Internet of Things (IoT) for Smart Precision Agriculture and Farming in Rural Areas

PROJECT REPORT

Submitted in the fulfilment of the requirements for

the award of the degree of

Bachelor of Technology
in
Electronics and Communication Engineering

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VIGNAN'S
Foundation for Science, Technology & Research
(Deemed to be University)
-Estd. u/s 3 of UGC Act 1956

(ACCREDITED BY **NAAC** WITH **"A^{+}"** GRADE)

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
(ACCREDITED BY **NBA**)

VIGNAN'S FOUNDATION FOR SCIENCE, TECHNOLOGY AND RESEARCH
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May 2024

CERTIFICATE

This is to certify that project report entitled **"Internet of Things (IoT) for Smart Precision Agriculture and Farming in Rural Areas"** that is being submitted by Bapanapalli Abhignu [201FA05003], Paramkusam Chandu Gopala Krishna [211LA05015], Kothuri Mahesh [211LA05034] in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering, Vignan's Foundation for Science Technology and Research University, is a record of bonafide work carried out by them under the guidance of Dr. Sk. Jakeer Hussain of ECE Department.

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DECLARATION

We hereby declare that the project report entitled **"Internet of Things (IoT) for Smart Precision Agriculture and Farming in Rural Areas"** is being submitted to Vignan's Foundation for Science, Technology and Research (Deemed to be University) in fulfilment for the award of B. Tech degree in Electronics and Communication Engineering. The work was originally designed and executed by us underthe guidance of Dr. Sk. Jakeer Hussain at the Department of Electronics and CommunicationEngineering, Vignan's Foundation for Science Technology and Research (Deemed to be University) and was not a duplication of work done by someone else. We hold the responsibility of the originality of the work incorporated into this project report.

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Abstract

Internet of Things (IoT) gives a new dimension in the area of smart farming and agriculture domain. With the use of fog computing and Wi-Fi-based long-distance network in IoT, it is possible to connect the agriculture and farming bases situated in rural areas efficiently. To focus on the specific requirements, we propose a scalable network architecture for monitoring and controlling agriculture and farms in rural areas. Compared to the existing IoT based agriculture and farming solutions, the proposed solution reduces network latency up to a certain extent. In this, a cross-layer based channel access and routing solution for sensing and actuating is proposed. We analyze the network structure based on coverage range, throughput, and latency

KEYWORDS: Precision Agriculture, ESP-NOW PROTOCOL.

Major Design (Final Year Project Work) Experience Information

Student Group	BAPANAPALLI ABHIGNU (201FA05003)	PARAMKUSAM CHANDU GOPALA KRISHNA (211LA05015)	KOTHURI MAHESH (211LA05034)
Project Title	Internet of Things (IoT) for Smart Precision Agriculture and Farming in Rural Areas		
Program ConcentrationArea	IoT and Embedded System Design and Sensors.		

Constraints – Examples

Economic	Cost Effective Systems
Environmental	Yes
Sustainability	Yes
Implementable	Yes
Ethical	Followed the standard professional ethics
Health and Safety	NA
Social	Applicable for farmers
Political	NA
Other	This paper focus on the specific requirements, we propose a scalable network architecture for monitoring and controlling agriculture and farms in rural areas. Compared to the existing IoT based agriculture and farming solutions, the proposed solution reduces network latency up to a certain extent

Standards

1. IEEE 802.15.4 with 2.4 GHz 2. IEEE 802.11	1.Provides a standardized frame work for building low-power, low-cost wireless communication solutions suitable for wide range of applications. 2. It is crucial for precision agriculture because it enables the use of sensor networks.
Prerequisite Course Required for the Major Design Experience	1.Data Communications and Computer networks
	2. Internet of Things (IoT)

Supervisor

Project coordinator

24/5/24.

