PREDICTIVE
ANALYTICS FOR SMART GREENHOUSE BASED ON IOT TECHNOLOGIES

Submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

in

CSE with IoT

by

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VIT, Vellore.

May, 2024

DECLARATION

I, Prachurya Priyadarshini hereby declare that the thesis entitled "Predictive Analytics for Smart Greenhouse Based on IoT Technologies" submitted by me, for the award of the degree of *Bachelor of Technology in CSE with IoT* to VIT is a record of bonafide work carried out by me under the supervision of Prof. Krishnamoorthy A.

I further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place: Vellore

Date: 08-05-2024

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This is to certify that the thesis entitled "Predictive Analytics for Smart Greenhouse Based on IoT Technologies" submitted by **Prachurya Priyadarshini & 20BCT0155, SCOPE**, VIT, for the award of the degree of *Bachelor of Technology in CSE with IoT*, is a record of bonafide work carried out by her under my supervision during the period, 03. 01. 2024 to 08.05.2024, as per the VIT code of academic and research ethics.

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8/5/24

Place : Vellore

Date : 08-05-2024

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Prachurya Priyadarshini

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Executive Summary

The field of agriculture has seen a revolutionary change with the introduction of machine learning, which has made it possible to analyze crucial soil parameters like temperature, chemical composition, and moisture content in great detail. These elements are crucial for both crop growth and the health of the livestock. This cutting-edge technology has allowed farmers to cultivate crops with previously unheard-of precision. Basically, each plant and animal is treated separately.

Additionally, the incorporation of machine learning algorithms enables us to make hitherto unthinkable predictions about harvest yields, evaluate crop quality for specific plant species, and identify weed infestations and crop illnesses. The network of sensor nodes operates autonomously, enabling real-time monitoring and rapid response to changes in environmental conditions. Analytics algorithms are employed at the edge device to provide actionable insights, such as predicting crop health and recommending optimal irrigation schedules.

Furthermore, by leveraging machine learning techniques, the system can adapt and optimize its performance over time based on historical data and observed trends. This integration of cutting edge technology enhances efficiency, reduces resource wastage, and promotes sustainable farming practices. Farmers can make data-driven decisions that lead to higher yields, improved crop quality, and ultimately, increased profitability.

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List of Abbreviations

DHT22:	Digital Temperature Humidity Sensor
CO_2	Carbon Dioxide
API	Application Programming Interface
GridSearchCV	Grid Search Cross Validation
EMES	Engineering of Modern Electric Systems
MAC	Medium Access Control

Symbols and Notations

°	Degree
e	Logarithmic Irrational Constant
N	Nitrogen
P	Phosphorous
K	Potassium

1. INTRODUCTION

1.1. OBJECTIVE

The first goal of the project is to create a highly intelligent and flexible smart greenhouse system that will be powered by a Arduino Nano serving as the central control unit and a variety of sensors. This system will be adaptable to a variety of greenhouse environments, including commercial operations and facilities with a research focus, making it a useful tool for many different stakeholders.

Second, a key component of this research is the ongoing monitoring of important environmental variables by concentrating on factors like humidity and temperature at four levels.

Third, the proposal gives resource management and security inside the greenhouse a lot of weight. By identifying the presence of intruders or pests, the inclusion of an ultrasonic sensor improves security.

Fourth, the goals of the project are around real-time data processing. It seeks to make the Arduino Nano device capable of processing and analysing the real-time data gathered by the sensors. This capacity is essential for quickly making well-informed judgements, adapting to shifting environmental circumstances, and maximising crop development.

Fifth, the project is dedicated to offering an intuitive online interface. Regardless of where they are physically located, users will be able to access and interact with greenhouse data remotely thanks to this interface. Its user-friendly design will provide users with ease of use, flexibility, and the ability to monitor conditions, set thresholds, and make seamless real-time modifications.

Ultimately, the main objective is to empower farmers, horticulturists, and by giving them access to an effective tool for monitoring greenhouses. It intends to promote efficiency and sustainability in greenhouse operations by bridging the gap between conventional greenhouse techniques and state-of-the-art technology.

1.2 MOTIVATION

Optimized Resource Management: Predictive analytics can help optimize resource usage within the greenhouse environment, including water, fertilizers, and energy. By analyzing historical data and current conditions, the system can make accurate predictions about future needs, reducing waste and increasing efficiency.

Crop Yield Optimization: Understanding environmental factors such as temperature, humidity, light levels, and soil moisture can significantly impact crop yield. Predictive analytics can forecast optimal conditions for plant growth and adjust greenhouse parameters accordingly, leading to higher yields and better-quality produce.

Early Detection of Issues: By continuously monitoring various parameters using IoT sensors, predictive analytics can detect anomalies or deviations from expected patterns. This early detection enables proactive intervention to prevent crop damage due to pests, diseases, or environmental stressors.

Energy Efficiency: Greenhouses require significant energy inputs for heating, cooling, and lighting. Predictive analytics can analyze weather forecasts and historical data to anticipate temperature fluctuations, allowing the system to adjust heating and cooling systems preemptively for optimal energy efficiency.

Remote Monitoring and Management: With IoT technologies, greenhouse operations can be monitored and managed remotely. Predictive analytics enable real-time monitoring of environmental conditions and crop health, allowing growers to make informed decisions and adjustments from anywhere, enhancing convenience and productivity.

Data-Driven Decision Making: By collecting and analyzing large volumes of data from sensors and other sources, predictive analytics provides valuable insights for decision making. Growers can use this information to fine-tune cultivation practices, improve crop management strategies, and ultimately increase profitability.

1.3 BACKGROUND

Smart Greenhouse: A smart greenhouse is equipped with various sensors and actuators that monitor and control environmental factors such as temperature, humidity, light, soil moisture, and CO2 levels. These sensors continuously collect data on the conditions inside the greenhouse.

IoT Technologies: The Internet of Things refers to the network of interconnected devices (things) that communicate and exchange data with each other over the internet. In the context of a smart greenhouse, IoT technologies enable the seamless integration of sensors, to collect, transmit, and analyze data in real-time.

Data Collection: Sensors installed throughout the greenhouse collect data on environmental conditions such as temperature, humidity and soil moisture. This data is typically transmitted wirelessly to a firebase as a cloud platform for storage and analysis.

Predictive Analytics: Predictive analytics involves using historical and real-time data to make predictions about future events or outcomes. It can be used to forecast how environmental conditions will change over time and how these changes will impact plant growth.

Optimization: By analyzing historical data and predicting future trends, predictive analytics can help optimize various aspects of greenhouse operations. For example, it can suggest the optimal temperature, humidity, and light levels for different types of plants, helping greenhouse operators adjust conditions accordingly to maximize yield and minimize resource usage.

Automation: Predictive analytics can also be integrated with automation systems to automate the control of environmental factors within the greenhouse. For example, based on predictions about future temperature trends, the system can automatically adjust heating or cooling systems to maintain optimal conditions for plant growth.

Monitoring and Alerts: Predictive analytics can also be used to monitor the health and status of plants in real-time. By analyzing data from sensors that monitor plant growth, predictive models can identify potential issues such as pests, diseases, or nutrient deficiencies and alert greenhouse operators to take corrective actions.

2. PROJECT DESCRIPTION & GOALS

a. Survey on Existing System

[1] Mohabuth, Abdool Qaiyum, and Devashish Nem. "An IoT-Based Model for Monitoring Plant Growth in Greenhouses." Journal of Information Systems and Informatics 5, no. 2 (2023): 536-549. The research article entitled "A Survey of MAC Protocols for Energy Conservation in Wireless Sensor Networks" addresses the critical challenge of power conservation in wireless sensor networks, where the main source of energy is typically batteries with limited capacity. The paper explores the integration of IoT technology in greenhouses, aiming to enhance plant growth monitoring and control. Traditional methods are highlighted as limited in precision and data provision, necessitating a shift towards automated systems. The proposed IoT-based model utilizes microcontrollers, sensors, fans, pumps, and networking technology to constantly monitor plant growth conditions.

Advantages:

- Real-time Monitoring: Provides immediate insights into plant conditions.
- Precision Agriculture: Optimizes resource use for higher yields.
- Resource Efficiency: Reduces water and energy waste.

Disadvantages:

- Cost: Initial setup can be expensive.
- Complexity: Requires technical expertise.
- Reliability: Depends on stable internet and hardware.

[2] Bersani, Chiara, Carmelina Ruggiero, Roberto Sacile, Abdellatif Soussi, and Enrico Zero. "Internet of things approaches for monitoring and control of smart greenhouses in industry 4.0." Energies 15, no. 10 (2022): 3834. The academic paper titled 'Internet of Things Approaches for Monitoring and Control of Smart Greenhouses in Industry 4.0' undertakes an exhaustive analysis of the existing body of literature on the utilization of Internet of Things (IoT) applications in intelligent greenhouse environments. The implementation of IoT solutions in intelligent greenhouses requires the real time monitoring and collection of data facilitated by a network of sensors, devices, and information. It

highlights the potential of IoT to revolutionize and enhance agricultural practices by enabling precise monitoring and regulation of critical parameters within greenhouse environments. This technology is poised to play a vital role in addressing the urgent demands and environmental challenges faced by the agricultural sector today.

Advantages:

- Precision Agriculture: IoT optimizes greenhouse conditions for higher crop yields and quality.
- Resource Efficiency: Reduces resource wastage, such as water and energy, lowering operational costs.
- Real-Time Monitoring: Enables quick responses to changing conditions, preventing crop damage.

Disadvantages:

- Initial Cost: High setup expenses may be a barrier for smaller growers.
- Complexity: Requires technical expertise for setup and management.
- Data Security: Concerns about safeguarding sensitive data.

[3] Khuwaja, Komal, Aliza Aliza, Noorain Mukhtiar, Radu Tarcă, Dan Noje, Mansoor Juman, and Bilawal Ali. "Sustainable Agriculture: An IoT-Based Solution for Early Disease Detection in Greenhouses." In 2023 17th International Conference on Engineering of Modern Electric Systems (EMES), pp. 1-4. IEEE, 2023. The paper titled "Sustainable Agriculture: An IoT-Based Solution for Early Disease Detection in Greenhouses" explores the integration of IoT technology in agriculture, focusing on the monitoring of critical environmental parameters for plant growth and the early detection of plant diseases using convolutional neural network models. The study employs deep learning techniques and a dataset comprising images of healthy plants and those affected by Bacterial Blight, Anthracnose Bacteria, and Thrips insects. The results propose an IoT-based framework for early disease detection in greenhouses, offering advanced crop monitoring and productivity enhancement. Convolutional neural network models achieve accurate plant health classification. Additionally, continuous monitoring and control of environmental parameters, such as humidity, temperature, soil moisture, and water pH, empower farmers to optimize plant growth and yield. This research highlights IoT's transformative potential in agriculture for sustainable and efficient crop management.

Advantages:

- Early Disease Detection: IoT enables timely disease detection, reducing crop loss.
- Higher Productivity: Optimizes conditions for increased crop yield and plant health.
- Precision Agriculture: Ensures plants receive optimal environmental conditions.

Disadvantages:

- Cost: Initial setup can be expensive, particularly for small-scale farmers.
- Technical Complexity: Requires technical expertise for setup and maintenance.
- Data Security: Raises concerns about data privacy, necessitating cybersecurity measures.

[4] Afzali, Shirin, Sahand Mosharafian, Marc W. van Iersel, and Javad Mohammadpour Velni. "Development and implementation of an IoT-enabled optimal and predictive lighting control strategy in greenhouses." Plants 10, no. 12 (2021): 2652. The paper titled "Development and Implementation of an IoT-Enabled Optimal and Predictive Lighting Control Strategy in Greenhouses" introduces a novel lighting control strategy for greenhouses utilizing IoT technology to minimize electricity costs through sunlight prediction, plant light requirements, and variable electricity pricing. The study conducted experimental trials in Athens, GA, USA, involving "Green Towers" lettuce during winter and spring seasons. This innovative approach was compared to a heuristic method in terms of cost reduction and growth parameters. The results demonstrated a significant reduction in electricity costs by 4.16% during winter and a substantial 33.85% reduction during spring, validating the effectiveness of the proposed strategy. Importantly, the paired t-test analysis indicated no significant differences in growth parameters between the two lighting methods, suggesting that the IoT-enabled approach did not compromise plant growth. In summary, the paper underscores the potential of IoT technology to optimize greenhouse lighting control, reduce operational costs, and enhance resource efficiency.

Advantages:

- Cost Reduction: IoT-based lighting control minimizes electricity costs and reduces waste.
- Resource Efficiency: Precisely adapts lighting to plant needs, saving energy.
- Predictive Accuracy: Employs a reliable sunlight prediction model.

Disadvantages:

- Initial Costs: Implementation can be expensive.
- Technical Expertise: Requires technical know-how for setup and maintenance.
- Data Security: Raises privacy and cybersecurity concerns.

[5] Sagheer, Alaa, Maged Mohammed, Khaled Riad, and Mohammed Alhajhoj. "A cloud-based IoT platform for precision control of soilless greenhouse cultivation." Sensors 21, no. 1 (2020): 223. The paper introduces a cloud-based Internet of Things (IoT) platform tailored for precision control of soilless greenhouse farming, with a specific focus on mitigating food security issues in arid regions. This review aims to provide context for the paper's findings within the broader agricultural technology landscape. Arid regions often grapple with severe agricultural challenges stemming from water scarcity and harsh environmental conditions. Precision agriculture, facilitated by IoT, offers a data-driven approach to farming by enabling real-time monitoring and remote control of environmental factors. Soilless greenhouse cultivation, a resource-efficient method, has gained traction due to its ability to optimize nutrient delivery and environmental conditions. Cloud-based platforms have revolutionized data management in agriculture by facilitating the collection and analysis of IoT-generated data. The paper's core findings include increased cucumber yields, improved quality, enhanced water efficiency, and reduced energy consumption. These outcomes have the potential to address food security concerns in arid regions by optimizing crop production and resource management. Furthermore, the research highlights the broader applicability of the IoT platform and underscores its role in revolutionizing agriculture in challenging environments. Future developments in technology, such as advanced data analytics and artificial intelligence, hold promise for further enhancing agricultural efficiency and sustainability worldwide.

Advantages:

- Precision: IoT optimizes farming by closely monitoring and controlling conditions.
- Data-Driven: Real-time data helps farmers make informed decisions.
- Resource Efficiency: IoT reduces water and energy use.

Disadvantages:

- Costly: Setting up IoT can be expensive.
- Technical Knowledge: Requires expertise.
- Security Concerns: Vulnerable to cyberattack

[6] Ragab, Mohammed Ali, Mo’men M. Badreldeen, Abdelrahman Sedhom, and Wael M. Mamdouh. "IOT based smart irrigation system." International Journal of Industry and Sustainable Development” Sensors 3, no. 1 (2022): 76-86. The paper titled "IoT based Smart Irrigation System" highlights the pivotal role of IoT technology in modernizing agricultural irrigation practices. This innovation addresses longstanding challenges faced by farmers by automating and optimizing irrigation processes. By leveraging real-time data

from sensors monitoring soil conditions and weather, farmers can make informed decisions, ensuring crops receive the precise amount of water needed for optimal growth. This not only enhances crop yields but also conserves water resources, a critical factor in regions grappling with water scarcity. Additionally, the automation of irrigation tasks reduces the labour burden on farmers, freeing up their time for other essential farming activities. Consequently, IoT-based smart irrigation systems have the potential to significantly improve agricultural productivity, promote sustainability, and contribute to global food security.

