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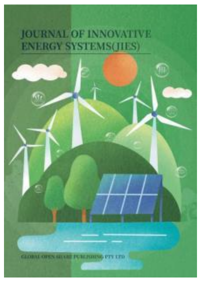


Article

Greenhouse Environmental Monitoring and Control Using ThingSpeak

Kshitimoni Gogoi, Neeraj Semwal, Devendra Kumar, Arun Uniyal*, Arvind Kumar

Department of Electronics & Communication Engineering, Institute of Technology Gopeshwar, Chamoli, Uttarakhand, India

*Corresponding author: Arun Uniyal, arunavenue@gmail.com

Abstract

Real-time data of environmental factors such as temperature, soil moisture, and humidity are essential not only in climate studies but also agriculture since they have a big impact on crop yield, growth, and health. In addition, knowledge of these factors can assist farmers to improve growing conditions by comprehending and controlling the factors, which will boost productivity and profitability, avoid pests and diseases and minimize resource waste. The proposed work uses the ThingSpeak platform to visualize real-time environmental monitoring data from a greenhouse system. Temperature, humidity, and soil moisture sensor readings were gathered and sent to the cloud for display and analysis. Dynamic changes in the greenhouse environment during a recorded period are revealed by the data. Around 17:37:04, the temperature showed a significant increase, going from about 23.7 °C to 24.6 °C and gradually increasing during the evening to decreasing in later part of the night. In general, the humidity trended upward, beginning at about 64% and peaking at about 87% in the most recent measurements. Around 17:36:12, there was a noticeable variation in the soil moisture levels; they were high at first, then dropped precipitously, recovered, and then began to diminish gradually. These data points offer important insights into the greenhouse's microclimate and the possible effects of external influences or automated control systems on these crucial environmental parameters. Effective visualization and almost real-time monitoring of these crucial agricultural factors were made possible by the ThingSpeak platform.

Keywords

Greenhouse monitoring, Real-time data, IoT, Sensor, ThingSpeak, Smart agriculture

Article History

Received: 19 April 2025

Revised: 21 May 2025

Accepted: 26 May 2025

Available Online: 09 June 2025

1. Introduction

Agriculture is an important industry as well as the foundation of the Indian economy. Furthermore, weather monitoring is the process of assessing the weather of the area and its surroundings for a large cropping area. In other words, the environmental conditions of the area of work are analyzed to identify the risks and develop strategies through which the adversities could be mitigated. The implementation of a Wireless Sensor Network (WSN) could again be regarded as an imperative way in which different sensors are interconnected with each other to monitor physical environmental conditions The country's population is rapidly increasing and with the increasing population rate the demand for food also increases. The growing demand for food and changing consumer preferences have emerged as significant challenges for the agriculture industry in developing effective techniques and practices to meet these rising needs and expectations [1-3]. Agriculture is one of the most crucial sectors playing a key role in the development of society. Hence, it's essential to implement advancements in this industry to enhance overall productivity and efficiency. To meet the evolving demands of consumers innovations in food production technology are required for significant improvements [4].

It is critical to make use of agricultural resources since the majority of the country's population relies on the agricultural sector [5]. Smart irrigation is an emerging scientific discipline that utilizes data-driven techniques to boost agricultural productivity while minimizing the impact on the environment. Contemporary farming practices rely on various sensors to collect data, providing deeper insights into both the farming environment and operational processes [6-9]. With the adoption of smart irrigation technologies decision-making becomes more precise and efficient. The advancements help optimize the use of resources ensuring that the objectives of agriculture are met effectively. By integrating such technologies into irrigation systems water conservation improves significantly supporting the Sustainable Development Goals (SDGs), particularly Goal 6, which focus on sustainable water management. Implementation of these innovations contributes to sustainable development by promoting long-term benefits for both agriculture and the planet [10-13].SDG 6 is focused on addressing water scarcity by measuring two key factors: water-use efficiency and water stress i.e., it emphasizes the need to use water resources more effectively while reducing the pressure on available supplies, ensuring sustainable water management for the future [14-16]. The accuracy of this indicator largely depends on the quality of available water data. There is increasing pressure to improve the development and management of irrigation systems to meet the demand for healthier and more sustainable food systems. However, inefficient use of agricultural resources can lead to environmental pollution and harmful consequences [17-20]. One of the primary reasons for water scarcity is the limited availability of freshwater land reservoirs and a shortage of field expertise. Continuous extraction of water from the earth has led to declining water levels resulting in more areas that cannot be irrigated. Hence enhancing agricultural systems and prompting farmers to adopt effective frameworks has become essential to ensure the efficient management of the available resources [21]. The Smart irrigation system is an advanced technology that enhances performance by automating irrigation processes while making use of water efficiently. It operates by adjusting irrigation based on real-time soil and weather conditions, enabling farmers to meet their irrigation needs more effectively [22]. This system includes sensors for data collection, irrigation control, wireless communication, data processing, fault detection, and the pH level of soil. These elements can be integrated into IoT devices, making the system more intelligent and adaptable.