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CONTENTS

LIST OF FIGURES

ACRONYMS and ABBREVIATIONS:

- Arduino IDE: Arduino Integrated Development environment
- DHT-11: Digital Humidity and temperature
- IoT: Internet of things
- NODEMCU: Node microcontroller unit

CHAPTER-1

INTRODUCTION

Soft precision agriculture depends on visual observation of crops and soil management decisions based on experience and intuition, rather than statistical and scientific analysis. In contrast, hard precision agriculture uses all modern techniques such as GPS, remote sensing, and variable rate technology. As a result, an agriculture company manager or farmer will be able to adapt to and predict environmental changes, reduce risks when creating distribution strategies, and make informed decisions. Sensors. They have the capacity to detect a range of bimolecular, chemical, optical, thermal, electrical, radiation,and biological metrics to get a 360-degree view on the health of crops. By mounting health monitoring sensors on animals, farmers can track the state of livestock in real time. Precision farming software. Controller tools are widely used in IoT-based precision agriculture technology. IoT improves software maintenance (e.g. automatic equipment updates) and introduces new solutions for farm management (managing a safe-driving tractor remotely via a controller). The capacity of modern precision agriculture and IoT allows controlling dozens of equipment units simultaneously. While a fair share of network protocols works efficiently on short rangers (ZigBee or Wi-Fi), it's the long-range ones that are the most beneficial for precision agriculture. The most widely used connectivity protocols used by intelligent farming are cellular connection, Lora WAN, LPWAN, and a few others. Satellites are widely used to estimate the amount of water in the soil, crop biomass, and many other metrics. The data collected by connected GPS satellites or a location monitoring solution is then used by crop insurance companies, governments, scientists, policy makers and commodity bodies. Crop management devices are a crucial component for using precision Ag technology efficiently. These devices are typically placed on the field they will monitor water levels crop health, and other relevant biochemical and physical properties. Using crop monitoring tools, a farmer can proactively manage anomalies, build prediction-based models and strategies, and prevent potentially harmful diseases.

1.1 MOTIVATION

The Internet of Things (IoT) is a modern developing mechanism that has taken over networked cloud applications, ranging from electrical to digital systems, mechanical, as well as individuals with unique IDs. By far the most important consideration of the IoT is the potential to transmit data without the need for a human transmission interface. Attributed to the reason that the field is stretched across a large region of farmland for agricultural or animal gazing, the application of Wireless Sensor Nodes (WSN) is the best way to solve the problem. The actuator modules are interconnected to the Personal Area Network (PAN) as they consume a huge amount of power which is not as numerous as the sensor nodes. This comprehensive framework can be integrated into an IoT-based system by utilizingexisting Local Area Network (LAN) and Internet infrastructure. Agricultural digitization is advancingin the majority of emerging countries. In Japan, computerized crop breeding, insect utilization agricultural management, and the preparation of meteorological reports are all common. Farmers in the United States (US) have access to large data cloud systems, as well as government databases for agriculture, research institutes, and libraries. Farmers can use the database to acquire up-to-date market prices, crop improvement, and growing skills and technology in the agriculture sector. Computers can assist farmers in determining the best crops to plant, the best seasons to grow them, and the best farming mode to use, resulting in farms with the maximum yields and benefits.

1.2 OBJECTIVES OF WORK

- The primary objective is to establish a robust and reliable communication infrastructure utilizing the ESP-NOW protocol to facilitate seamless data transmission between sensor nodes deployed across agricultural fields and the Thing-Speak cloud platform.
- Another key objective is to ensure the secure and efficient storage of sensor data in the Thing-Speak cloud, enabling farmers and agricultural practitioners to access historical andreal-time data insights from any location with internet connectivity.

CHAPTER-2

2.1 LITERATURE REVIEW

S.NO	Title	Authors	Year	Content
1	Enhancing Crop Yields through IoT-Enabled Precision Agriculture	Dr. Rashmi Sharma	2023	It provides the soil with the proper crop based on a number of factors, including soil moisture content
2	Indoor Performance Evaluation of ESP-NOW	Dnislam Urazayev	2023	ESP-NOW can achieve a slightly longer range than a typical Wi-Fi TCP approach in presence of manyobstacles
3	IOT Based Monitoring System for Precision Agriculture	Yash Bhoani	2020	It is very useful in making accurate decisions based on the visualized data. All the data collected by different sensors is analyzed and visualized in the form of graphs.
4	Efficient IoT system for Precision Agriculture	George Suciu	2019	IoT technology used in irrigation management systems of precision agriculture should meet water needs to increase crop productivity

