SMART PLANT MONITORING SYSTEM FOR CUCUMBER

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Abstract—The integration of Internet of Things (IoT) technologies into precision agriculture presents transformative opportunities for enhancing crop management and sustainability. This study proposes an IoT-based smart monitoring system tailored for cucumber cultivation, focusing on real-time environmental sensing, automated irrigation, and remote accessibility. Utilizing a microcontroller-based platform integrated with soil moisture, temperature, humidity, and light sensors, the system enables continuous monitoring of key growth parameters. Data is transmitted via Wi-Fi to a cloud interface, where it is visualized and used to control irrigation automatically. The system's modular and scalable design supports adaptability across various crop types and farming scales. Unlike conventional manual methods, this approach reduces resource consumption, labor dependency, and the risk of under- or over-irrigation. Comparative analysis with existing smart agriculture systems demonstrates improved efficiency in water usage and enhanced plant health metrics. This work contributes to the growing body of research on sustainable agriculture by offering a low-cost, accessible solution that combines automation with real-time analytics. The proposed system sets a foundation for future advancements in smart farming technologies, encouraging further exploration into crop-specific IoT applications.

I. Introduction

As the demand for sustainable and efficient farming practices continues to grow, the use of technology in agriculture—particularly Internet of Things (IoT) solutions—has become increasingly important. IoT allows farmers to monitor crops in real time, automate routine tasks like irrigation, and make better decisions based on data. While many smart farming systems have been developed, most are either too general, too complex, or too expensive for small-scale farmers to adopt effectively.

Cucumber is a commonly grown crop that is sensitive to changes in soil moisture, temperature, humidity, and light. Maintaining the right balance of these factors is essential for healthy growth and good yield. However, in many cases, farmers still rely on manual monitoring and guesswork, which can lead to water waste, inconsistent growth, and lower productivity.

This research introduces a cost-effective, crop-specific IoT-based monitoring system designed especially for cucumber cultivation. The system uses sensors to collect real-time data and automatically manages irrigation while allowing remote access through a simple interface. By focusing on the unique needs of cucumber plants and making the solution affordable and scalable, this project addresses a clear gap in current smart farming tools—offering a practical step forward for precision agriculture.

II. LITERATURE REVIEW

A. *Smart Plant Monitoring System using Aquaponics (2022)*

This project proposed a smart plant monitoring system based on aquaponics that utilizes an Atmega328p microcontroller, GSM communication, and environmental sensors. The system provides wireless automation, weatherproofing, and a notification mechanism for large-scale agricultural fields. While technically robust, the implementation is marked by high cost due to the number of actuators and communication modules required. Additionally, the complexity of setup and signal synchronization between multiple components presents operational challenges, making it less suitable for users with limited technical expertise.

B. *Greenhouse Smart Control and Monitoring System (2019)*

Using Arduino UNO and relays, this system supports water quality monitoring and provides real-time feedback via LCD. It is relatively easy to set up and moderately priced. Nonetheless, the use of separate microcontrollers increases cost and system complexity, while delayed data transmission limits real-time responsiveness. developed a prototype for a greenhouse monitoring and control system using Arduino UNO, relays, water pumps, and environmental sensors. This system is relatively easy to deploy and capable of monitoring water quality while displaying real-time data on an LCD screen. However, the use of separate microcontrollers increases the overall cost and design complexity. Furthermore, the system suffers from data transmission delays, limiting its responsiveness in time-critical scenarios such as irrigation control.

C. *Automatic Plant Watering System for Small Gardens (2021)*

The system uses Arduino UNO, a Wi-Fi module, and basic environmental sensors such as soil moisture detectors and sprinklers. It allows users to personalize watering schedules through a mobile application. Although the system is simple and budget-friendly, it lacks critical features such as pest detection, security mechanisms (e.g., motion detection), and adaptive automation. Its functionality is largely confined to sprinkler control, making it unsuitable for more complex agricultural or multi-sensor environments.

III. METHODOLOGY

This section outlines the structured approach taken to design, develop, and implement the Smart Plant Monitoring System for Cucumber. The methodology encompasses both hardware and software integration, sensor calibration, data transmission, and display logic. It was developed in iterative phases to ensure accuracy, reliability, and user-friendliness.

