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IOT-Based Smart Crop Cultivation & Monitoring

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Abstract: With the requirement for new and effective procedures to improve crop cultivation, blending of modern technology, such as the Internet of Things (IoT), and ancient agricultural methods holds greater relevance. In the following study, the feasibility and importance of implementing an IoT-based smart crop cultivation and monitoring system are discussed. The smart agricultural technology will provide control, anti-toxic, and an optimum level of environment to yield crops in any remote or short on resources areas across the globe and beyond. The smart agricultural system enables professionals to manage, monitor, and analyze crop yields remotely with the help of an integrated mobile application. With limitations in natural resources and time, crop cultivation needs to be robust but safe and technologically empowered through smart agricultural systems such as the one we are presenting. The research work aims to mitigate the carbon footprint associated with conventional agriculture, add more precision to the crop yield by offering an optimized farming space, educate the farmers about advanced technology, and most importantly, enable quality crop cultivation in remote regions. With the help of IoT, the proposed procedure for crop cultivation gets precision in results, scalability for resources, remote control, and an optimized environment for cultivating multiple crops.

Keywords: Internet of Things (IoT); Agricultural; Smart Crop Cultivation; Mobile Application

1. Introduction

With advancements in human civilization, agriculture has evolved through the use of tools, methods, and technologies to meet the growing demand for food. As resources and time become limited, agriculture has adopted artificial procedures and technologies to enhance crop cultivation. The integration of IoT in agriculture increases efficiency, sustainability, and precision in crop cultivation.

This research paper proposes a smart crop cultivation and monitoring system using IoT and a mobile application. The system collects data on crop yield, growth factors, and resource levels through sensors in a controlled wood-and-glass chamber. Parameters like temperature, humidity, and soil moisture are monitored, and the data is used to optimize crop growth and quality. The system also incorporates the Blynk Software platform for remote monitoring and management, ensuring ease of use and better control.

With the global population expected to reach 9 billion by 2050, such systems are essential for ensuring food security [1]. The proposed system combines traditional agricultural practices with modern technology to improve crop yield, reduce toxic factors, and shorten cultivation cycles, providing scalable and high-quality results.

1.1. Research Objectives

1. **Improve Food Quality & Growth Rate:**
   - In the research paper, we discuss a control environment for the key factors such as air moisture, soil pH, light intensity, temperature, and irrigation levels for attaining a high quality of crop yield.
   - By setting ideal conditions for plant growth, the crop yield can be increased by 20 percent.
2. **Optimize Resource Utilization:**
   - The paper discusses a smart system that reduces over-irrigation by 30 percent with a scheduled water flow system.
   - With the availability of optimum conditions for growth, the crop will not require any growth enhancers or pesticides, etc., which will reduce the toxic factors.
3. **Reduce Environmental Impact:**
   - In the research paper, there is a focus on resource optimization, with the effective implementation of the smart system, with the possibility of 10-15 percent of the total carbon footprint.
   - With no usage of pesticides, the crop cultivation will not be accompanied by any toxic gases or pollutants.
4. **Empower Farmers with Technology:**
   - The smart system under discussion has smart sensors integrated across its architecture, which provides real-time data monitoring and control of the environment with the help of the Blynk platform, i.e. Blynk Platform is a mobile application.
   - The usage of such a smart system in agriculture will help in educating farmers with IoT technology and making it useful to attain quality crops.
5. **Scalability and Adaptability:**
   - The research paper discusses the implementation of the smart system on a smaller scale initially and afterwards goes on to large commercial-level applications of the technology.
   - The research work covers a scalable and easy-to-integrate smart system that can be applied to different means of crop cultivation, such as vertical farming, urban agriculture, and also extra-terrestrial environments.

1.2. Related Work

During the research work, various technologies and smart farming systems were observed, highlighting the different limitations that still exist in the integration of IoT in agriculture, as the technologies we discuss in the following paper add more scalability and precision with data-driven functionality.

The following sections highlight the key contributions of the research papers for addressing the challenges faced by the agriculture industry:

IoT in Agriculture:

If we look into the details given, we will explore the integration of IoT-based smart systems in agriculture, primarily emphasizing real-time data monitoring for improving crop yield and cutting down overhead resources, as it suggests a system for achieving 25% of the operational efficiency [2]. Similarly, if we look into the challenges, we will note that it is focused on resource optimization and climate variability [3] .

Deep Learning and IoT:

Artificial intelligence (AI) plays a key role in the advancement of the modern industrial era, as the potential of AI and its procedures in securing IoT systems is studied in a study on *An interpretable deep learning framework for intrusion detection in industrial Internet of Things* [4]. The main feature of the research work is focused on implementation in the industrial IoT, but its algorithms can be applied to modern agriculture smart systems for achieving advanced data processing and result-driven decisions to carry out essential operations.

Generative AI in IoT:

Like any other advanced research work, the study in *Generative AI for Consumer Internet of Things: Challenges and Opportunities,* emphasizes the importance of generative Artificial Intelligence (AI) for the development of predictive models for the IoT smart systems [5]. To improve the crop cultivation patterns, enhance data-driven decisions, and optimize resource utilization in farming. To mitigate over-irrigation in agriculture with 90 percent accuracy, these generative AI models can be used for climate forecasts.

IoT in Drone-Based Agriculture:

To enable farmers to monitor large-scale fields, the following research paper, "*Sensing and Communication Coverage in Internet of Drone Things: Challenges and Opportunities,*" discusses the implementation of drones in IoT smart systems [6]. The research paper is focused on the utilization of drones in an effective manner for large-scale applications.

System Architecture and Automation:

Several novel and review papers provide technical information related to the importance of well-integrated system architecture for achieving high efficiency in the IoT-based agriculture industry. As discussed, it emphasizes the role of smart sensors and intelligent algorithms for attaining a high quality of crop yield [7]. Implementation of such a smart system aims to reduce the losses in crop yield by 25%, with the early warning related to disease detection. The use of intelligent robotics is discussed, which detects target crops for spraying, achieving high efficiency as well as reducing the total overhead resource in farming [8].

Our Research Work:

Our research work compensates for the gaps left by the above-discussed when it comes to precision, accuracy, and real-time control by integration with a mobile app, such as the one discussed in our research work, the Blynk Platform. Our paper proposes such a smart system, which ensures crop cultivation is done in a controlled environment with higher precision and adaptability.

1.3. Problem Statement

The overuse of natural resources has led to ecological and agricultural imbalances worldwide. Modern agriculture faces significant challenges in meeting the food demands of a growing population, projected to reach 9 billion by 2050. Conventional farming methods, requiring more labor and yielding lower precision and quality, are insufficient to address these challenges.

This study proposes a smart IoT-based agricultural system to enhance precision, quality, and scalability in crop cultivation. By integrating advanced sensors and technology, the system optimizes plant growth, automates processes, reduces resource consumption, and lowers the carbon footprint. It offers a robust solution to combat food insecurity, adapt to climate change, and meet global food demands while contributing to environmental recovery.