CHAPTER-3

3.1 Proposed work flow

The proposed workflow for precision agriculture utilizing the ESP-NOW protocol in conjunction with the ThingSpeak cloud platform entails a streamlined process geared towards optimizing crop management practices. Beginning with the deployment of ESP-NOW-enabled sensor nodes across the agricultural field, data collection commences promptly. These sensors, equipped with a range of environmental monitoring capabilities, gather essential data on soil moisture, temperature, humidity, and other pertinent factors crucial for crop health. Leveraging the efficient communication protocol of ESP-NOW, collected data is seamlessly transmitted to a central gateway device within the field. Acting as a conduit, this gateway device aggregates the incoming data before facilitating its transfer to the ThingSpeak cloud platform. Once within the cloud, the data is organized and stored in channels, ready for analysis and visualization. Farmers gain access to real-time insights via user-friendly dashboards, empowering them to remotely monitor field conditions and make informed decisions. By harnessing ThingSpeak's analytical tools, users can delve deeper into the data, identifying trends, anomalies, and correlations that inform strategic agricultural interventions. Furthermore, integration with decision support systems augments decision-making capabilities, offering personalized recommendations tailored to specific farming contexts. Alerts and notifications serve as proactive measures, alerting farmers to critical events or deviations from predefined thresholds. This iterative process of data collection, analysis, and action fosters continuous monitoring and optimization of crop management practices, driving improvements in productivity, efficiency, and sustainability across agricultural operations.

IEEE 802.15.4:

The IEEE 802.15.4 standard defines several PHY and MAC layer options, including different frequency bands such as 868 MHz, 915 MHz, and 2.4 GHz. The 2.4 GHz frequency band is particularly popular due to its availability and worldwide acceptance.

Devices compliant with IEEE 802.15.4 standards often form mesh networks, enabling communication between multiple devices in a network without requiring a centralized access point. These networks can be self-organizing and self-healing, meaning devices can join or leave the network dynamically, and the network can adapt to changes in topology automatically.

Overall, IEEE 802.15.4 with 2.4 GHz provides a standardized framework for building low-power, low-cost wireless communication solutions suitable for a wide range of applications.

ESP-NOW (Espressif Simple Protocol - Network of Wares) is not directly related to the IEEE 802.11 standards, but it is a proprietary wireless communication protocol developed by Espressif Systems, the company behind the popular ESP8266 and ESP32 microcontroller platforms.

IEEE 802.11:

While IEEE 802.11 standards (Wi-Fi) are commonly used for traditional wireless networking applications, ESP-NOW is optimized for low-power, low-latency, and peer-to-peer communication between ESP8266 and ESP32 devices. It operates on the 2.4 GHz frequency band, similar to Wi-Fi, but it is designed for simpler and more direct communication between devices within a local network.

Peer-to-Peer Communication- Devices communicate directly with each other without the need for a centralized access point (AP). This makes ESP-NOW suitable for scenarios where devices need to exchange data quickly and efficiently in a peer-to-peer manner.

Overall, ESP-NOW offers a lightweight and efficient alternative to Wi-Fi for certain IoT and embedded applications, particularly those requiring low-power, low-latency, and peer-to-peer communication between ESP8266 and ESP32 devices.