Advantages:

- Water Conservation: Precise water management minimizes wastage.
- Increased Crop Yield: Optimized irrigation leads to better yields.
- Labor Savings: Automation reduces manual labour requirements.

Disadvantages:

- Initial Cost: High setup costs for IoT equipment.
- Technical Complexity: Requires expertise for installation and maintenance.
- Data Security: Concerns about protecting sensitive farming data.

[7] Navarro, Emerson, Nuno Costa, and António Pereira. "A systematic review of IoT solutions for smart farming." Sensors 20, no. 15 (2020): 4231. IoT-based smart farming revolutionizes agriculture through its real-time data collection and analysis. Sensors monitor soil moisture, weather conditions, and crop health, enabling precise irrigation and automation of tasks. This data-driven approach enhances water management, conserves resources, and boosts crop yields. However, implementing IoT systems can pose challenges. The initial investment, including sensors and network infrastructure, can be substantial, limiting accessibility for small-scale farmers. Technical complexity demands specialized knowledge, and system reliability concerns may arise. Moreover, safeguarding sensitive agricultural data from cyber threats is paramount. Overall, IoT technology offers immense promise in agriculture by addressing water scarcity, automating processes, and enabling data-driven decisions. Despite challenges, its benefits make it a compelling solution for sustainable and efficient farming practices.

Advantages:

- Water Efficiency: IoT enables precise irrigation, conserving water resources.
- Automation: Reduces labor, ensures consistent tasks, and streamlines operations.
- Data-Driven Decisions: Real-time data improves crop management and resource allocation.

Disadvantages:

- High Initial Costs: Expensive setup may hinder small-scale farmers.
- Technical Complexity: Requires specialized knowledge and can face technical issues.
- Data Security: Potential vulnerabilities demand robust data security measures.

[8] Prodanović, Radomir, Dejan Rančić, Ivan Vulić, Nenad Zorić, Dušan Bogićević, Gordana Ostojić, Sohail Sarang, and Stevan Stankovski. "Wireless sensor network in agriculture: Model of cyber security." Sensors 20, no. 23 (2020): 6747. The paper focuses on the development of a data security model for wireless sensor networks (WSN) used in agriculture monitoring. The authors highlight the importance of securing data in real time scenarios to avoid malicious adversaries. The model takes into consideration practical aspects, sensor node architecture, energy efficiency, and the application of organizational and technical measures. The evaluation of the model is conducted through simulation, specifically in terms of energy consumption. The results show that the proposed model ensures good data security, albeit with a slight increase in energy consumption at receiver and sender nodes, as well as energy consumption per bit due to added authentication overhead in the network.

Advantages:

- Data Security: Addresses agricultural data security effectively.
- Versatility: Applicable across various agriculture monitoring scenarios.
- Practical Approach: Considers sensor nodes, energy efficiency, and measures.

Disadvantages:

- Energy Impact: Slightly increases energy consumption at nodes.
- Energy Efficiency: Adds overhead, raising energy per bit.

- Complex Implementation: Can be challenging to set up and manage.

[9] Maraveas, Chrysanthos, D. Piromalis, K. G. Arvanitis, T. Bartzanas, and D. Loukatos. "Applications of IoT for optimized greenhouse environment and resources management." Computers and Electronics in Agriculture 198 (2022): 106993. The role of IoT in precision agriculture and smart greenhouses has been reinforced by recent R&D projects, growing commercialization of IoT infrastructure, and related technologies. The integration of intelligent technologies offers unlimited potential in precision commercial agriculture, but optimal resource management remains a challenge due to uneven distribution of IoT infrastructure and concentration in high-income countries. The utilization of IoT technologies in smart greenhouses involves a trade-off between the cost of agricultural production, environmental conservation, ecological degradation, and sustainability. The installation of IoT infrastructure is capital-intensive and often translates to higher energy demand, elevating the risk for climate change. The widespread use of IoT sensors and networks increases challenges in the management of electronic waste, depletion of finite resources, and destruction of fragile ecosystems, resulting in climate change. The integration of IoT systems in greenhouses would be augmented by the global deployment of advanced 5G technology and Low-Earth Orbit (LEO) constellation broadband internet. Intelligent application of agrochemicals and need-based irrigation and fertilizer application can yield significant savings and improve crop yields. The review article contributes new insights on the role of IoT in agriculture 4.0, the challenges, and future prospects for developing nations lacking resources for precision agriculture technologies.

Advantages:

- Technological Progress: IoT in agriculture benefits from ongoing R&D and commercialization.
- Resource Efficiency: Optimizes resource use, enhancing productivity.
- Advanced Agriculture: Supports precision farming for improved yields.

Disadvantages:

- Unequal Access: IoT infrastructure disparity hinders accessibility.
- Environmental Impact: Capital-intensive IoT setup can increase energy demand.
- Waste Management: IoT use poses electronic waste management challenges.

[10] Tripathy, Pradyumna K., Ajaya K. Tripathy, Aditi Agarwal, and Saraju P. Mohanty. "MyGreen: “An IoT-enabled smart greenhouse for sustainable agriculture." IEEE Consumer Electronics Magazine 10, no. 4 (2021): 57-62. The paper discusses the potential of IoT in greenhouse farming and smart agriculture, focusing on monitoring parameters such as humidity, water nutrients solution level, pH and EC value, temperature, UV light intensity, CO_2 level, mist, and number of insecticides or pesticides. It presents a decision support system (DSS) as the central operating system that governs and coordinates all the activities in the greenhouse. The work highlights the challenges of greenhouse rose farming and proposes an IoT-based solution that is smart and sustainable. The model presented in the paper is well adapted to the changing environment, redefining the terms of sustainability

Advantages:

- Enhanced Crop Quality: Fine-tuned environmental control results in better crop quality and yields.
- Sustainability: IoT-driven automation contributes to sustainable farming practices.
- Adaptability: The model adjusts to changing conditions, promoting long-term sustainability.

Disadvantages:

- Initial Investment: Setting up IoT infrastructure can be costly.
- Technical Complexity: Requires specialized knowledge for setup and maintenance.
- Data Security: Sensitive agricultural data collected by IoT devices needs robust protection

Fig-2.1: Table for Literature Survey

S.No.	Authors	Title	Source	Year	Findings
1.	Mohabuth, Abdool Qaiyum, and Devashish Nem.	An IoT-Based Model for Monitoring Plant Growth in Greenhouses	Journal of Information Systems and Informatics 5, no. 2 536-549	2023	• It focuses on key growth indicators such as soil moisture, temperature, and humidity. • It provides immediate insights into plant conditions. • It reduces water and energy waste.
2.	Bersani, Chiara, Carmelina Ruggiero, Roberto Sacile, Abdellatif Soussi, and Enrico Zero.	Internet of things approaches for monitoring and control of smart greenhouses in industry 4.0.	Energies 15, no. 10 834	2022	• IoT optimizes greenhouse conditions for higher crop yields and quality. • It reduces resource wastage, such as water and energy, lowering operational costs. • It enables quick responses to changing conditions, preventing crop damage.
3.	] Khuwaja, Komal, Aliza Aliza, Noorain Mukhtiar, Radu Tarcă, Dan Noje, Mansoor Juman, and Bilawal Ali.	Sustainable Agriculture: An IoT-Based Solution for Early Disease Detection in Greenhouses	17th International Conference on Engineering of Modern Electric Systems (EMES), pp. 1-4. IEEE	2023	• IoT enables timely disease detection, reducing crop loss. • It optimizes conditions for increased crop yield and plant health. • It ensures plants receive optimal environmental conditions.
4.	Afzali, Shirin, Sahand Mosharafian,	Development and implementation	Plants 10, no. 12 2652	2021	• IoT-based lighting control minimizes electricity costs and reduces waste.

	Marc W. van Iersel, and Javad Mohammadpour Velni.	of an IoT-enabled optimal and predictive lighting control strategy in greenhouses			• It precisely adapts lighting to plant needs, saving energy. • It employs a reliable sunlight prediction model.
5.	] Sagheer, Alaa, Maged Mohammed, Khaled Riad, and Mohammed Alhajhoj.	A cloud-based IoT platform for precision control of soilless greenhouse cultivation	Sensors 21, no. 1 223	2020	• IoT optimizes farming by closely monitoring and controlling conditions. • Real-time data helps farmers make informed decisions. • IoT reduces water and energy use.
6.	Ragab, Mohammed Ali, Mo'men M. Badreldeen, Abdelrahman Sedhom, and Wael M. Mamdouh	IOT based smart irrigation system." International Journal of Industry and Sustainable Development	Sensors 3, no. 1 76-86	2022	• Precise water management minimizes wastage. • Optimized irrigation leads to better yields. • Automation reduces manual labour requirements.
7.	Navarro, Emerson, Nuno Costa, and António Pereira	A systematic review of IoT solutions for smart farming	Sensors 20, no. 15 4231	2020	• IoT enables precise irrigation, conserving water resources. • It reduces labor, ensures consistent tasks, and streamlines operations. • Real-time data improves crop management and resource allocation.
8.	Prodanović, Radomir, Dejan Rančić,	Wireless sensor network in	Sensors 20, no. 23 6747	2020	• It addresses agricultural data security effectively.

	Ivan Vulić, Nenad Zorić, Dušan Bogićević, Gordana Ostojić, Sohail Sarang, and Stevan Stankovski.	agriculture: Model of cyber security.			• It is applicable across various agriculture monitoring scenarios. • It considers sensor nodes, energy efficiency, and measures.
9.	Maraveas, Chrysanthos, D. Piromalis, K. G. Arvanitis, T. Bartzanas, and D. Loukatos.	Applications of IoT for optimized greenhouse environment and resources management.	Computers and Electronics in Agriculture 198	2022	• It optimizes greenhouse environment and resource management. • It highlights the integration of IoT sensors to monitor environmental conditions and manage resources efficiently. • It emphasizes the potential of IoT in enhancing greenhouse operations for improved productivity and sustainability.
10.	Tripathy, Pradyumna K., Ajaya K. Tripathy, Aditi Agarwal, and Saraju P. Mohanty	An IoT-enabled smart greenhouse for sustainable agriculture	IEEE Consumer Electronics Magazine 10, no. 4	2021	• It focused on sustainable agriculture. • It optimizes resource usage and crop health. • It offers remote management, energy efficiency, and data-driven insights to enhance agricultural sustainability and productivity.

b. Gaps Identified

- Integration of Security Measures:

While several studies focus on IoT solutions for smart farming and greenhouse management, there seems to be a gap in addressing cybersecurity concerns comprehensively. The study by Prodanović et al. touches upon the model of cybersecurity but further research could explore more robust security measures and protocols specifically tailored for agricultural IoT systems.

- Holistic Approach to Smart Farming:

The existing literature primarily focuses on specific aspects of smart farming, such as greenhouse monitoring or plant growth tracking. However, there is a potential gap in research that takes a holistic approach to smart farming systems, integrating various IoT solutions for crop monitoring, irrigation management, pest control, and resource optimization.

- Scalability and Adaptability:

While some studies discuss IoT-enabled solutions for specific agricultural settings, such as greenhouses, there appears to be limited discussion on the scalability and adaptability of these solutions to different agricultural environments and scales. Future research could explore adaptable IoT frameworks that can be tailored to diverse farming contexts.

- Interoperability and Standardization:

There seems to be a gap in research addressing interoperability and standardization challenges in IoT solutions for smart farming. As agricultural IoT systems often involve heterogeneous devices and platforms, there is a need for standards and protocols that facilitate seamless communication and data exchange among different components.

- Sustainability and Environmental Impact:

Although the literature discusses the use of IoT for sustainable agriculture, there is potential for further exploration of the environmental impact of these technologies. Future research could investigate the sustainability aspects of IoT-enabled farming practices, including energy consumption, waste reduction, and ecological footprint.

- User-Centric Design and Adoption:

There is a gap in research focusing on the user-centric design and adoption of IoT solutions in agriculture. Understanding the needs, preferences, and challenges faced by farmers and agricultural stakeholders is crucial for the successful implementation and uptake of these technologies.

c. Problem Statement

Within the framework of greenhouse agriculture, economical and effective methods for observation and management are required for environmental elements. The usefulness of traditional greenhouse management systems is typically limited by their lack of real-time data access and remote control capabilities. Small-scale farmers and horticulturists are further hindered by the large upfront costs associated with advanced greenhouse automation systems. Precise environmental monitoring is also necessary for conducting research or preservation activities and guaranteeing the health of crops in greenhouses.

3. TECHNICAL SPECIFICATION

3.1 Requirements

3.1.1 Functional

- **Real-time Data Monitoring:** The system should be able to collect data from various sensors installed in the greenhouse in real-time, including temperature, humidity and soil moisture.
- **Remote Control Capabilities**: It should allow users to remotely monitor and control greenhouse environmental parameters and equipment, such as adjusting temperature, humidity, irrigation systems, and ventilation.
- **Predictive Analytics**: The system should incorporate predictive analytics algorithms to analyze historical and real-time data to predict future environmental conditions and optimize greenhouse management strategies accordingly.
- **Alerts and Notifications**: It should be capable of generating alerts and notifications to users in case of abnormal environmental conditions or equipment malfunctions, enabling timely intervention to prevent crop damage or loss.
- **Data Visualization and Reporting**: The system should provide intuitive data visualization tools and customizable reports to allow users to interpret and analyze greenhouse data effectively, facilitating informed decision-making.
- **Integration with External Systems**: It should support integration with external systems, such as weather forecast services, agricultural databases, and crop management software, to enhance decision-making and provide contextual insights.
- **Scalability and Flexibility**: The system should be scalable to accommodate the varying needs of different greenhouse sizes and configurations, as well as flexible to integrate new sensors or functionalities in the future.

3.1.2 Non-Functional

- **Reliability:** The system should be highly reliable, ensuring continuous operation and minimal downtime to prevent disruptions in greenhouse management activities.
- **Security**: It should implement robust security measures to protect sensitive greenhouse data from unauthorized access, tampering, or cyber-attacks, ensuring the integrity and confidentiality of information.
- **Usability**: The system should be user-friendly and intuitive, with a clear interface and easy navigation, catering to users with varying levels of technical expertise.
- **Performance**: It should demonstrate high performance in terms of data processing speed, response time to user inputs, and scalability to handle large volumes of data efficiently.
- **Interoperability**: The system should be interoperable with existing greenhouse management systems and compatible with different types of sensors, communication protocols, and IoT platforms to ensure seamless integration and operation.
- **Cost-effectiveness**: It should be cost-effective, minimizing upfront investment costs for small-scale farmers and horticulturists while providing significant long-term benefits in terms of improved crop yield, resource efficiency, and operational savings.
- **Environmental Sustainability**: The system should prioritize environmental sustainability by promoting energy efficiency, reducing resource consumption, and minimizing environmental impact throughout its lifecycle.

3.2 Feasibility Study

3.2.1 Technical Feasibility

- **Data Collection and Sensors**: IoT technologies enable the deployment of various sensors for real-time monitoring of environmental parameters such as temperature, humidity, light intensity, soil moisture, and CO_2 levels within the greenhouse.
- **Connectivity and Communication**: IoT devices can communicate wirelessly, allowing seamless data transmission to centralized systems or cloud platforms for

analysis and decision-making.

