpoint and the actual temperature. The authors provide a detailed analysis of the PID control algorithm, describing the roles of the proportional, integral, and derivative terms in achieving the desired temperature response.

The paper also highlights the challenges in designing a temperature control system that can accurately track changes in temperature and maintain stability under varying conditions.

Singh et al. emphasize the importance of tuning the PID controller parameters for optimal performance. The authors also explore the practical applications of the system, particularly in industrial and laboratory settings, where precise temperature control is critical. By implementing the PID controller, the system is able to minimize temperature fluctuations and ensure more consistent and reliable operations.

The paper concludes that the PID-controlled temperature system offers a robust and flexible solution for temperature regulation across a variety of fields. The authors suggest that future research could focus on further optimization of the PID algorithm and its integration into more complex control systems

- **Madhankumar, S., et al. (2020).**
  "Design and Modelling of Self-Balancing Electric Two-Wheeler Using the Gyroscope." *Journal of Critical Reviews*, 7(9), 953-957.

In this paper, Madhankumar et al [12]. (2020) focus on the design and modeling of a self-balancing electric two-wheeler that utilizes a gyroscope for stability. The authors explore the challenges of maintaining balance in electric two-wheelers, especially in the absence of traditional support mechanisms like training wheels or kickstands.

The study presents a novel approach to balance control by integrating a gyroscope system, which helps maintain the upright position of the two-wheeler while in motion. The gyroscope measures the angular velocity and provides real-time feedback to the control system, allowing it to make adjustments to the motor's speed and direction to maintain stability.

Madhankumar et al. emphasize the importance of sensor integration in maintaining dynamic balance in an electric vehicle. They model the system's behavior using mathematical equations that describe the interaction between the gyroscope, the vehicle's center of gravity, and the control system. This allows for the optimization of the balancing mechanism, ensuring that the vehicle can stay upright even when stationary or moving at low speeds.

The authors discuss the potential applications of this self-balancing electric two-wheeler in various industries, including transportation and delivery services. They also highlight the advantages of electric two-wheelers in terms of sustainability, reduced carbon emissions, and energy efficiency.

The paper concludes with a discussion on the feasibility of implementing this design in real-world applications, while suggesting that future work could focus on enhancing the system's robustness, improving its energy efficiency, and reducing the overall cost of production.

- **Vijayananth, D., Sivakumar, V., Ramkumar, S., & Thirumarimurugan, M. (2016).** "Control of Tray Dryer Using PID Controller." *Middle-East Journal of Scientific Research*, 24, 254-258.

In this paper, Vijayananth et al [13]. (2016) explore the application of a Proportional-Integral-Derivative (PID) controller in regulating the operation of a tray dryer for industrial food drying processes. The authors focus on improving the control and efficiency of the drying process, which is a crucial aspect of maintaining product quality in food preservation.

The study discusses the limitations of traditional drying techniques, particularly in terms of temperature fluctuations and uneven drying, which can lead to quality degradation. By implementing a PID controller, the authors aim to regulate the drying temperature and ensure more uniform drying across the trays. The PID controller adjusts the heating system to maintain the set temperature, compensating for any variations due to external factors like ambient temperature or humidity.

Vijayananth et al. use mathematical models to simulate the drying process, taking into account factors such as the moisture content of the material, air temperature, and the dynamics of the drying chamber. The authors highlight the advantages of PID control in achieving precise temperature control, leading to reduced drying time and improved energy efficiency.

The paper also examines the challenges involved in controlling the tray dryer, such as tuning the PID parameters to achieve optimal performance and dealing with non-linearities in the system. The authors conclude that using a PID controller significantly enhances the drying process by providing greater control over temperature fluctuations, improving product consistency, and optimizing energy consumption.

Future work, according to the authors, could focus on integrating advanced control systems, such as fuzzy logic or adaptive controllers, to further improve the performance and scalability of the tray dryer.

- **Nadu, T. (2020).**
  "Design and Fabrication of Portable Food Dehydrator." *International Journal of Food Science and Nutrition*, 5(4), 49-52.

In this paper [14], Nadu (2020) discusses the design and fabrication of a portable food dehydrator aimed at improving food preservation in small-scale or household settings. The study focuses on creating a user-friendly and energy-efficient dehydrator that can effectively remove moisture from various food types to prevent spoilage and extend shelf life.

The paper provides a detailed explanation of the design process, including the selection of materials, the development of the heating system, and the integration of airflow management to ensure uniform drying. Nadu emphasizes the importance of portability in the design, making the dehydrator accessible for small-scale applications where space and energy resources may be limited.

The study explores various technical aspects of the dehydrator, such as its energy efficiency, drying capacity, and ease of use. The author also discusses the challenges associated with creating a compact system that can handle different types of food while maintaining optimal temperature and humidity levels for effective drying. Through testing and prototype fabrication, the author presents the results showing that the portable dehydrator is capable of drying fruits, vegetables, and herbs effectively within a reasonable time frame.

In conclusion, Nadu (2020) highlights the potential of portable food dehydrators as an accessible and sustainable solution for food preservation in small-scale settings, especially in regions with limited access to refrigeration or other preservation methods. The paper recommends further improvements in the design to enhance the dehydrator’s efficiency and scalability for broader applications.

- **Madhankumar, S., Suryakumar, H., Sabarish, R., Suresh, M., & A, U. F. (2021).** "Fabrication of Pineapple Peeling Machine Using Pneumatic Solenoid Valve." *IOP Conference Series: Materials Science and Engineering*, 1059, 1-4.

In this paper, Madhankumar et al [15]. (2021) describe the fabrication of a pineapple peeling machine using a pneumatic solenoid valve. The authors focus on developing an efficient, automated system for peeling pineapples, aimed at reducing labor costs and increasing productivity in food processing operations.

The study explores the use of pneumatic technology to operate the solenoid valve, which controls the peeling mechanism. This design offers several advantages over traditional manual methods, including higher peeling precision, increased speed, and reduced manual labor. The authors discuss the process of selecting appropriate materials and components, as well as the challenges encountered in the design and fabrication stages.

The machine is designed to automate the peeling process by applying controlled pneumatic pressure to peel the pineapple skin without damaging the fruit. The authors also highlight the efficiency and cost-effectiveness of using pneumatic systems in food processing machinery, particularly for small and medium-scale operations.

Through experimentation, the authors demonstrate that the pineapple peeling machine operates effectively with minimal human intervention. The results indicate that the machine is capable of peeling pineapples quickly and with consistency, leading to improved efficiency in food processing.

In conclusion, Madhankumar et al. (2021) highlight the potential of pneumatic systems in food processing equipment and recommend further research into optimizing the design for broader applications in the food industry. The paper emphasizes the importance of automation in improving the scalability and efficiency of food processing operations.

- **Madhankumar, S. R. S., Vignesh, T., Anand Raj, P., Anirudh, & Arul Praveen.** "Design and Modelling of L-type Bi-Directional Roller Conveyors for Glass Hauling." *Lecture Notes in Electrical Engineering*.

In this paper [16], Madhankumar et al. focus on the design and modeling of L-type bi-directional roller conveyors intended for glass hauling applications. The authors address the specific challenges associated with transporting glass sheets, which require specialized handling to prevent damage and ensure safe transportation within manufacturing environments.

The paper discusses the development of a roller conveyor system that utilizes bi-directional movement to efficiently transport glass sheets in both directions. The L-type design is chosen for its space-saving features and ability to facilitate smooth transitions between different sections of the conveyor system. The authors model the conveyor system's operation using a combination of mechanical and electrical components to achieve optimal efficiency.