1.4. Key Components of the System Architecture

Smart Sensors:

Soil Moisture Sensor: The soil moisture sensor has the capacity to record data with an accuracy of ± 3% with a 1-second response time.

Temperature Sensor: The functionality of temperature sensors is limited in the range of 40 °C to 125 °C, with an accuracy in the result reaching ± 0.5°C.

Humidity Sensor: For humidity sensors, the limitations for functionality are between the range of 0–100% RH and an accuracy of ± 2%.

Light Intensity Sensor: Like every smart sensor, the light intensity sensor has its limitation set between 0–100,000 lux and a response time of 0.5 seconds.

Actuators:

Water Pump: The water pump is activated when the soil moisture inside the enclosed space for farming falls below 30 percent, with the capacity to control a flow rate of 5 liters per minute.

Ventilation System: The ventilation system of the smart system comprises fans with a 50 cubic feet per minute (CFM) flow rate, which operate when the temperature crosses the threshold of 25°C or the humidity exceeds 60%.

Grow Lights: To keep the light intensity balanced inside the farming space, the threshold for lumens light falls below 300 Lux, powered by the 50 Watts LED lights.

Data Processing Hub: Data Processing and actions are carried out by the integrated Raspberry Pi 4 Model B with a 1.5 GHz quad-core processor and 4 GB RAM.

Cloud Storage: With a minimum latency rate of 100 ms for real-time monitoring and analysis, the data is processed across the selected platform.
Mobile Application: For remote control and real-time data visualization, the Blynk platform provides a user-friendly interface that offers a backbone for controlling crop cultivation.

The system architecture of "IoT-Based Smart Crop Cultivation & Monitoring", is briefly elaborated in the **Figure 1**.

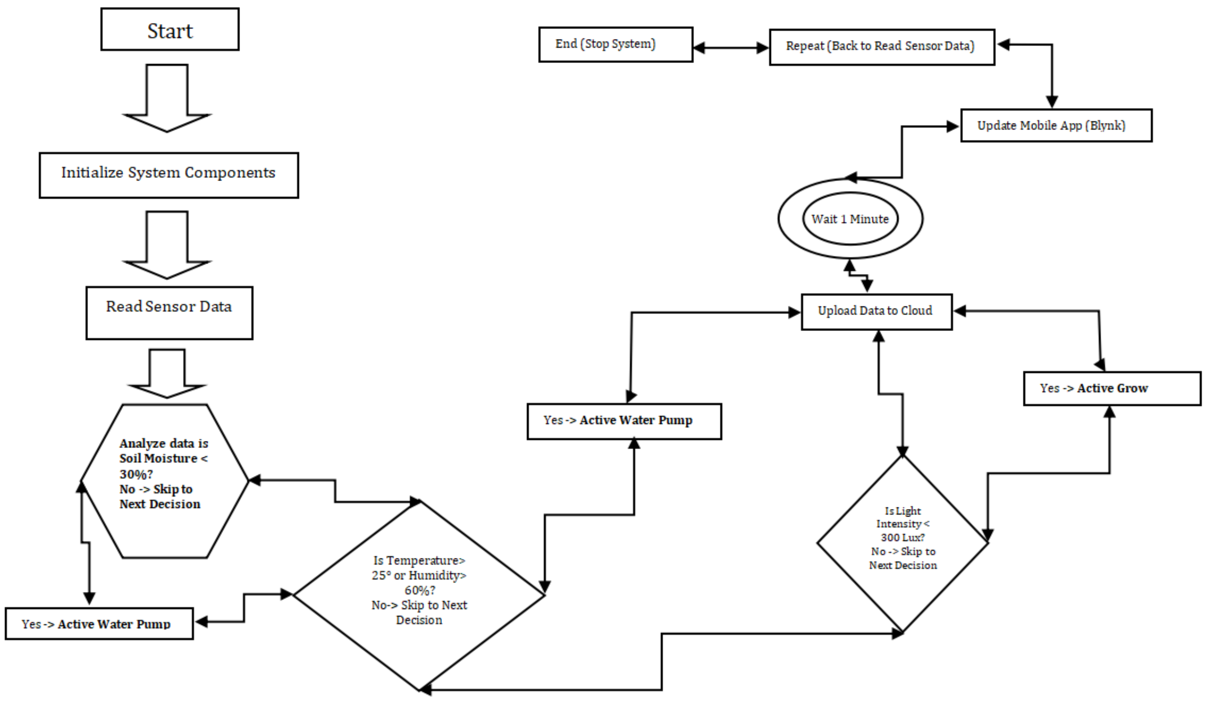

Figure 1. System Architecture of "IoT-Based Smart Crop Cultivation & Monitoring".

1.5. Pseudocode for Decision-Making Algorithm

The pseudocode for the decision-making algorithm is shown in **Algorithm 1**.

Algorithm 1 Pseudocode for Decision-Making Algorithm.

```
START
// Initialize sensors and actuators
Initialize soilMoistureSensor, temperatureSensor, humiditySensor, lightSensor
Initialize waterPump, ventilationSystem, growLights
// Set threshold values
soilMoistureThreshold = 30 // in percentage
temperatureThreshold = 25 // in degrees Celsius
humidityThreshold = 60 // in percentage
lightThreshold = 300 // in lux
WHILE systemIsRunning:
  // Step 1: Read data from sensors
  soilMoisture = read(soilMoistureSensor)
  temperature = read(temperatureSensor)
  humidity = read(humiditySensor)
  lightIntensity = read(lightSensor)
```

Algorithm 1 Pseudocode for Decision-Making Algorithm.

```
    // Step 2: Decision-making logic
    IF soilMoisture < soilMoistureThreshold:
      activate(waterPump)
    ELSE:
      deactivate(waterPump)
    IF temperature > temperatureThreshold OR humidity > humidityThreshold:
      activate(ventilationSystem)
    ELSE:
      deactivate(ventilationSystem)
    IF lightIntensity < lightThreshold:
      activate(growLights)
    ELSE:
      deactivate(growLights)
    // Step 3: Send data to cloud storage
    uploadToCloud(soilMoisture, temperature, humidity, lightIntensity)
    // Step 4: Update mobile application
    updateMobileApp(soilMoisture, temperature, humidity, lightIntensity)
    WAIT for 1 minute  // Delay before next iteration
  END WHILE
  STOP
```

1.6. Application Areas

The IoT-based smart crop cultivation and monitoring system has a multi-purpose and extended spectrum of application areas in agriculture. Mainly, this modern system enhances the precision in decision-making, reduces the cost, and improves the delivery time of crops. Once tested on a smaller scale, the specialized incubation can be developed on a commercial scale, which will lead to optimized and top-quality plant growth, helping the food markets across the globe. Not only do the crops like corn, rice, and wheat cultivated through its implementation, but it also offers a scalable and data-driven platform for the growth of delicate fruits and vegetables throughout the year. The proposed system is not limited but can be adapted in both vertical farming and in urban agriculture.

Universities and research institutions can utilize the technology for trial and testing of various plant types, which can lead to the growth of crops in extraterrestrial lands in the future, such as in space exploration and on Planet Mars, too. Moreover, the proposed smart system enables us to achieve the sustainable goals, mitigating carbon footprint, and merging new technology to add value to the conventional form of agriculture.