Technologies such as the Internet of Things (IoT), smartphone applications, and sensors help farmers monitor their fields with precision by providing real-time data on factors like soil temperature, water requirements, soil pH, and weather conditions that allow better decision-making and resource management [23]. IoT is the extension of the Internet to various devices that can interact with electronic systems and stay connected over the Internet. This connectivity makes devices more user-friendly and easier to manage. For enhancing productivity and improving overall efficiency IoT plays a crucial role in agriculture [24]. Sensors play a crucial role in helping farmers gain better insights into their crops, minimize environmental impact, and conserve valuable resources. With the adoption of Smart agriculture, farmers can achieve higher yields while using fewer inputs like fertilizers, water, and seeds, making farming more efficient and sustainable [25-26]. Ayua et al. has investigated potential of solar energy for agriculture enhancement employing angstrom and novel analytical models [27].

Soil and Weather Monitoring

Accurate and efficient monitoring systems have an impact on plant growth and development. They are essential for designing effective irrigation control systems that maximize food production while minimizing water waste [28].

Monitoring involves collecting real-time data on plant conditions, soil moisture, and weather in areas where irrigation is to be done using IoT and WSN. IoT enables the development of cost-effective monitoring systems that enhance irrigation control and efficiency [29].

Soil moisture is an essential parameter for plant growth. For maintaining an optimal irrigation schedule monitoring soil moisture levels effectively is crucial. The sensing technology for soil moisture is designed to be cost-effective and primarily relies on capacitance-based measurements, which operate using the principles of a dielectric device [30]. For efficient irrigation management, accurate monitoring of soil moisture levels is essential which plays a vital role in plant growth. A cost-effective sensing technology based on capacitance measurements and functions according to the principles of a dielectric device is used to ensure an optimal watering schedule [31]. A threshold is set by the user to start the process of irrigation when the soil fails to meet the required moisture levels [32]. Moreover, weather monitoring includes analyzing the weather conditions of a large agricultural area and its surroundings. This process helps assess environmental factors, identify potential risks, and develop strategies to mitigate adverse effects.WSN play a key role in this by connecting various sensors to monitor and track physical environmental conditions in real time [33]. Real-time monitoring includes analyzing data collected from sensors and a feedback loop is activated to control the devices. An IoT-based weather monitoring system has been developed to track environmental factors such as humidity, air temperature, soil moisture, and pH level. Real-time data from the sensors are transmitted through the wireless communication network. Detailed weather insights could be gained with this approach which helps farmers with improved irrigation strategies for long-term agricultural sustainability [34]. Many researchers have proposed novel analytical methods for improvement in agriculture sectors [35-41].

The objective of this study is to develop and analyse an IoT based greenhouse monitoring system that integrates soil and weather data for efficient irrigation management. Several existing solutions address this problem by integrating soil moisture sensors with IoT-based platforms. The proposed system allows for remote monitoring of soil moisture, making it easier for farmers to make informed decisions. ThingSpeak IoT platform, offers cloud-based data monitoring and analysis, making it an appealing option for agricultural monitoring and moreover it is an open source with zero cost for monitoring real time data for farmers.