- **Predictive Analytics**: Advanced algorithms can analyze the collected data to predict environmental conditions, plant growth patterns, and potential issues such as pest infestations or disease outbreaks.

3.2.2 Economic Feasibility

- **Cost of Implementation**: While traditional greenhouse management systems may have high upfront costs, IoT technologies offer scalable solutions that can be implemented gradually based on budget constraints. This scalability reduces the financial burden on small-scale farmers and horticulturists.

- **Operational Efficiency**: By providing real-time insights and remote control capabilities, IoT technologies can optimize resource utilization (e.g., water, energy) and reduce operational costs associated with manual monitoring and intervention.

- **Return on Investment (ROI)**: The potential benefits of improved crop yields, resource efficiency, and reduced labor costs can outweigh the initial investment in IoT infrastructure, leading to a positive ROI over time.

3.2.3. Social Feasibility

- **Accessibility and Inclusivity:** IoT technologies can democratize access to advanced greenhouse management capabilities by offering affordable solutions tailored to the needs of small-scale farmers and horticulturists.

- **Knowledge Transfer and Training:** Efforts to promote the adoption of IoT technologies should include training programs and educational resources to ensure that users can effectively utilize these tools for greenhouse management.

- **Environmental Sustainability:** By enabling precise environmental monitoring and resource optimization, IoT technologies contribute to sustainable agriculture practices, thereby promoting environmental stewardship and ensuring food security for future generations.

3.3. System Specification

3.3.1 Hardware Specification

ARDUINO NANO:

- Operating Voltage: 5V
- Digital I/O Pins: 14 (of which 6 provide PWM output)
- EEPROM: 1 KB (ATmega328P)
- Clock Speed: 16 MHz
- Dimensions: Length: 45 mm, Width: 18 mm, Weight: 7 grams

ULTRASONIC SENSOR

- Measurement Range: 0-30 cm
- Operating Voltage: 5V to 24V DC
- Output Interface: Displays in distance unit (cm or inches)
- Compatibility: Arduino and Raspberry Pi

DHT22 SENSOR:

- Temperature Measurement Range: -40°C to 80°C (-40°F to 176°F)
- Temperature Accuracy: ±0.5°C
- Humidity Measurement Range: 0% to 100% RH
- Humidity Accuracy: ±2% RH
- Operating Voltage: 3.3V to 5.5V DC
- Dimensions: Length: 15.5 mm, Width: 12 mm, Height: 5.5 mm

SOIL MOISTURE SENSOR:

- Measurement Range: 0% (dry soil) to 100% (saturated soil)
- Operating Voltage: 3.3V to 5V DC
- Output Interface: Indicates whether the soil is wet or dry.
- Compatibility: Arduino and Raspberry Pi

3.3.2 Software Specification

- **FIREBASE:** It is a cloud-based database and backend platform provided by Google that allows developers to build real-time web and mobile applications. In the code used here, Firebase is used to store and retrieve the sensor data collected by the Arduino Nano.
- **PYTHON:** It is used to read the values of temperature, humidity, and distance using the DHT22 and ultrasonic sensors, respectively. The collected data is then formatted into a dictionary and sent to the Firebase database using the Pyrebase library, which is a Python wrapper for the Firebase API.

3.3.3. Standards and Policies

- Interoperability Standards: Develop standards that ensure compatibility and interoperability among different IoT devices, sensors, and platforms used in smart greenhouses. This would facilitate seamless communication and data exchange, allowing farmers to integrate various sensors and systems into a unified monitoring and control infrastructure.
- Data Security and Privacy Policies: Establish policies and regulations to address data security and privacy concerns associated with IoT technologies in smart greenhouses. This may include encryption standards, access control mechanisms, and guidelines for data sharing and storage to protect sensitive information about crop yields, environmental conditions, and operational practices.
- Environmental Sustainability Guidelines: Implement guidelines and best practices for the sustainable deployment and operation of IoT technologies in smart greenhouses. This could involve energy efficiency standards, waste reduction measures, and guidelines for the responsible use of resources to minimize environmental impact and promote long-term sustainability in agriculture.
- Affordability and Accessibility Policies: Develop policies and initiatives to make IoT technologies more affordable and accessible to small-scale farmers and horticulturists. This may include subsidies to reduce the upfront costs associated with implementing advanced greenhouse automation systems, thereby enabling broader adoption and uptake of predictive analytics solutions.

4. DESIGN APPROACH AND DETAILS

4.1 System Architecture

In this architecture, sensors collect data from the physical world and send it to edge devices. Edge devices can process and analyse the data locally, or they can send it to the cloud for further processing. The cloud can also store data and provide access to it from anywhere in the world. Computing devices run the software that powers edge devices, the cloud, and other computing systems.

- **Edge Devices:** Edge devices are small, low-power computing devices that are located at the edge of the network, close to the data sources. They collect data from sensors and other devices, and they can process and analyze that data locally before sending it to the cloud. Edge devices are often used in applications where it is important to have real-time or near-real-time data processing, such as industrial automation, smart cities, and wearable devices.
- **Cloud:** The cloud is a network of remote servers that provide computing resources, storage, and databases to users over the internet. Cloud computing allows businesses to access these resources on-demand, without having to invest in and maintain their own infrastructure. The cloud is often used for applications that require a lot of computing power or storage, such as web applications, e-commerce platforms, and big data analytics.
- **Sensors:** Sensors are devices that collect data about the physical world, such as temperature, humidity, pressure, and motion. Sensors can be embedded in edge devices, or they can be connected to edge devices via wired or wireless communication. Sensors are essential for collecting the data that is needed for edge computing and cloud computing applications.
- **Computing Devices**: Computing devices are the physical devices that run the software that powers edge devices, the cloud, and other computing systems. Computing devices can range from small microcontrollers to large mainframes. The specific type of computing device that is used depends on the specific application and the required level of performance.