CHAPTER-4

Components

4.1.1 NODEMCU

Node-MCU is a highly versatile and widely embraced open-source development board renowned for its integration of the ESP8266 or ESP32 microcontrollers alongside on board Wi-Fi capabilities. Originally crafted for IoT prototyping, Node-MCU's appeal lies in its user-friendly interface, low-cost accessibility, and compatibility with the Arduino IDE and Lua scripting language. Furthermore, Node-MCU's support for the Arduino IDE and Lua scripting language provides developers with flexible programming options, ensuring accessibility and adaptability in project development. Boasting GPIO pins and expansion headers, Node-MCU boards enable easy integration with external sensors, actuators, and peripherals, facilitating the creation of tailored IoT solutions. Its USB connectivity simplifies both power supply and serial communication, enhancing usability and accessibility for developers. Supported by a vibrant and extensive community, Node-MCU benefits from a wealth of shared resources, tutorials, and project ideas, fostering a collaborative environment conducive to innovation and learning. Overall, Node-MCU stands as a stalwart platform for IoT exploration, offering a potent combination of versatility, affordability, and community support for developers seeking to realize their IoT aspirations. GPIO Pins Node-MCU/ESP8266 has 17 GPIO pins which can be assigned to functions such as I2C, I2S, UART, PWM, IR Remote Control, LED Light and Button programmatically. Each digital enabled GPIO can be configured to internal pull-up or pull-down, or set to high impedance. At the heart of Node-MCU is the ESP8266 or ESP32 microcontroller, renowned for its low cost, energy efficiency, and robust wireless communication capabilities. With onboard Wi-Fi connectivity, Node-MCU enables seamless integration with wireless networks, facilitating data exchange and communication with other IoT devices and services over the internet. This feature makes Node-MCU ideal for applications requiring remote monitoring, control, and automation, such as home automation, environmental sensing, and smart agriculture. Node-MCU stands as a versatile and accessible development board renowned in the IoT community for its integration of the ESP8266 Wi-Fi module. Designed to simplify IoT project development, Node-MCU offers a myriad of features and capabilities. Initially recognized for Lua scripting language support, Node-MCU allows for rapid prototyping and development through its straightforward scripting interface. Moreover, its compatibility with the Arduino IDE expands its appeal, enabling users familiar with Arduino programming to leverage their existing knowledge. Equipped with GPIO pins supporting digital and analog I/O, as well as communication protocols like I2C, SPI, and UART, Node-MCU facilitates seamless interfacing with a diverse range of peripheral devices. Its built-in Wi-Fi connectivity empowers developers to create IoT applications that can connect to local networks, access the internet, and communicate with other devices wirelessly. The USB interface simplifies programming, debugging, and powering the board, enhancing its usability. Node-MCU's vibrant community contributes to its ecosystem with a wealth of libraries, tutorials, and resources, fostering collaboration and support for users of all skill levels.

Whether for home automation, sensor networks, or remote monitoring, Node-MCU continues to serve as a go-to platform for IoT enthusiasts and professionals seeking a versatile, affordable, and feature-rich solution. Node-MCU, an ESP8266-based development board, revolutionizes IoT prototyping with its blend of versatility, affordability, and connectivity. At its heart lies the ESP8266 module, renowned for its powerful MCU and integrated Wi-Fi capabilities, enabling seamless communication with networks and devices. - support for Lua scripting simplifies development, offering ahigh- level language ideal for rapid prototyping and experimentation. Moreover, its compatibility with the Arduino IDE broadens its appeal, catering to a diverse range of developers and projects. Equipped with GPIO pins, Node MCU facilitates interfacing with sensors, actuators, and displays, while its USB interface streamlines programming and debugging workflows. The board's compact form factor and low cost make it accessible to hobbyists, students, and professionals alike, empowering them to explore the vast potential of IoT. From home automation and smart agriculture to industrial monitoring and beyond, Node MCU serves as a versatile platform for bringing innovative ideas to life. Its vibrant community fosters collaboration and knowledge-sharing through forums, tutorials, and open-source contributions, enriching the ecosystem and supporting users at every step of their journey. As the IoT landscape continues to evolve, Node-MCU remains at the forefront, driving innovation and enabling new possibilities in connected systems and smart devices. Node-MCU's appeal extends beyond its hardware specifications, encompassing a rich ecosystem of software tools and resources. The board's compatibility with popular development environments like Platform and Visual Studio Code enhances its versatility, catering to diverse programming preferences and workflows. Additionally, Node-MCU benefits from extensive third-party support, with a vast array of community-contributed libraries and projects available for users to leverage. This wealth of resources spans various domains, including sensor libraries, communication protocols, and IoT frameworks, accelerating development and reducing time to market for projects. Furthermore, Node-MCU's open-source nature fosters innovation and collaboration, allowing users to modify and extend the platform to suit their specific needs. Its robust documentation and active community forums serve as valuable knowledge hubs, providing troubleshooting assistance, project ideas, and best practices. As IoT adoption continues to surge, Node-MCU remains a stalwart ally for developers, empowering them to create scalable, reliable, and feature-rich IoT solutions with ease. Whether embarking on educational endeavors, hobbyist projects, or commercial ventures, Node-MCU stands ready to unlock the potential of the Internet of Things for all.

