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Research Paper

Proactive Plant Health Guardian using WSN in Glass house

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ABSTRACT

ESP32-based sensors communicate via LoRa signals, creating a network that closely monitors greenhouse conditions. Farmers receive real-time updates on temperature, humidity, soil moisture, and sunlight levels, eliminating guesswork. LoRa's low power consumption allows these devices to transmit data over long distances without quickly depleting batteries. The modular design enables seamless integration with existing systems. Testing demonstrated the system's ability to detect subtle changes in growing conditions, providing reliable data for automated adjustments. Continuous monitoring supports informed decisions on irrigation, lighting, and scheduling, promoting crop health and efficient resource use. Beyond typical signal ranges, LoRa technology transmits data efficiently with minimal energy use. The system, centered on a compact, energy-efficient microcontroller, offers a greater range than previous designs. Its adaptable greenhouse network structure allows for safe integration of additional devices without excessive hardware. Even under heavy use, data transmission remains reliable and timely. Each unit continuously monitors temperature and humidity in real time.

Keywords: ESP32, LoRa, IoT, Sensors, WSN.

I Introduction

Modern farms increasingly use wireless sensor networks, especially in greenhouses, to maintain optimal growing conditions. This system integrates LoRa technology with ESP32 chips to monitor temperature, humidity, soil moisture, and light in real time. LoRa's long-range, low-power capabilities, combined with the ESP32's processing power, enable reliable data transmission across large areas. Continuous updates allow farmers to respond quickly, improving yields and optimizing resource use. Consistent monitoring supports precision farming by enabling proactive decision-making. Close monitoring of greenhouses is essential for improving plant growth, conserving resources, and increasing yields. Traditional manual checks are time-consuming and prone to error. The ESP32 and LoRa system addresses these challenges by providing real-time, accurate data remotely. Automated monitoring detects changes quickly, reduces waste, and eliminates the need for frequent manual inspections. LoRa signals cover long distances and penetrate obstacles, ensuring reliable data delivery. Automation enhances greenhouse management, supporting precision agriculture through continuous, dependable sensor readings. Out in greenhouses, the ESP32 steps in quietly,handling sensors while speaking both Wi-Fi and Bluetooth. Built to withstand tough conditions, yet running on limited power, it thinks quickly enough to keep up with the changing air, earth, and light. Instead of draining energy, it stays awake for days, checking how wet the soil feels or whether the sun's too strong. Temperature shifts? Humidity drops? It sees those clues early. Because plants whisper through numbers, catching small changes means fewer surprises later. With this steady pulse of info, decisions come clearer, even before problems grow. A few kilometers away, signals still move quietly through LoRa without draining energy. Not like most wireless systems, this one stretches far yet runs slow and steady. When greenhouses sit distant from control centers, messages pass without breaking stride. Even when the weather turns rough or interference rises, links stay firm. Long reach meets minimal power use - making remote connections possible by design. This tool tracks key conditions inside greenhouses without stopping, feeding live updates. Because of that flow, choices about growing crops get sharper and more timely. Instead of costly or shaky older methods, this version focuses on staying low-budget yet steady. It works around flaws found in current models by keeping things simple but strong. A fresh approach inside greenhouses boosts how things run while supporting longer-term growing methods. Resource loss drops when systems work smarter, shrinking the impact on surroundings. Step by step, fitting in smart tools moves farming into sharper focus, aligning with worldwide efforts to grow more food as needs climb steadily. This project shows how fresh tech can update old farming ways. Instead of just checking settings inside greenhouses, the finished tool opens paths toward smarter field methods later on. A working model comes alive when chips talk clearly through strong signal rules. Most changes start small,here it begins with soil, air, and light tracked without pause. When machines share data smoothly, better choices grow naturally.