In this work, we propose a low-cost, user-friendly system that uses a soil moisture sensor and a Digital Humidity and Temperature 11(DHT11) sensor to monitor environmental conditions in real-time. Data collected from the sensors is sent to ThingSpeak for analysis and remote access, allowing for efficient and cost-effective environmental monitoring of the greenhouse and scheduled the irrigation process. Our system is designed to be easy to deploy and energy-efficient, making it accessible to farmers in remote areas with limited infrastructure.

The current paper discusses the real time results obtained for the greenhouse monitoring system for soil moisture, temperature, humidity parameters. Section 2 describes the design considerations of the proposed work. Section 3 describes the simulated results and its discussions. Section 4 describes the conclusion of the proposed work.

2. Design Considerations and Methodology

The system shown in Figure 1. uses an Espressif Systems Protocol 32 (ESP32) microcontroller to track soil moisture, temperature, and humidity. It uses this data to automate irrigation by controlling a water pump through a relay module. For data administration and possibly remote access, the system can potentially establish a connection with the cloud.

Figure 2. shows the circuit diagram of the proposed system. The Voltage Common Collector (VCC) of the soil moisture and DHT11 sensors are connected to VCC of the ESP32 and the Ground (GND) of these sensors to GND of ESP32 and VCC and GND of breadboard.

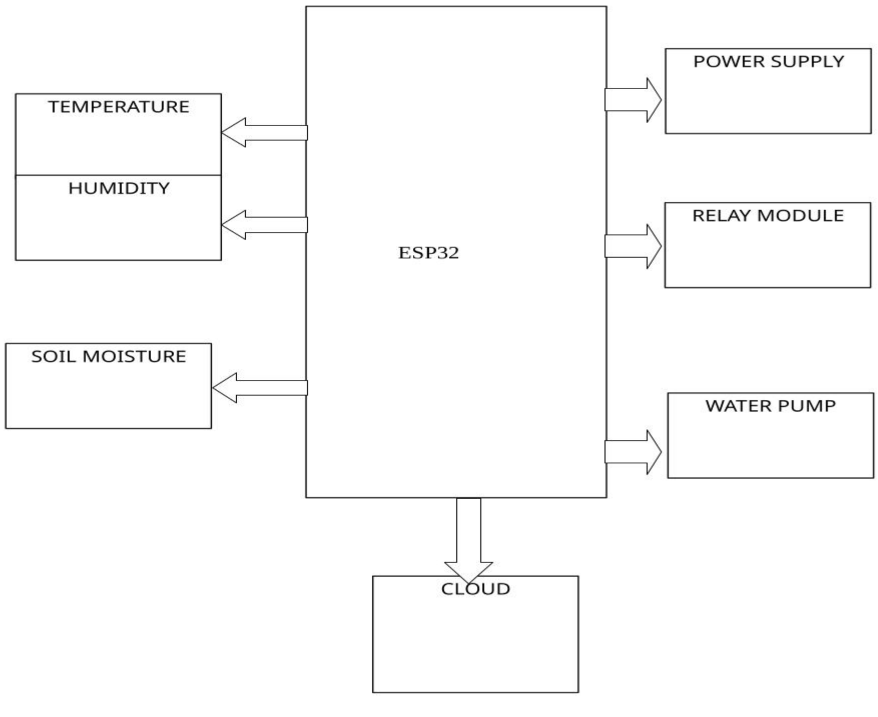


Figure 1. Block diagram of greenhouse monitoring and control system.

WSN Architecture

The proposed system is structured around a star topology as shown in Figure 3. The ESP32 microcontroller acts as the central node (gateway), directly interfacing with the environmental sensors and transmitting data to a cloud platform without relying on intermediate nodes. This simplifies the network architecture, making it ideal for small-scale agricultural deployments. The ESP32 collects data from two sensors that are a DHT11 for temperature and humidity, and a soil moisture sensor for monitoring soil conditions. These sensors are connected via wired interfaces—digital General Purpose Input/Output (GPIO) for DHT11 and analog input for the soil moisture sensor. Data is transmitted over Wi-Fi using the HTTP REST API to the ThingSpeak IoT platform, where each sensor reading is assigned to a specific field for visualization and analysis.