Key aspects of the design include the choice of materials for the rollers, the motor system for driving the conveyor, and the incorporation of safety features to protect the glass from damage during transit. The authors also explore the modeling of the conveyor system to predict its performance under various operational conditions, such as load capacity and speed.

The study highlights the importance of precision in the design of conveyor systems, especially for delicate items like glass. By analyzing the system's functionality, the authors demonstrate that the L-type bi-directional roller conveyor provides an effective solution for glass hauling, offering improved reliability and efficiency compared to traditional conveyor systems.

Madhankumar et al. conclude that the L-type bi-directional roller conveyor is an effective design for glass hauling and could be adapted for other industries that require the transportation of fragile materials. They recommend further testing and optimization to ensure the system meets industrial requirements.

2.1 Summary

The literature survey provides insights into the development of a cost-effective and user-friendly solution for automated fruit dehydration with remote monitoring and control.
Traditional fruit drying methods, such as sun drying or conventional dehydrators, face challenges related to inconsistent drying, high energy consumption, and lack of real-time monitoring. These limitations particularly affect small-scale farmers and food processors who require an affordable and efficient drying solution. Studies highlight the need for intelligent automation in food dehydration to improve drying uniformity, reduce wastage, and maintain fruit quality.

Several research works propose IoT-based solutions for food drying, leveraging microcontrollers like ESP32 due to their affordability, low power consumption, and built-in Wi-Fi and Bluetooth connectivity. Sensors play a crucial role in monitoring temperature, humidity, and drying progress, ensuring optimal dehydration conditions. Capacitive and resistive humidity sensors are commonly used for precise moisture detection, while temperature sensors help regulate the drying process.

The literature also outlines the essential components required for an IoT-integrated dehydrator, including microcontrollers, sensors, a heating system, a fan, cloud storage for data logging, and a mobile or web-based application for remote access. Additionally, MQTT communication is frequently employed for efficient data transmission between the device and the user interface.

Future research and development in this area focus on improving energy efficiency through smart power management, enhancing machine learning models for predictive drying optimization, and integrating AI-driven recommendations for different fruit types. Wireless connectivity options such as LoRaWAN and 5G are also explored to expand accessibility in rural and remote locations.

The literature survey highlights the potential of an IoT-based fruit dehydrator for automation, efficiency, and ease of use, revolutionizing small-scale drying, food preservation, and sustainable agriculture.

PROPOSED SYSTEM

CHAPTER 3

PROPOSED SYSTEM

3.1 Introduction

In the realm of food preservation technology, precision and efficiency are paramount for maintaining the quality and shelf life of fruits. Among the critical factors influencing fruit dehydration success is the control of temperature and moisture levels, ensuring optimal drying while retaining nutritional value and flavour. However, accessing accurate and timely control over the dehydration process has often been a challenge, hindered by the limitations of traditional methods and the lack of real-time monitoring capabilities.

To address these challenges, we propose a groundbreaking solution: an IoT-based fruit dehydrator utilizing an ESP32 microcontroller in conjunction with temperature and humidity sensors. This innovative system offers a cost-effective, user-friendly, and automated approach for users to efficiently dehydrate fruits while ensuring consistent quality and minimal energy consumption.

The proposed system harnesses the versatility and accessibility of the ESP32 microcontroller, renowned for its Wi-Fi capabilities, energy efficiency, and robust performance. Paired with sensors specifically calibrated for temperature and humidity monitoring, this system provides users with real-time insights and remote control over the dehydration process, enabling informed decision-making throughout the drying cycle.

In this introduction, we present a comprehensive overview of the proposed system, highlighting its key components, functionalities, and anticipated benefits for both small-scale users and commercial applications. We delve into the technical intricacies of IoT-based sensor integration, cloud communication, and the practical implications for food preservation management.

By empowering users with a reliable and intuitive tool for fruit dehydration, our proposed system aims to revolutionize food preservation practices, fostering efficiency, sustainability, and quality control in the drying process. Through the integration of IoT technology and smart automation, we aspire to drive innovation in the food processing sector, ensuring better preservation techniques and reducing food waste.

3.2 Advantages

1 Optimized Dehydration Process: The IoT-based fruit dehydrator ensures precise control over temperature and drying time, optimizing the dehydration process for different types of fruits. By continuously monitoring temperature and humidity levels, the system prevents over-drying or under-drying, preserving the natural flavor, texture, and nutritional value of the fruit. This automation enhances efficiency and reduces the need for manual intervention, making the dehydration process more reliable and consistent.

2 Improved Energy Efficiency: Traditional fruit dehydration methods often lead to unnecessary energy consumption due to inefficient heating and lack of real-time monitoring. Our IoT-based system uses smart sensors and automated controls to optimize energy usage, reducing operational costs and minimizing environmental impact. By maintaining precise drying conditions, the system ensures that only the necessary amount of energy is used, improving overall sustainability and cost-effectiveness.

3 Remote Monitoring and Control: One of the key advantages of the proposed system is its ability to allow users to monitor and control the dehydration process remotely. Through the mobile application, users can start, stop, and adjust drying parameters from anywhere, ensuring flexibility and convenience. This feature is particularly beneficial for commercial applications where continuous monitoring may not be feasible.

4 Enhanced Product Quality and Shelf Life: Properly dehydrated fruits have a longer shelf life, reduced microbial growth, and retained nutritional content. By ensuring precise control over the drying process, our system helps maintain the quality and integrity of the fruit, preventing spoilage and extending storage life. This not only benefits individual users but also enhances the commercial viability of dehydrated fruit products by ensuring consistent quality for consumers.

5 Data Logging and Analysis: The system records historical data on temperature, humidity, and drying times, allowing users to analyze trends and optimize future dehydration cycles. This data-driven approach enhances process improvement, helping users refine dehydration settings for different fruit types. Additionally, cloud storage ensures that users can access past data for reference, enabling better decision-making and process efficiency.

6 Increased Food Safety: By maintaining optimal drying conditions and preventing excess moisture retention, the IoT-based fruit dehydrator reduces the risk of microbial contamination and spoilage. This ensures higher food safety standards and compliance with health regulations, making the dehydration process safer for consumers. With real-

time monitoring and automated adjustments, the system helps prevent inconsistencies that could compromise food quality and safety.

3.3 Workflow of the system

The overall operation of the system is managed by the ESP32 microcontroller, which handles all data transfer and process automation. The user initiates the dehydration process via a mobile application, which sends an MQTT command. The MQTT broker forwards this command to the ESP32, which then loads the appropriate drying profile based on predefined settings.

The ESP32 continuously reads temperature and other environmental parameters using integrated sensors. Based on real-time data, it dynamically controls the heater gun to maintain optimal drying conditions. Additionally, the ESP32 publishes live updates, allowing users to monitor the dehydration progress remotely through the app. Once the process is complete, the system notifies the user, ensuring a precise and efficient fruit dehydration process.