II Literature Review

A wireless sensor network (WSN) architecture in greenhouse monitoring system design consists of various sensor nodes. Each node consisted of an ESP32 microcontroller with a LoRa communication module. In this greenhouse, a host of sensor nodes were installed to capture environmental parameters like temperature, humidity, soil moisture, and light. The data collection point was a central gateway constructed on an ESP32 using a LoRa module. The data collected was transmitted to a monitoring interface through Wi-Fi or Ethernet. Reference [1] utilizes a wireless solution to overcome problems of a wired monitoring system regarding high installation cost, inflexibility, and an insufficient number of measurement points. The research highlights that temperature, humidity, and irradiance of the plant must be accurately and reliably tracked for the desired growth of the plant. Wireless Sensor Network (WSN) is based on the IEEE 802.15.4 standard and 6LoWPAN. Unlike the later studies, this experiment assesses the viability of deployment in a commercial greenhouse with tough environmental conditions. The star topology network that has been developed uses Sensinode platforms and is implemented at Martens Research Foundation. It has four sensor nodes and a coordinator node to collect data. In [2], not every system runs the same way. One setup tries hard to keep indoor farm settings just right - temperature, humidity, light - so plants grow better while saving power. Instead of old-school central controls that adjust constantly, it uses smart triggers. Sensors talk only when something shifts past a set point. That change wakes up the network. Communication happens through wireless links built on ZigBee rules inside a Simulink test space called TrueTime. Physical changes mix with digital signals in one shared run. Predictions shape decisions before problems show. Machines learn what patterns matter most. Data moves less often than in systems that report nonstop. Less chatter means longer battery life. Efficiency climbs without pushing hardware harder. Each decision ties back to real-time shifts, not clock ticks. What matters is how much things move, not how long they've been still. As a refresher, in Study number [3], researchers created something quite interesting: a wireless system that consumes little power, yet has a long lifespan, intended for greenhouses. This system, when working on its own, employs fuzzy logic to regulate the climate itself, without human intervention. This system works on a star configuration, where one central unit is at the core, making decisions, akin to a brain. Four devices outside, monitoring temperature and humidity, utilize precise sensors known as SHT75. Then, three devices take action, switching on or off things such as a heater, a ventilation system, and a moisture booster. Every ten minutes, these sensors collect information on the surroundings. Only if they detect a change beyond a certain range, they transmit information onward. This means if a temperature varies by half a degree, or if a level of wetness varies by a single percent, they transmit information. This limits messages being sent, thus reducing power consumption. This system, collecting information from all sensors, calculates averages, then employs a logic system to determine action, utilizing twelve different rules, based on differences between actual readings and target readings, varying by time of day and night, within limits. Pulse width signals transmit decisions, making precise calculations to adjust temperature, ventilation, and moisture boosters. Wireless chips, employing Jennic's 32-bit design, operate Zigbee PRO, whereas small devices operate on small batteries, whereas central and output devices operate on a normal electrical outlet. In the past, in study [4], researchers examined ways to repair old-school greenhouse systems, like those weighed down by excessively high costs, messy wires, and the inability to grow things bigger. Instead, they decided to utilize wireless networking based on AVR microchip technology. This system divides a large rectangular greenhouse into sections, each with a base station. Inside these sections, invisible grids divide the area into blocks, and these blocks do not overlap. Nodes within these grids group together, and one becomes the leader, or the sink, and the rest follow, or tag along, carrying both sensing and executing devices. These small nodes collect information about the air and soil and send it directly to their leader. The messages then travel to the base station and then to a central hub, where knowledge is derived. The power runs through solar units, which feed power to multiple reserves, one of which uses supercapacitors, and below that, lithium batteries, which can be used when needed. The operation runs uninterruptedly, utilizing this silent marriage of sun power and stored power, waiting in reserve. From reference [5], messages travel between soil sensors in a sugarcane field and a computer located in a remote area near CENICANA in Colombia. This does not use one method, but two, which work in concert to compensate for the limitations of each. The first, ZigBee, utilizing XBee, creates a network of interconnected devices in the area under test. This method allows messages to jump from one device to another, or node, without wasting power. Additionally, cell-based technologies like GPRS, HSDPA, and UMTS allow remote devices to reach out to the sensor group in the test area, utilizing modem connections. This reaching out over long distances becomes possible. One design pattern described in source [6] is based on a layered architecture for IoT systems. Here, detection, communication, and application are the three stages of an IoT system. Instead of stacking components next to each other but separated from each other, this design pattern links them together closely by design. The focus is on a CC2530-based circuit. Here, every sensing device and the central control point rely on a single base element. Without segregating the processing and wireless components of the design, it integrates an 8051 processor and an internal radio part designed for ZigBee protocols. When joining links together, a gateway device relies on an STM32F107 chip to connect Ethernet, ZigBee, and GPRS into a single chain. Data transmission from sensing devices out in the field passes through these links and into distant locations. A thin Linux implementation runs inside the device and remains active even when a simple web interface and basic control options are in use. In [7], three different wireless sensor systems were developed. Here, different devices and codes were tested along with different link options. While based on the IEEE 802.15.4 protocol, ZigBee is based on a star topology for testing purposes in tomato-growing greenhouses in the high Andes of Ecuador. DigiMesh, also based on the same protocol, is based on a topology where all the nodes are connected in a web-like fashion for similar farms. The WiFi systems are based on a hub topology and are based on the 802.11 protocol for these farms. Testing revealed the on signals in moving through different plant heights. It also revealed disruptions or delays in the signals. Some quirks in the setup were noted depending on the placement of the sensors within the setup. Scaling issues were more evident in one model compared to another, even under the same environmental conditions. This was because performance was not only based on the rate but also the consistency in transferring information from one device to another, which were placed among the crops. In [8], there was a network of smart gadgets that controlled everything. Probes, accompanied by a brain-like module, were used to control everything. Inside the greenhouse, there were gadgets like the YL69, which measures the earth's dampness, and the DHT11, which measures the warmth and moisture levels. The information was sent in real time. This information was then sent to a small computer called Raspberry Pi 3, which functions like a hub. The information was then processed by the computer, which analyzed it and compared it to the set limits. After this, the gadgets that were relevant to the information would start working automatically. Through Wi-Fi, the information was sent to the online space of ThingSpeak. The information appeared live as it was recorded. It appeared on the screen of a website, and one could view it even from a far distance. It sensed, thought, decided, and then acted. It made the plants happy without requiring any human input. In [9], farm losses, especially during wet seasons, were addressed through the development of a smart greenhouse. When there are storms, its roof will close, while when there is clear sky, its roof will open. The source of power is from solar panels installed on its roof, which powers the system, eliminating the need to rely on other power sources while using green power. The temperature of the air, dampness of the ground, and humidity are monitored through sensors installed in the system. The crops are protected from rain showers through responsive design considerations. When planting Serrano peppers, careful considerations are made to their growth conditions to get better results than those obtained using conventional approaches, which are commonly used in farms today. Water falls on the roof of the greenhouse, which is then collected through a system that operates either on its own or through manual control. When there is rain, this system collects water from what falls on its roof, which would have otherwise gone to waste. This water is then used for watering crops or other farm activities when needed in the future, reducing the quantity of fresh water they would have otherwise used from their common source. In [10], a setup operates on its own, responding to its environment without any external control needed. The gear is triggered by limits programmed in the Arduino, engaging when measurements surpass these limits. Information received from sensors is directly sent to an Android app, which gives farmers live updates from anywhere in the world. This change brings clarity along with convenience. Water consumption is reduced by 20% to 30% less than other techniques, while plants flourish with this method due to proper management of resources. A setup using an Arduino chip is presented in [11], which is designed to be cheap, allowing basic farming activities to use this system without incurring huge expenses. Messages are sent away through a GSM or Wi-Fi network, giving users information on their greenhouse from anywhere in the world. Being away from the greenhouse will not hinder a person from getting live updates on their greenhouse, as this system will send information through text messages or internet signals. This system is within budget while still functioning effectively. In [12], a smart system is presented, which helps in fine-tuning the management of a greenhouse, increasing crop yield and profit. The system incorporates artificial intelligence, sensors, and internet storage. Unlike other systems, a neural network is used, which continues to improve over time, simulating how a plant will respond to its environment in a greenhouse. Unlike other systems, this system simulates complex interactions, such as temperature changes and their effect on plant growth and increase in yield, instead of individual components. There are two levels in this system, which are always updated with new information through trial and error or evolutionary techniques. The system will always respond, with new information always changing its outputs, while results are used to adjust future outputs to get closer to perfect control without having to manually adjust the system. The system will change with changes in conditions, ensuring smooth running through different seasons. The work in [13] developed a smart tech system for monitoring and managing the climate information in factory-style greenhouses. Instead of numbers, it translates data into words such as "warm" or "dry" through fuzzy logic, specifically the Mamdani method. It is useful in situations where changes are not predictable. Rules dictate how these words interact, leading to decisions on changes required. The testing took place in software environments such as MATLAB and Simulink. In these environments, parts of the system for monitoring and managing were shaped into digital forms. Before approval, each of these parts underwent testing. The testing ground for the entire design was simulation. The work in [14] involved studying information on tools and tech in smart farming, specifically wireless sensors and IoT devices. It highlighted how these can help in better crops, resource use, and decisions in farming. Another aspect of the work in [14] focused on the challenges of integrating such high-tech solutions into traditional farming. However, it also highlighted the benefits of these solutions for sustainability. The information came from previous studies, cases, and tested tech frameworks. Various parts of smart farming were reviewed: sensor networks, location devices, flying cameras, number-crunching techniques, data hubs on the internet - each reviewed not only in terms of function but also in terms of place in daily farm life. In [15], the aim is to design a cost-effective model with several sensors to measure factors like heat, moisture, ground acidity, brightness, and the distribution of carbon dioxide over large areas by saving power to send data. The main idea behind this is to contribute to the growth of food while using the resources in the right way, especially for people with smaller agricultural lands to access the tools which are out of their reach. Devices in the network have different sensors, both natural and electrical, connected to small processors to collect data repeatedly. Data is transferred using LoRaWAN technology, which is selected because it can travel far without using much power, moving from the smart relay nodes to the main hub. Data collected is stored and shown live online, where people can watch the changes happening live through the visual displays installed in the structure. In [16], the aim is to design a greenhouse monitoring system using a Vehicular Ad-hoc Network, with two robots functioning as sensors. Unlike the earlier design, these moving sensors can cover larger areas because they change positions to collect data about the climate. Their movement is controlled using a predetermined path designed using the kinematics framework. Their movement is controlled using calculations based on the Lyapunov stability theorem to maintain accuracy and precision. Signal quality during the transfer is ensured by checking the strength of the signals received at the main hub using the simulation of different wave spread patterns using MATLAB. The Design [17] has a smart farming system in two parts, which utilizes IoT technology. The first part monitors outdoor conditions over a large distance, while the other part deals with the work in the greenhouse. The former utilizes LoRa technology, while the latter utilizes wireless internet. The two parts are then connected. In [18], this strategy, which starts from a smart system, not only enhances the performance of greenhouses but also saves resources. Instead of working blindly, it saves on power and water by thinking ahead. It also allows users to check in from a far without necessarily being there through the use of online tools that connect everything. Different strategies are used to address different aspects of the climate. Some work on a schedule, while others work when the situation gets messy or unclear. The machine intelligence then kicks in by looking at patterns from previous information to guess what is next. The fans, heaters, or the drip lines all adjust on their own because of changes in the conditions. All these changes are in response to feedback from the environment. They adjust little by little to achieve a more constant environment. Information is accumulated over time to help in making better decisions. Over time, changes happen naturally because the machine has learned what works. Decisions are made instantly instead of guessing from the information available. Viewing from a far is then possible because changes are updated continuously. Small changes are made to avoid more problems later on, thus keeping the plants happy. Performance is enhanced without forcing it by paying more attention over time. In a research paper [19], the scientists designed a system to monitor the environment. This system uses an ESP32 microcontroller, a soil moisture sensor and a DHT11 temperature and humidity sensor. These sensors keep track of the environment all the time. The ESP32 microcontroller processes the data from these sensors. The ESP32 then sends the data to the ThingSpeak cloud using Wi-Fi. The system is set up like a star, with the ESP32 as the part. The ESP32 works directly with the sensors. It sends data using HTTP. Based on the sensor data the system can control watering automatically using a pump. The sensor data is analyzed continuously. This helps the scientists see changes in the environment .The system keeps monitoring the environment. It processes sensor data. Sends it to the ThingSpeak cloud for more analysis. The system keeps running in a loop. Another research paper [20] talks about a system. This system combines hardware and software to make decisions automatically. Sensors in the field keep track of the environment. The ESP32 microcontroller processes the data, from these sensors. The ESP32 then sends the data to a server that uses Python and Flask. The data is stored in a MySQL database. The data is shown on a dashboard. The system can control watering automatically based on limits. It uses a relay module for this. The system keeps running in a loop monitoring the environment processing data and sending it to the server. The system monitors conditions and processes data from the sensors. The ESP32 microcontroller sends data to a Python Flask server. The system operates in a loop. The system monitors conditions. The system processes data from the sensors. The ESP32 microcontroller transmits data to a Python Flask server.