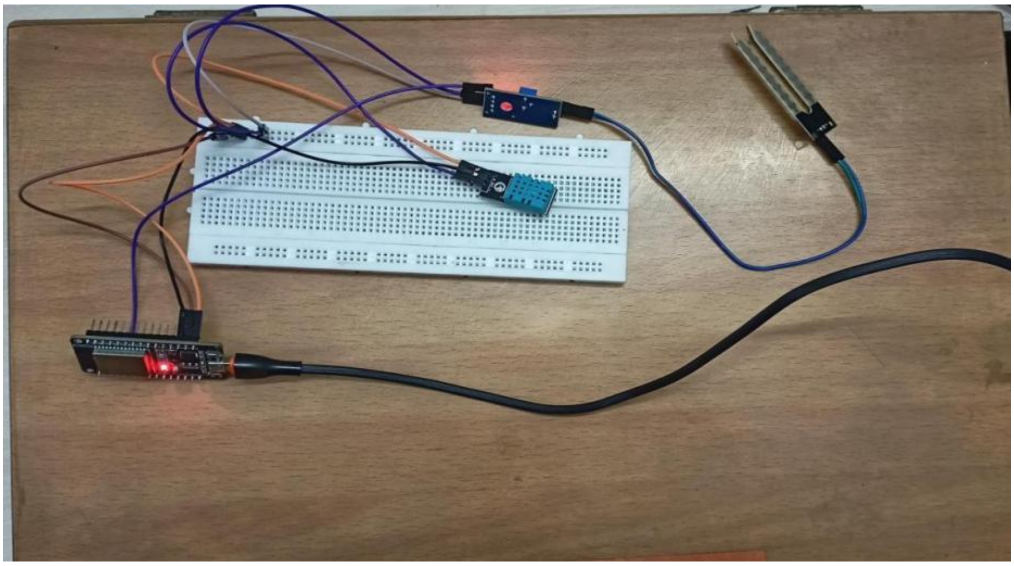


Figure 2. Circuit diagram of the proposed system.

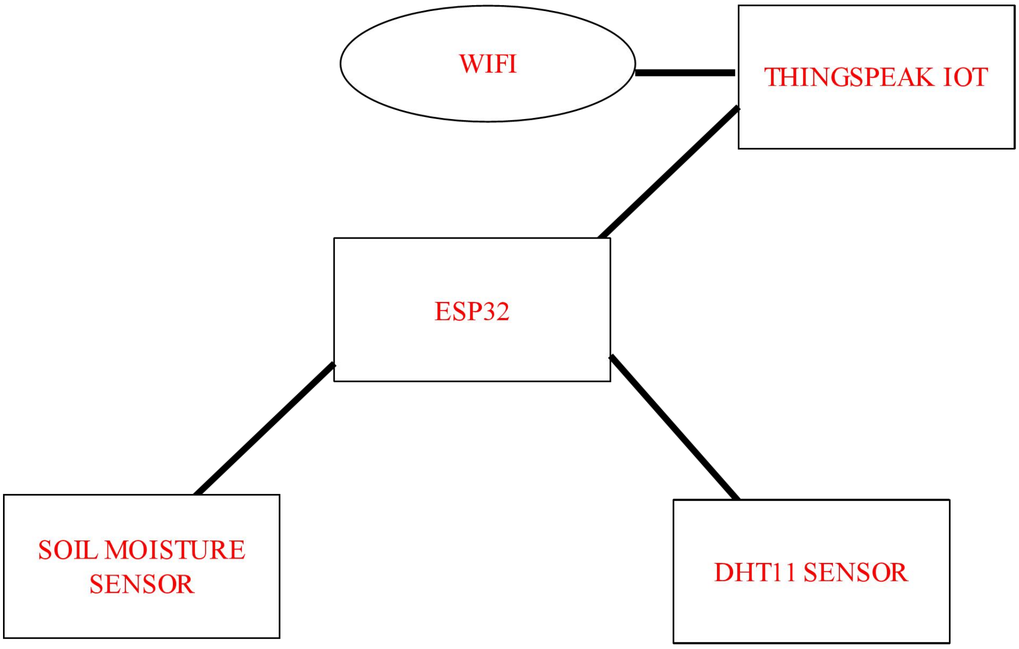


Figure 3. WSN Architecture with star topology.