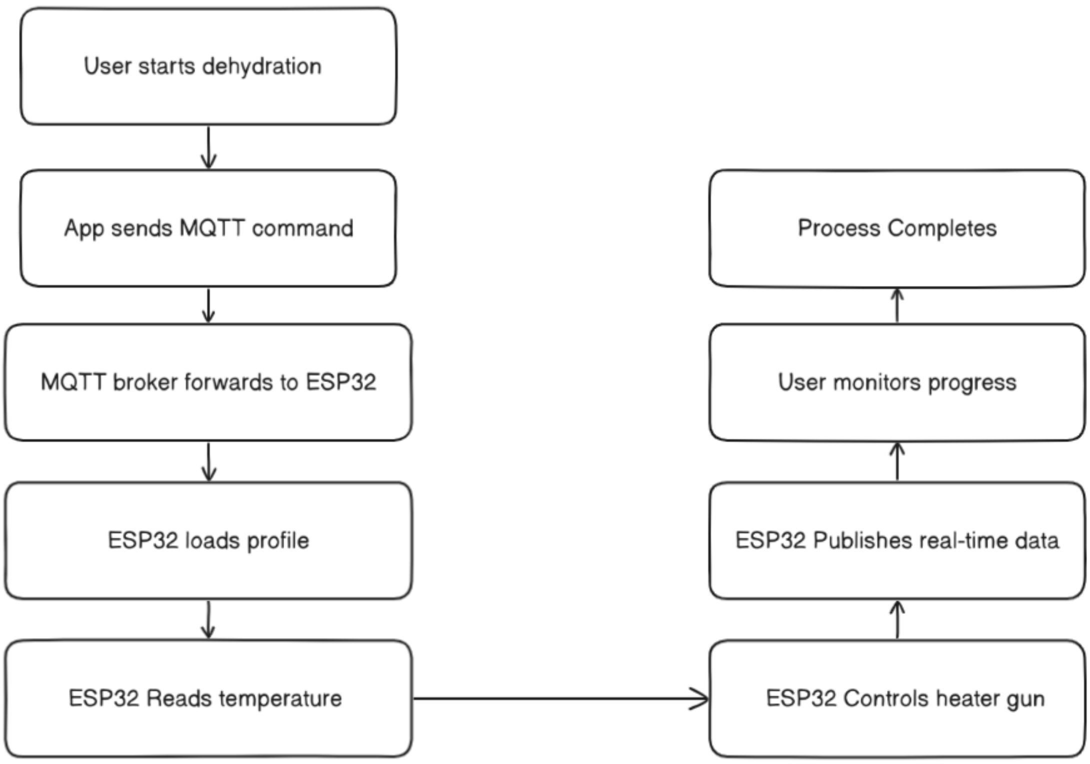

Fig. 3.1 – Workflow of the system

3.4 Methodology

Step 1: Preparation of Fruits for Dehydration

Fruits are collected and prepared by washing, peeling (if necessary), and slicing them into uniform sizes to ensure consistent dehydration. Proper preparation is essential for maintaining quality and achieving even moisture reduction.

Step 2: System Initialization

The user initiates the dehydration process through a mobile application. The app sends an MQTT command, which is forwarded to the ESP32 microcontroller via the MQTT broker. The ESP32 loads the appropriate drying profile based on the selected fruit type and predefined parameters.

Step 3: Temperature and Humidity Monitoring

The ESP32 reads real-time temperature and humidity data from integrated sensors. These values are crucial for maintaining optimal drying conditions and ensuring efficiency in the dehydration process.

Step 4: Heater Gun Control

Based on the sensor readings, the ESP32 dynamically adjusts the operation of the heater gun to regulate temperature levels. This ensures the dehydration process occurs at optimal conditions without overheating or under-drying the fruits.

Step 5: Real-Time Data Transmission

The ESP32 continuously publishes real-time temperature and humidity data to the mobile application, allowing the user to monitor progress remotely. This feature provides better control and flexibility in managing the dehydration process.

Step 6: Completion of Dehydration Process

Once the predefined dehydration time is reached, or the system determines that the desired moisture content has been achieved, the process is automatically stopped. The user receives a notification via the mobile application indicating the completion of the dehydration cycle.

Step 7 : Data Logging and Quality Assurance

All process data, including temperature variations, drying duration, and humidity levels, are logged for future analysis. Regular calibration of sensors and validation of drying profiles ensure consistency and efficiency in the dehydration process.

3.5 Summary

This chapter outlines the methodology of the proposed IoT-based fruit dehydration system. It describes the hardware and software control flow, detailing the sequence of operations from user input to automated drying control. Additionally, the data acquisition process from sensors and the role of real-time monitoring through the mobile application are explained step by step. The methodology ensures an efficient, automated, and user-friendly approach to fruit dehydration, improving quality and reliability.

HARDWARE AND SOFTWARE REQUIREMENTS

CHAPTER 4

HARDWARE AND SOFTWARE REQUIREMENTS

4.1 Introduction

This chapter provides an overview of the various hardware and software components used in the IoT-based fruit dehydration system. The ESP32 microcontroller serves as the core processing unit, handling sensor data acquisition, temperature control, and real-time data transmission. The detailed explanation of the major components of the system is provided below.

4.2 Block diagram

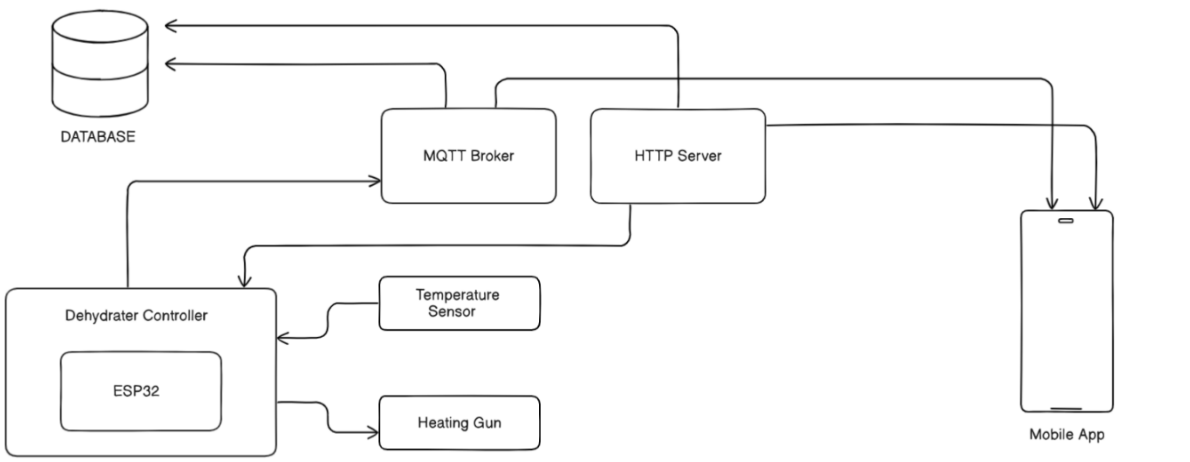

Fig.4.1 - Block diagram of IOT Based Fruit Dehydrator

Major Components of the IoT-based Fruit Dehydration System:

- ESP32 Microcontroller
- Temperature and Humidity Sensors
- Heater Gun
- MQTT Communication System
- Mobile Application/User Interface (UI)

4.3 ESP32 Microcontroller

The ESP32 is a powerful and widely used microcontroller with integrated Wi-Fi and Bluetooth capabilities, making it ideal for IoT applications. It is based on a dual-core Tensilica LX6 processor, with robust memory and peripheral support for various sensor connections.

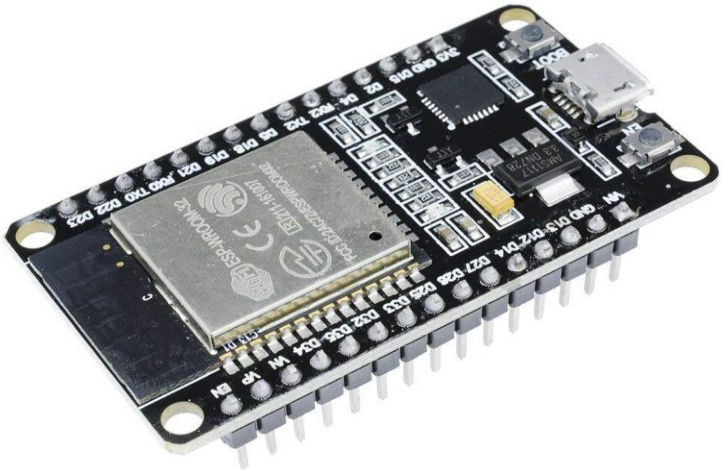

Fig.4.2 - ESP32

The ESP32 is a powerful and versatile Wi-Fi and Bluetooth-enabled microcontroller, widely used in IoT applications due to its high performance and energy efficiency. Unlike traditional microcontrollers such as the Arduino Uno, the ESP32 integrates a dual-core Tensilica Xtensa LX6 processor, operating at up to 240 MHz, making it suitable for complex computations and real-time data processing. It features 520 KB of SRAM and 4 MB of Flash memory, providing ample space for code storage and execution. Additionally, it includes integrated Wi-Fi (802.11 b/g/n) and Bluetooth (BLE 4.2/5.0), allowing seamless communication with cloud platforms, mobile applications, and other IoT devices.