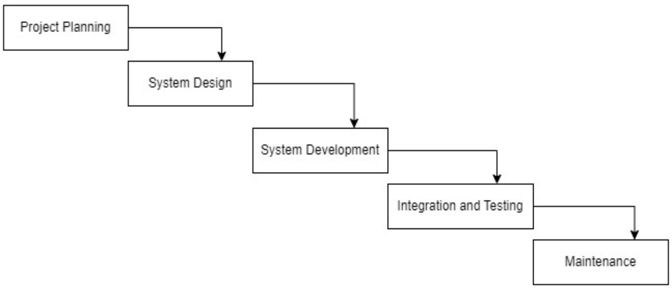


Figure 1: Graphical Illustration of Prototype Model

A. *Project Planning Phase*

The planning phase involves identifying project objectives, defining system requirements, and selecting appropriate tools and components. In the planning phase, the project objectives were identified, system requirements were defined, and appropriate tools and components were selected. The scope and timeline of the project were established, existing solutions were researched to identify gaps and IoT components such as environmental sensors, the ESP32 microcontroller, and communication protocols that were chosen.

B. *System Design Phase*

The design phase centered on developing a detailed plan for the system's architecture, outlining the interaction between hardware components and software functions. A block diagram was created to visualize the data flow from sensors to the cloud-based dashboard, a flowchart was constructed to represent the system's operational logic, and a schematic diagram was produced to assist with hardware assembly and integration.

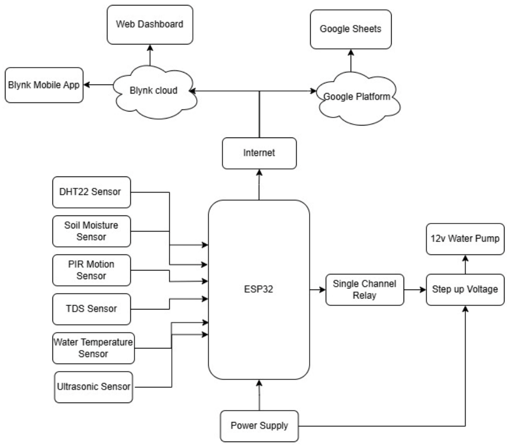


Figure 2: Block Diagram Smart Plant Monitoring System for Cucumber

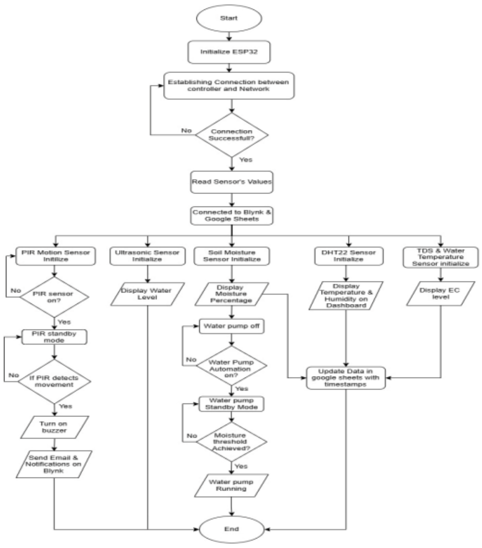


Figure 3: Flowchart Smart Plant Monitoring System for Cucumber

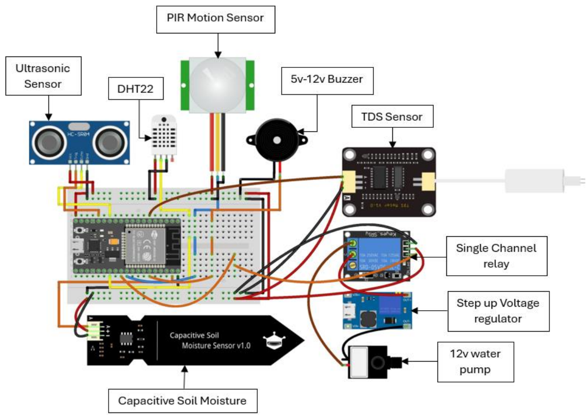


Figure 4: Circuit Diagram Smart Plant Monitoring System for Cucumber

C. System Development Phase

The development phase involved both hardware assembly and software programming. Hardware components such as current and voltage sensors, relays, and the ESP32 microcontroller were assembled and wired correctly. For software development, the ESP32 was programmed using the Arduino IDE, a cloud-based dashboard was set up using Blynk for data visualization, and the Blynk API protocol was implemented to enable real-time communication.