4.2 Design

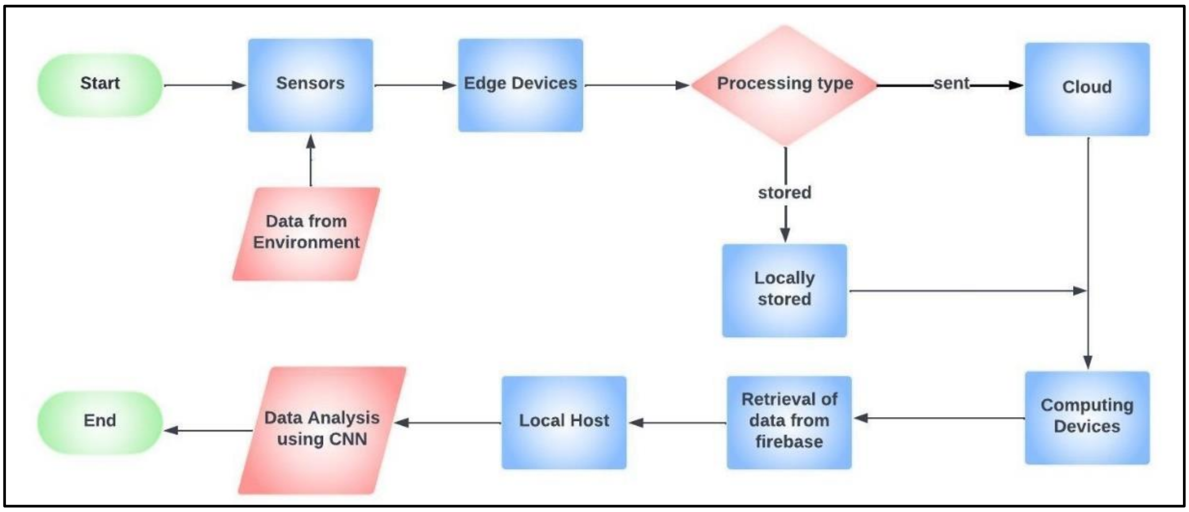

Fig: 4.2.1: Data Flow Diagram

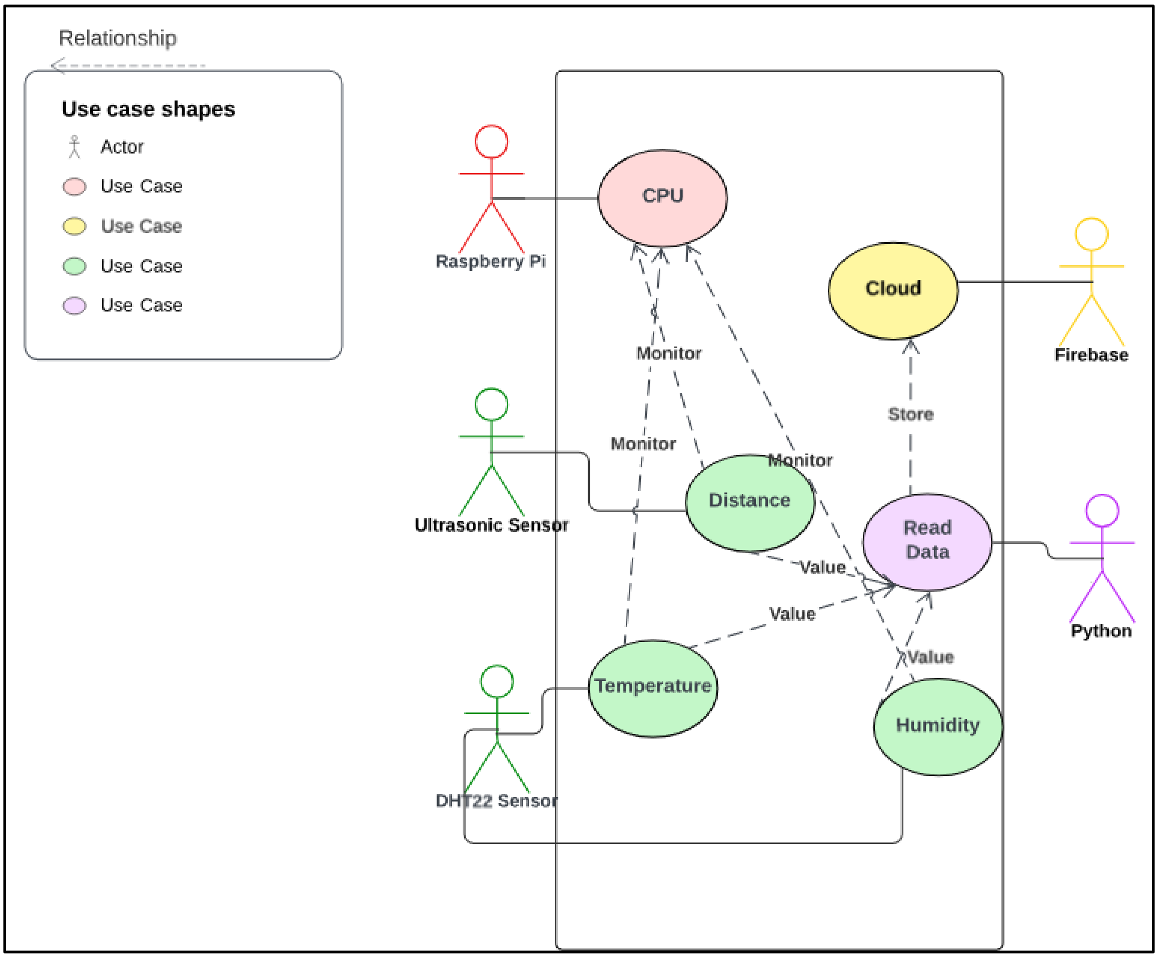

Fig: 4.2.2: Use Case Diagram

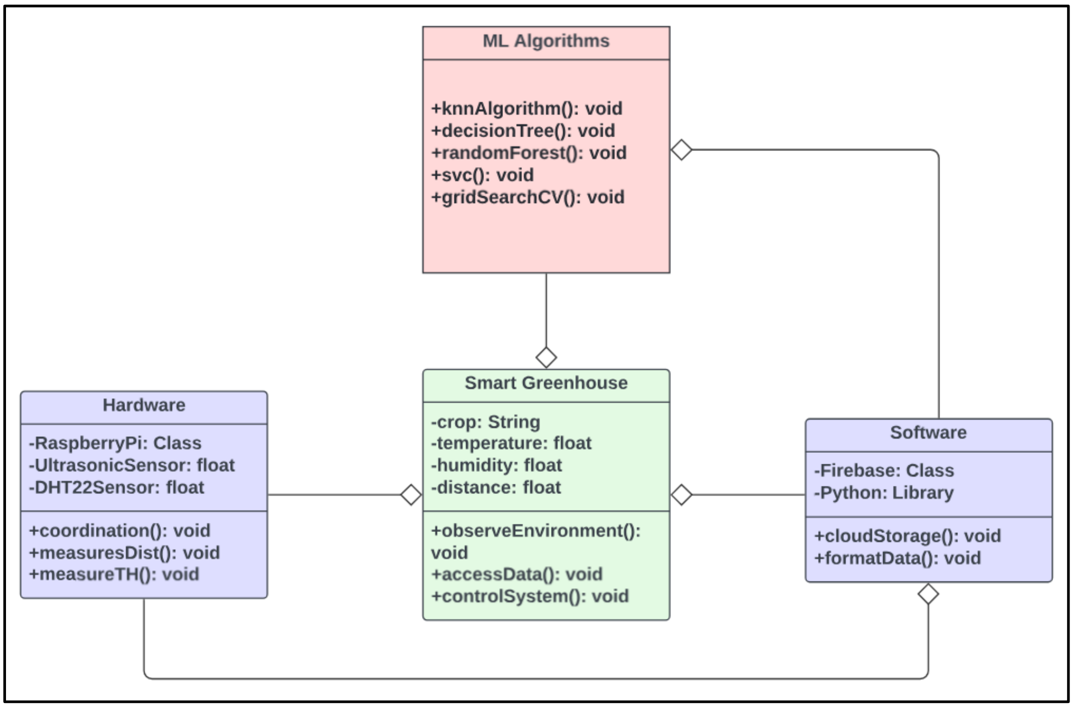

Fig: 4.2.3: Class Diagram

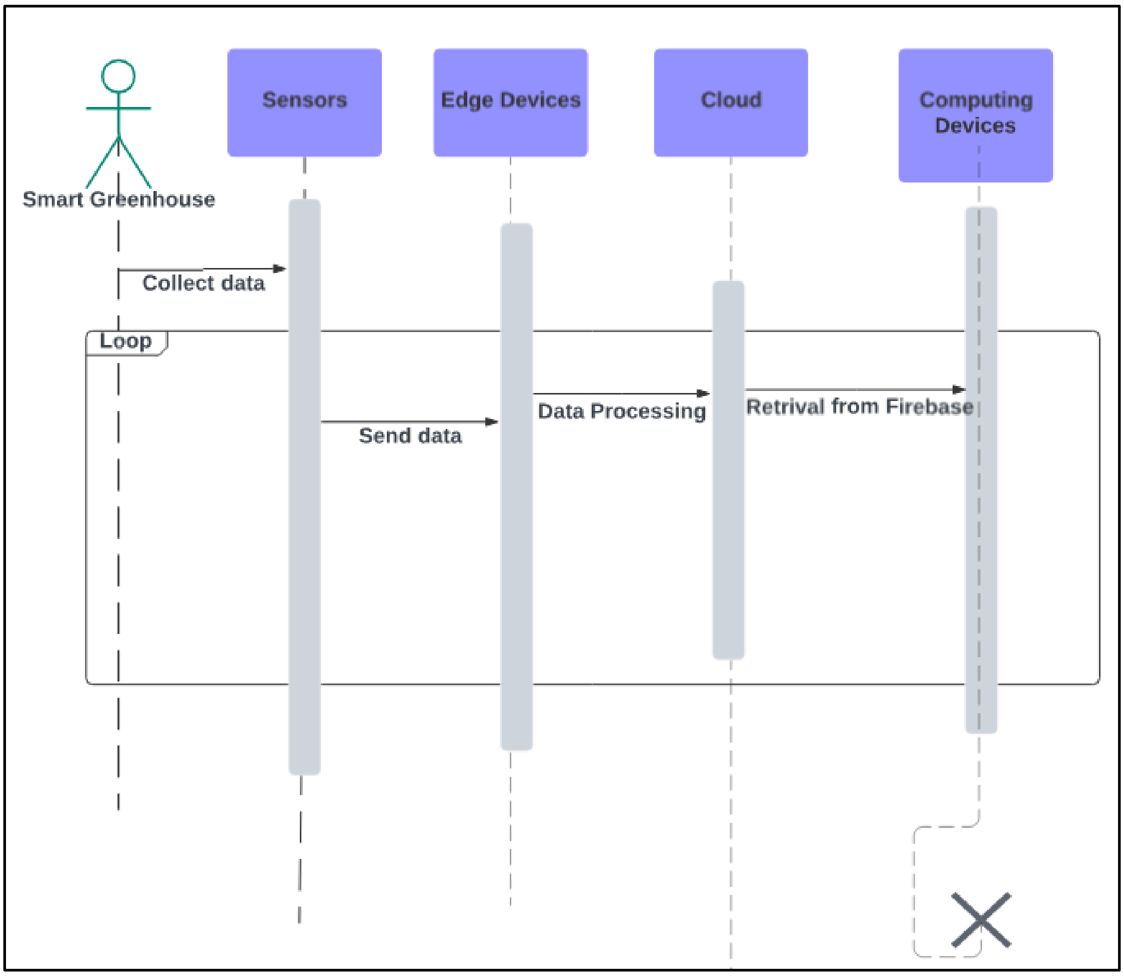

Fig: 4.2.4: Sequence Diagram

4.3 Constraints, Alternatives and Tradeoffs

Data Quality and Availability:

Constraint: The accuracy and reliability of predictive models heavily depend on the quality and availability of data collected from sensors. Inaccurate or incomplete data can lead to unreliable predictions.

Alternative: Implement data validation and cleansing techniques to ensure data quality. Explore alternative sensor technologies or data sources to supplement or improve data availability.

Computational Resources:

Constraint: Predictive analytics algorithms may require significant computational resources, which could be constrained in IoT devices with limited processing power and memory.

Alternative: Optimize algorithms for efficiency and resource usage. Consider offloading computational tasks to cloud-based services or edge computing devices to reduce the burden on IoT devices.

Latency:

Constraint: Real-time prediction and response may be critical for timely adjustments in greenhouse conditions. However, processing data and generating predictions may introduce latency, impacting responsiveness.

Alternative: Balance the trade-off between prediction accuracy and latency by optimizing algorithms and data processing pipelines. Implement streaming analytics or edge computing to reduce latency and enable faster response times.

Energy Consumption:

Constraint: IoT devices are often powered by batteries or have limited access to power sources. Continuous data collection and predictive analytics may consume significant energy, reducing battery life or requiring frequent recharging.

Alternative: Implement energy-efficient data collection techniques, such as intermittent sensing or duty cycling. Optimize algorithms to minimize computational energy consumption without sacrificing prediction accuracy.

Privacy and Security:

Constraint: Smart greenhouse systems collect sensitive data about environmental conditions, crop growth, and operational activities. Ensuring the privacy and security of this data is essential to prevent unauthorized access or misuse.

Alternative: Implement robust encryption, authentication, and access control mechanisms to protect data both in transit and at rest. Consider using privacy-preserving techniques such as differential privacy or data anonymization to mitigate privacy risks.

Cost:

Constraint: Deploying IoT-enabled smart greenhouse systems involves upfront costs for hardware, sensors, networking infrastructure, and software development. Additionally, ongoing maintenance and operational costs must be considered.

Alternative: Explore alternative hardware and sensor options to reduce upfront costs. Consider the long-term benefits of improved crop yield, resource efficiency, and operational optimization when evaluating the cost-effectiveness of predictive analytics solutions.

Scalability and Interoperability:

Constraint: As the scale of greenhouse operations grows or evolves, scalability and interoperability become important considerations. Deploying and managing a large number of IoT devices and integrating with existing systems may pose challenges.

Alternative: Design scalable and modular architectures that allow for easy expansion and integration with other systems. Use standardized protocols and communication interfaces to ensure interoperability with existing infrastructure and future upgrades.

5. SCHEDULE, TASKS AND MILESTONES

Fig: 5.1 Gantt Chart depicting the entire timeline for the completion of the project.

5.2 Module Description

5.2.1 Arduino Nano

It is a compact and versatile microcontroller board based on the ATmega328P microcontroller chip that can be used to adjust environmental variables like temperature, humidity, and lighting. It is used to interface with various sensors, including a DHT22 temperature and humidity sensor and an ultrasonic sensor, and to send the data collected from these sensors to a Firebase database for remote monitoring and analysis.

5.2.2 DHT22 Sensor

The DHT22 sensor is a digital temperature and humidity sensor that uses a capacitive humidity sensor and a thermistor to measure relative humidity and temperature. Here, the DHT22 sensor is used to monitor the temperature and humidity levels inside a greenhouse. The code uses the Adafruit DHT library to read temperature and humidity data from the sensor, and the data is then sent to a Firebase database for remote monitoring and analysis.

5.2.3 Soil Moisture Sensor

The Soil Moisture Sensor is used to gauge the volumetric content of water within the soil. It uses capacitance to measure dielectric permittivity of the surrounding medium. It is inserted into the soil and the status of the water content in the soil can be reported in the form of a percent.

5.2.4 Ultrasonic Sensor

The ultrasonic sensor is used to measure the distance between the sensor and an object in front of it. Ultrasound sensor is a type of sensor that uses sound waves to measure distance. The sensor sends out an ultrasonic pulse and measures the time it takes for the pulse to bounce back. The time it takes for the pulse to return is proportional to the distance between the sensor and the object.

5.2.5 Firebase

It is a cloud-based database and backend platform provided by Google that allows developers to build real-time web and mobile applications. In the code used here, Firebase is used to store and retrieve the sensor data collected by the Raspberry Pi

5.2.6 Python

Python is used to read the values of temperature, humidity, and distance using the DHT22 and ultrasonic sensors, respectively. The collected data is then formatted into a dictionary and sent to the Firebase database using the Pyrebase library, which is a Python wrapper for the Firebase API.

5.3 Testing

5.3.1 Unit Testing

Sensor Data Processing Functions:

- Testing functions responsible for processing raw sensor data (e.g., temperature, humidity, soil moisture).
- Verifying that data normalization, validation, and transformation functions work correctly.
- Testing edge cases such as out-of-range values, missing data, or unexpected data formats.

Predictive Analytics Algorithms:

- Testing the predictive analytics algorithms used to forecast environmental conditions or plant growth metrics.
- Using mock data or historical datasets to validate the accuracy and performance of

the algorithms.

- Testing various scenarios and input parameters to ensure the algorithms produce reliable predictions.

Edge Cases and Error Handling:

- Identifying edge cases and error scenarios that could arise during normal operation or due to unexpected conditions.
- Designing test cases to cover these scenarios and ensure that the application handles errors gracefully

5.3.2 Integration Testing

End-to-End Data Flow Testing:

- Testing the end-to-end flow of sensor data from the IoT devices to the Firebase Realtime Database.
- Verifying that sensor data is collected, processed, and stored correctly in the database.
- Using sensor data to validate the entire data pipeline.

Integration with Firebase Services:

- Testing the integration with Firebase services such as Authentication, Realtime Database, Firestore Database.
- Taking care of the firebase host and web API key.

Integration of Predictive Analytics:

- Testing the integration of predictive analytics algorithms with the data processing pipeline.
- Validating that predictive models receive the necessary input data and produce accurate predictions.

Scalability and Performance Testing:

- Testing the system's ability to handle a large volume of sensor data, concurrent user requests, and predictive analytics computations.
- Identifying and addressing any bottlenecks or performance issues in the integrated system.

6. PROJECT DEMONSTRATION

Model Setup:

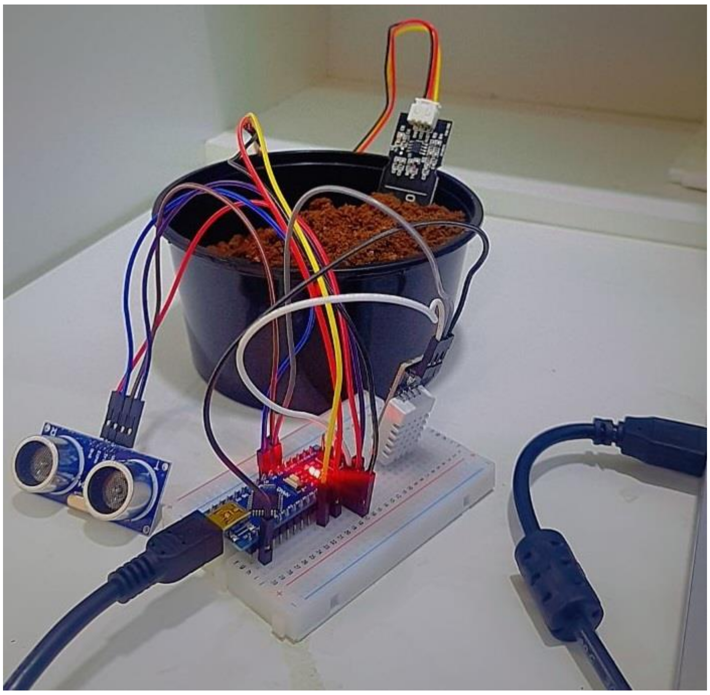

Fig-6.1: Sensors Connected to Arduino Nano

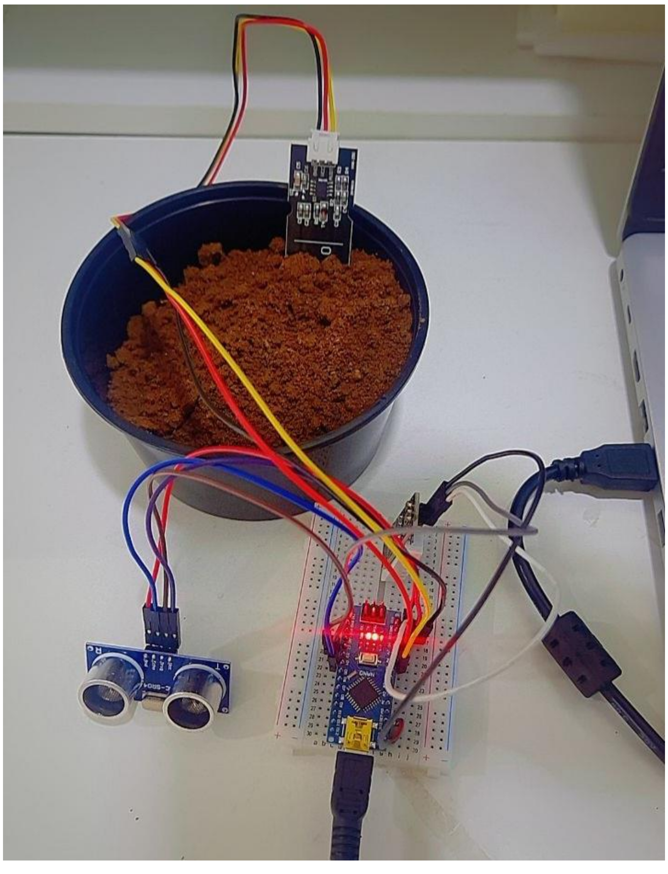

Fig-6.2: The Soil here is Dry

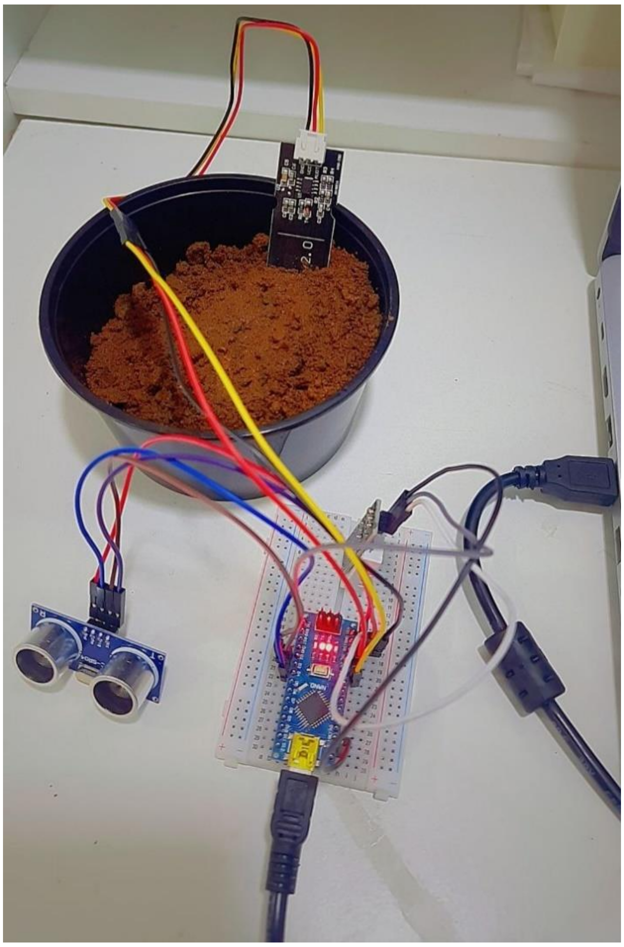

Fig-6.3: Soil is watered to obtain adequate Moisture

1. **Hardware Selection:**

- The first and foremost step in designing an IoT-based greenhouse monitoring system is the careful selection of appropriate sensors. These sensors are the "eyes" and "ears" of the system, providing crucial data on the greenhouse environment.
- When choosing sensors, factors like accuracy, reliability, and compatibility should be considered. For example, temperature sensors must be accurate within a narrow range, humidity sensors should be able to withstand moisture-rich environments, and ultrasound sensors should have a suitable detection range.
- Additionally, the sensors chosen should be compatible with the central processing unit, in this case, the Arduino Nano, to ensure seamless integration.

2. Hardware Setup:

- Once the sensors are selected, the next step involves physically setting up the hardware in the greenhouse. This entails connecting the sensors to the Arduino Nano.

- Proper placement of sensors is critical. For instance, temperature sensors should be strategically positioned to capture variations in temperature across the greenhouse. Humidity sensors should be placed in areas where moisture levels are critical.
- The Arduino Nano acts as the central brain of the system, collecting data from sensors and facilitating data processing and communication with other devices.