A brief description of each module used in the proposed work is as under:

(1) ESP32: The ESP32 is a low-cost, low-power system-on-a-chip (SoC) microcontroller that has bluetooth and Wi-Fi built in. It serves as the smart irrigation system's brain, taking in information from the sensors, processing it, managing

the water pump, and coordinating with the cloud. It has a dual-core processor, memory, and a few peripherals, such as digital input/output (GPIO) pins for controlling other modules and analog-to-digital converters (ADCs) for reading sensor data.

(2) Temperature and Humidity Sensor: This module gauges the air's relative humidity as well as its temperature. As temperature and humidity fluctuate, these sensors frequently detect changes in the electrical resistance or capacitance of a sensing device. Analog sensors that provide a voltage proportionate to the measured values and the DHT11 and DHT22, which offer digital output, are typical examples. The ESP32 uses this information to determine whether irrigation is necessary due to environmental circumstances.

(3) Soil Moisture Sensor: The soil moisture sensor measures the soil's volumetric water content. It typically measures the electrical conductivity or capacitance between two underground probes. Higher moisture content leads to improved conductivity (lower resistance) or better capacitance. The module transmits an analog or digital signal that the ESP32 can decipher to determine whether the soil is dry and needs to be watered.

(4) Relay: Electrically operated relay modules enable a low-power circuit (such as the one managed by the ESP32) to switch a high-power circuit (such as the water pump's power supply). It has an electromagnetic coil that opens or closes the high-power circuit by moving a set of contacts when the ESP32 activates it. This ensures safety and correct functioning by providing electrical isolation between the pump and the microcontroller.

(6) Water Pump: A water pump is a machine that transfers water to plants for irrigation from a source, such as a tank or water supply. The relay module in this system oversees turning the pump on or off in response to signals from the ESP32. Depending on the size and needs of the irrigation system, many types of water pumps (such as surface or submersible pumps) may be used.

(7) Power Supply:This module supplies the electricity required for the smart irrigation system's many parts to operate. Usually, it transforms AC mains electricity into the DC voltages needed by the water pump, ESP32, sensors, and relay module. For all connected devices to receive enough current and voltage, the power supply must be suitably rated.

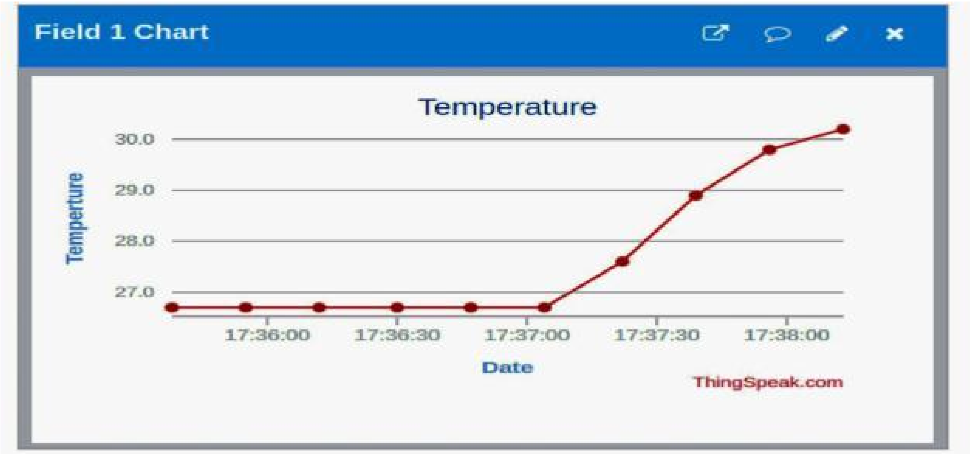
3. Results and Discussions

First, we connected the soil moisture sensor with ESP32, we measured the soil moisture level of the dry soil so we got the value of 4095 i.e. 0% moisture level for first two entries. After that, the soil moisture sensor is inserted in wet soil, so we get the value of 1140 i.e. 99.89% moisture level in third entry similar other entries are calculated using the equation (i). Moreover, the first ten entries of the Table 1 are displayed in the graph obtained in ThingSpeak IoT platform as shown in Figure 4 (c).