III Methodology

The LoRa-based greenhouse monitoring system using ESP32 is created to keep an eye on the environment and alert, allowing plants to thrive in such an environment. This system uses sensors along with ESP32 microcontrollers and LoRa wireless communication technology to transmit information over a long distance using a small amount of power. The transmitter ESP32 continuously collects sensor data and is ready to send it. This system also uses an HC-12 module, facilitating reliable wireless communication even with interference, making it suitable for greenhouses where wires are impractical. The collected sensor data is wirelessly sent to a receiver ESP32 at another location, enabling people to monitor the greenhouse remotely. The information is sent to the receiver ESP32. The information sent is processed. The information sent, such as temperature, humidity, soil moisture, and rain, is displayed on an LCD screen in real time. This enables people to get an idea of what is happening inside the greenhouse, allowing them to make good decisions. The system also has a method of sending an alert if the environment is not safe. When the soil moisture level is too low or if the temperature is too high, the receiver ESP32 will activate a buzzer. The loud buzzing will act as an alert to people that something is not right, and they will take action to correct the problem by turning on the water or adjusting the ventilation.The process of how it works is that the sensors are constantly monitoring the environment. Then the transmitter ESP32 will read the information from the sensors. Next, it will send the information wirelessly to the receiver ESP32 via the HC-12 LoRa module. Finally, the receiver ESP32 will display the information on an LCD screen for people to view. The LoRa-based greenhouse monitoring system using ESP32 is very important for keeping the greenhouse safe and healthy.