FIG 1 Node-MCU

4.1.2 Pin configuration of Node-MCU

- **Vin**: This pin is used to supply external power to the board. It can accept voltages between 5V and 12V.
- **GND (Ground**): This pin is connected to the ground of the system.
- **3V3**: This pin outputs a regulated 3.3V voltage. It can be used to power external components that require 3.3V.
- **EN (Enable):** This pin is used to enable or disable the module. It is typically connected to VCC (3.3V) to enable the module.
- **D0 to D8**: These pins are general-purpose digital I/O pins. They can be used for digital input or output.
- **A0**: This pin is an analog input pin. It can measure analog voltages between 0V and 3.3V.
- **RX (Receive**): This pin is used for serial communication. It is the receive pin for the UART interface.
- **TX (Transmit):** This pin is used for serial communication. It is the transmit pin for the UART interface.
- **SDA (Serial Data):** This pin is used for I2C communication as the data line.
- **SCL (Serial Clock):** This pin is used for I2C communication as the clock line.
- **GPIO16 (D0):** This pin is also labelled as D0. It is special because it can be used to wake up the ESP8266 from deep sleep mode.
- **Reset**: This pin is used to reset the module.

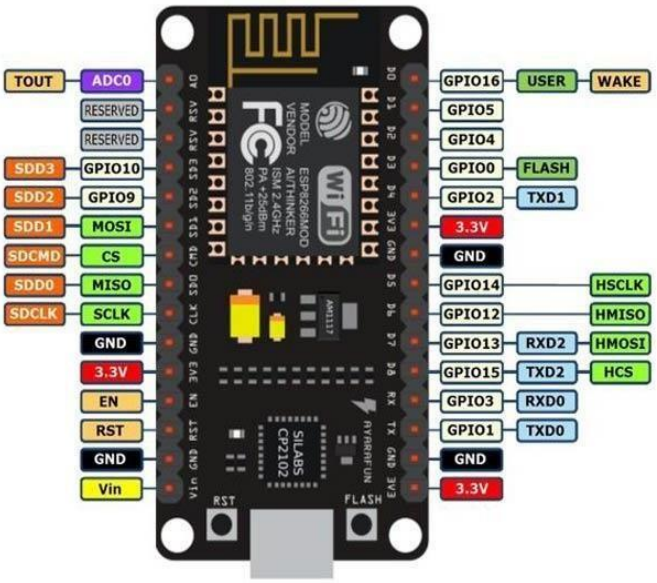


FIG 2 Pin configuration of Nodemcu

4.1.3 DHT 11 Sensor

The DHT11 is a commonly used Temperature and humidity sensor that comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data. The sensor can measure temperature from 0°C to 50°C and humidity from 20% to 90% with an accuracy of ±1°C and ±1%. So if you are looking to measure in this range then this sensor might be the right choice for you. he sensor comes with a dedicated NTC to measure temperature and an 8-bit microcontroller to output the values of temperature and humidity as serial data. The sensor is also factory calibrated and hence easy to interface with other microcontrollers. The DHT11 sensor stands as a fundamental component in various IoT applications, renowned for its capability to accurately measure temperature and humidity levels. Its design typically incorporates a capacitive humidity sensor and a thermistor for temperature measurement, encapsulated within a compact housing. Operating on a digital communication protocol, the DHT11 sensor provides a simple yet effective means of monitoring environmental conditions in real-time. With its affordability, ease of use, and widespread availability, the DHT11 sensor finds extensive use in projects spanning from home automation to weather monitoring systems. Despite its lower accuracy and slower response times compared to more advanced sensors, the DHT11 remains a popular choice among hobbyists, students, and professionals alike, owing to its simplicity and reliability. When integrated into microcontroller-based platforms like Arduino or NodeMCU, the DHT11 sensor facilitates seamless data collection, enabling users to gain valuable insights into temperature and humidity variations within their environments. Whether deployed in smart thermostats, weather stations, or agricultural monitoring systems, the DHT11 sensor continues to play a pivotal role in enabling data-driven decision-making and enhancing overall efficiency and comfort in a variety of applications.