Figure 5: Hardware assembly Testing

D. Integration and Testing Phase

Integration and testing phase is an important phase to develop any IoT-based system, where individual components are combined and tested as an integrated system to ensure uniform communication, data flow, and overall functionality. Relative on this system, integration testing focuses on verifying the correct interaction between sensors, actuators, the ESP32 microcontroller, and cloud platforms such as Blynk and Google Cloud. Each of the sensors are tested with the microcontroller to achieve the expected result.

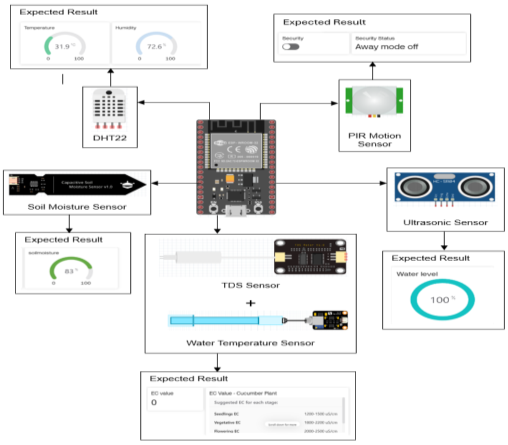


Figure 6: ESP32 Integration with expected results

By managing integration testing, I can validate that the system behaves as expected when all modules are working together, and any inconsistencies or failures can be identified and corrected before deployment. This ensures robustness, efficiency, and user-friendliness of the complete system. Following the successful simulation, the project proceeded to the physical testing phase using real components. The sensors were physically wired to the ESP32 microcontroller and connected to a power supply for practical validation.

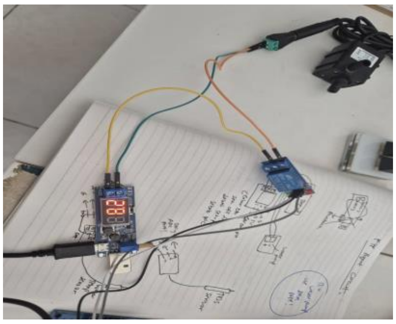


Figure 7: Physical testing phase using real components

E. Deployment Phase

The deployment phase involved transitioning the system from a simulated environment to a real-world setting to ensure its operational readiness. The hardware components, including sensors, relays and the ESP32 microcontroller, were installed at the designated location, ensuring secure and proper connections. The cloud-based dashboard was configured to provide end-users with seamless access to monitor energy consumption and receive real-time alerts. This phase also included fine-tuning the system to adapt to the physical environment, ensuring that the hardware and software worked cohesively. Initial tests were conducted post-installation to validate system functionality and performance under real-world conditions. These steps ensured a smooth transition from development to implementation.

F. Maintenance Phase

The maintenance phase focused on evaluating the system's performance and identifying areas for improvement over a defined monitoring period. Data collected from the system was analyzed to validate its accuracy, efficiency, and reliability under actual usage conditions. User feedback was actively gathered to understand end-user experiences, address any usability concerns, and refine the system for better performance. Additionally, the data trends were studied to detect any inconsistencies, verify energy consumption patterns, and ensure the system met the established project objectives. This phase also included a thorough assessment of the hardware and software components to identify potential upgrades or optimizations that could enhance system functionality and durability.

IV. PROJECT DEVELOPMENT

The development of the Smart Plant Monitoring System for Cucumber involved a structured and iterative process combining both software and hardware components to achieve accurate energy monitoring, real-time data transmission, and clear local display. The project was developed in phases—beginning with research and planning, followed by simulation, prototyping, hardware assembly, software integration, testing, and refinement. Each stage was guided by practical considerations such as cost-efficiency, component availability, and system reliability. Emphasis was placed on ensuring the system could measure Environment Sensors' value accurately while providing a user-friendly interface through Blynk. This chapter outlines the tools used, the configuration and connection of components, the code development process, and the final prototype integration.