The ESP32 offers a wide range of input and output (I/O) options, making it ideal for sensor-based automation. It has 34 GPIO pins that can be configured for both digital input and output operations. With 16 ADC (Analog-to-Digital Converter) channels, it enables precise sensor readings. The ESP32 supports PWM (Pulse Width Modulation) on most GPIOs, allowing fine-tuned control of actuators like motors and heating elements. Furthermore, it includes SPI, I2C, and UART communication protocols for seamless interfacing with sensors, displays, and external modules. An additional feature is the inclusion of 10 capacitive touch sensor pins, which can be utilized for human interface applications.

Operating at 3.3V, the ESP32 can accept an input voltage of 5V through the USB port. It features multiple power-saving modes, making it an energy-efficient choice for continuous data monitoring applications. The ESP32 is highly suitable for the IoT-based Fruit Dehydration System due to its built-in Wi-Fi connectivity, which allows remote monitoring of temperature and humidity via a mobile application. Its wireless capabilities eliminate the need for wired communication, supporting MQTT-based cloud integration. The ability to interface with DHT11/DHT22 temperature and humidity sensors ensures accurate environmental control, while its low-power operation enables extended, energy-efficient performance.

In the fruit dehydration system, the ESP32 serves as the central processing unit, efficiently handling sensor data, processing it, and transmitting relevant information to the user interface. Its ability to support real-time monitoring, wireless communication, and low-energy operation makes it an ideal microcontroller for the project.

The ESP32 board includes the following specifications:

- Powered by a **dual-core Tensilica Xtensa LX6 processor** (up to **240 MHz**)
- Operating voltage: **3.3V**
- Input voltage range: **5V via USB, 3.3V for logic levels**
- **34 General Purpose I/O (GPIO) pins**
- **16 ADC (Analog-to-Digital Converter) channels**
- **2 DAC (Digital-to-Analog Converter) channels**
- Supports **PWM on most GPIO pins**
- Integrated **Wi-Fi (802.11 b/g/n) and Bluetooth (BLE 4.2/5.0)**
- Supports multiple communication protocols: **SPI, I2C, UART**
- Capacitive touch support on **10 GPIOs**
- Flash memory: **4 MB**
- SRAM: **520 KB**
- EEPROM: **Not available (can be emulated in Flash)**
- Clock speed: **Upto 240 MHz**
- Built-in Hall effect sensor and temperature sensor
- Multiple power-saving modes for low-energy applications

- Board dimensions: **51 mm × 26 mm**
- Weight: **Approximately 10 g**

ESP32 R3 Pin Diagram

The ESP32 pin diagram is shown below. It consists of 34 General Purpose Input/Output (GPIO) pins, which support multiple functions such as PWM, ADC, DAC, I2C, SPI, UART, and touch sensing. This board includes digital and analog I/O pins, a USB connection, a power jack, an onboard voltage regulator, and a reset (RST) button.

The power supply for the ESP32 can be provided through USB or an external power source. The external power supply (3.3V to 5V) can be supplied using a battery or an AC to DC adapter. If using an adapter, it can be connected through the micro-USB port or VIN and GND pins. The power pins of the ESP32 include the following:

- **Vin (Voltage In)**: Used to supply external **5V power** to the ESP32 when not using USB.
- **3V3 (3.3V Output)**: Provides **regulated 3.3V output** to power external components. The maximum current draw is around **500 mA**, depending on the ESP32 model..
- **GND (Ground Pins)**: Multiple **GND pins** are available for circuit grounding.
- **EN (Enable Pin)**: This pin is used to **enable or disable** the microcontroller. Pulling it low will put the ESP32 in a low-power state.

Input and Output: We know that an arguing Uno R3 includes 14-digital pins which can be used as an input otherwise output by using the functions like pin Mode (), digital Read(), and digital Write(). These pins can operate with 5V, and every digital pin can give or receive 20mA, & includes a 20k to 50k ohm pull up resistor. The maximum current on any pin is 40mA which cannot surpass for avoiding the microcontroller from the damage. Additionally, some of the pins of an Arduino include specific functions.

Serial Pins: The ESP32 has three UART (Universal Asynchronous Receiver-Transmitter) interfaces (UART0, UART1, and UART2). The default serial communication pins are TX (GPIO1) and RX (GPIO3), but additional UART ports can be mapped to other GPIOs as needed.

External Interrupt Pins: Any GPIO pin can be configured as an external interrupt pin, allowing it to trigger an interrupt on a rising or falling edge, a low level, or a change in value.

PWM Pins: The ESP32 supports PWM on almost all GPIOs, providing high-resolution PWM signals with adjustable frequency and duty cycle using the ledcWrite() function.

SPI (Serial Peripheral Interface) Pins: The ESP32 supports **multiple SPI buses**, with the default SPI pins being **MOSI (GPIO23), MISO (GPIO19), SCK (GPIO18), and SS (GPIO5)**. These pins can be remapped for flexibility.

LED Pin: The ESP32 typically does not have a built-in LED on GPIO13 like Arduino but might include one on GPIO2 in some variants. This LED can be controlled by setting the pin HIGH or LOW.

AREF (Analog Reference) Pin: The ESP32 does not have a dedicated AREF pin, but ADC reference voltage can be configured in software.

Reset (RST) Pin: The EN (Enable) pin functions as the reset pin. Pulling it LOW will reset the ESP32. Additionally, a physical reset button is usually present on ESP32 development boards.

Communication: The ESP32 supports multiple communication protocols, including SPI, I2C, UART, Wi-Fi, and Bluetooth. The built-in Wi-Fi and Bluetooth capabilities make it highly suitable for IoT and wireless applications.