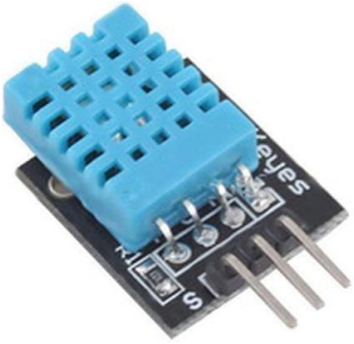


Fig 3 DHT 11 sensor

4.1.4 Specifications of DHT 11 Sensor

S.NO	Specifications	Range
1	Operating Voltage	3.3V to 5.5V
2	Operating current	0.3mA
3	Output	Serial data
4	Temperature Range	0°C to 50°C
5	Humidity Range	20% to 90%
6	Resolution	Temperature and Humidity both are 16-bit

4.1.5 Pin configuration of DHT 11 Sensor

The DHT11 sensor typically has four pins, which are used for power supply, data communication, and ground connection. Here's the pin configuration of the DHT11 sensor:

- **VCC (Power):** This pin is used to supply power to the sensor. It is usually connected to the 3.3V or 5V pin of the microcontroller or development board.
- **Data**: This pin is used for bidirectional communication between the sensor and the microcontroller. It sends temperature and humidity data from the sensor to the microcontroller and receives commands or initialization signals from the microcontroller.
- **NC (Not Connection):** Some DHT11 sensor modules may have an additional pin labelled as NC, which is not connected and can be left unused.
- **GND (Ground**): This pin is connected to the ground (GND) of the microcontroller or development board.

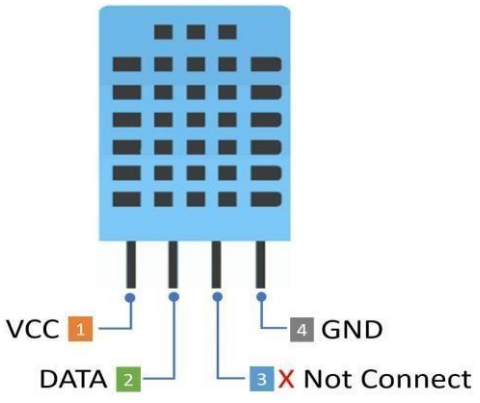
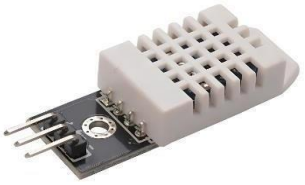


Fig 4 Pin configuration of DHT 11 Sensor

4.1.6 Comparison between DHT11 and DHT 22 Sensor

S.NO	Specifications	DHT 11	DHT 22
1	Diagram		
2	Operating voltage	3.3V to 5.5V	3.3V to 5.5V
3	Operating current	0.3mA	1.5mA
4	Temperature Range	0°C to 50°C	-40°C to 80°C.
5	Humidity Range	20% to 90%	0-100%RH.
6	Sampling rate	1Hz	0.5Hz
7	Accuracy	Less	High