1.7. Scope of Paper

The implementation of an IoT-based smart crop cultivation and monitoring system is both innovative and case-sensitive at the same time. As it would need to have an ideal environment, which will initially, for test purposes, consist of a wooden plank inside a glass-enclosed chamber. The hardware will also consist of a variety of smart sensors, which are well-suited to monitor real-time data related to the soil moisture, air quality, light intensity, and temperature inside the enclosed chamber. The hardware will be interconnected through both wireless and a complex wired network, which will serve as a core nervous system for monitoring, collecting, processing, and transmission of the real-time data to both the admin panel and mobile application. This data is processed by the utilization of advanced algorithms and logic systems. It is used for the optimization of temperature, humidity, scheduling irrigation, and monitoring the quality of plant growth. This data is displayed on an intuitive Blynk Platform, which enables remote control and management of crop cultivation. Not only this, but it also empowers users, mainly farmers, to acquire a sustainable environment for crop cultivation, mitigate the toxic gas density, decrease the carbon footprint, reduce the consumption of natural resources such as water, and lower the cost of crop cultivation by not using any low-grade urea in the process. To educate and provide essential knowledge about crop cultivation, the smart system also includes an educational module that helps in acquiring technical knowledge. Implementation of the IoT-based smart crop cultivation and monitoring system will merge the conventional form of agriculture with the advanced technology stack, increasing precision in food quality and lowering the threshold of climate change.

2. Background and Literature Review

This section discusses the background and literature review for the experimentation conducted.

2.1. Background

IoT technology is used by smart agriculture monitoring systems to track and manage different elements of farming, such as crop health, soil conditions, weather patterns, and more. IoT (Internet of Things) is used for remote sensing, monitoring, and management of several household, commercial, and industrial procedures.

In this case, an IoT-based smart crop cultivation and monitoring system is applied for the collection, processing, management, and control of data related to crop cultivation. This set of data includes factors such as soil quality, air humidity, temperature, water volume, and many other key data sets. The overall system comprises a comprehensive network of sensors, communication technology, and actuators etc. The data collected through the system is later optimized for acquiring quality crop cultivation and making precise decisions. This will also help in delivering enough food resources through productive techniques.

The conventional form of agriculture is facing great challenges in the shape of climate change, high labor costs, the use of unhealthy precursors for plant growth, and, most importantly, flash floods. Smart crop cultivation systems have long been in demand, and to serve the needs, we have proposed this IoT-based system, which is highly functional, safe to implement, and precise in results.

There is a need for an easy-to-implement and result-driven smart system in agriculture, not only in the subcontinent but also across the globe, to replace the conventional form of agriculture.

Such a smart crop cultivation system will not only provide us with improved quality of crops, but also mitigate both the carbon footprint and the labor cost related to farming. The system also holds great relevance for the Middle East and the Gulf region, where quality food is always top priority, but a lack of an optimized environment limits their crop growth [9]. The price of the smart system is way low, but varies depending on the level of implementation. This system can also be merged with other systems and machinery in the farming sector. This would also decrease the imports of quality food items for countries with high demand, and would make them self-sufficient through an IoT-based smart crop cultivation and monitoring system [10].

2.2. Literature Review

Various research work is carried out to explore the integration of IoT in Agriculture, highlighting its immense potential to cope with challenges such as pest control, climate adaptability, and water resource optimisation. Just as in the research by Goap et al. [2], the study is emphasised over the real-time data monitoring for improvement of crop yields as well as minimising the overhead resources, as it suggests the utilisation of a smart system which is capable of attaining a 25 per cent operational efficiency. There are many research works carried out to enable remote control of crop cultivation with the integration of IoT along with other smart systems. However, still there are many loopholes in each of these research works, which require to be address with a complete and clearer pathway to attain remote remote-controlled environment to yield sustainable crop cultivation. After analysing the existing research works, it has been found that none of these are able to provide a proper pathway for the transformation of the conventional form of agriculture into a sustainable and IoT-based smart agriculture. For such reasons, we have carried out this research work to enable farmers to cut down overhead resources, utilise the mobile app to control crop yield, and sustainably provide high-quality crops.

2.3. Research Paper Significance

The proposition of smart crop cultivation through IoT-based models holds great significance when it comes to research and the modernization of ancient agricultural procedures. This not only plays a role in the cultivation of quality crops but also provides data related to the optimized environment required for crop growth.

The conventional form of agriculture has dealt with challenges related to an increase in demand for food resources due to a rise in global population, climate change, and the rise in the cost of farming, etc. To deliver the best results related to crop cultivation, the IoT-based smart crop cultivation and monitoring system provides an innovative pathway, reshaping agriculture across the globe. An IoT-based system collects and processes the data with high precision, limiting the errors in different operations, which can also be tested in revolutionizing the plant growth by remote access to control soil moisture, temperature in the environment, air quality, light intensity, and other key parameters that are essential in crop cultivation [11]. Not only this, but smart sensors also detect the potential risk of pests and plant diseases, which decreases losses in crop cultivation. The desktop display is coupled with the integration of a dedicated mobile application, which not only receives the same data but also increases the capabilities of its users to monitor and manage remote crop cultivations. The smart system not only modernizes the conventional form of agriculture but also educates and trains farmers and related individuals in the industry [12].

3. System Design and Implementation

This section discusses the design and implementation of the proposed architecture. In the **Figure 2** below, the designing methodology for "IoT-Based Smart Crop Cultivation & Monitoring" is elaborated in detail.