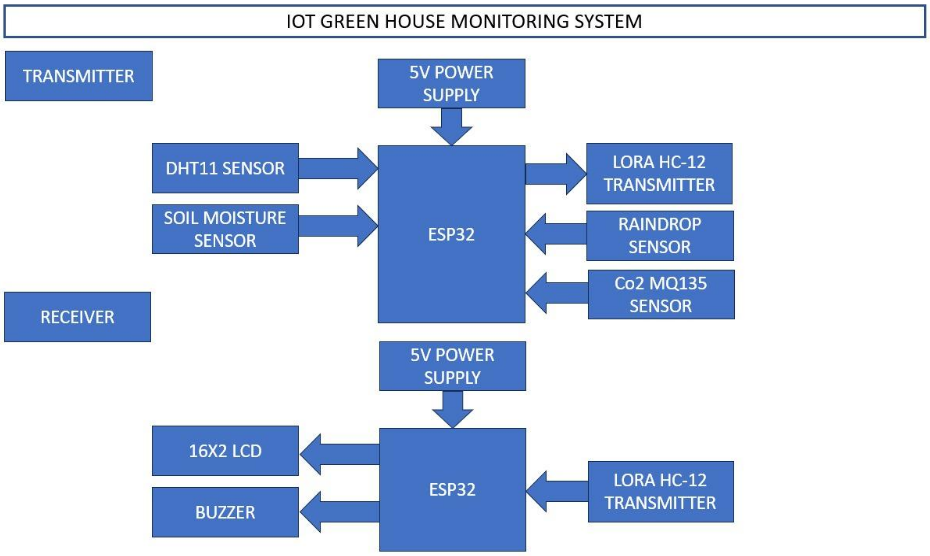

Figure 1. Block diagram

All sensor data is processed by the ESP32 and sent wirelessly through the LoRa HC-12 module. At the receiver side, another ESP32 receives the information and displays it on the LCD. If the readings exceed the safe range, the buzzer turns ON. Greenhouse monitoring through the use of LoRa and ESP32, along with DHT11, soil moisture, raindrop, and CO2 sensors, using the Blynk platform, begins with the hardware setup, which includes ESP32 microcontrollers, along with a communication module such as HC-12, to enable wireless communication through a wireless medium. The system architecture begins with the setup and deployment of multiple sensor nodes strategically placed throughout the greenhouse, collecting sensor data continuously, and sending the sensor data wirelessly through a wireless medium such as a communication channel, using a frequency around 433 MHz, through a wireless communication protocol such as LoRa, using the wireless communication capabilities of ESP32 and the long-range communication capabilities of the LoRa communication module, which has a range of several hundred. The received sensor data from multiple sensor nodes, sent wirelessly through a wireless medium such as a communication channel, are received by a LoRa gateway, along with an ESP32 communication module, and connected to the internet either directly or through a device such as a raspberry pi, to enable data routing and forwarding. For software implementation, the ESP32 microcontrollers use the Arduino IDE for programming. Sensor-specific libraries, such as DHT.h for the DHT11 sensor, along with analog or digital reading functions for the soil moisture and raindrop sensor, and UART or analog functions for the CO2 sensor, are used for implementation. The LoRa libraries are used to implement wireless communication protocols, such as frequency, spreading factor, and packet handling functions, for wireless communication among nodes and the gateway. The gateway software is implemented to receive packets from different nodes and forward them to the cloud platform using MQTT or HTTP protocols. The Blynk IoT platform is used as a cloud-based interface for real-time monitoring and control of greenhouse conditions. The Blynk project is created, and virtual pins are defined for each sensor's data stream, such as temperature, humidity, soil moisture levels, raindrops, and CO2 levels. Using Blynk API authentication tokens, the gateway or intermediate server sends data to Blynk, allowing users to view and control conditions in a greenhouse through a smartphone or a web interface. The implementation process involves steps such as sensor installation and calibration in the greenhouse to obtain accurate sensor output, programming and testing the ESP32 sensor node, and implementing the gateway software with stable internet connectivity to forward sensor data to the cloud platform. The implementation process also includes calibration and testing to verify sensor output and wireless communication reliability. Once implemented, the system continuously updates the Blynk app with real-time status from the greenhouse, allowing users to take appropriate decisions for plant management and maintenance. Additionally, this methodology can be made more comprehensive through the inclusion of automation controls that use sensor data to operate pumps or fans using Blynk commands, Node-RED or other middleware technologies, and notification tools that allow growers to be notified of critical environmental changes. The proposed solution, which uses ESP32 microcontrollers, LoRa, various environmental sensors, and Blynk, has been shown to be an effective, scalable, and user-friendly solution for precision greenhouse management.

ESP32

The ESP32 is a 32-bit microcontroller that integrates Wi-Fi, Bluetooth, and Bluetooth Low Energy (BLE) connectivity on a single chip. Designed by Espressif Systems, it is an affordable, energy-efficient microcontroller widely used in various embedded and IoT applications. The ESP32 can be programmed using either C/C++ or MicroPython, giving developers flexibility in choosing their preferred programming language. The following section introduces the IDEs that support ESP32 development for both programming environments.