A. *Software Setup*

The software setup plays a crucial role in enabling communication between the hardware components, processing data, and visualizing the output in the Smart Plant Monitoring System for Cucumber. The key tools used include the Arduino IDE for programming, Blynk for cloud monitoring, and google sheets for data logging history data.

1) Arduino IDE: The program development of project's system is developed using the Arduino IDE. The libraries and packages need to be installed. Once all the necessary libraries and packages are installed, the functions they provide can be called in the program. This allows the program to access the added functionality.

2) Blynk Platform: Blynk was used to create a real-time dashboard accessible via PC and mobile. A template was configured to display values for Environment Temperature, Ambient Humidity, water level and soil moisture level. Furthermore, the system allows users to turn on or off the security switch while displaying the status of the switch. If the switch is turned on and detects any motion within its range, it will turn on the buzzer and send an alert email to the user. An auto mode button was added to give flexibility to only turn it on depending on the situation. The water pump auto mode is synchronized with the water threshold value that allows users to maintain the soil moisture value. EC value measurement is added to keep user updated of the fertilizer mixture in the water tank.

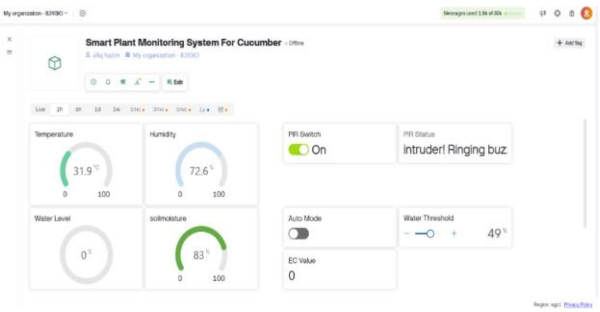
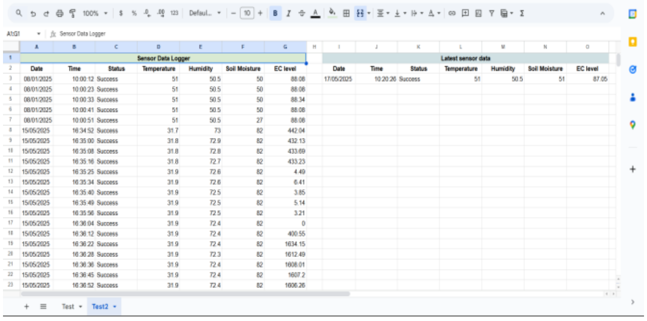


Figure 8: Blynk Dashboard

3) Google Sheets Platform: Google Sheets is utilized in this project as a cloud-based platform for real-time data logging, enabling remote access, automatic data backup, and easy visualization of sensor readings, while also offering a cost-effective and user-friendly solution for storing and analyzing environmental parameters essential to cucumber plant monitoring.



Sensor Data Logger						
Date	Time	Status	Temperature	Humidity	Soil Moisture	EC level
08/01/2025	10:00:12	Success	51	50.5	50	88.08
08/01/2025	10:00:23	Success	51	50.5	50	88.08
08/01/2025	10:00:33	Success	51	50.5	50	88.34
08/01/2025	10:00:41	Success	51	50.5	50	88.08
08/01/2025	10:00:51	Success	51	50.5	27	88.08
15/05/2025	16:34:52	Success	31.7	73	82	442.04
15/05/2025	16:35:00	Success	31.8	72.9	82	432.13
15/05/2025	16:35:08	Success	31.8	72.8	82	433.69
15/05/2025	16:35:16	Success	31.8	72.7	82	433.23
15/05/2025	16:35:25	Success	31.9	72.6	82	4.49
15/05/2025	16:35:34	Success	31.9	72.6	82	6.41
15/05/2025	16:35:40	Success	31.9	72.5	82	3.85
15/05/2025	16:35:49	Success	31.9	72.5	82	5.14
15/05/2025	16:35:56	Success	31.9	72.5	82	3.21
15/05/2025	16:36:04	Success	31.9	72.4	82	0
15/05/2025	16:36:12	Success	31.9	72.4	82	400.55
15/05/2025	16:36:22	Success	31.9	72.4	82	1634.15
15/05/2025	16:36:28	Success	31.9	72.3	82	1612.49
15/05/2025	16:36:36	Success	31.9	72.4	82	1608.01
15/05/2025	16:36:45	Success	31.9	72.4	82	1607.2
15/05/2025	16:36:52	Success	31.9	72.4	82	1606.26