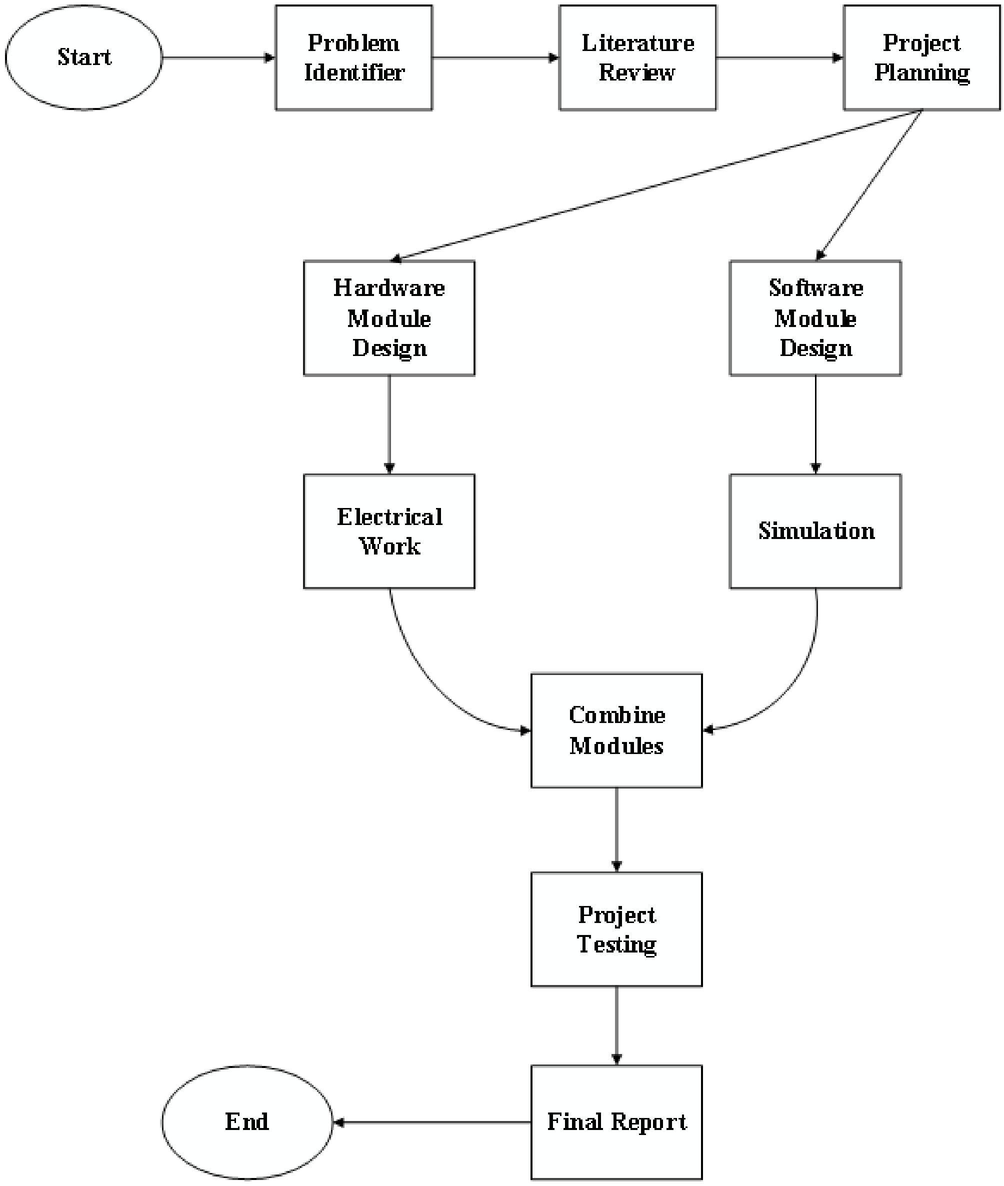

Figure 2. Designing Methodology For "IoT-Based Smart Crop Cultivation & Monitoring".

3.1. System Design

The system is designed inside an enclosed glass chamber on top of a wooden slab, which supports the soil medium. For testing purposes, the scale of the chamber is kept to a limited size, but it can be increased if implemented on an industrial scale. The enclosed chamber has an interlinked network of wires connecting different sensors, actuators, and other essential equipment. These sensors analyze the data related to soil moisture, air quality, PH level, water volume, humidity, and light intensity inside the enclosed chamber. A smart central data hub plays an integral part in data processing and analysis, for which the central processing or hub unit utilizes different pre-set algorithms [13]. The central hub is in seamless connection with the Blynk Platform and the mobile application, which provides remote control and access to its users (mainly the farmers). The decisions are data-driven, which means farmers need to check on the parameter levels and take actions to either increase or decrease each parameter's magnitude in the enclosed chamber. That is how crop cultivation is optimized, resource allocation is carried out efficiently, and it also reduces the cost of labor related to crop cultivation [14]. With the application of the IoT-based smart crop cultivation and monitoring system, global agriculture can be improved, leading to a smarter way for growing essential food items even in remote regions and limited resources [15], as shown in **Figure 3**.

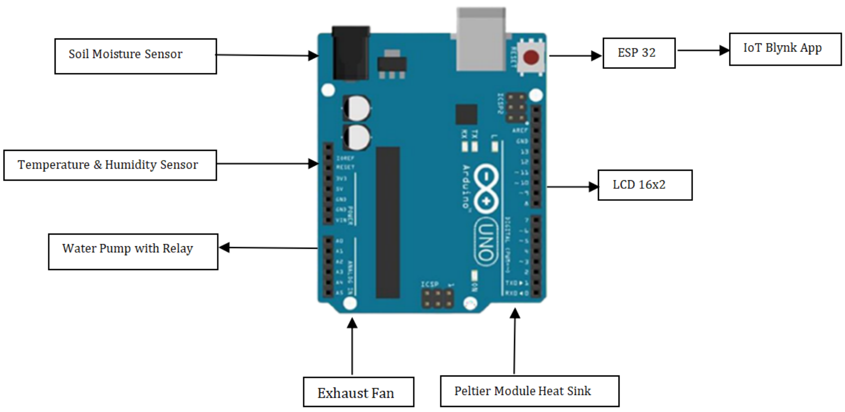

Figure 3. System Architecture of Arduino UNO (ATMEGA 328).

3.2. System Architecture

To elaborate the smart system's agriculture system, the **Figure 4** visualizes the diagram from the proteus software and shows how the system is tested in a simulated environment.

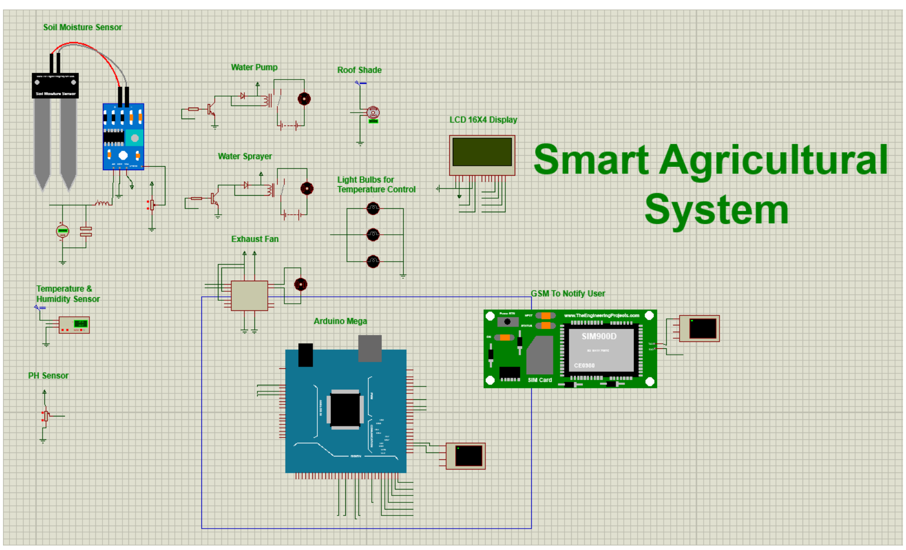

Figure 4. Diagram from the Proteus Software Showing How the System Was Tested in a Simulated Environment.

3.2.1. Controlled Environment Chamber

The smart system comprises an enclosed glass chamber that is supported by a wooden slab base. This glass-enclosed chamber is integrated with interlinked sensors and actuators.