3. Software Installation:

- The software setup on the Arduino Nano is a pivotal part of the project. It's where the system's intelligence is implemented.
- Installing the Raspbian operating system, a lightweight and efficient Linux distribution for Arduino Nano, ensures a stable platform for running the software stack.
- Python, a versatile and widely-used programming language, is chosen for its ease of use and rich ecosystem of libraries. It enables developers to create custom scripts for data collection, analysis, and control.
- The installation of specific libraries and drivers allows the Arduino Nano to interface with the selected sensors seamlessly.

4. Data Collection:

- The selected sensors continuously gather data about the greenhouse environment. Temperature sensors monitor the warmth of the air, soil, or water. Humidity sensors measure moisture levels in the air. Ultrasound sensors detect the presence of objects or people.
- This real-time data collection is essential for ensuring that the greenhouse maintains the ideal conditions for plant growth.
- The collected data is stored locally on the Arduino Nano, ensuring that historical data is readily accessible for analysis and decision-making.

5. Data Processing:

- The heart of the system lies in its ability to process the collected data. Python scripts are used to process and analyze the data.
- Statistical analysis is employed to identify trends, anomalies, and correlations in the

environmental data. Visualization techniques, such as charts and graphs, can help farmers gain a deeper understanding of the greenhouse conditions.

- This processed data provides valuable insights, allowing farmers to make informed decisions about adjusting environmental factors to optimize plant growth, improve resource utilization, and minimize environmental impact.

6. Cloud Integration:

- The final step is to integrate the system with the cloud. This integration brings several advantages:
- Remote access: Farmers can monitor and control the greenhouse from anywhere with an internet connection, providing flexibility and convenience.
- Long-term data storage: Cloud storage ensures that historical data is securely retained for future analysis and reference.
- Advanced analytics: With data stored in the cloud, farmers can leverage more advanced analytics, such as machine learning models, to predict optimal planting times, pest outbreaks, or resource needs.
- Scalability: Cloud integration allows for easy scalability as more sensors or greenhouses are added to the system

7. COST ANALYSIS / RESULT & DISCUSSION

Table-7.1: Cost Analysis

Item	Count	Cost (INR)
Arduino Nano	1	450
Ultrasonic Sensor	1	200
DHT22 Sensor	1	350
Soil Moisture Sensor	1	200
Breadboard	1	150
Jumper Wires	40	150

Total Cost: 1500 INR

Results:

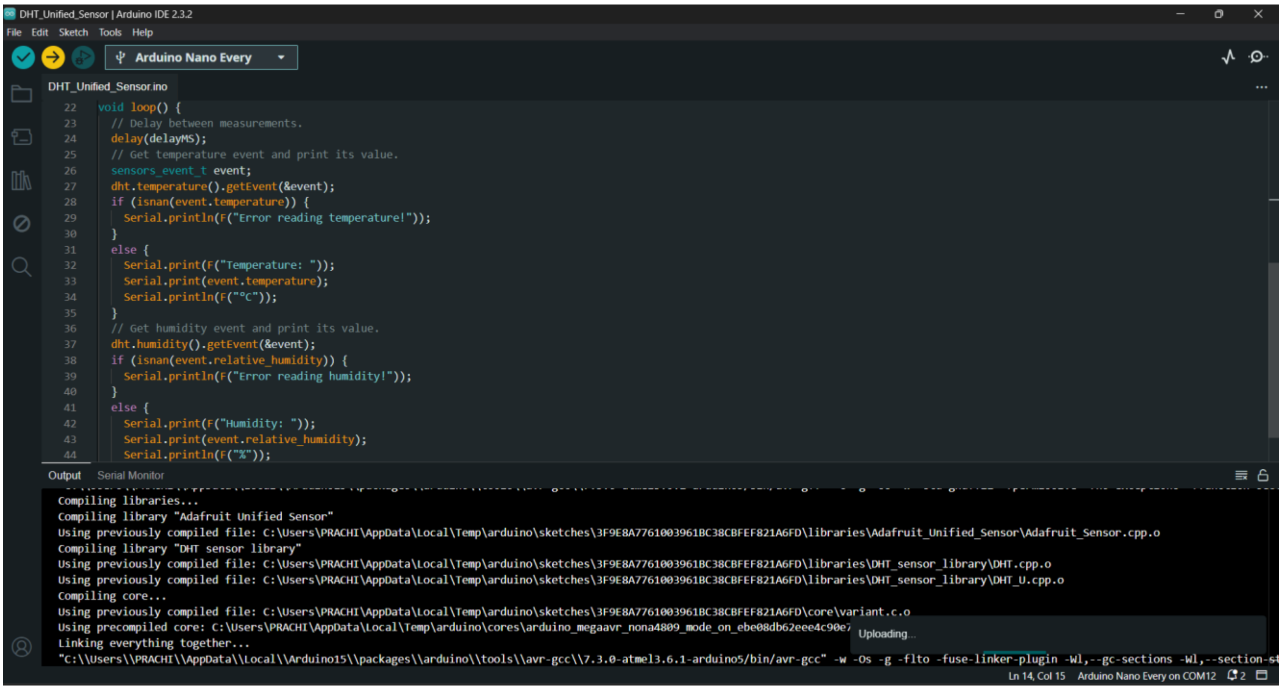

Fig-7.1: DHT22 Sensor Code Upload. The pin to which the DHT sensor is connected (DHTPIN) and the type of DHT sensor (DHTTYPE) are defined. The code waits for the delay set earlier, then reads the temperature and humidity values from the sensor.

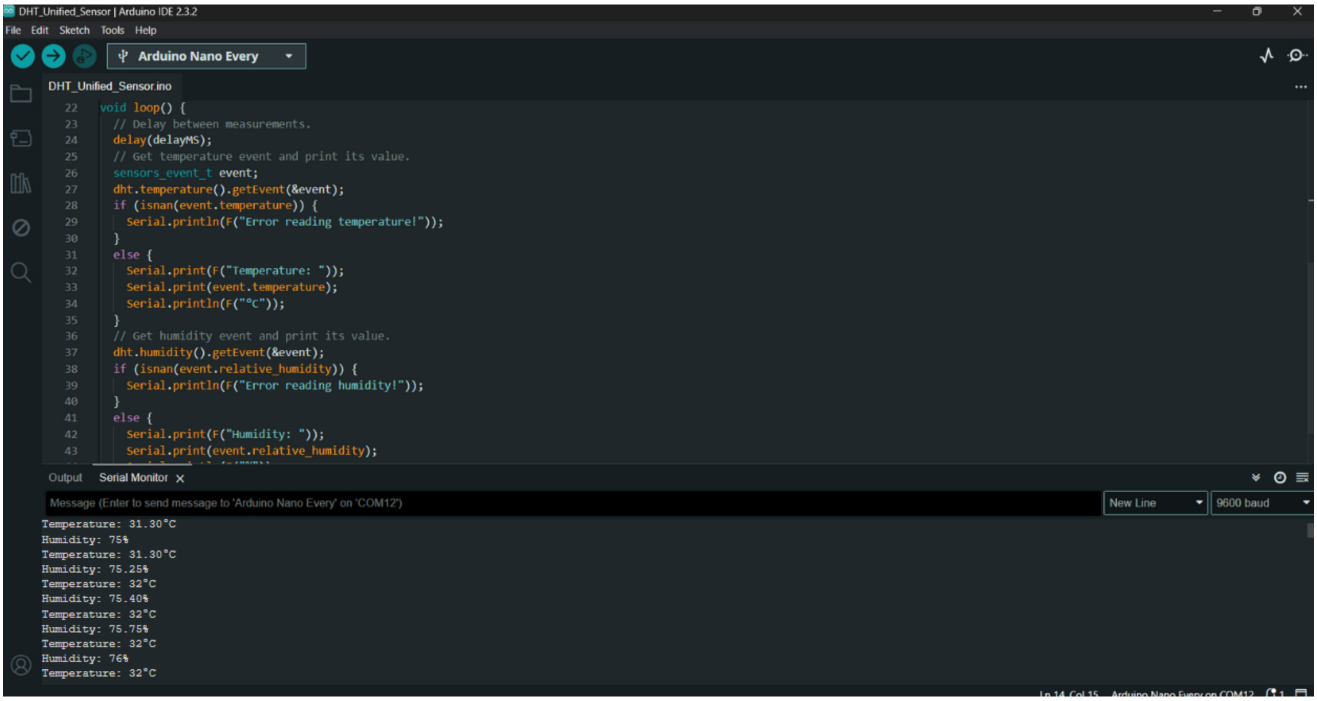

Fig-7.2: DHT22 Sensor Code Output. If the readings are valid, it prints the temperature and humidity values to the serial monitor. The loop() function continues to execute repeatedly, reading and printing sensor values.

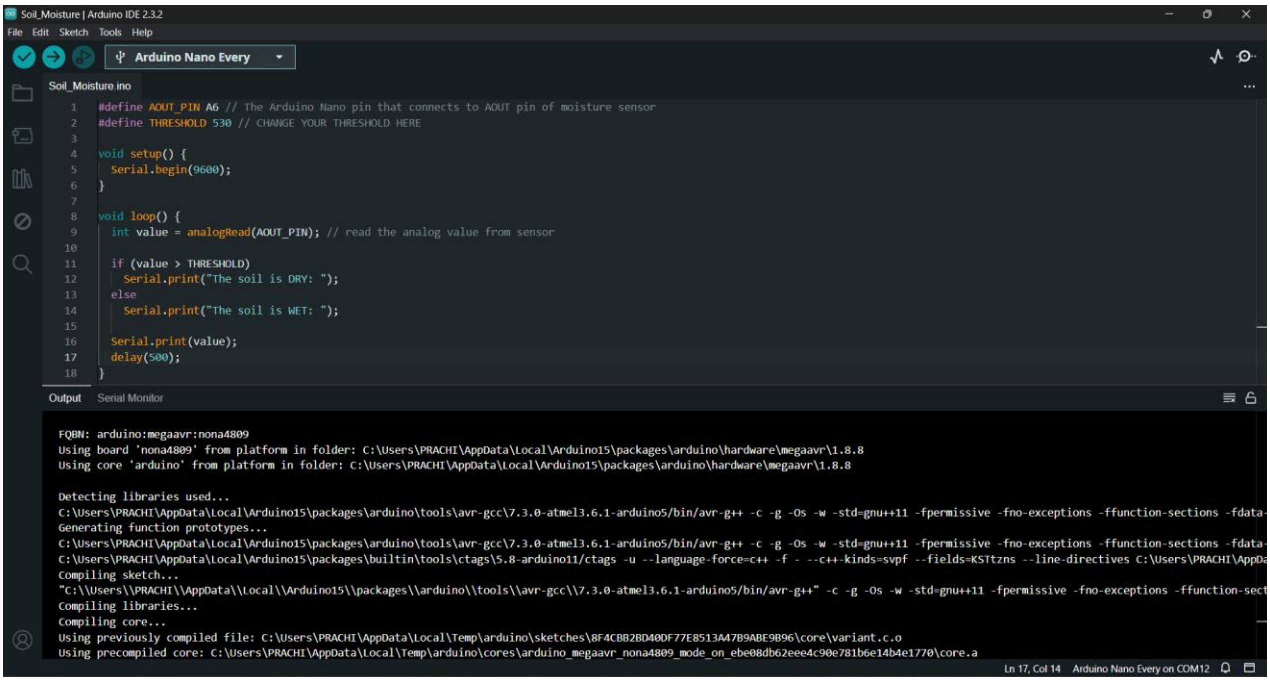

Fig-7.3: Soil Moisture Sensor Code Upload. It compares predicted value to the threshold value. If the analog value is greater than the threshold, it prints "The soil is DRY:" Otherwise, it prints "The soil is WET:". Finally, there's a delay of 500 milliseconds before the loop repeats.

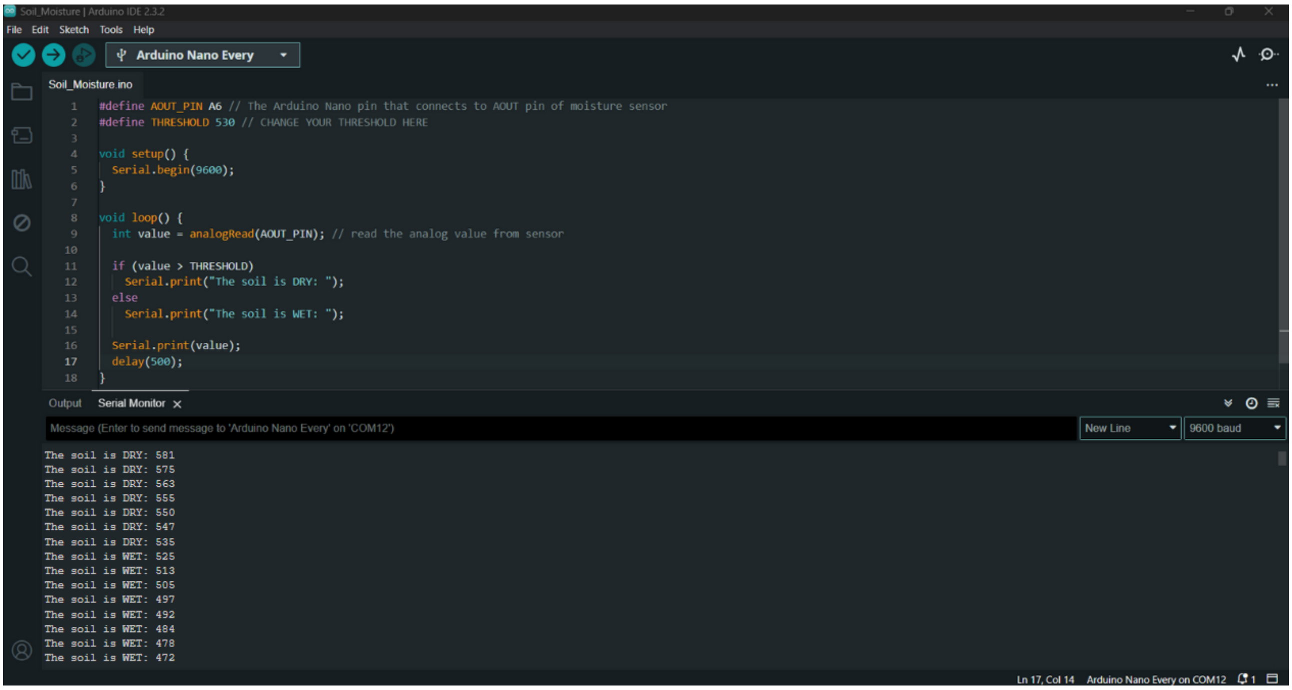

Fig-7.4: Soil Moisture Sensor Code Output. This code provides a simple way to monitor soil moisture levels using an Arduino Nano and a moisture sensor connected to pin A6. Adjustments to the threshold value can be made to suit different soil conditions and sensor sensitivities.