Latest sensor data						
Date	Time	Status	Temperature	Humidity	Soil Moisture	EC level
17/05/2025	10:20:26	Success	51	50.5	51	87.05

Figure 9: Google Sheets Data Logging

B. *Hardware Setup*

The hardware components used in this project were selected based on their compatibility, precision and suitability for Plant Monitoring Applications. Below is a detailed explanation of the specifications and roles of each key component in the system.

1) ESP32 Microcontroller: The ESP32 is a powerful 32-bit dual-core microcontroller equipped with built-in Wi-Fi and Bluetooth functionalities. It serves as the central processing unit of the project, handling the acquisition of sensor data, computation of power and energy usage and communication with the Blynk IoT platform. Its high-speed ADC, multiple GPIO pins, and energy efficiency make it ideal for real-time monitoring applications. The ESP32 receives analog signals from both the current and voltage sensors, processes the data internally and transmits the results to both the local LCD and cloud dashboard.

2) ESP32 shield and Jumper Wires: A standard ESP32 Shield to mount the ESP32 microcontroller is used for prototyping the circuit. All components, including the ESP32, sensors and relay, are mounted onto the ESP32 shield and connected using jumper wires. This setup provides flexibility for modifications and testing during the development phase. It is especially helpful during the initial design and debugging process, where frequent adjustments may be necessary.

3) DHT22: The DHT22 sensor was selected for this project due to its ability to accurately measure two crucial environmental parameters: temperature and humidity, both of which significantly influence cucumber plant growth and health. Compared to its predecessor, the DHT11, the DHT22 offers a wider sensing range and greater precision. The sensor communicates digitally, reducing the chances of signal degradation over longer distances and simplifying the interface with microcontrollers like the ESP32. Its low power consumption also supports energy-efficient system operation, which is important in field deployments or battery-powered applications. Additionally, the DHT22 is cost-effective, readily available, and easy to integrate into both prototype and production-level systems. These advantages collectively make it a reliable and practical choice for continuous, real-time environmental monitoring in smart agriculture systems focused on crops like cucumber.

4) Soil Moisture Sensor: This sensor is used to monitor the water content in the soil, which is a critical factor in cucumber cultivation. Cucumber plants require consistent and optimal soil moisture levels to avoid issues such as under-irrigation or over-irrigation. This sensor provides real-time data that enables the system to automate irrigation efficiently, ensuring that water is supplied only when needed. Its integration supports water conservation and enhances overall crop health.

5) PIR motion Sensor: The PIR (Passive Infrared) motion sensor is incorporated into the system for basic crop protection and monitoring. It detects movement near the plant area, which can be useful for identifying the presence of animals or unauthorized human activity. While not directly related to plant growth, it adds a layer of security to the smart agriculture setup. This can help prevent crop damage or theft, especially in open-field or minimally supervised environments.

6) TDS sensor + Water Temperature sensor: In this project, the TDS sensor, in conjunction with a water temperature sensor, is used to measure the Electrical Conductivity (EC) of the irrigation water. EC is a critical parameter in agriculture, as it reflects the concentration of dissolved salts and nutrients in the water, which directly influences plant nutrient availability and uptake efficiency. Cucumber plants are sensitive to nutrient imbalances; both deficiency and excess can impact growth, yield, and fruit quality. The TDS sensor estimates EC by detecting the conductivity of the solution, while the water temperature sensor compensates for temperature variations that can affect conductivity readings. Accurate EC measurement ensures that the nutrient solution or irrigation water maintains optimal salinity levels, supporting healthy root function and reducing the risk of osmotic stress.

7) Ultrasonic sensor: The ultrasonic sensor is employed in this project to accurately measure the water level in the irrigation reservoir. Maintaining an adequate water supply is essential for the continuous operation of the automated irrigation system. The ultrasonic sensor functions by emitting ultrasonic waves and measuring the time it takes for the echo to return after reflecting off the water surface. This time is then converted into a distance measurement, which allows the system to calculate the current water level.