3.2.2. IoT Sensors

Sensors play the primary source for sensing and data collection; these sensors vary in their functionality as they are dedicated sensors for analyzing each factor, such as soil moisture, temperature, air quality, water volume, PH level, and other essential factors. These sets of sensors seamlessly collect and analyze the data related to crop cultivation inside the glass-enclosed chamber.

3.2.3. Data Processing Hub

The central command unit, or in this case, the central data processing hub, is the endpoint for receiving all the data from the sensors, which it then directs onwards to the Blynk platform via a mobile application or can be done with a custom-developed desktop application, etc, for the user's view. The data processing or central data processing hub has a pre-set algorithm by which it processes the data.

3.2.4. User Interface

For real-time view and remote control of the crop cultivation inside the controlled environment, the Blynk platform is integrated, which provides data for visualization on a mobile application or can be directed to a custom-developed desktop application.

3.2.5. Control Actuators

The enclosed glass chamber also comprises full operational actuators such as fans, relay modules, and a Peltier module integrated with a heat sink. These modules are responsive to the remote-control commands that are received by the central data processing hub.

3.2.6. Power Supply and Circuitry

The smart system is made functional with a reliable power supply, coupled with a well-connected circuitry and a Vero Board. All of this is to ensure sensors, actuators, and the data processing hub are functional as per demands.

3.3. System Workflow

The Smart sensors and the central processing hub are seamlessly receiving and monitoring the data related to the enclosed glass chamber. At the same time, the data processing hub is responsible for the real-time data control, by utilizing different algorithms that provide insights into controlling the specialized environment, irrigation of the soil, and most importantly, to detect the presence of any unwanted factor. Farmers have all the control related to the enclosed chamber for managing the crop cultivation, as it receives real-time data on the Blynk platform or can be directed to a custom-based website. Users/farmers can view, control, and manage the different actuators through data-driven decisions. Depending upon the scenario, actuators can be controlled, managed, and turned off to acquire the desired level of temperature, water volume, soil pH, humidity in the air, or even ventilation. This smart IoT-based system not only provides data-driven precise decisions but also provides comfort for the farmers, empowering them with resource-efficient and reliable crop cultivation.

3.4. Requirements/Requirements Analysis

The requirements analysis for this paper encompasses the identification and prioritization of key functional and non-functional requirements. Functionally, the system must seamlessly integrate IoT sensors to monitor critical environmental parameters within the cultivation chamber. This includes soil moisture, temperature, humidity, light intensity, and air quality. Real-time data processing and analysis, coupled with precise control algorithms, are imperative for optimal crop growth.

There are two parts to it, which include the analysis of key functional and non-functional requirements. The integration and interlinking of the sensors with the IoT system inside the enclosed chambers comes under the functional part. It includes the seamless flow of data and processing of the key parameters such as temperature, soil moisture, humidity, and light intensity. While the non-functional part of the requirements includes the communication of data sets across the system, and the control of the actuator controls. This also includes the visualization of the processed data sets on the Blynk platform on the mobile application.

Reliability of historical analysis, data logs, and system performance is essential for remote sensing and control systems operations [16]. The requirements analysis provides the basis for designing the system, development, and validation of the smart system operations, providing insights into the system's capability to achieve the required objectives. This also ensures the farmers acquire the required results from the application of the smart IoT for the purpose of efficient and sustainable crop cultivation.

3.5. Methodological/Implementation Detail

Real-time implementation of the IoT-based smart crop cultivation and monitoring system starts from the setup of the controlled enclosed glass chamber. The enclosed glass chamber consists of a wooden base and is covered with an air-tight glass, which provides insulation from the outside environment. This enclosed chamber hosts the interlinked smart sensors, which are again connected with the rest of the smart system. These sensors are mainly responsible for regulating the inside environment according to the pre-set conditions for crop cultivation.

Data flows seamlessly across these IoT sensors to the central processing hub. The central processing hub is responsible for the uninterrupted control and reliable functionality of the smart crop cultivation chamber. It operates as per the pre-defined set of rules in the format of a control algorithm, which makes it reliable for taking data-driven decisions. All of this for regulating the key environmental factors such as temperature, soil moisture, light intensity, and humidity etc. All of this critical data is visualized on the Blynk platform integrated on the mobile application for the farmers or the users to see, and provides remote access.

Control actuators include the set of relay modules, a peltier module with a heat sink, and fans, as these sets of hardware are controlled by the data decisions carried out by the central processing hub in order to regulate the environment. It also includes the detection of any harmful gas in order to mitigate the presence of unwanted gas molecules inside the enclosed chamber. The scale of all this hardware depends on the magnitude or dimensions of the enclosed chamber for crop cultivation.

The smart IoT system is provided by a reliable power supply, which ensures the full operational capacity of the system. For this, an essential circuitry and functional Vero board for sensors and an actuator is added to the enclosed chamber's hardware. Operational capacity and integrity of the smart IoT system depend on how secure and reliable seamless communication across the interlinked smart hardware and processing system [17]. Implementation of this proposed system will result in a controlled environment for crop cultivation, which is regulated and remotely controlled by farmers through a mobile application. Reducing the total cost of labor while mitigating unnecessary food nutrients helps in efficient crop cultivation [18].

3.6. Hardware/Development Setup

The IoT-based smart crop cultivation and monitoring system consists of the following set of hardware, given below.

3.6.1. Physical Earth Condition

The initial functionality of smart systems starts from the detection and collection of the soil moisture data through the sensors, which directs this analogue data format to the ATMEGA 328 UNO, a microcontroller that is responsible for the conversion of this format of data to a digital one. For making this data remotely accessible for the users through the utilization of the NODE MCU ESP8266, which works via the internet connectivity for transmitting the data to the Thingspeak channel (an IoT data analytics platform, originally developed by Mathworks, for the live data collection, analysis, and visualization. Mainly, utilized for the IoT smart systems that have real-time analysis and data-driven operations.

3.6.2. Measure Amount of Light

For the analysis of the light intensity inside the enclosed glass chamber, the smart system utilizes the Light Dependent Resistor (LDR) sensors. These LDS analyze the ambient light conditions, transmitting the analogue data format towards the Arduino UNO (ATMEGA 328), a microcontroller which converts it into a digital format for the NODE MCU ESP8266. The digital data is communicated to the ThingSpeak Channel (an IoT data analytics platform, originally developed by Mathworks, for the live data collection, analysis, and visualization. Mainly, utilized for the IoT systems that have real-time analysis and data-driven operations, channel via the use of the Internet by the NODE MCU ESP8266. The seamless communication of the interlinked smart sensors with the microcontrollers provides the visualization of the real-time data related to light intensity to the farmers on a mobile application, as shown in **Figure 5**.