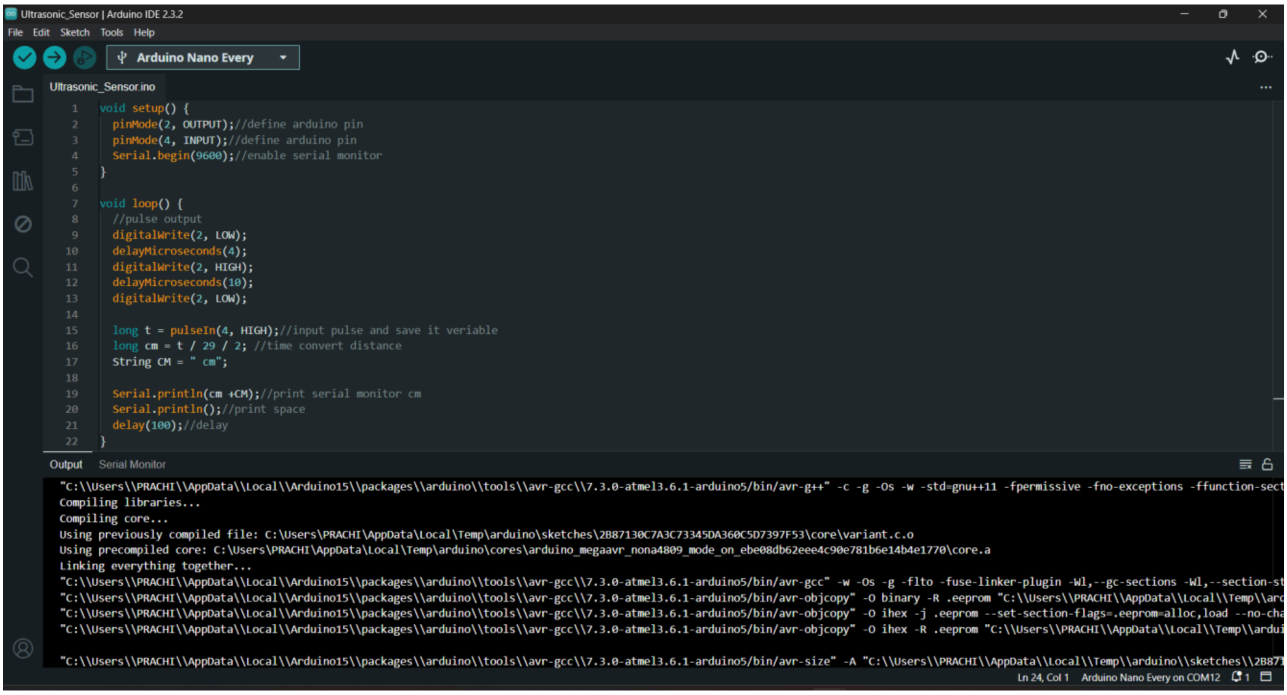

Fig-7.5: Ultrasonic Sensor Code Upload. A trigger pulse is sent to the ultrasonic sensor by setting pin 2 LOW for 4 microseconds, then HIGH for 10 microseconds, and finally LOW again. This pulse triggers the sensor to send an ultrasonic wave.

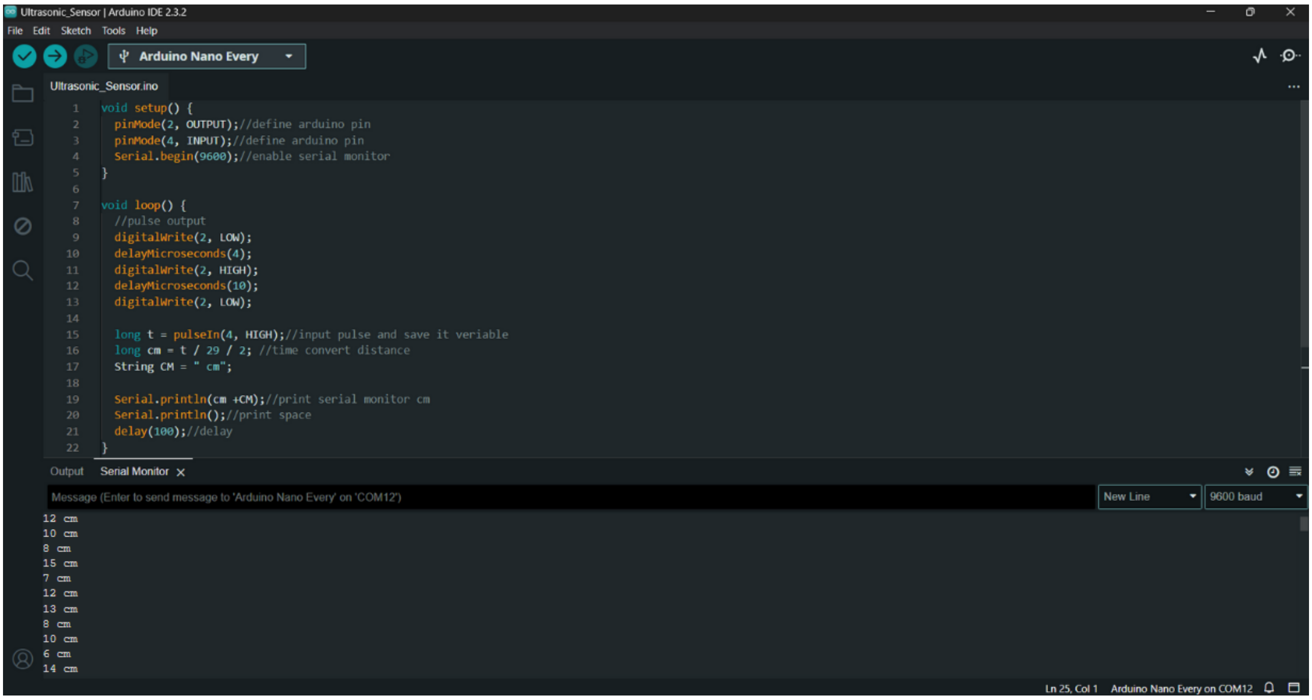

Fig-7.6: Ultrasonic Sensor Code Output. The distance in centimeters is printed to the serial monitor, followed by an empty line for formatting. There's a delay of 100 milliseconds before the next measurement to avoid rapid serial output and allow time for the ultrasonic sensor to settle before the next measurement.

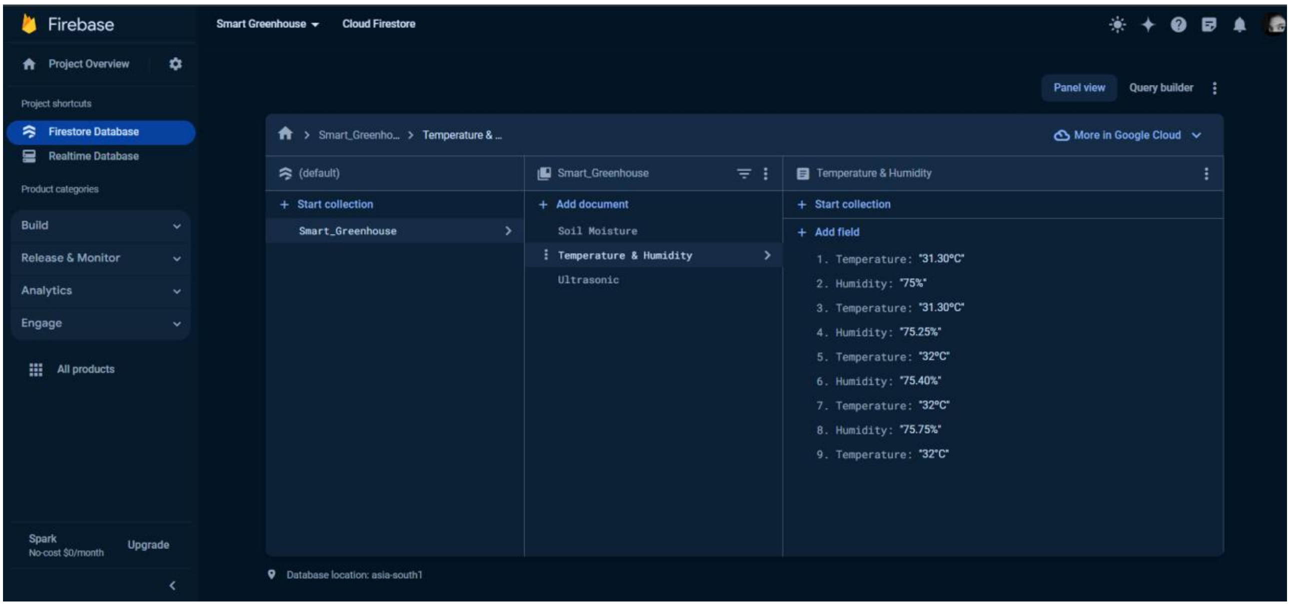

Fig-7.7: Data fetched from DHT22 Sensor to Firestore Database. It involves capturing environmental data such as temperature and humidity from the sensor and storing it in the Firestore cloud database provided by Google.

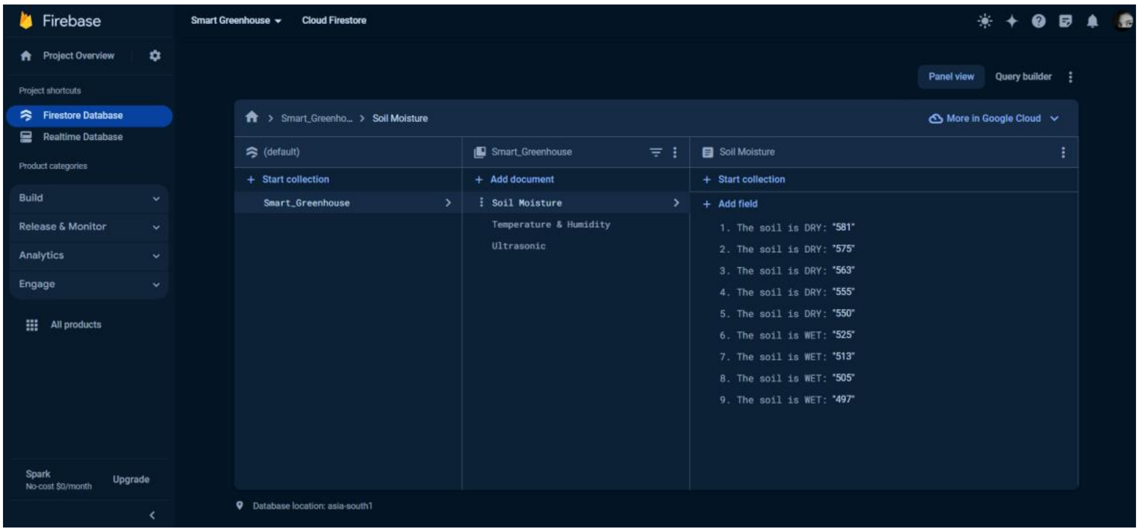

Fig-7.8: Data fetched from Soil Moisture Sensor to Firestore Database. Once in the database, the data can be accessed, analyzed, and utilized for various applications such as monitoring environmental conditions in real-time, historical data analysis, or triggering automated actions based on predefined thresholds.

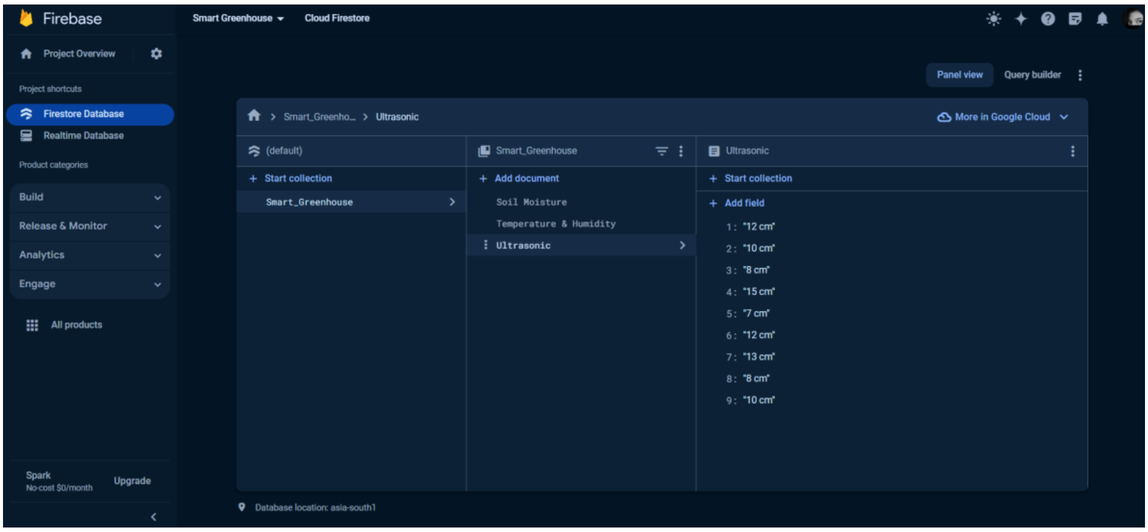

Fig-7.9: Data fetched from Ultrasonic Sensor to Firestore Database. It involves capturing distance measurements using the sensor and storing them in the Firestore cloud database provided by Google. Typically, this process requires setting up Arduino Nano to read distance data from the sensor at regular intervals.

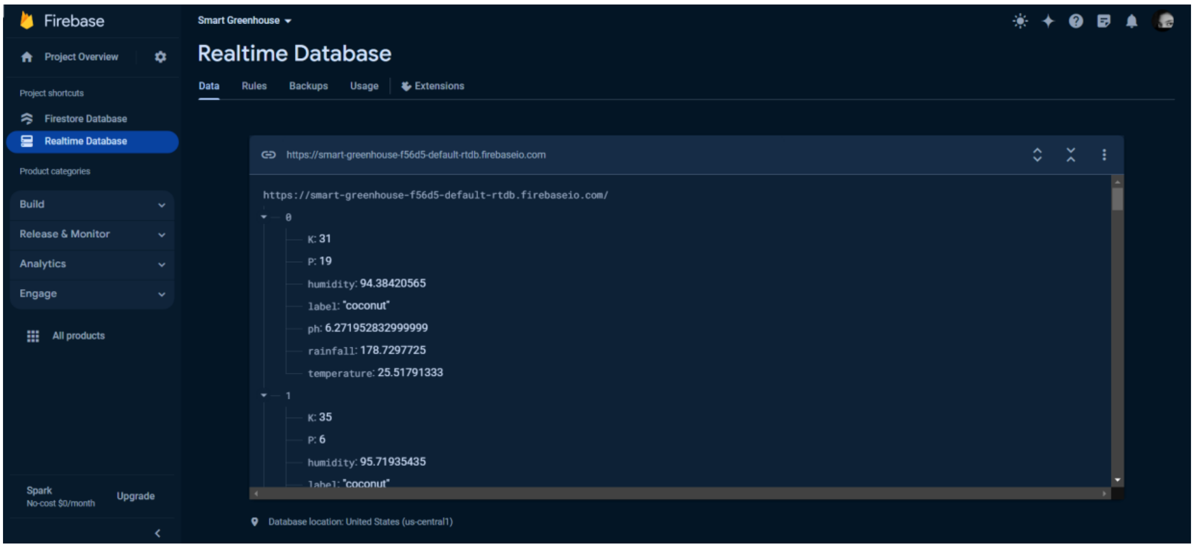

Fig-7.10: Data fetched from Crop Recommendation dataset to Realtime Database. It involves transferring information from a dataset containing crop recommendations (which may include factors like soil moisture, temperature, humidity, pH and crop nutrients) to Firebase Realtime Database.