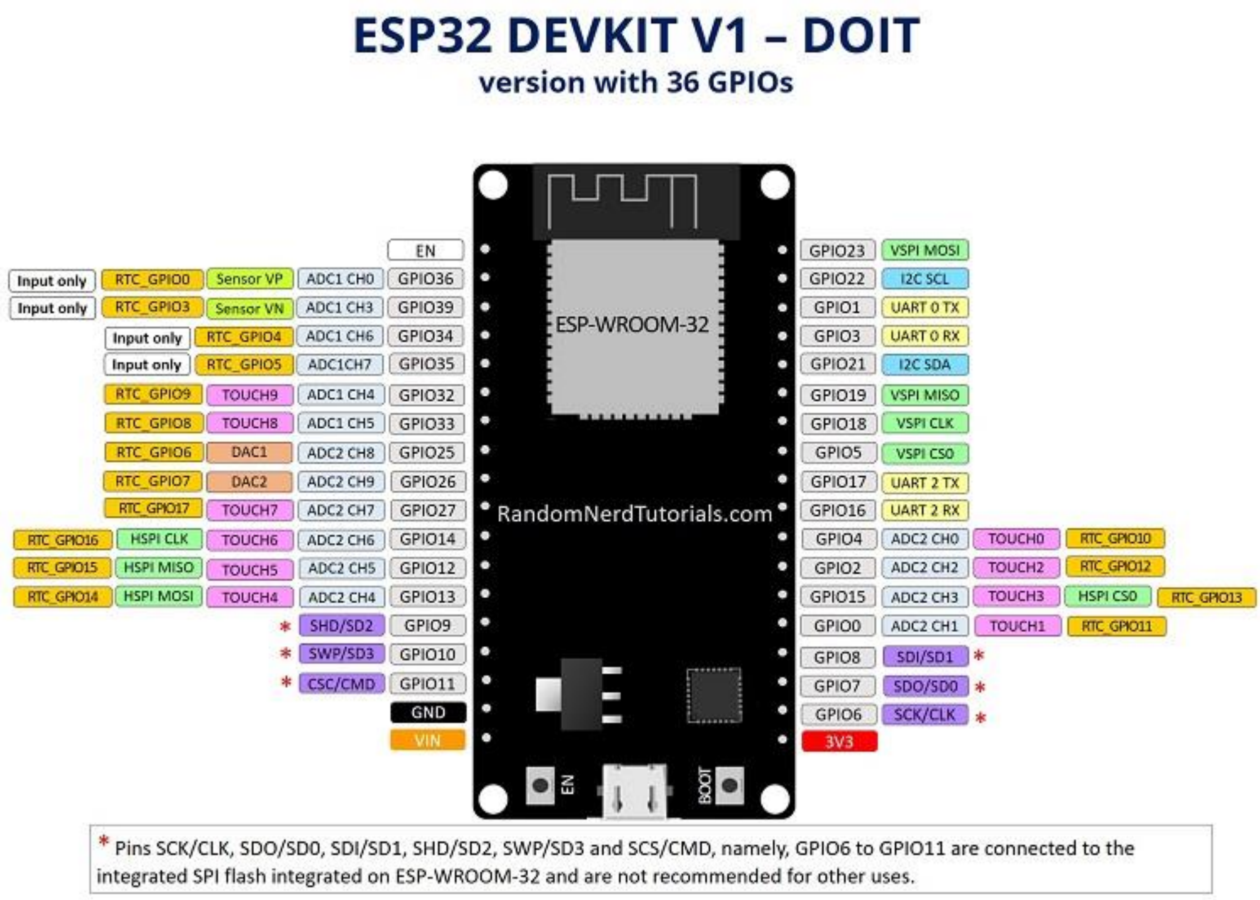

Fig. 4.3- Pin out Diagram of ESP32

4.4 Sensors

A sensor is an electronic device used to measure the quantity or quality of a specific parameter. Sensors are broadly classified into two types based on their output: Analog sensors and Digital sensors.

Temperature Sensor (DS18B20)

The DS18B20 temperature sensor is a key component of our IoT-based fruit dehydrator, responsible for continuously monitoring the internal chamber temperature to ensure precise drying conditions. This sensor operates using the **1-Wire** communication protocol, allowing multiple sensors to be connected to a single data line. It provides accurate temperature readings with a resolution ranging

from **9-bit to 12-bit** and has an operational range of **-55°C to +125°C**, making it highly suitable for the dehydration process.

One of the main advantages of the DS18B20 sensor is its **digital output**, which reduces signal degradation over long distances and eliminates the need for additional analog-to-digital conversion. Additionally, it is **factory-calibrated**, ensuring reliable temperature readings without complex external calibration.

In our fruit dehydrator system, the DS18B20 sensor continuously monitors the chamber's temperature, sending real-time data to the ESP32 microcontroller. The ESP32 then processes this data and adjusts the heating element accordingly to maintain optimal drying conditions.

While discussing accuracy, the sensor may exhibit minor deviations due to environmental factors such as airflow variations and sensor placement. To improve accuracy, calibration can be performed by comparing its readings with a standard thermometer under controlled conditions. This allows for mapping minimum and maximum temperature values to the required drying profiles, ensuring consistent dehydration results

Fig.4.4- Temperature Sensor (DS18B20)

While discussing accuracy, the temperature sensor used in our IoT-based fruit dehydrator may exhibit slight deviations due to environmental factors. However, calibration can be performed to achieve the most precise readings. By running a simple test, users can record temperature values under controlled conditions—such as placing the sensor in a stable ambient environment and then inside the dehydrator chamber at different heat levels. This allows us to establish the minimum and maximum temperature readings, which can be mapped to the required drying profiles, ensuring accurate temperature regulation for optimal dehydration performance.

4.5 Connecting Components

4.5.1 Jumper wires

Generally, jumpers are tiny metal connectors used to close or open a circuit part. They have two or more connection points, which regulate an electrical circuit board. Their function is to configure the settings for computer peripherals, like the motherboard. Suppose your motherboard supported intrusion detection. A jumper can be set to enable or

disable it. Jumper wires are electrical wires with connector pins at each end. They are used to connect two points in a circuit without soldering. You can use jumper wires to modify a circuit or diagnose problems in a circuit. Further, they are best used to bypass a part of the circuit that does not contain a resistor and is suspected to be bad. This includes a stretch of wire or a switch. Suppose all the fuses are good and the component is not receiving power; find the circuit switch. Then, bypass the switch with the jumper wire.

Fig.4.5 -Jumper wires

Types of Jumper Wires

- Male-to-male jumper
- Male-to-female jumper
- Female-to-female jumper

The difference between each is in the endpoint of the wire. Male ends have a pin protruding and can plug into things, while female ends do not but are also used for plugging. Moreover, a male connector is referred to as a plug and has a solid pin for centre conduction.

Meanwhile, a female connector is referred to as a jack and has a centre conductor with a hole in it to accept the male pin. Male-to-male jumper wires are the most common and what you will likely use most often. For instance, when connecting two ports on a breadboard, a male-to-male wire is what you will need.

4.5.2 Bread board

A breadboard (sometimes called a plugblock) is used for building temporary circuits. It is useful to designers because it allows components to be removed and replaced easily. It is useful to the person who wants to build a circuit to demonstrate its action, then to reuse the components in another circuit.

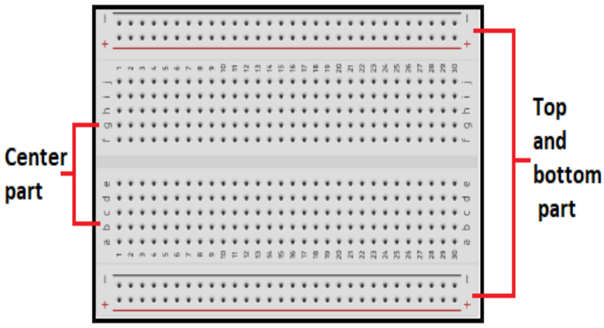

Fig 4.6- Bread board

A breadboard consists of plastic block holding a matrix of electrical sockets of a size suitable for gripping thin connecting wire, component wires or the pins of transistors and integrated circuits (ICs). The sockets are connected inside the board, usually in rows of five sockets. A row of five connected sockets is filled in at the top right of the figure. The rows are 2.54 mm apart and the sockets spaced 2.54 mm apart in the rows, which is the correct spacing for the pins of ICs and many other components.

4.6 Arduino IDE

The Arduino IDE is an open-source software, which is used to write and upload code to the Arduino boards. The IDE application is suitable for different operating systems such as Windows, Mac OS X, and Linux. It supports the programming languages C and C++. Here, IDE stands for Integrated Development Environment. The program or code written in the Arduino IDE is often called as sketching. We need to connect the Genuino and Arduino board with the IDE to upload the sketch written in the Arduino IDE software. The sketch is saved with the extension '.ino'.