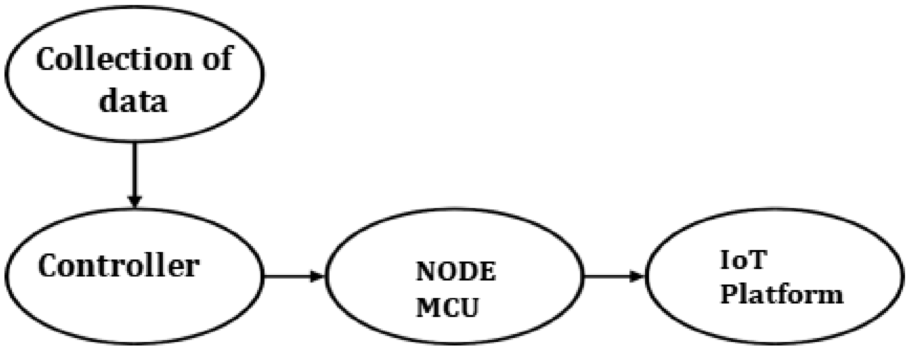

Figure 5. Data Flow Diagram from Collection to IoT Platform.

3.6.3. Hardware Component Detail

To analyze one of the key parameters in crop cultivation, DHT22, a smart sensor, is used for collecting data related to monitoring temperature and humidity. These smart sensors are operational around the clock to ensure the collection and seamless communication of the data for regulating the environmental conditions.

The Arduino UNO (ATMEGA 328) receives the analog data related to the temperature and humidity from the DHT22. Converting it into the digital format before transmitting it to the NODE MCU ESP8266, which then communicates this data to the "Things Speak Channel", for serving the visuals on the Blynk Platform integrated on the mobile application. This seamless communication of the data occurs for the visualization of the data on the mobile application for the remote control and access for the farmers, as shown in **Figure 6**. **Table 1** lists the hardware used in this investigation.

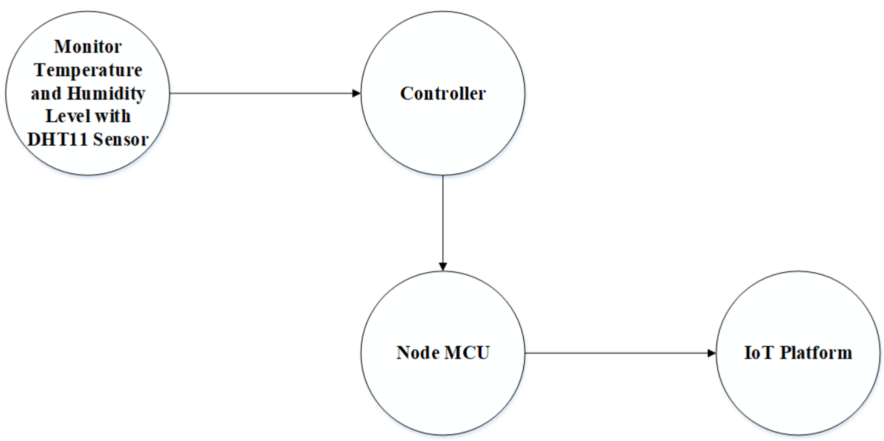

Figure 6. Data Flow Diagram Represents Process to Measure Temperature and Humidity Level with DHT-22.

Table 1. List of Hardware Components to be used.

Hardware Component Name	Number of Components for Testing Purposes
Wooden Try	1
Glass	1
Peltier Module	> 2
Water Pump	> 2
Heat Sink	> 1
NodeMCU ESP-WROOM-32 Code	1
Temperature And Humidity Sensor	> 2
Male And Female Jumper Wires	> 50
Soil Moisture Sensor	> 2
Power Supply	1
Lcd	1
Vero Board	2
Silicon	-
Relay	>4

3.6.4. Why Are We Using Temperature and Humidity Sensors?

Due to efficiency and precision in data collection, the DHT22 is integrated as a sensor for Temperature and Humidity. The smart sensor ensures the accurate regulation of both the temperature and humidity inside the enclosed chambers. Seamless communication capabilities, low error records, and near 100 % precision make the use of such sensors essential to collect the data. The real-time data of temperature and humidity is processed through several algorithms, enabling the actuators to regulate the conditions inside the chamber, yielding enhanced crop cultivation. Farmers are empowered by the IoT's remote monitoring and control capabilities, bringing innovation to the conventional form of agriculture [19].

3.6.5. Pin Configuration

For the temperature and humidity sensors, the DHT22 is set with a straightforward pin configuration, which ensures the key functionality of the smart sensors. A power supply of +3.3V to +5V is connected to the smart sensors via the VCC (Voltage Common Collector) pin configuration. The transmission of the collected data to the microcontrollers via the Data Out/ Signal Pin is utilized. The Ground (GND) pin ensures the zero grounding for the sensors' optimal operations, establishing an electrical reference (as shown in **Table 2** below).

Table 2. List of Hardware Components to be used.

Pins	Connection
VCC	+3.3 V–5.5 V (Input High)
GND	Ground (LOW)
Data Pin	Ground (LOW)

In some scenarios, there are unused pins that are labelled as Not Connected (NC) pins. Before the configuration of the smart system, there is a need for every engineer or technician to review the data sheets provided by each manufacturer.

3.6.6. Soil Moisture Sensor

Soil moisture sensors are designed to detect the level of moisture by utilizing two electrodes or probes. For making the soil moisture sensor operational, these two probes are placed inside the soil medium in the enclosed chamber. The soil moisture is evaluated by the relative analysis of the resistance between these two electrodes or probes. In scenario 1, if the value of resistance between the two electrodes is visualized as high, the solid moisture is visualized as low, while in scenario 2, if the value of the resistance is visualized as low, then the moisture is termed high. The data collected related to the soil moisture is in analog format, which is then processed and converted to digital format by the microcontrollers. This data is utilized for the regulation of water volume for the irrigation of crops inside the enclosed chamber, as shown in **Table 3**.

Table 3. List of Hardware Components to be Used.

Pins	Connection
VCC	Power Supply (+3.3V or +5V)
GND	Ground (0V)
Signal (Analog/Digital)	Data Output (Moisture Level)

3.6.7. Liquid Crystal Display (LCD) 16x2

For visualization of the data processed, a 16x2 LCD is featured with two rows of 16 characters for the digital data. Farmers are provided with an alternative for monitoring the data processed related to crop cultivation, avoiding the need for rapid checks on the mobile application.

3.6.8. Relay

Relays are utilized for the control and regulation of various IoT devices such as irrigation, lighting, and ventilation systems. Relays are basically electrically powered switches that are integrated in smart circuits, which have high voltage or current, using signals accompanied by signals with lower currents or voltages.

1. **Isolation:** To provide electrical isolation between the load and control circuit of the smart system, which helps in the protection of the microcontrollers and other low-voltage components from any high-voltage or current in the circuitry system.
2. **Control High Voltage/Current:** Relays have the capabilities of regulating high current and voltage loads with low voltage control signals. To make it compatible for the microcontrollers to process as well as for other low-voltage electronic devices.
3. **Remote Control & Automation:** For remote access and regulation of light intensity or other irrigation systems inside the enclosed chamber, the relays can provide data to the microcontrollers for adjusting their functionality depending upon the signal received from the data cloud.
4. **Safety:** Relays are used to safeguard the smart IoT system from any hazard, mainly when temperature relays are used. Along with the control of different devices integrated in the smart system to seamlessly automate all sensors, and ensure a secure data flow across the circuitry.