IDEs for Programming ESP32 with C/C++

1.ESP-IDF

2.Arduino IDE

3.VS Code

• Arduino-like (soft) hardware IO

• Can be programmed in Lua (for embedded developers) or Arduino IDE (for faster prototyping)

• USB-TTL included, plug & play

• 10 GPIOs D0-D10, PWM, IIC, SPI, 1-Wire, ADC A0 etc.,

• Wifi connectivity (can be used as an access point and/or station, host web server), connect to internet to send or receive data

• Event-based API for Internet of Things applications,

• PCB antenna.

LORA HC-12

The HC-12 is a flexible module for sending and receiving serial data wirelessly. It is used to talk to people who are far away. The module uses the ISM band at 433 MHz. So, the module can be used for a number of projects where range is important. The UART pins connect the module to the microcontroller. A DC supply between 3.3V and 5V powers the module. AT commands are used to control the module.

1. Operating Frequency: 433.4–473.0 MHz, divided into 100 channels.
2. Communication Range: Up to 1 kilometer in open areas (depending on antenna and environment).
3. Modulation: GFSK .
4. Data Rate: Configurable, with maximum rates up to 57.6 kbps.
5. Power Supply: 3.2V to 5.5V, making it compatible with many microcontrollers.
6. Power Consumption:
    - Transmission: 22 mA (default).
    - Standby: 16 µA (low power mode).

7. Interfacing: Communicates via a simple UART (serial) interface, compatible with devices like Arduino, Raspberry Pi, and other microcontrollers.

Operation modes of hc-12

FU1 : A reduced latency balanced mode for moderate energy saving scenarios with 250,000 baud rate in air.

FU2 : Designed for low power use (80μA idle), supports 1200, 2400, 4800 bps. The best mode for simple low data sensor nodes. Range is limited to 100m or less.

FU3 : Full Speed Mode; this mode is ideal for most applications. All baud rates are supported, and maximum range is 1 km. Air baud rate will adjust automatically based on serial baud rate.

FU4 : Maximum distance - will provide up-to 1.8 km in open area. Sets the air baud rate to low rate for maximum receiver sensitivity. Provides the highest latency and limits the buffer size (only 60 bytes at 1200 bps).

DHT11

The DHT11 is a simple, very cheap digital sensor that measures temperature and humidity. It has a capacitive humidity sensor and a thermistor that measure the air around it. It sends out a digital signal on the data pin, so there are no analog input pins needed. It's not too hard to use, but you have to be careful about when you grab data. The only limitation we have found is that the data can only be accessed every 2 seconds. This means that, using our library, your sensor data will be up to 2 seconds ‘old’.

- Low cost
- powered from 3 to 5V
- I/O logic also 3 to 5V
- Current consumption only 2.5 mA typical during conversions (when reading data)
- Relative Humidity accuracy of +/-5% for range of 20 to 80%
- Temperature range of 0 to 50C +/-2C
- Sampling rate up to 1 Hz (one sample per second)
- Package size 15,5x12x5,5 mm.

CO2 Sensor

The MQ-135 gas sensor can detect gases such as Ammonia (NH3), sulfur (S), Benzene (C6H6), CO2, and smoke as well as many other toxic gasses. There are two output pins: a digital output pin and an analog output pin. As soon as the concentration of the gases reaches a set threshold, the digital output pin will generate a high signal. This threshold level can be adjusted with the onboard potentiometer. The analog output pin provides an analog voltage output that can be used as an indication of the concentration of these gases present in the air.The MQ135 air quality sensor module operates at a voltage of 5V and draws approximately 150mA; it needs to warm up before providing accurate measurements.

Soil moisture sensor

Soil moisture sensors check how much water is in the soil by volume. Because taking a direct gravimetric measurement of free-soil moisture means taking a sample, drying it, and weighing it, soil moisture sensors measure the volumetric water content indirectly by using another property of the soil, like electrical resistance, dielectric constant, or interaction with neutrons, as a stand-in for the moisture content.

The relationship between the measured property and soil moisture needs to be calibrated, and it may change based on things like the type of soil, the temperature, or the electrical conductivity. Soil moisture affects reflected microwave radiation, which is used for remote sensing in agriculture and hydrology. Farmers and gardeners can use portable probe instruments. When people talk about soil moisture sensors, they usually mean sensors that measure the amount of water in a volume. Tensiometers and gypsum blocks are two types of sensors that measure another property of moisture in soils called water potential. These sensors are often called soil water potential sensors.

Rain drop sensor

A rain sensor or rain switch is a device that turns on when it rains. Rain sensors have two main uses. The first is a water-saving device that is linked to an automatic irrigation system. If it rains, the system will turn off. The second is a device that keeps rain from getting inside a car and helps the automatic mode of the windshield wipers. Another use for professional satellite communications antennas is to turn on a rain blower on the antenna feed's aperture. This blows water droplets off the mylar cover that keeps the wave-guides dry and pressurized.

LCD 16X2

LCDs are used in a wide range of applications from computer monitors to televisions, to instrument panels, to aircraft cockpit displays, to indoor and outdoor signs. Small Crystal Displays are commonly found in portable electronic devices such as digital watches, calculators, mobile phones, and laptop computers. Other uses for LCDs include TVs, DVD players, video and audio equipment, and clocks. These displays have completely replaced older, heavier, and bulkier CRT displays. They are used in all sizes, ranging from small displays used in PDAs and digital watches to larger television LCDs.

Table 1. LCD Pin Description

Pin No	Function	Name
1	Ground (0V)	Ground
2	Supply voltage; 5V (4.7V – 5.3V)	Vcc
3	Contrast adjustment; through a variable resistor	V_{EE}
4	Selects command register when low; and data register when high	Register Select
5	Low to write to the register; High to read from the register	Read/write
6	Sends data to data pins when a high to low pulse is given	Enable
7	8-bit data pins	DB0
8		DB1
9		DB2
10		DB3
11		DB4
12		DB5
13		DB6
14		DB7
15	Backlight V_{CC} (5V)	Led+

The command register holds the instructions for the LCD. A command tells the LCD to perform a specific task, such as initializing it, clearing the screen, setting the cursor position, or controlling the display. The data register contains the information to be shown on the LCD. The data is the ASCII value of the character that will appear on the screen.