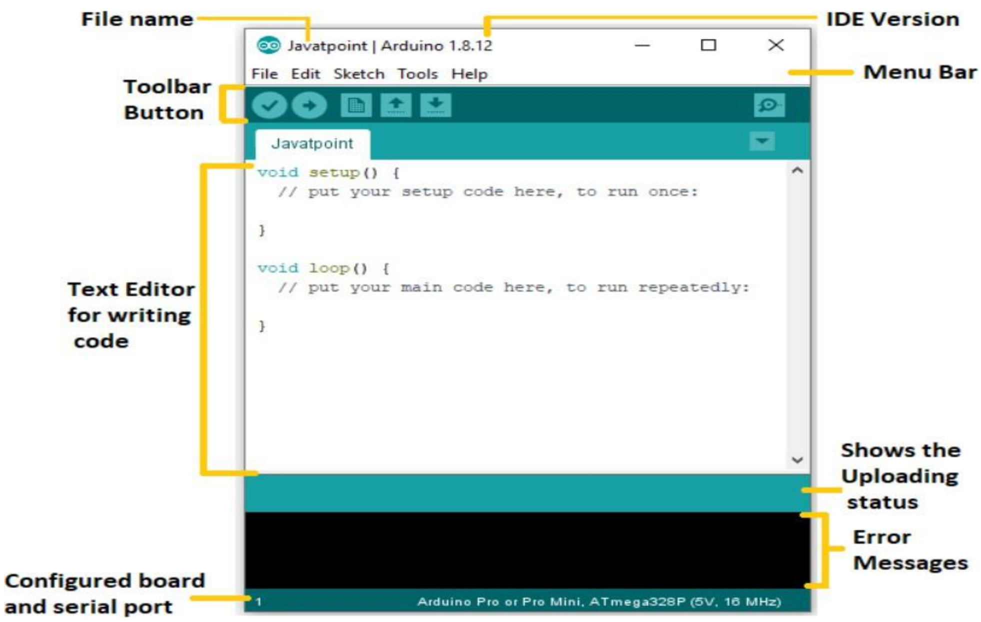

Fig.4.7 - Arduino IDE

Upload: The Upload button compiles and runs our code written on the screen. It further uploads the code to the connected board. Before uploading the sketch, we need to make sure that the correct board and ports are selected. We also need a USB connection to connect the board and the computer. Once all the above measures are done, click on the Upload button present on the toolbar.

The latest Arduino boards can be reset automatically before beginning with Upload. In the older boards, we need to press the Reset button present on it. As soon as the uploading is done successfully, we can notice the blink of the Tx and Rx LED. If the uploading is failed, it will display the message in the error window.

We do not require any additional hardware to upload our sketch using the Arduino Bootloader. A Bootloader is defined as a small program, which is loaded in the microcontroller present on the board. The LED will blink on PIN 13.

Fig.4.8 - Toolbar

Open: The Open button is used to open the already created file. The selected file will be opened in the current window.

Save: The save button is used to save the current sketch or code.

New: It is used to create a new sketch or opens a new window.

Verify: The Verify button is used to check the compilation error of the sketch or the written code.

Serial Monitor: The serial monitor button is present on the right corner of the toolbar. It opens the serial monitor. When we connect the serial monitor, the board will reset on the operating system Windows, Linux, and Mac OS X. If we want to process the control characters in our sketch, we need to use an external terminal program. The terminal program should be connected to the COM port, which will be assigned when we connect the board to the computer.

HARDWARE IMPLEMENTATION

CHAPTER 5

HARDWARE IMPLEMENTATION

5.1 Introduction

This chapter provides a brief introduction to the hardware implementation of the IoT-Based Fruit Dehydrator. The ESP32 microcontroller is used to control and monitor the dehydration process. The connections of various hardware components required for designing the dehydrator system are discussed below.

5.2 Interfacing of sensor with ESP32

The DS18B20 temperature sensor is interfaced with the ESP32 microcontroller to monitor the internal temperature of the dehydrator. The connection of hardware components required for temperature sensing and system control is detailed below.

5.2.1 Interfacing DS18B20 Temperature Sensor with ESP32

The **DS18B20 temperature sensor** operates using the **1-Wire protocol**, which enables multiple sensors to communicate over a single data line. It is widely used for temperature monitoring applications due to its **high accuracy and digital output**. The sensor measures temperature changes inside the drying chamber and sends the data to the ESP32 for processing and control of the heating element.

To interface the **DS18B20 temperature sensor** with **ESP32**, the following materials are required:

- ESP32 microcontroller
- DS18B20 temperature sensor
- 4.7kΩ pull-up resistor
- Jumper wires
- Breadboard (optional)

Connection Setup:

1. Connect the **VCC pin** of the DS18B20 sensor to the **3.3V** pin of the ESP32.
2. Connect the **GND pin** of the sensor to any **GND** pin on the ESP32.
3. Connect the **Data pin** of the sensor to a **GPIO pin** on the ESP32 (e.g., **GPIO4**).

4. Place a **4.7kΩ pull-up resistor** between the **VCC and Data pin** to ensure proper signal transmission.

ESP32 Code Implementation:

- Initialize the **OneWire** and **DallasTemperature** libraries in the ESP32 firmware.
- Read temperature data from the sensor periodically.
- Send the temperature readings to the cloud via MQTT for real-time monitoring.
- Control the heating element based on temperature readings to maintain optimal dehydration conditions.

Monitoring Sensor Output: Once the ESP32 is programmed, the sensor data can be observed in **real-time** through:

- The **Serial Monitor** in the Arduino IDE for debugging and verification.
- The **mobile application**, where live temperature readings are displayed.
- Cloud storage, where historical temperature logs are maintained for analysis.
-

5.2.2 Heating Gun (Actuator)

The heating gun serves as the primary actuator in the IoT-based fruit dehydrator. Its main function is to raise and maintain the temperature inside the dehydration chamber according to the selected dehydration profile. By generating a steady stream of hot air, the heating gun ensures efficient and uniform drying of fruits placed inside the chamber.

This hot air circulates throughout the dehydration chamber, effectively removing moisture from the fruits. The controlled application of heat plays a crucial role in preserving the nutritional value, texture, and flavor of the dried fruits. The heating process must be carefully managed to prevent excessive drying, which can lead to undesirable texture changes, or insufficient drying, which may result in microbial growth.

The heating gun is regulated by the ESP32 microcontroller, which continuously monitors and adjusts its operation based on real-time temperature sensor readings. These sensors provide accurate data on the chamber’s internal temperature, allowing precise adjustments to maintain optimal drying conditions.

To ensure consistent temperature control, a PID (Proportional-Integral-Derivative) algorithm is implemented within the system. This advanced control method helps prevent overheating or underheating by making real-time corrections to the heating gun’s power levels. The PID controller continuously calculates the difference between the desired and actual temperature, adjusting the heat output accordingly to maintain stability.

Fig .5.1 – Heating Gun

5.2.3 MicroSD Card Module

The MicroSD card module is used to store dehydration profiles locally, allowing the system to access pre-defined drying parameters quickly. This eliminates the need for constant cloud communication, reducing latency and ensuring offline functionality. The ESP32 reads and writes data to the MicroSD card, which contains information such as temperature settings, duration, and sensor logs. This feature is particularly useful in remote locations where internet connectivity may be limited.

5.2.4 Power Supply Unit

A dedicated power supply unit is essential to provide stable and adequate power to the ESP32, heating gun, sensors, and other peripherals. Since different components operate at different voltages, voltage regulators are incorporated to ensure proper power distribution. The ESP32 runs on 3.3V, while the heating gun and some actuators require higher voltages (typically 12V or 24V). To safeguard against power fluctuations, a backup power system (such as a battery or UPS) is used to ensure uninterrupted operation, preventing data loss or system failures in case of sudden power outages.