3.6.9. Water Pump

For automated irrigation of the crops, the water pumps are utilized in the IoT-based smart agriculture system. The following are some features of the use of the water pump:

- **Irrigation Automation & Remote Control:** Through the integration of the water pump, accompanied by smart sensors that are capable of detecting soil moisture, temperature levels, and humidity. The automation of the irrigation system in the modern agricultural system can be achieved. This will result in improving the efficiency of water consumption, adding timely nutrients to crops, and most importantly, adding remote regulation for the farmers.
- **Cost-effective & Efficiency:** The integration of automated and remotely controlled water pumps will cut the labor cost, adding more efficient and practical solutions for the farmer [20]. It also increases the precision and quality of the automated irrigation system.
- **Scalable System:** It can be adjusted to the different types and requirements of the irrigation systems, which are drip irrigation, sprinkler systems, and flood irrigation.

3.6.10. Watering in a Dry Area

For remote regions where water resources are limited, along with little to no rain, in such regions, crops are irrigated by the use of water pumps. In our research paper, the entire smart system can be applied on a larger scale in such regions, which include the Middle East and the Gulf, for crop cultivation. In case the water moisture percentage drops to less than 50 percent, the automated water pumps can provide the required water volume for making it to the optimum 70 percent moisture.

3.6.11. Heat Sink & Fan

To make sure the smart system and its operational hardware are functional, a heat sink and fan are added to the system. These two devices basically remove unwanted heat from the system; this unwanted energy can be created due to the Peltier module or any actuator. The heat sink and the fan act as a primary resource for regulation of the inside temperature, preventing the overheating of the smart system, enhancing the reliability, and increasing the optimal performance of the smart system [21].

3.6.12. Peltier Module

The Peltier module provides precision temperature control inside the enclosed glass chamber. Basically, it is a thermoelectric cooler (TEC) that operates for the precise regulation and ideal temperature stability of the enclosed environment. The Peltier module has a dual functionality, which means it can operate for both cooling and heating applications, making it adaptable to a variety of environmental conditions and crop cultivation requirements. The thermoelectric cooler (TEC) acts for the timely adjustment of the temperature inside the enclosed chamber to remove any extra heat or add some for the optimal growth of the plants, which also affects the humidity inside the soil.

The peltier module is an energy-efficient hardware that only consumes electricity when it is functional; otherwise, the consumption of electricity is zero.

3.6.13. USB Cable

The smart system is interlinked by using different types of USBs, such as USB-A, USB-B, USB-C, and micro-USB, for achieving various functionalities. These cable types are integrated for transmission, charging purposes, and connecting peripherals such as keyboards, external hard drives, or mice to microcontrollers. USB cables are integrated for the interlinking and powering up of the electronic devices.

3.6.14. NodeMCU ESP-WROOM-32

Smart crop cultivation demands a reliable and robust microcontroller, which the NodeMCU ESP-WROOM-32 can fulfil. The microcontroller is one known for its reliability in data transmission via Wi-Fi and Bluetooth, as it is developed with the ESP32 chipset (a member of the ESP8266/ESP32 family). The microcontroller is featured with a dual-core Tensilica LX6 microprocessor, making it compatible with the connectivity to a list of peripheral devices, and enough GPIO (General Purpose Input/Output) pins. The NodeMCU ESP-WROOM-32 is compatible with the Arduino IDE, and the Espressif (Espressif IoT Development Framework (ESP-IDF) serves as a basic toolkit for the creation of smart hardware by using Espressif's ESP32 chips. The core functionality of the ESP-IDF is to connect smart sensors, enable data cloud communications, and secure the data transmission in the system. IoT Development Framework (ESP-IDF), accommodating the expertise of engineers.

3.6.15. Wood and Glass Chamber

The foundation for the IoT smart system is provided by the wood and glass chamber, which offers an enclosed and controlled environment for plant growth. The temperature and humidity sensors, such as DHT22, are integrated in the circuitry for the regulation of temperature. The test crop is provided with natural supplementary lighting by the grow lights, while the light intensity is carefully measured. The enclosed chamber is supported by a well-designed wooden frame and glass walls, which provide isolation for the plants.

3.6.16. Vero Board

To design and assemble the different sensors, resistors, power supply, and earthing, etc. The vero board or stripboard is used.

3.7. Software Detail

3.7.1. Arduino IDE

The source code for the smart IoT system is developed in the Arduino IDE (Integrated Development Environment), which is an easy-to-scale and code platform for the Arduino boards. The software developed has the capabilities of receiving, processing, and even enabling engineers to make changes in the code, as there is an availability of an editor with syntax highlighting. The Arduino IDE platform receives all the data from smart sensors by utilizing a secure and reliable USB cable. For the purpose of debugging and testing the code, the serial monitor is available in the Arduino IDE. For control systems and most of the test environments, the Arduino IDE is one of the ideal platforms for coding and programming effectively [22].

For any developer or engineer, it is very easy to add different libraries to the Arduino IDE. The following are a few steps to add libraries to the platform:

- Open Arduino IDE
- In the Left Top Corner, click on Sketch » Include Library.

3.7.2. Afterwards, Engineers Can See Two Different Menus on the Display

Developers are required to download the direct libraries from the Arduino IDE platform by exploring the Manage Libraries menu. These are the pre-provided libraries that are provided by the Arduino and GitHub. The following menu on display is visible after clicking on the Library Manager. Developers can add more libraries depending on the requirements or need for functionalities.

The secondary method to add a library is by selecting "Second Add Library"; the library required to be added needs to be in a Zip File.

a. LiquidCrystal_I2C.h
b. DHT11 Sensor

3.8. Simulation Details

Proteus software is a popular simulation software that can be used to simulate and test the IoT-based smart agriculture monitoring system before deploying it in the field. This software allows you to simulate the behavior of the system, test the code, and verify the overall functionality of the system. It can simulate the behavior of the Arduino board, sensors, and actuators, and test the code that controls the actuators.

For the simulation and testing of the full functionality of the smart IoT system, the Proteus software is utilized. Proteus is a great fit for testing the functionality and results of the IoT-based smart agriculture monitoring system, as developers can check the analysis, code testing, and debug any errors if there are any in the system's functionality [23]. It can be used instead of the Arduino board. Proteus software has the capabilities of controlling and commanding the smart sensors as well as the actuators, and all this with precision in the results. The technology can also be used under different scenarios, and for different values of the light intensity and soil moisture levels, all of this for efficiency and utilizing fewer overhead resources [24].

4. Testing and Validation

4.1. Prototype

The proposed IoT-based smart agriculture system is as good as the precision in data flow across the system, and the collection of the different sets of data from various smart sensors integrated in the enclosed glass chamber. By using different communication pathways, mainly the Wi-fi or LoRa network protocols, the data is communicated across the system.