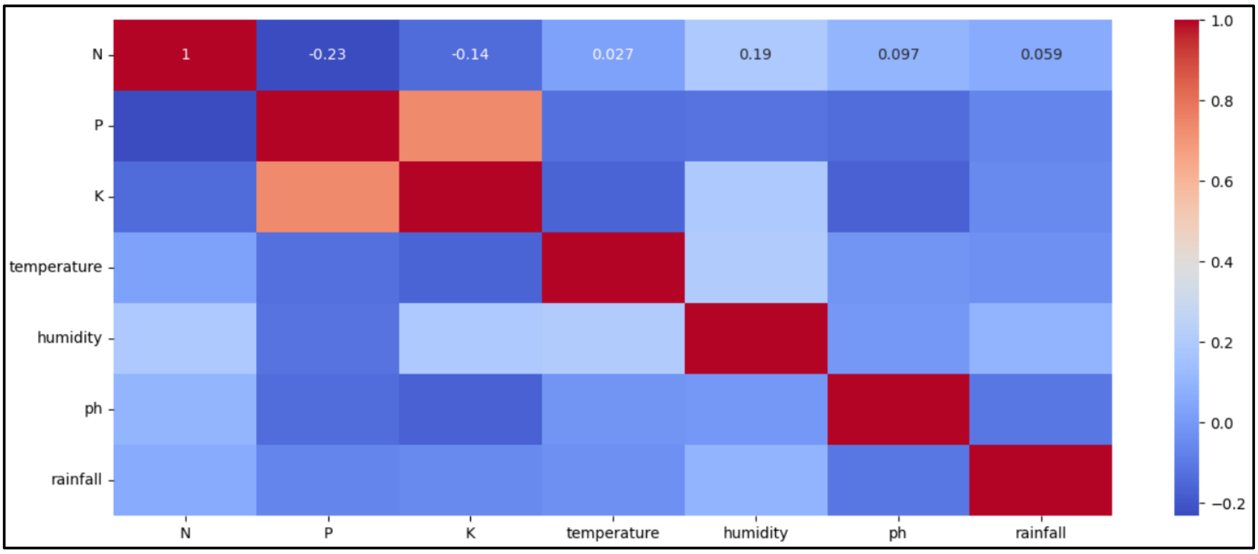

Fig-7.11: Heatmap visualizes the correlation between variables like NPK levels, temperature, humidity, soil moisture, pH, and recommended crops in a crop recommendation dataset. It illustrates how these factors relate to each other and influence crop suitability.

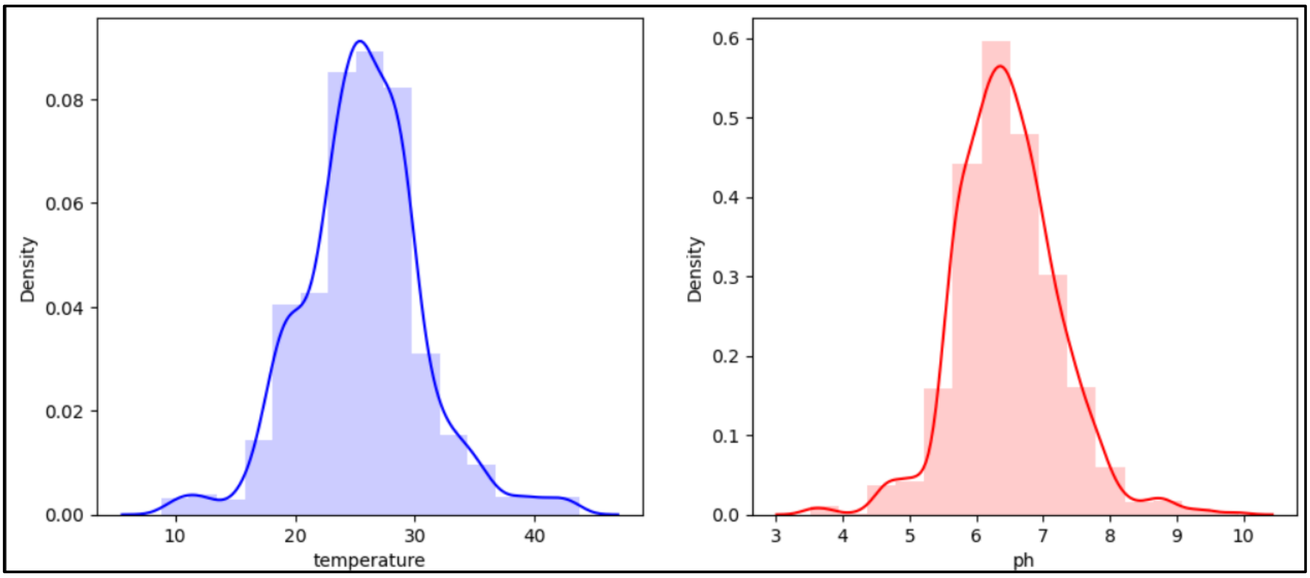

Fig-7.12: Distplot visually represents the distribution of each variable's values. It helps to understand the spread and central tendency of data, aiding in identifying patterns or outliers in the dataset.

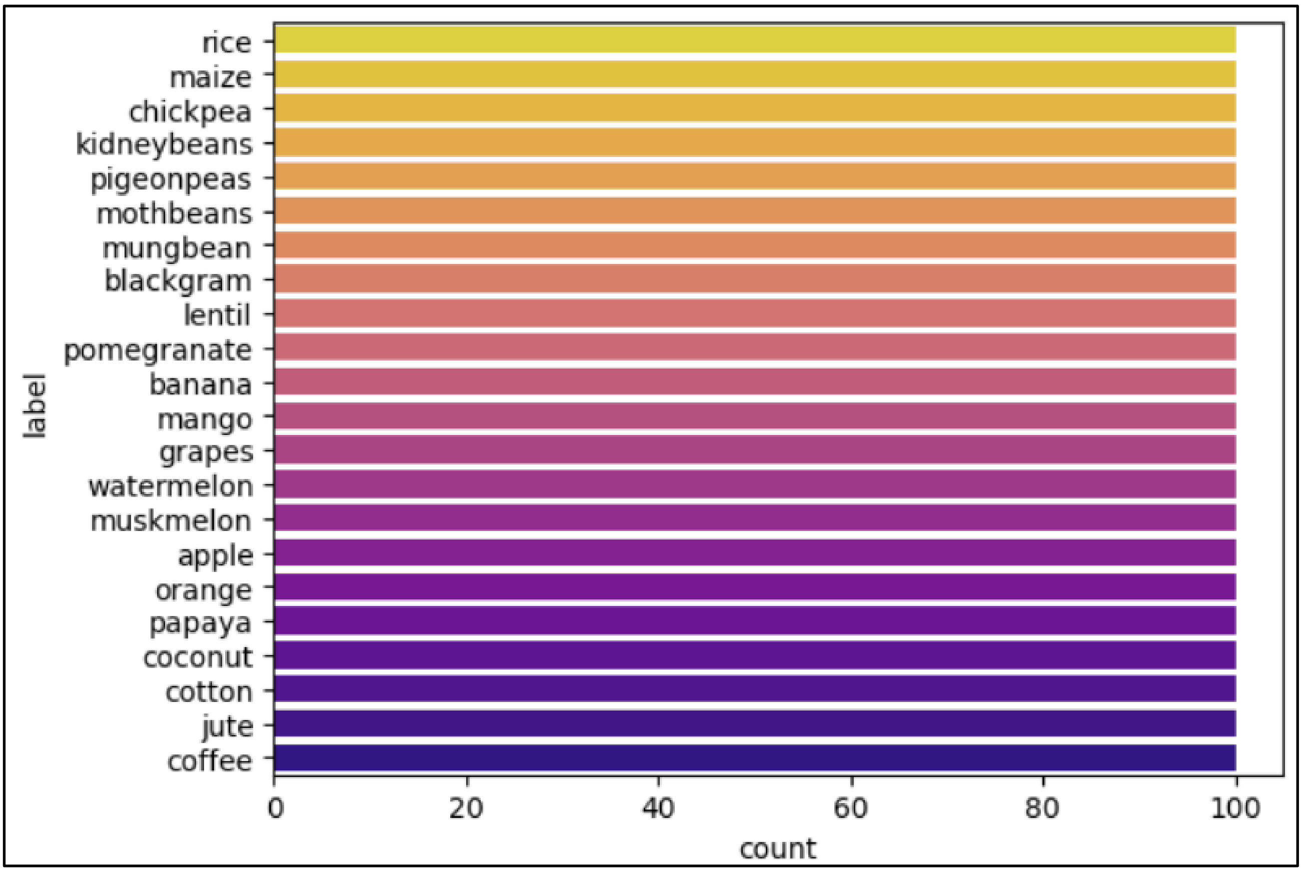

Fig-7.13: Countplot displays the frequency of occurrence of different categories within each variable. It provides a visual summary of the distribution of categorical data, aiding in identifying prevalent conditions or trends in the dataset.

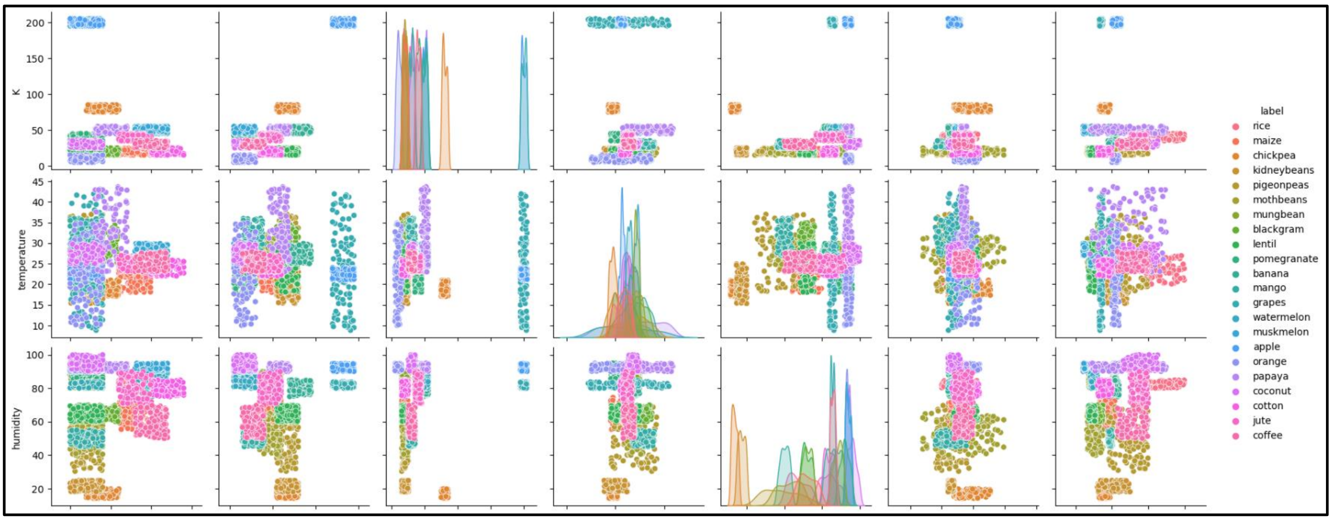

Fig-7.14: Pairplot creates a grid of scatterplots illustrating the relationships between every pair of variables. This visualization helps to identify correlations and patterns between different environmental factors and their collective impact on crop recommendations.

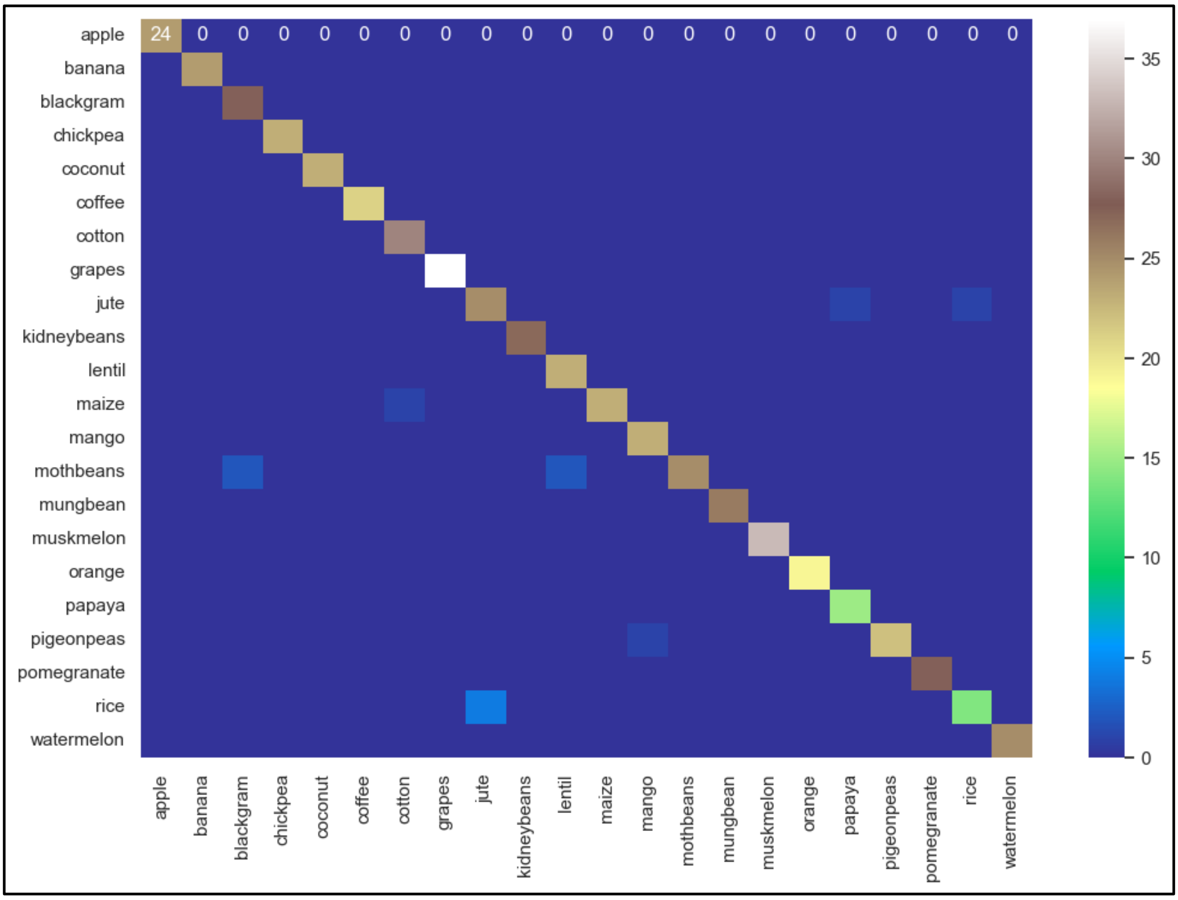

Fig-7.15: Confusion Matrix evaluates the performance of a classification model by comparing predicted crop recommendations with actual recommendations. It summarizes the true positive, true negative, false positive, and false negative predictions, providing insights into the model's accuracy and errors.