Buzzer

A buzzer (or beeper) is an audio signaling device that can be made of metal, plastic, or piezoelectric materials. A buzzer is a multifunctional electronic device that consists of an electrical transducer, DC power supply, and is used for creating sound in electronic devices including but not limited to computers, printers, copiers, alarms, electronic toys, automotive electronics, telephones, and timers. Commonly used for sound applications, buzzers and beepers may also be used as alarm devices, timing devices, and can confirm to users their input, e.g., on a mouse click or keystroke.

The Passive buzzer has 3 pins as follows:

1. I/O
2. Vcc
3. Gnd

5V Battery

Electronic devices have become an essential aspect of our daily lives in this ever-growing digital and connected world. From smartphones and tablets to IoT devices and other electronics, there are no limits to what type of device can be created; they all need a steady and reliable standard power source for them to work. The 5V adaptor, also known as a 5V power supply or 5V charger, is a critical component to accomplish this. A 5V adaptor is a power supply unit that takes higher voltage levels (i.e., AC or DC) and transforms them into a stable 5V direct current (DC) output to help power or charge numerous different types of electronic devices, which is why the 5V output level is so commonly referred to as "standard" because it represents the majority of all consumer electronics and micro-electronics component in existence today. These adaptors come in various forms, such as wall adapters, USB chargers, or standalone power supplies, and are typically equipped with a cable or connector that matches the device's input port. When connected to a compatible device, the 5V adaptor provides a reliable and safe source of power, ensuring the device functions optimally.

IV Discussion

LoRa HC-12, an ESP32, and DHT-11 Humidity, and Soil Moisture Sensors were integrated into a Greenhouse monitoring system that demonstrates an effective and dependable solution for getting, storing, and transmitting real-time data on environmental monitoring conditions. Critical environmental parameters were captured by the monitoring system. The monitoring system did provide accurate and sufficient environmental data to identify critical parameters, allowing the production zone maintain optimal greenhouse growing conditions. The MQ135 Air Quality Sensor accurately identified air quality through measuring pollutants and provided enough information about harmful gases that adversely affect plants in a timely manner so that action could be taken as necessary. The soil moisture sensor was able to accurately represent actual and immediate soil moisture content to efficiently find a baseline for precise irrigation management, while also preventing under and/or over-watering. The raindrop sensor effectively provided information on when rain occurred to give the Greenhouse Monitoring System an understanding of the environmental parameters that responded with rain, allowing the irrigation schedule to be changed if necessary based on the rainfall event. Collected temperature and relative humidity data from the DHT11 Sensor confirm that the DHT11 Sensor is appropriate for monitoring a microclimate within a Greenhouse setting for obtaining accurate temperature and relative humidity. Overall, the ESP32 microcontroller proved to be an important part of this system due to its high processing power and built-in Wi-Fi; when combined with the LoRa HC-12 module, it provided the ability to communicate over long distances with very low power requirements using wireless communication. This hybrid communications system also assured the integrity of the data being transmitted and reduced latency even if the greenhouse is located far from the monitoring station; by using the MQTT protocol, it provided a method for transmitting data quickly and efficiently between the greenhouse sensors and a cloud platform or local server where that data can be analyzed or visualized. From analyzing the data from the sensors, it was determined that this system was able to detect changes in the greenhouse's environment very quickly; therefore, timely intervention can take place to ensure optimal conditions in which to grow plants. For example, sporadic changes in soil moisture levels were consistent with the timing of each irrigation event to validate that the system was working as intended to monitor the supplies of water used for irrigation. Additionally, spikes in MQ135 data showed that there are times when the presence of pollutants in the greenhouse increases, indicating that ventilation adjustments should be made. By using multiple types of sensors, it also provided a more complete view of the greenhouse's environment rather than just measuring one parameter at a time. In addition, the modular design of the system allows flexibility with the ability to expand it to more greenhouses or change the size and/or type of crop to grow in the greenhouse. Due to the technology being advanced, there is a much lower amount of energy required for operation, which results in much longer field dead time when working remotely or with larger agricultural sites. The ability for growers to have access to data in real time provides them with applications to potentially improve their overall yield quality and sustainability by optimizing their use of resources.