8) Water pump + Relay: A relay module is integrated into the system to control the operation of the water pump responsible for irrigation. Since microcontrollers like the ESP32 operate at low voltage and current levels, they cannot directly power high-voltage devices such as water pumps. The relay acts as an electrically operated switch, allowing the microcontroller to safely turn the pump on or off by controlling a separate high-power circuit. Using a relay ensures safe isolation between the low-voltage control circuitry and the high-voltage pump, protecting the system and users from electrical hazards. It also enables automated irrigation based on sensor readings, improving water efficiency and crop health by delivering water precisely when needed without manual intervention.

V. RESULTS AND DISCUSSION

A. Prototype

The prototype of the smart cucumber plant monitoring system was developed using modular components connected to an ESP32 shield to facilitate flexible testing and iteration. The core hardware includes the ESP32 microcontroller, soil moisture sensor, DHT22 temperature and humidity sensor, TDS sensor paired with a water temperature sensor for EC measurement, an ultrasonic sensor for water level monitoring, and a relay module to control the water pump. ESP32 collects data from these sensors and transmits real-time information to the Blynk dashboard for remote monitoring while logging data to google sheets.

The relay enables automated irrigation based on soil moisture and water availability data. This modular setup allows for efficient integration, testing, and refinement of the system components to ensure reliable environmental monitoring and irrigation control tailored for cucumber cultivation.

Figure 10: Hardware Prototype

B. Final Prototype

After testing the functionality of the model, the components were securely mounted on a project board or enclosed for stability and reduced interference.

The microcontroller was loaded with the final firmware for smooth operation, and all sensor inputs were neatly arranged. This compact cucumber plant monitoring system provides real-time data, updates both locally and remotely, and runs autonomously.

Figure 11: Final Prototype

The TDS (Total Dissolved Solids) sensor and the DS18B20 water temperature sensor are used together to monitor the quality of the irrigation or nutrient solution. The TDS sensor measures the electrical conductivity (EC) of the water, which indicates the concentration of dissolved substances such as salts, minerals, and nutrients. Monitoring TDS levels helps ensure that the plants are receiving an appropriate amount of nutrients. The analog signal from the TDS sensor is sampled ten times and averaged. The resulting raw value is then converted to voltage using the formula:

$$Voltage = \frac{Analog\ Value\ \times VREF}{4095.0}$$

However, the accuracy of the TDS sensor is affected by water temperature, as electrical conductivity varies with temperature. To account for this, the DS18B20 digital temperature sensor is used to measure the current water temperature. This temperature value is then used to apply compensation to the EC reading, ensuring that the calculated TDS value reflects what it would be at the standard reference temperature of 25°C using this formula:

$$\begin{aligned} &CompensationCoefficient \\ &\quad = 1 + 0.02 \times (Temperature - 25.0) \end{aligned}$$

The measured voltage is then adjusted:

$$CompensatedVoltage = \frac{Voltage}{CompensationCoeficcient}$$

The compensated voltage is used to compute EC using a third-degree polynomial curve fitting derived from empirical calibration data:

$$\begin{aligned} EC = {} & 133.42 \times (CompensatedVoltage)^3 \\ & - 255.86 \times (CompensatedVoltage)^2 \\ & + 857.39 \times CompensatedVoltage \end{aligned}$$

Together, the TDS sensor and water temperature sensor provide reliable and accurate information about the nutrient content of the water, enabling better decision-making for irrigation and nutrient management in the plant monitoring system.

The water level in the tank is determined using an ultrasonic sensor, which operates by emitting a short ultrasonic pulse from the trigger pin and measuring the time it takes for the echo to return to the echo pin after bouncing off the surface of the water. This time duration is then used to calculate the distance between the sensor and the water surface.