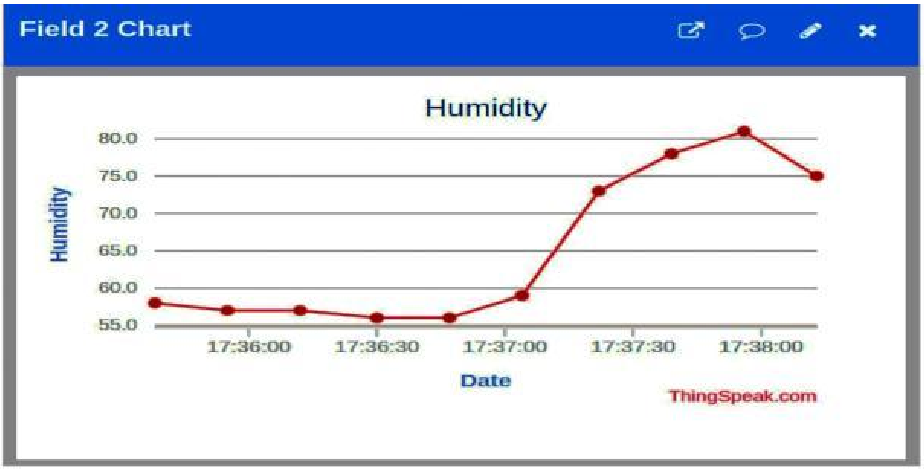
Table 1. Parameters measured in the current study.

Entry	Soil Moisture (%)	Humidity (%)	Temperature (^{o}c)	Time(sec)
1	0.00	64.00	23.7	17:35:38
2	0.00	63.00	23.7	17:35:55
3	99.89	63.00	23.7	17:36:12
4	97.31	62.00	23.7	17:36:30
5	93.48	62.00	23.7	17:36:47
6	0.00	65.00	23.7	17:37:04
7	0.00	79.00	24.6	17:37:22
8	0.00	84.00	28.9	17:37:39
9	99.98	87.00	25.8	17:37:56
10	17.47	81.00	27.2	17:38:13
11	84.84	79.00	18.4	23:10:16
12	50.13	78.00	18.4	00:14:44
13	70.25	78.00	18.4	00:15:01
14	13.86	81.00	17.2	02:34:00
15	7.16	81.00	17.2	02:34:17
16	38.94	80.00	16.8	02:58:22
17	60.01	80.00	16.4	02:58:38
18	50.67	80.00	16.4	02:58:56
19	43.20	87.00	14.8	03:08:32
20	42.46	87.00	15.6	03:22:22

Now we connect the DHT11 sensor with ESP32 firstly we measure the real-time temperature of the surrounding environment which was 23.7 °C at 17:35:38 on 3rd may and gradually increases on seventh entry to 24.6 °C at 17:37:22 as shown in Figure 4 (a). This can be calculated by equation (ii). Then we measured the real-time humidity percentage in the environment which was 64% at the first entry and the gradually decreases and then started to increase from seventh entry as shown in Figure 4 (b). This can be calculated by equation (iii). Moreover the first ten entries of the DHT11 sensor of Table 1 are displayed in the graph obtained in ThingSpeak IoT platform as shown in Figure 4 (a) and Figure 4 (b).



(a)



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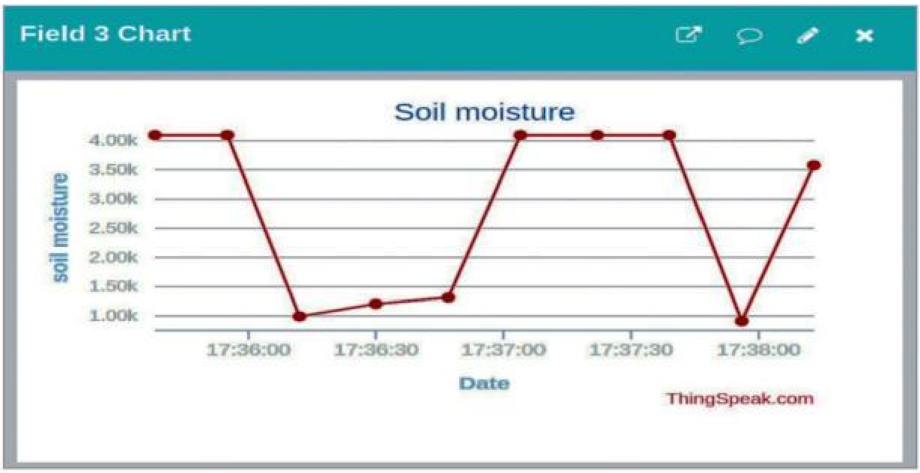