TRANSMITER

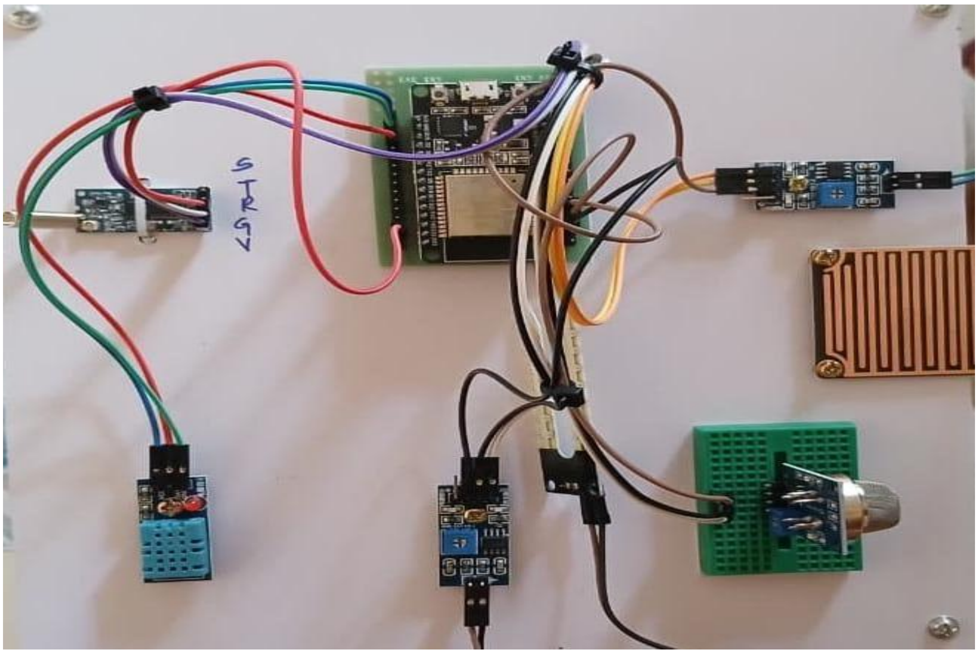

Figure 2. Transmitter Section

RECEIVER

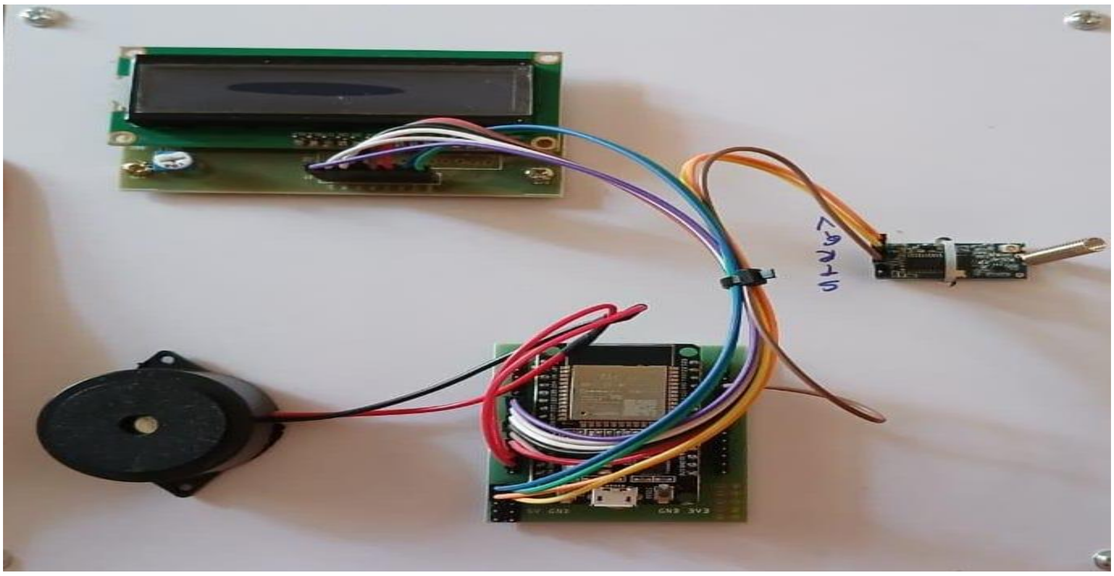

Figure 3. Receiver Section

Figure 4. Sensor readings

V Conclusion

The greenhouse monitoring system proved that a combination of LoRa HC12 communications, ESP32 processing, and multiple sensors can create a complete and integrated, real-time monitoring solution. This monitoring system improves the overall environmental conditions within greenhouses, provides growers with many options for utilizing and controlling multiple types of resources, and reduces the amount of environmental stressors placed on their crops through sustainable agricultural practices.

VI Future Scope

Greenhouse monitoring systems using the integration of LoRa, HC-12, and ESP32 with MQ-135, DHT-11, soil moisture sensors and raindrop sensors is very large and has many opportunities for improvement and growth. One area of focus is the development of advanced machine learning algorithms for the analysis of the sensor data to provide more accurate predictions for crop health, potential disease outbreaks and to better plan for irrigation schedules. This would allow the greenhouse monitoring system to evolve from being simply a monitoring device to becoming an intelligent decision-making platform capable of intervening proactively in managing the conditions of the greenhouse. In addition, there is the possibility of expanding the sensor array to include additional environmental parameters such as light intensity, CO2 concentration, and nutrient levels. Expanding the number of environmental parameters being monitored will increase the overall environmental profile of the greenhouse, which will improve the overall accuracy and reliability of the greenhouse monitoring system. Another area of focus for future developments will be the enhancement of communications protocols. Both LoRa and HC-12 provide long-range, reliable wireless communication; however, adding future technology such as NB-IoT or 5G would improve the speed at which data can be transmitted and provide better scalability of the network for larger greenhouse operations. Additionally, the implementation of edge computing on the ESP32 microcontroller could reduce latency through data processing at the local level before transmitting to the cloud, increasing real-time responsiveness and minimizing bandwidth. The final step in enabling large-scale commercial agriculture production using this system would be to use multiple sensor network hubs across multiple greenhouses or larger agricultural fields and have them communicate back to a centralized data management system for all the data collected from those locations. More importantly, integrating automated systems that control water, air and shade using actuators would complete the loop between monitoring, control and environmental management in an autonomous greenhouse management system.

Declaration

1.Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

2.Funding information

This research received no external funding.

3.Author contribution

All authors contributed to the conception and design of the study. The hardware and software development, data collection, system implementation, testing, and analysis were carried out collaboratively. The manuscript was drafted, reviewed, and approved by all authors, who agree to be accountable for all aspects of the work.

4.Data Availability Statement

The data generated and analyzed during this study are available from the corresponding author upon reasonable request. The source code and hardware design details are described within the manuscript.

5.Research Involving Human and/or Animals

This research did not involve human participants, human biological materials, or animals. Therefore, ethical approval was not required.