The duration of the echo is first captured in microseconds. This value is then converted into distance in centimeters using the formula:

$$Distance(CM) = \frac{Duration\ \times 0.034}{2}$$

To determine the water level as a percentage, the measured distance is mapped within a predefined range, typically assuming the maximum tank depth is 20 cm. The map() function in the code translates the measured distance into a percentage scale. The result is then subtracted from 20 to convert the distance into a water level percentage using formula:

$$Water\ Level\ (\%) = 20 - map(Distance, 0{,}20{,}0{,}20)$$

The soil moisture sensor outputs an analog voltage that varies depending on the moisture content of the soil. This analog signal is read by the ESP32 using the analogRead() function, which returns a value between 0 and 4095. Referring to the formula:

$$Soil\ Moisture\ (\%) = 100 - map(analog\ value, 0{,}4095{,}0{,}100)$$

By subtracting the mapped value from 100, the system inverts the scale to express the result in terms of moisture content rather than dryness. This gives a more intuitive output where higher percentages represent wetter soil conditions.

These calculations are updated every second using the BlynkTimer function. The results are simultaneously:

- Display real-time values from the sensors to Blynk Dashboard Depending on the BlynkTimer function.
- Uploaded to the Blynk dashboard via virtual pins
- Stored in Google Sheets for data logging

Users can view real-time data via their mobile devices using the Blynk app, which makes the system practical for plant health management.

Figure 12: Readings from sensors sent to Blynk

Figure 12: Data on Blynk mobile

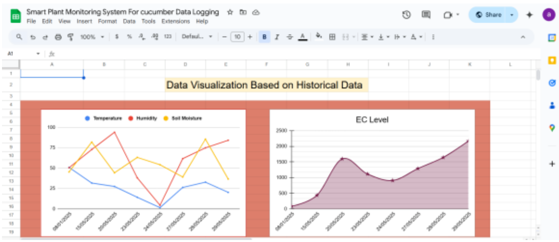


Figure 13: Data Visualization Google Sheets

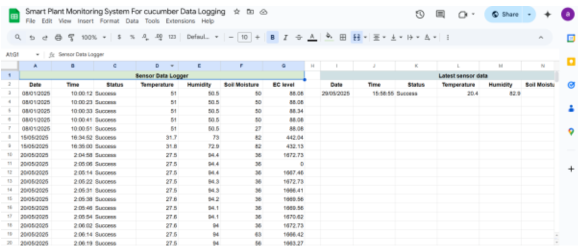


Figure 14: Data Logging Google Sheets

The system was subjected to various load conditions to test its performance and accuracy. The TDS and Water temperature sensor was needed to calibrate a few times to get its reading as accurate as possible. The ultrasonic sensor was also tested to ensure the correct tank levels. Soil moisture sensor is calibrated to measure the right amount of moisture of soil.

The Blynk dashboard proved to be responsive, reflecting real-time updates without noticeable lag. Users were able to monitor:

- The Environment Temperature & Ambient Humidity.
- Water Level in the water tank.
- EC quantities in the water tank.
- Refer to EC levels based on the plant growth stages.
- The soil moisture percentage.

These values were consistent across tests, suggesting reliable sensor calibration and effective data processing.
Strengths of the system include:

- Real-time monitoring of environmental sensors
- Local and cloud-based display for flexibility.
- Persistent data logging through Google sheets.
- Automation controlled water pump through Blynk.
- Control PIR motion sensor using Blynk.
- Notification-enabled Security system

Limitations:

- Absence of automated mixture of fertilizer.
- PIR motion sensor detection range is limited.
- Estimated battery level is not stated in the system.
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Despite these limitations, the system fulfilled its core goal of providing users with visibility into their Cucumber plant monitoring system, which can support behavioural changes for improved plant growth and efficiency.

VI. CONCLUSION

In conclusion, this project focused on developing a Smart Plant Monitoring System for Cucumber using the ESP32 microcontroller, integrated with multiple sensors including DHT22 (temperature and humidity), PIR (motion), ultrasonic sensor (water level), soil moisture sensor, TDS (Total Dissolved Solids), and a water temperature sensor. The system not only gathers environmental data but also provides automation, such as triggering a water pump via a relay when soil moisture is low and transmits data in real time to both Blynk and Google Sheets for visualization and storage.

The successful integration of hardware and software demonstrated the potential of IoT systems in automating agricultural and environmental monitoring tasks. Sensor data collection, real-time alerts, data logging, and remote-control functionalities were all achieved as planned.

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