(c)

Figure 4. Observed values of temperature, Humidity, and Soil moisture level in (a), (b), (c) respectively on the ThingSpeak website.

In the Figure 4 (a), the temperature values are varied. The temperature values are constant and increase after some time. In the Figure 4 (b), the humidity values are varied. The variation is in the form of decreasing gradually from 64% and increasing after some time giving the real-time surrounding data. In the Figure 4 (c), the soil moisture values are varied. The variation is in the form of decreasing and increasing and stable sometimes.

Table 1 shows a sample of successfully received environmental data for soil moisture, temperature, and humidity over time. In general irrigation is needed when soil moisture levels drop below 30-50% of Available Water Holding Capacity (AWC). The sensor values updates after every 17 seconds (approx).

In the proposed system the soil moisture sensor has a raw value of 4095 when dry and 1137 when wet under all environmental conditions. The formula to assume a linear relationship between moisture and sensor output is:

Soil Moisture (%) = (Dry－Measured Value÷Dry－Wet)×100 (i)

The DHT11 gives a 3 °C high temperature than the actual temperature on every conditions.

Tcorrected = Tmeasured－3 °C; T = Temperature (ii)

Moreover, the relative humidity (RH) measured in the sensors is 6% less then the actual humidity content in the atmosphere under all environmental conditions.

RHcorrected = RHmeasured＋6%; RH = Relative Humidity (iii)

First, we connected the soil moisture sensor with ESP32, we measured the soil moisture level of the dry soil, so we got the value of 4095 i.e. 0% moisture level for first two entries. After that, the soil moisture sensor is inserted in wet soil, so we get the value of 1140 i.e. 99.89% moisture level in third entry similar other entries are calculated using the equation (i). Moreover, the first ten entries of the Table 1 are displayed in the graph obtained in ThingSpeak IoT platform as shown in Figure 4.

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In the Figure 4 (a), the temperature values are varied. The temperature values are constant and increase after some time. In the Figure 4 (b), the humidity values are varied. The variation is in the form of decreasing gradually from 64% and increasing after some time giving the real-time surrounding data. In the Figure 4 (c), the soil moisture values are varied. The variation is in the form of decreasing and increasing and stable sometimes. Figure 5. This graph essentially shows the changes in temperature, humidity, and soil moisture during the data collection period. In disciplines like meteorology, agriculture, and environmental monitoring, this type of data can be useful for comprehending environmental dynamics.