6.Informed consent-Not Applicable

References

[1] Ahonen, T., Virrankoski, R., & Elmusrati, M. (2008). Greenhouse monitoring with wireless sensor network. In *2008 IEEE/ASME International Conference on Mechtronic and Embedded Systems and Applications* (pp. 403-408). Beijing, China. https://doi.org/10.1109/MESA.2008.4735744

[2] Pawlowski, A., Guzman, J. L., Rodríguez, F., Berenguel, M., Sánchez, J., & Dormido, S. (2009). Simulation of greenhouse climate monitoring and control with wireless sensor network and event-based control. *Sensors* 2009, 9, 232-252. https://doi.org/10.3390/s90100232

[3] Sabri, N., Aljunid, S. A., Ahmad, R. B., Abd Malek, M. F., Yahya, A., Kamaruddin, R., & Salim, M. (2012). Smart prolong fuzzy wireless sensor-actor network for agricultural application. *Journal of Information Science and Engineering*. 28. 295-316.

[4] S. Somarathi, "Design of Greenhouse Control System Using Wireless Sensor Networks", *IJSBAR*, vol. 2, no. 1, pp. 1–8, Oct. 2010, Accessed: Mar. 24, 2026. [Online].

[5] M. E. Diago Mosquera and J. A. Carbonell Gonzalez, "Communications system for a soil monitoring network in Valle del Cauca, Colombia," *2015 Workshop on Engineering Applications - International Congress on Engineering (WEA)*, Bogota, Colombia, 2015, pp. 1-5, doi: 10.1109/WEA.2015.7370131.

[6] L. Dan, C. Xin, H. Chongwei and J. Liangliang, "Intelligent Agriculture Greenhouse Environment Monitoring System Based on IOT Technology," *2015 International Conference on Intelligent Transportation, Big Data and Smart City*, Halong Bay, Vietnam, 2015, pp. 487-490, doi: 10.1109/ICITBS.2015.126.

[7] Erazo-Rodas, M.; Sandoval-Moreno, M.; Muñoz-Romero, S.; Huerta, M.; Rivas-Lalaleo, D.; Naranjo, C.; Rojo-Álvarez, J.L. Multiparametric Monitoring in Equatorian Tomato Greenhouses (I): Wireless Sensor Network Benchmarking. *Sensors* 2018, *18*, 2555. https://doi.org/10.3390/s18082555.

[8] Danita, M. & Mathew, Blessy & Shereen, Nithila & Sharon, Namrata & Paul, J.. (2018). IoT Based Automated Greenhouse Monitoring System. 1933-1937. 10.1109/ICCONS.2018.8662911.

[9] Anjana M , Sowmya M S , Charan Kumar A , Monisha R, Sahana R H, 2020, IOT in Agricultural

Crop Protection and Power Generation, INTERNATIONAL JOURNAL OF ENGINEERING RESEARCH & TECHNOLOGY (IJERT) Volume 09, Issue 05 (May 2020).

[10] V. Kumar. P, K. C. Ramya, A. J.S, A. T.S, B. B and G. V, "Smart Garden Monitoring and Control System with Sensor Technology," *2021 3rd International Conference on Signal Processing and Communication (ICPSC)*, Coimbatore, India, 2021, pp. 93-97, doi: 10.1109/ICSPC51351.2021.9451788.

[11] M. Anisha *et al*., "Arduino based Low-Cost Greenhouse Monitoring System for Small Scale Farmers," *2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV)*, Tirunelveli, India, 2021, pp. 1120-1127, doi: 10.1109/ICICV50876.2021.9388402.

[12] Cao, X., Yao, Y., Li, L., Zhang, W., An, Z., Zhang, Z., ... & Luo, D. (2022, June). igrow: A smart agriculture solution to autonomous greenhouse control. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 36, No. 11, pp. 11837-11845).

[13] Laktionov, Ivan, et al. "Information Technology for Comprehensive Monitoring and Control of the Microclimate in Industrial Greenhouses Based on Fuzzy Logic." *Journal of Artificial Intelligence and Soft Computing Research*, vol. 13, no. 1, SAN University, 2022, pp. 19-35. https://doi.org/10.2478/jaiscr-2023-0002.

[14] M. Dhanaraju, Poongodi Chenniappan, Kumaraperumal Ramalingam, S. Pazhanivelan, and R. Kaliaperumal, "Smart Farming: Internet of Things (IoT)-Based Sustainable Agriculture," *Agriculture*, 2022, doi: 10.3390/agriculture12101745.

[15] Attila Simó, Simona Dzitac, Amalia Duțu, and Ionut Pandelica, "Smart Agriculture in the Digital Age: A Comprehensive IoT-Driven Greenhouse Monitoring System," *International Journal of Computers Communications & Control*, 2023, doi: 10.15837/ijccc.2023.6.6147.

[16] F. Avendaño Macias, "VANET Network Simulation for Greenhouse Monitoring Utilizing Two Mobile Differential Robot Nodes", *Int. Journal of COP and Infor.*, vol. 15, no. 5, pp. 64–74, Nov. 2024.

[17] Nabiha Ben Abid, Abdalla M. Khattab, Hani A.M. Harb, Chokri Souani . An IoT-based Smart Agriculture System using LoRa and Cloud Monitoring for Automated Greenhouse Control. International Journal of Computer Applications. 187, 52 (Nov 2025), 7-15. DOI=10.5120/ijca2025925788.

[18] Sabyasachi Mondal, and Patil Manisha Prashant, "IoT-Enabled Smart Greenhouses: Real-Time Environmental Monitoring and Climate Control," *SHS Web of Conferences*, vol. 216, 2025, doi: 10.1051/shsconf/202521601067.

[19] Kshitimoni Gogoi, Neeraj Semwal, Devendra Kumar, Arun Uniyal, and Arvind Kumar, "Greenhouse Environmental Monitoring and Control Using ThingSpeak," *Innovative Energy Systems and Technologies*, 2025, doi: 10.64229/0e52d969.

[20] Prof. Palwe Priyanka, Atharva Ubale, Piyush Shipankar, Jagruti Shinde, Gaikwad Balkisan, and Pravin Meher, "Smart Agriculture Monitoring and Automated Irrigation System Using IoT,"

International Journal of Advanced Research in Science Communication and Technology, 2026, doi: 10.48175/ijarsct-31036.