5.2.5 Enclosure Design

The enclosure is a crucial part of the fruit dehydrator, designed to ensure uniform heat distribution and efficient drying. It is typically constructed using insulated materials to retain heat, reducing energy consumption and improving dehydration efficiency. The chamber is designed with ventilation points to allow proper air circulation, ensuring that fruits dry evenly without overheating. Additionally, sensors are strategically placed within the chamber to monitor temperature variations, helping the system make real-time adjustments to maintain the optimal drying conditions. The enclosure also includes a transparent viewing window for manual inspection and a sealed door to minimize heat loss.

SOFTWARE IMPLEMENTATION

CHAPTER 6

SOFTWARE IMPLEMENTATION

6.1 Introduction

This chapter provides a detailed overview of the software implementation of the IoT-based fruit dehydrator project. The system integrates multiple software components, including **ESP32 firmware development, backend server implementation, mobile application development, and cloud integration**. Each layer plays a crucial role in ensuring smooth communication between the hardware, cloud, and user interface.

6.2 ESP32 Firmware Development

The ESP32 microcontroller serves as the **core processing unit** in the system, responsible for managing sensors, actuators, and communication with the cloud. The firmware was developed using **Arduino IDE and C++**, integrating key libraries for MQTT, HTTP, and temperature sensing.

6.2.1 Functionalities Implemented in ESP32 Firmware:

- **Sensor Data Acquisition:** Reads temperature data from the DS18B20 sensor.
- **Heating Control:** Activates and regulates the heating gun based on the dehydration profile.
- **Cloud Communication:** Sends real-time temperature updates to the MQTT broker.
- **Command Execution:** Receives remote instructions from the cloud or mobile app.
- **Local Data Logging:** Stores essential parameters on the MicroSD card in case of connectivity issues.

6.3 Backend Development

The backend server was developed using **Golang** to manage **data exchange, profile storage, and user requests**. It facilitates smooth interaction between the ESP32, mobile application, and cloud database.

6.3.1 Backend Components:

- **HTTP Server:** Manages REST API endpoints for data transmission.

- **PostgreSQL Database:** Stores user dehydration profiles, temperature logs, and system statuses.
- **Authentication & Security:** Implements authentication mechanisms to prevent unauthorized access.

6.4 Mobile Application Development

A **Flutter-based mobile application** was developed for both **Android and iOS** to provide an interactive interface for users to monitor and control the dehydration process remotely.

6.4.1 Key Features of the Mobile App:

- **Profile Management:** Allows users to upload and select dehydration profiles.
- **Real-Time Monitoring:** Displays live temperature readings using MQTT.
- **Graphical Representation:** Shows expected vs. real-time temperature trends.
- **Remote Control:** Enables users to start, stop, and adjust the dehydration process.
- **Alerts & Notifications:** Sends system alerts for anomalies or completed dehydration cycles.

6.5 Cloud Integration

To ensure **scalability and reliability**, the project employs **Google Cloud Platform (GCP)** to host the MQTT broker and HTTP server.

6.5.1 MQTT Broker Setup

- **Mosquitto MQTT broker** was deployed to manage real-time message exchange between ESP32 and the mobile application.
- The ESP32 **publishes** temperature data, while the mobile app **subscribes** for real-time monitoring.

6.5.2 HTTP Server Deployment

- The **Golang-based backend server** was deployed on a Google Cloud instance.
- API endpoints were secured using **SSL encryption** and authentication.

6.6 Summary

The software implementation of the IoT-based fruit dehydrator integrates **embedded firmware, a robust backend server, a user-friendly mobile app, and cloud-based services** to ensure efficient remote monitoring and control. The use of **ESP32, MQTT, PostgreSQL,**

and Google Cloud enhances system performance, making the dehydration process more automated, reliable, and scalable.

Future Enhancements:

- **AI-driven temperature adjustments** for optimized drying.
- **Multi-sensor integration** for improved environmental monitoring.
- **Advanced analytics** using machine learning for process optimization.

EXPERIMENTAL RESULTS

CHAPTER 7

EXPERIMENTAL RESULTS

7.1 Introduction

In this chapter the results are discussed for Micro Weather Station. Initially programs are dumped to the Raspberry Pi using the python IDE to execute the tasks. The detailed results are discussed in this chapter.

Step 1:

Dumping code onto the Arduino Uno is done via Arduino IDE installed in Windows OS. The dumping of code is shown in Figure 7.1.


```
#define sensor A2
#define wet 210
#define dry 510

void setup() {
  Serial.begin(9600);
}

void loop() {
  int value = analogRead(sensor);
  Serial.println(value);
  int pre = map(value, wet, dry, 100, 0);
  Serial.print("Moisture Percentage: ");
  Serial.print(pre);
  Serial.println("%");
  delay(1000); // Delay for readability, adjust as needed
}
```

Fig. 7.1 Dumping code to ESP32

Uploading code to the ESP32 involves several steps, starting with writing the firmware in the Arduino IDE or a compatible development environment. Once the code is ready, connect the ESP32 to the computer via a USB cable and select the correct board model and port in the IDE. Before uploading, ensure that the appropriate libraries for MQTT, HTTP communication, and temperature sensing are installed. Compile the code by clicking the "Verify" button to check for errors and convert it into machine-readable instructions. After successful compilation, upload the firmware to the ESP32 by clicking the "Upload" button. During this process, the IDE provides real-time feedback on the progress. If the upload is successful, a message indicating "Done uploading" appears. Once uploaded, test the system by monitoring the serial output to verify correct sensor readings and cloud communication. If adjustments are needed, modify the code, recompile, and upload again until the system functions as expected.

Step 2:

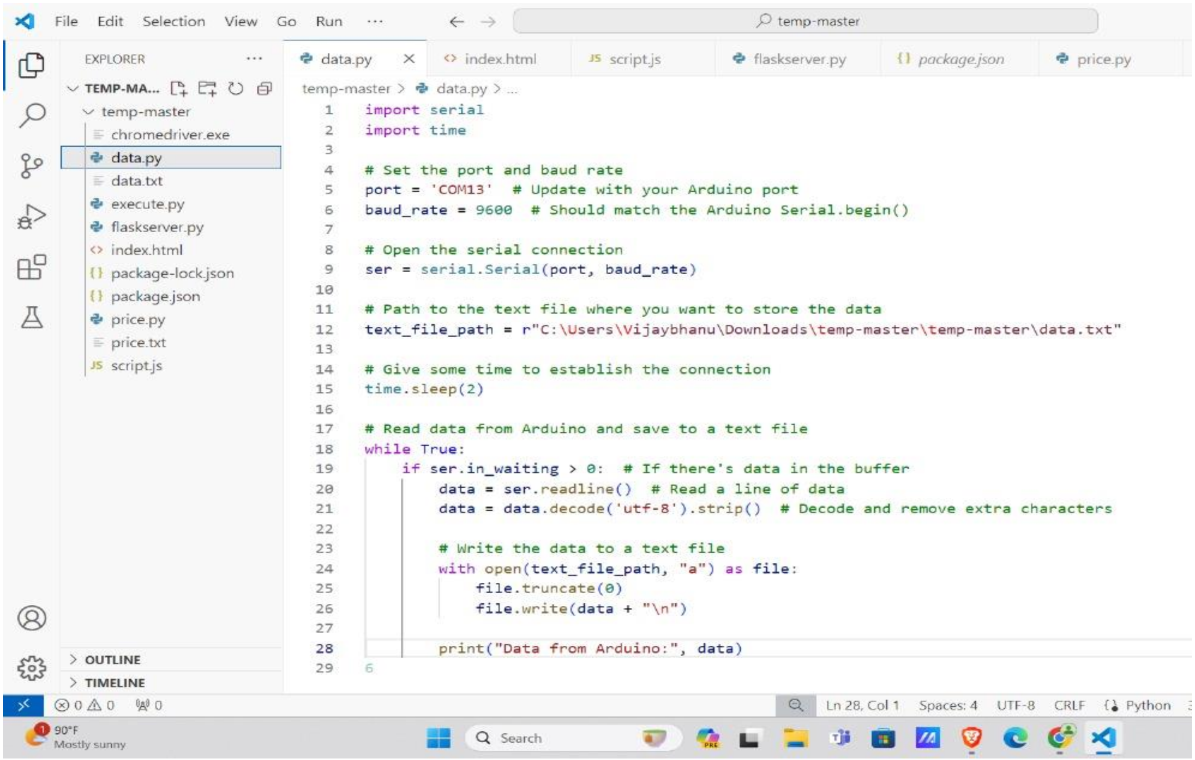

Fig. 7.2 Data is Read from ESP32

To read data from the ESP32 in the IoT-Based Fruit Dehydrator project, the DS18B20 temperature sensor is connected to its GPIO pins. The ESP32 firmware is developed using the Arduino IDE with C++, integrating libraries for MQTT, HTTP, and temperature sensing. In the setup() function, the temperature sensor and communication protocols are initialized. In the loop() function, the ESP32 continuously reads temperature data from the DS18B20 sensor using the appropriate library functions. This raw data is processed, scaled, and formatted before being transmitted to the cloud via MQTT for real-time monitoring. Additionally, the ESP32 sends HTTP requests to the backend server to store temperature logs in a PostgreSQL database. This approach ensures accurate temperature monitoring, seamless cloud integration, and efficient control of the dehydration process.

Step 3:

Fig.7.3 Dashboard of the APP

- The user launches the mobile application.
- A login screen appears, requiring the user to enter their credentials (email/username and password).
- After successful authentication, the user is directed to the dashboard.

Step 4:

Fig. 7.4 APP showing output in degree Celsius

- Dashboard Overview
- The dashboard displays real-time data from the fruit dehydrator.

- Users can view key parameters such as temperature, humidity, drying status, and remaining time.
- A graphical representation of sensor data may be available for better monitoring.

Step 5:

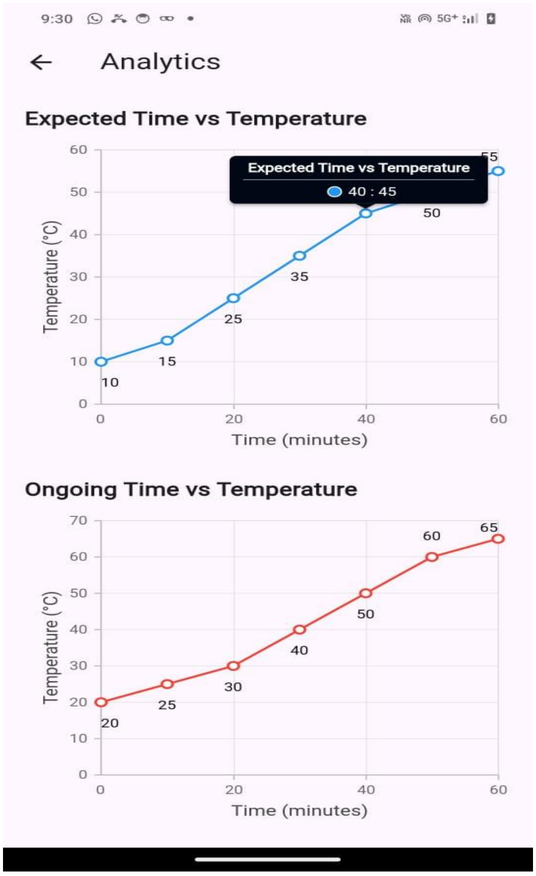

Fig.7.5 APP showing output of expected graph and actual graph

- The app continuously displays live updates on temperature, humidity, and drying progress.
- Users can track real-time changes through charts and numerical data.
- If the app detects any irregularities (e.g., overheating), it sends an alert.

Step 6:

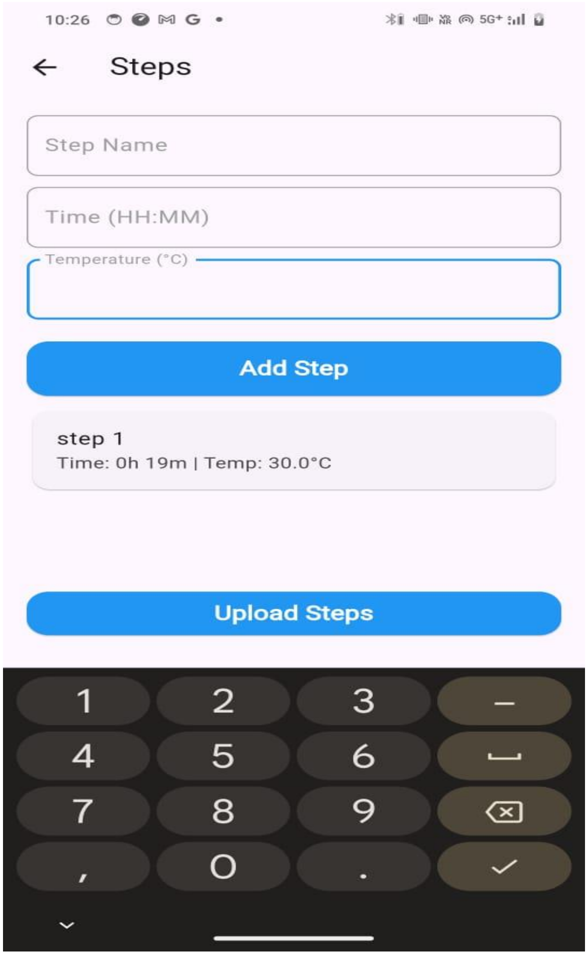

Fig.7.6. Fruit profile update section

- Users can modify drying parameters remotely if necessary.
- Controls for adjusting temperature, fan speed, or stopping the process are accessible.
- The app ensures seamless communication with the dehydrator using MQTT.

CONCLUSION AND FUTURE SCOPE

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

8.1 Conclusion

The IoT-based fruit dehydrator is a transformative solution for automated and efficient fruit drying, integrating real-time monitoring, cloud connectivity, and remote control capabilities. By leveraging IoT technology, the system ensures precise control over temperature, humidity, and drying duration, optimizing the dehydration process for different fruit types. This innovation minimizes energy consumption, reduces manual intervention, and enhances the quality and shelf life of dried fruits. Additionally, the app interface provides users with intuitive controls and data insights, making the drying process more accessible and efficient. The implementation of this system contributes to modernizing food processing techniques, supporting both small-scale and commercial fruit drying operations.

8.2 Future scope

The future of IoT-based fruit dehydration holds immense potential for further advancements in automation, energy efficiency, and intelligent data processing. Integration with AI and machine learning could enable predictive drying models that automatically adjust parameters based on fruit type and environmental conditions. Enhancing sensor precision with advanced technologies such as hyperspectral imaging and smart moisture detection could further improve drying accuracy. Cloud-based data analytics could provide insights into drying trends, helping users optimize their operations over time. Moreover, blockchain integration for traceability could add value to commercial fruit drying by ensuring quality control and authenticity in supply chains. As IoT technology continues to evolve, the fruit dehydrator can be expanded to support multi-stage drying, adaptive energy management, and integration with smart farming ecosystems. This project lays the foundation for innovative, data-driven food preservation techniques, contributing to sustainable and efficient agricultural practices.

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