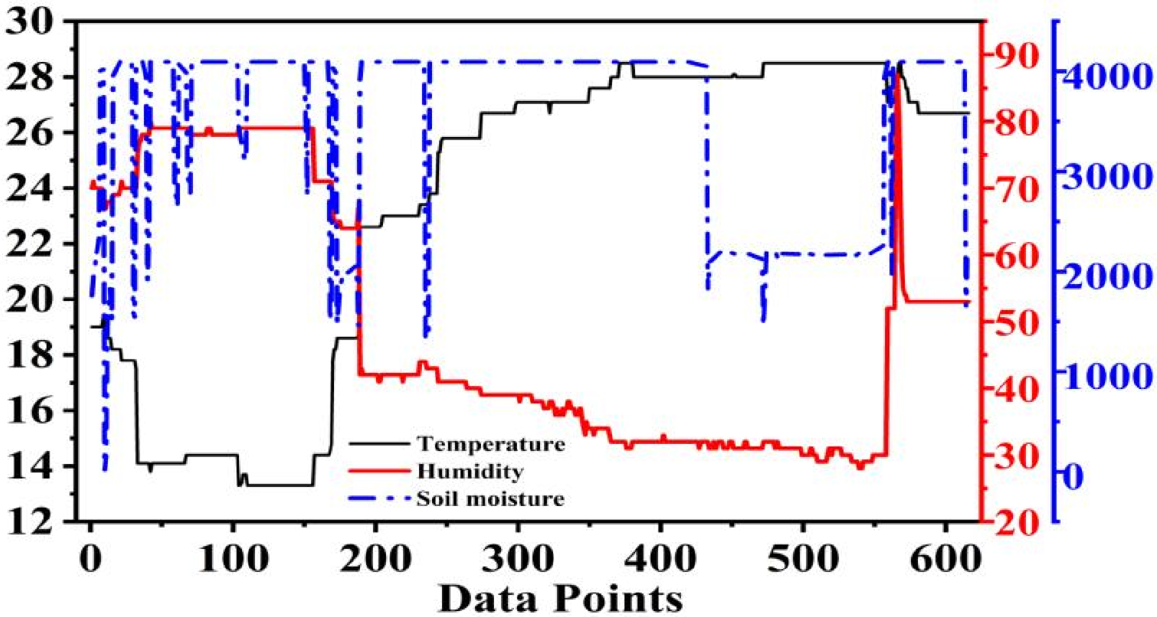

Figure 5. Temperature, humidity and soil moisture as a function of different data points.

A comparative analysis has been made in Table 2 at last which shows the key features of the proposed work with other relevant works in literature. Although certain factors can influence the reliability of the proposed work like: network connectivity can be erratic in field deployments, particularly in rural or isolated agricultural areas. Data transmission can be hampered by elements like weather, topography, and distance from base stations. For real-time control, latency, or the delay in data transmission, might be crucial. The promptness of irrigation choices may be impacted if sensor data takes a long time to get to the control system. The availability of power might be a significant limitation for remote deployments. The current implementation is optimized for small greenhouses. Scaling the system to large commercial operations may require more robust hardware, efficient network protocols, and data aggregation strategies.

Table 2. Comparative analysis between existing and current study.

Feature	**This Study (ESP32 & ThingSpeak)**	**WSN with Zigbee by Abedin et al.[22]**	**Arduino & Cloud Platform by Ayaz et al. [23]**	**LoRa WAN-based System by Kodali et al.[17]**
Microcontroller/Processor	ESP32	Microcontroller (e.g., ATmega)	Arduino (e.g., Uno, Mega)	Microcontroller
Communication	Wi-Fi	Zigbee	Wi-Fi/GSM	LoRaWAN
Cloud Platform	ThingSpeak	-	Cloud Platform X	-
Data Visualization	ThingSpeak	Local/Custom	Cloud Platform X	Local/Cloud
Strengths (from paper)	Cost-effective, real-time visualization	Low power, suitable for mesh networks	Ease of use, large community support	Long-range, low power consumption
Weaknesses (from paper & general)	Limited long-range capability, Wi-Fi dependency,	Limited range, complexity of mesh networking	Limited processing power compared to ESP32	Higher cost, complexity of setup
Power Consumption	Moderate	Low	Low to Moderate	Low
Range	Short	Short to Medium	Short to Medium	Long
Cost	Low	Low to Moderate	Low to Moderate	Moderate to High

4. Conclusion

The ability of an ESP32-based system combined with ThingSpeak to efficiently monitor and display environmental data in a greenhouse environment has been demonstrated by this work. By recording changes in temperature, humidity, and soil moisture, the system gave important information on the microclimate inside the greenhouse. Future studies must address important implementation concerns to transfer this system from a controlled environment to real-world agricultural use. Studies on the resilience of IoT connectivity are required to reduce the possibility of data loss and guarantee uninterrupted operation under a variety of field circumstances. Furthermore, prompt control actions depend on assessing and reducing data transmission latency. The maximum and minimum temperature recorded is 28.9 °C and 15.6 °C respectively. The maximum and minimum humidity percentage recorded is 87% and 62% respectively. The maximum and minimum soil moisture percentage is 99.98% and 0% respectively. Lastly, for long-term, sustainable deployment, especially in off-grid areas, a detailed examination of power use and the creation of energy-efficient techniques are required.

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