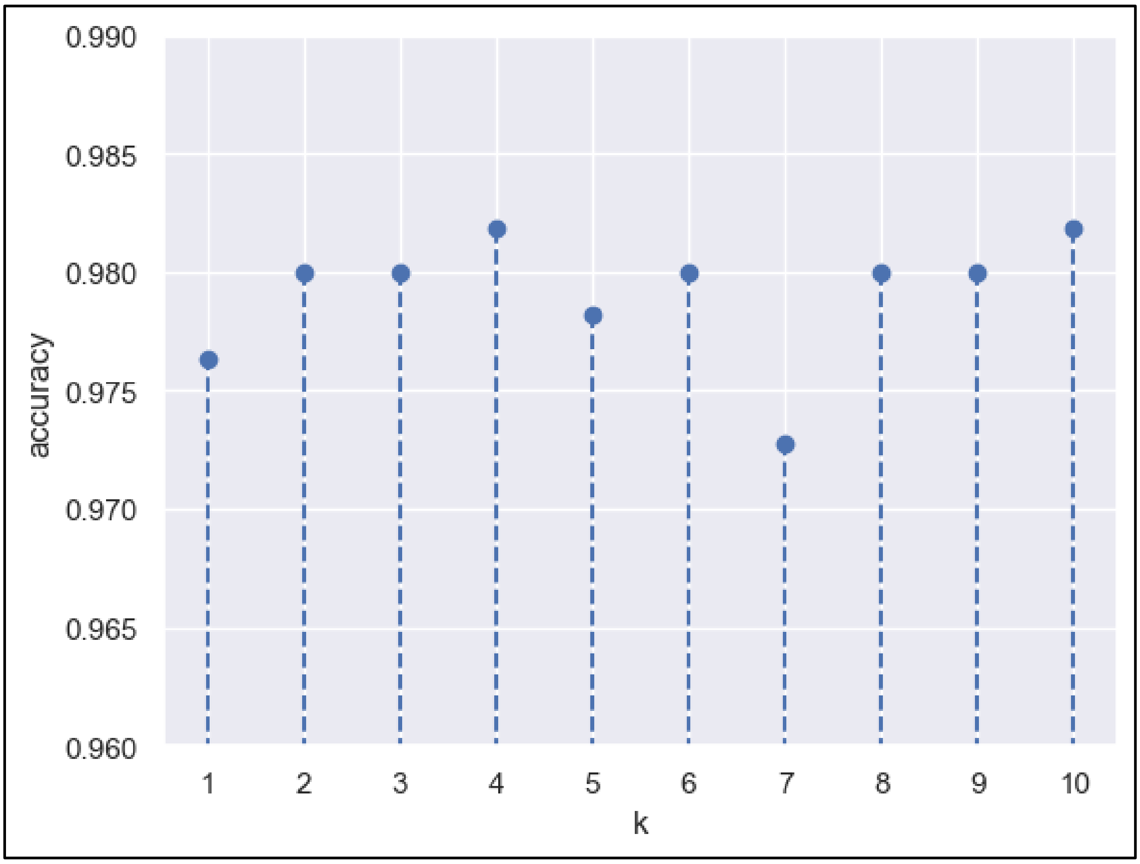

Fig-7.16: KNN Algorithm predicts suitable crops based on the similarity of their environmental conditions to those of neighboring samples. It calculates the distance between data points in a multi-dimensional space and assigns a new data point to the majority class among its k nearest neighbors

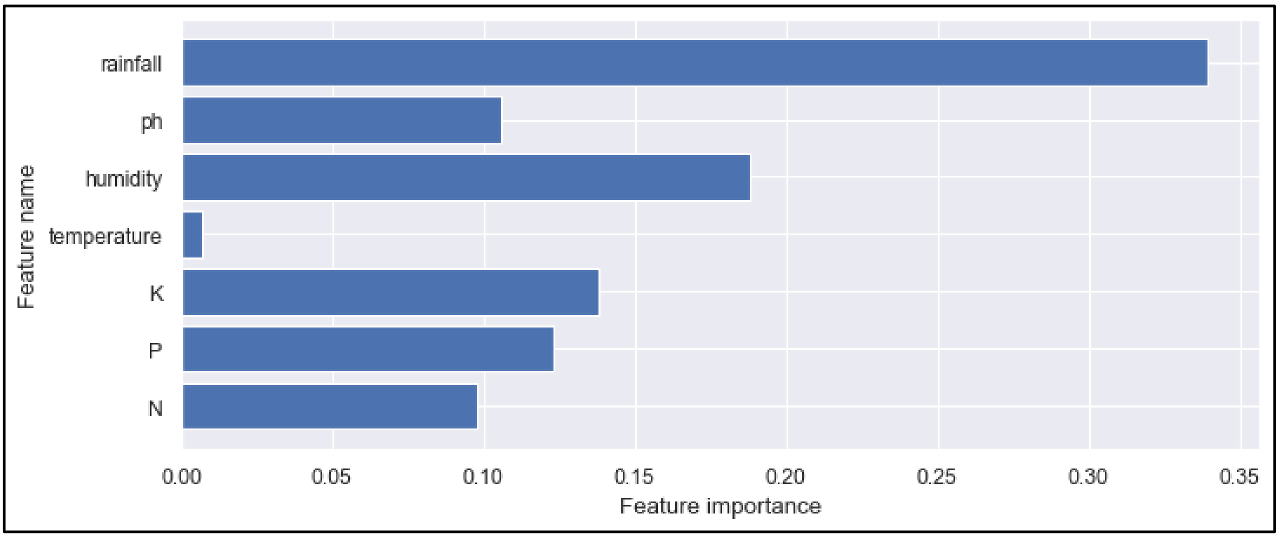

Fig-7.17: Decision Tree recursively splits the dataset into subsets, aiming to maximize homogeneity within each subset regarding recommended crops. By following the path of decisions, farmers can infer which combination of environmental factors leads to optimal crop choices, facilitating informed decision-making in agricultural practices.

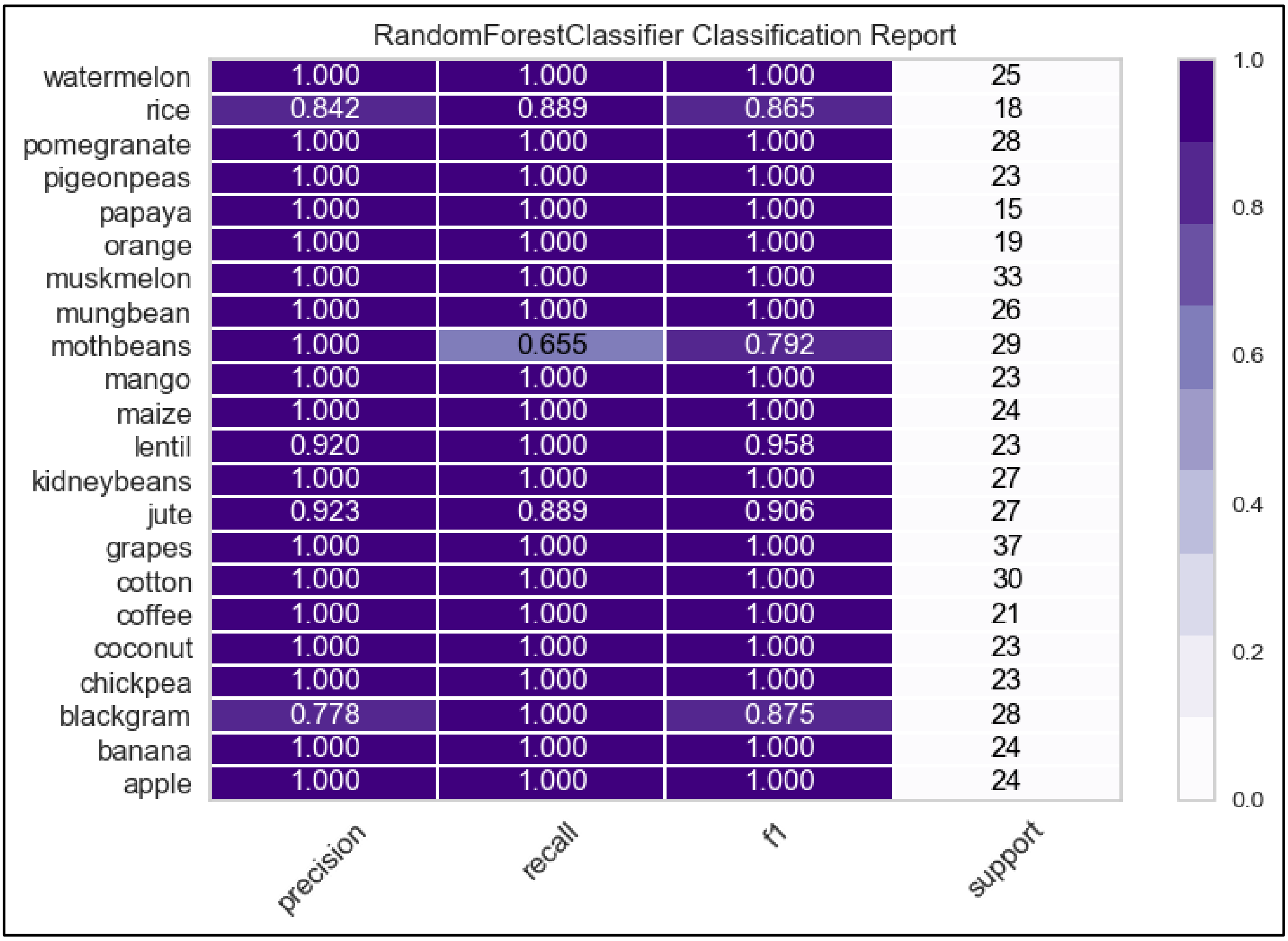

Fig-7.18: Random Forest Classifier constructs multiple decision trees and combines their predictions to determine the recommended crops. By aggregating the results of individual trees, it improves accuracy and reduces overfitting, providing robust recommendations based on diverse environmental factors.

8. SUMMARY

Objective: The primary goal is to leverage IoT devices and sensors to collect real-time data on environmental parameters such as temperature, humidity and soil moisture within the greenhouse.

Data Collection: Sensors strategically placed throughout the greenhouse continuously collect data, which is transmitted to a central database or cloud platform for processing and analysis.

Predictive Analytics Algorithms: Advanced predictive analytics algorithms are employed to analyze historical and real-time data, identify patterns, and forecast future trends in environmental conditions and plant growth parameters.

Decision Support System: The predictive analytics system provides actionable insights and recommendations to greenhouse operators, enabling them to make informed decisions about adjusting environmental parameters and optimizing resource allocation.

Automation and Control: Predictive analytics can be integrated with automation systems to enable real-time control of environmental factors such as heating, cooling, irrigation, and lighting, based on forecasted trends and recommendations.

Benefits:

- Maximizing Crop Yield: By optimizing environmental conditions, predictive analytics helps maximize crop yield and quality.
- Resource Efficiency: Efficient resource allocation based on predictive insights reduces water usage, energy consumption, and fertilizer usage.

Challenges:

- Data Quality: Ensuring the accuracy and reliability of sensor data is crucial for the effectiveness of predictive analytics models.
- Computational Resources: Processing large volumes of data and running complex analytics algorithms may require significant computational resources.
- Integration and Scalability: Integrating IoT devices, sensors, and analytics systems into existing greenhouse infrastructure and ensuring scalability can be challenging.

Future Directions:

- Continuous Improvement: Ongoing refinement of predictive analytics algorithms and integration with emerging technologies to further enhance performance and effectiveness.
- Expansion and Adoption: Widening the application of predictive analytics in agriculture and encouraging widespread adoption among greenhouse operators

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APPENDIX A

Dataset:
https://docs.google.com/spreadsheets/d/1lXXJ1m6gvoCgQBNYo2cDQuFZXvHn3p246KoqVj_DbxQ/edit?usp=sharing

Github:

https://github.com/LazyLassie/Predictive-Analytics-for-Smart-Greenhouse

Google Collab Notebook:

https://colab.research.google.com/drive/1SdtsUKFHSPI3RXJbiuLbDn7XUfqm9ON-?usp=sharing

Algorithm:

- Include necessary libraries
- Define pin and sensor type
- Initialize serial communication
- Get temperature and humidity data
- Define pin connected to the soil moisture sensor
- Define threshold value that determines whether soil is dry or wet
- Get the value from the capacitive soil moisture sensor
- Define Arduino pin and enable the serial monitor
- Ultrasonic Sensor measures time taken for the ultrasonic waves to reflect back from the obstacle
- Distance is calculated from the time and displayed
- Data collected is fetched to firebase
- Data analysis is done with various ML algorithms
- Heatmap, Countplot, Distplot,, Pairplot and Confusion Matrix of the dataset are obtained
- KNN, Decision Tree, Random Forest, SVC, Gradient Boosting, Logistic Regression algorithms are used
- The highest accuracy is obtained grom Gradient Boosting with a value of 99.4%.

SAMPLE CODE:

```
//Soil Moisture Sensor
#define AOUT_PIN A6
#define THRESHOLD 530

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

```
void loop() {
  int value = analogRead(AOUT_PIN); // read the analog value from sensor

  if (value > THRESHOLD)
    Serial.print("The soil is DRY: ");
  else
    Serial.print("The soil is WET: ");

  Serial.print(value);
  delay(500);
}


//Ultrasonic Sensor
void setup() {
  pinMode(2, OUTPUT);//define arduino pin
  pinMode(4, INPUT);//define arduino pin
  Serial.begin(9600);//enable serial monitor
}

void loop() {
  //pulse output
  digitalWrite(2, LOW);
  delayMicroseconds(4);
  digitalWrite(2, HIGH);
  delayMicroseconds(10);
  digitalWrite(2, LOW);

  long t = pulseIn(4, HIGH);//input pulse and save it veriable
  long cm = t / 29 / 2; //time convert distance
  String CM = " cm";

  Serial.println(cm +CM);//print serial monitor cm
  Serial.println();//print space
  delay(100);//delay
}

//DHT22 Sensor

#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <DHT_U.h>
#include <Firebase.h>

#define FIREBASE_HOST "https://console.firebase.google.com/project/smart-greenhouse-f56d5/database/smart-greenhouse-f56d5-default-rtdb/data/~2F"
#define FIREBASE_AUTH "AIzaSyCskwg8-Fm8UwQ2-kW23huGs7YLKbSRQNs"
#define DHTPIN 2     // Digital pin connected to the DHT sensor
#define DHTTYPE    DHT22

DHT_Unified dht(DHTPIN, DHTTYPE);
```

```
uint32_t delayMS;

void setup() {
  Serial.begin(9600);
  // Initialize device.
  dht.begin();
  sensor_t sensor;
  dht.temperature().getSensor(&sensor);
  dht.humidity().getSensor(&sensor);
  // Set delay between sensor readings based on sensor details.
  delayMS = sensor.min_delay / 1000;
}

void loop() {
  // Delay between measurements.
  delay(delayMS);
  // Get temperature event and print its value.
  sensors_event_t event;
  dht.temperature().getEvent(&event);
  if (isnan(event.temperature)) {
    Serial.println(F("Error reading temperature!"));
  }
  else {
    Serial.print(F("Temperature: "));
    Serial.print(event.temperature);
    Serial.println(F("°C"));
  }
  // Get humidity event and print its value.
  dht.humidity().getEvent(&event);
  if (isnan(event.relative_humidity)) {
    Serial.println(F("Error reading humidity!"));
  }
  else {
    Serial.print(F("Humidity: "));
    Serial.print(event.relative_humidity);
    Serial.println(F("%"));
  }
}
```