The collected data is transmitted to the Node-MCU ESP8266 for seamless communication between the interlinked electronic devices. After processing the data collected and transmitted, it is then communicated to the cloud-based platform, which in this case is Thingsspeak (an IoT data analytics platform, originally developed by Mathworks, for the live data collection, analysis, and visualization. Mainly, utilized for the IoT smart system that has real-time analysis and data-driven operations, or AWS IoT, for storing and analysing the critical data sets.

With the availability of the Blynk Platform integrated with the mobile application and an interactive LCD screen, users can also get a custom web-based software. The smart system is designed to provide automation of the enclosed chamber through algorithms that are preset for quality crop cultivation. Also, one of the fundamental features is empowering the farmers with remote access control and analysis based upon the data received from smart sensors related to the various key parameters such as soil moisture, humidity, air quality, light intensity, and temperature. The smart system is capable of providing precise results as it makes decisions based upon the data retrieved and processes each data set through a set of pre-defined algorithms.

4.2. Calibration

Each of the smart sensors is made capable of receiving the required data sets from the enclosed chamber, as the functionality of the electronic devices and the platforms used can only be ensured by calibrating every electronic device integrated in the system. Calibration of the microcontrollers with the smart sensors, along with the setup of the communication to the data cloud, is an essential part of making the system functional [25]. This also ensures that the communication of the data is carried out in a precise manner with seamless functionality of the smart system. To test the operational capacity of each smart sensor, we test its functionality of detecting and retrieving data, i.e., testing the soil moisture smart sensors by adding different sets of soil with various moisture levels, as we check the functionality of sensors by testing them against different results. The testing we carry out mirrors the actual environmental scenarios, which provide references for comparing the results retrieved from the smart sensors. While calibrating the smart sensors, we ensure to check the data sheets provided by the manufacturer in order to avoid any human-made errors, and make sure the pre-set algorithms are provided with the required reference data for comparison and analysis [26].

To check the precision of the data received and the results generated, a mapping or calibration curve is created for checking the operational capacity associated with each of the smart sensors. The sensors are tested across a wide spectrum of values related to the key parameters inside the enclosed glass chamber [27]. After implementation of the smart IoT system, there can be some wear and tear related to the optimum functionality of the sensors, which would require timely calibration of the smart sensors. Initially, the data collected and the calibration curve created are all documented for future use analysis.

4.3. Measure Temperature and Humidity Level through Sensor DHT22

To measure temperature and humidity levels through the DHT22 sensor, the sensor is connected to an Arduino or microcontroller. The DHT22 sensor provides a simple way to capture environmental data. In the code, you initialize the sensor, read temperature and humidity values, and display them. This data can be utilized for various applications, including climate monitoring, home automation, and greenhouse control, offering insights into the surrounding environment's conditions. The DHT22 is a capable smart sensor for collecting data related to the temperature and humidity of the enclosed chamber, while it processes the collected data sets via Arduino UNO (ATMEGA 328). The code contains different lines and rules that process different data sets related to climate monitoring, automation, and greenhouse control.

Serial Communication NODE MCU ESP32

In the proposed IoT-based smart crop cultivation and monitoring, serial communication plays a pivotal part in data exchange and precise control. By the interlinking of the transmit (TX) and receive (RX) pins between other smart devices and the NodeMCU ESP8266. Having a consistent baud rate is essential for paramount, providing an overview of the data transmission. Data transmission has a very critical part in the collection of critical environment data sets, i.e., temperature and humidity.

The following data sets are then communicated to the designated IoT platform (ThingSpeak Channel) from the NodeMCU ESP8266. The data is communicated securely and reliably, which ensures the decisions carried out by the smart system are all based upon real-time results and processed through the different algorithms [28]. To avoid any machine-made errors, glitches, and critical inconsistencies in communication, the smart system is integrated with the Serial Monitor tool for an error-checking mechanism, effectively detecting and addressing transmission errors. The addition of such error-checking systems will ensure the diagnosis of potential communication issues and verification of data packets [29]. The serial communication system will provide remote configuration, which is the foundation for the IoT-based smart crop cultivation and monitoring system.

4.4. Results

The data related to the key parameters, such as light intensity, temperature, soil moisture, and humidity, which are in the enclosed chamber, is collected and processed by the IoT-based smart crop cultivation and monitoring system. Upon reaching critical threshold values, the different smart sensors and other devices alert the farmers with notifications and automate the optimization of these key parameters inside the enclosed glass chamber. The optimization of the environment in the enclosed chamber is carried out by the function of actuators and fans. For the visualization of data, it is communicated to the Blynk Platform, which is integrated into the mobile application. All of this is for the remote access and control of the system through a mobile application, as shown in **Figure 7**.

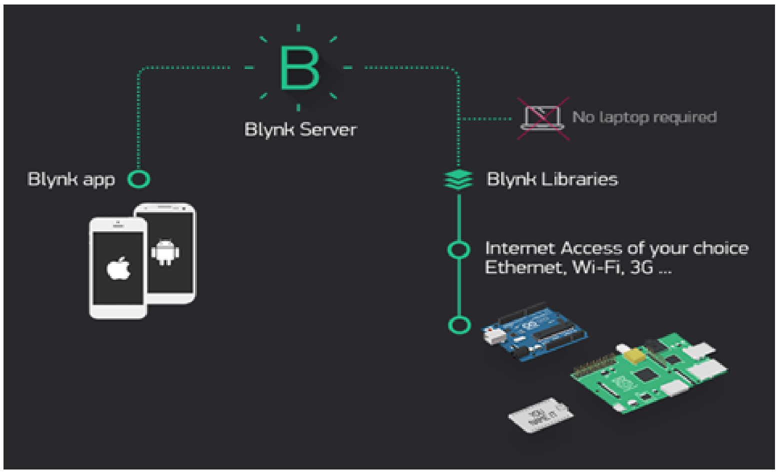

Figure 7. Data Flow Shows How the Blynk App Communicates with the Smart System for Seamless Data Flow.

5. Conclusions

- Optimization of plant growth by 20% with the integration of a smart system, which is both efficient and easy to control.
- Transforming the conventional form of agriculture by integrating advanced IoT systems in crop cultivation and educating farmers with new technology.
- Mitigating about 10–15% of the total carbon footprint, enhancing the growth of quality plants, and most importantly, avoiding the usage of toxic pesticides.
- Scalable and easy-to-integrate smart systems, which can enable remote regions to grow different crops through controlled smart systems [30].

For enhancing the capacity of the "IoT-based smart crop cultivation and monitoring system", it is high on precision AI (Artificial Intelligence) and ML (Machine Learning). This will not only increase the precision in data estimation and data-driven decisions, but also increase the scale of the smart system deployment on both commercial and industrial levels.

Author Contributions

Conceptualization, A.A.K.; methodology, A.A.K.; software, A.A.K.; validation, M.B. and S.I.M.; formal analysis, E.U.K. and S.I.M.; investigation, E.U.K.; resources, E.U.K.; data curation, E.U.K.; writing—original draft preparation, E.U.K.; writing—review and editing, E.U.K.; visualization, M.B. and S.I.M.; supervision, M.B. and S.I.M.; project administration, M.B. All authors have read and agreed to the published version of the manuscript.

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