4.1.7 Rain Sensor

Rain sensors serve as critical components in weather monitoring systems, providing valuable data on precipitation levels and rainfall patterns. These sensors employ various technologies, including conductivity, capacitance, and optical methods, to detect the presence and intensity of raindrops. One prevalent type utilizes a conductivity-based mechanism, where raindrops create a conductive path between two electrodes, resulting in a change in resistance that indicates rainfall intensity. Another approach involves capacitance-based sensors, which detect changes in capacitance caused by water droplets on a surface. Optical rain sensors utilize light-based techniques to detect raindrops passing through a beam of light, with variations in light intensity indicating rainfall intensity. Irrespective of the technology employed, rain sensors play a crucial role in agriculture, hydrology, and urban planning. In agriculture, these sensors aid farmers in optimizing irrigation schedules by providing real-time data on rainfall, ensuring efficient water management and crop health. In hydrological monitoring, rain sensors assist in assessing runoff and soil moisture levels, aiding in flood prediction and water resource management. Moreover, urban planners rely on rain sensors to design effective drainage systems and mitigate the impact of heavy rainfall on infrastructure and transportation networks. Overall, rain sensors are indispensable tools for monitoring and responding to changes in weather conditions, facilitating informed decision-making and resilience in the face of environmental challenges. Rain sensors, often integrated into automated irrigation systems, play a pivotal role in water conservation efforts and efficient landscape management. These sensors are designed to detect rainfall and trigger irrigation systems to suspend watering during periods of precipitation. By utilizing conductivity, capacitance, or optical methods, rain sensors can accurately measure the intensity and duration of rainfall, allowing for precise control over irrigation schedules. This technology not only prevents overwatering and water wastage but also helps preserve soil health and prevent runoff, erosion, and nutrient leaching. Additionally, rain sensors contribute to cost savings by reducing water bills and minimizing the need for manual adjustments to irrigation schedules. In both residential and commercial settings, rain sensors promote sustainable landscaping practices and environmental stewardship by aligning irrigation with natural weather patterns, ultimately leading to healthier plants, reduced water consumption, and a greener future. This module is similar to the LM393 IC because it includes the electronic module as well as a PCB. Here PCB is used to collect the raindrops. When the rain falls on the board, then it creates a parallel resistance path to calculate through the operational amplifier.

Fig 5 Rain sensor

4.1.8 Specifications of Rain sensor

- This sensor module uses good quality of double-sided material.
- Anti-conductivity & oxidation with long time use
- The area of this sensor includes 5cm x 4cm and can be built with a nickel plate on the side
- The sensitivity can be adjusted by a potentiometer
- The required voltage is 5V
- The size of the small PCB is 3.2cm x 1.4cm
- For easy installation, it uses bolt holes
- It uses an LM393 comparator with wide voltage
- The output of the comparator is a clean waveform and driving capacity is above 15mA

4.1.9 Pin configuration of Rain sensor

- VCC (Power): This pin is used to supply power to the rain sensor. It is typically connected to a 3.3V or 5V pin of the microcontroller or power supply.
- GND (Ground): This pin is connected to the ground (GND) of the microcontroller or power supply, completing the circuit.
- Analog Output: This pin provides an analog output voltage proportional to the intensity of the rain detected by the sensor. The voltage level varies depending on the amount of rain detected, allowing for analog sensing of precipitation.
- Digital Output: Some rain sensors also feature a digital output pin that provides a binary indication of rain presence or absence. This pin typically outputs a digital HIGH signal when rain is detected and LOW otherwise.

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4.2 Soil Moisture Sensor

The soil moisture sensor is one kind of sensor used to gauge the volumetric content of water within the soil. As the straight gravimetric dimension of soil moisture needs eliminating, drying, as well as sample weighting. These sensors measure the volumetric water content not directly with the help of some other rules of soil like dielectric constant, electrical resistance, otherwise interaction with neutrons, and replacement of the moisture content. The relation among the calculated property as well as moisture of soil should be adjusted & may change based on ecological factors like temperature, type of soil, otherwise electric conductivity. The microwave emission which is reflected can be influenced by the moisture of soil as well as mainly used in agriculture and remote sensing within hydrology. This module also includes a potentiometer that will fix the threshold value, & the value can be evaluated by the comparator-LM393. The LED will turn on/off based on the threshold value. This sensor mainly utilizes capacitance to gauge the water content of the soil (dielectric permittivity). The working of this sensor can be done by inserting this sensor into the earth and the status of the water content in the soil can be reported in the form of a percent. This sensor makes it perfect to execute experiments within science courses like environmental science, agricultural science, biology, soil science, botany, and horticulture. When electric current passes through these electrodes, they form an electromagnetic field in the soil. Soil moisture sensors are indispensable tools in modern agriculture, providing farmers with valuable insights into soil conditions crucial for optimizing crop health and yield. These sensors employ various technologies, including capacitance, resistance, and dielectric measurements, to quantify the moisture content of the soil accurately. By measuring the volumetric water content or relative humidity within the soil, these sensors enable farmers to determine the optimal timing and amount of irrigation required for different crops and soil types. In addition to irrigation management, soil moisture sensors play a vital role in precision agriculture practices such as variable rate irrigation and site-specific crop management. By integrating soil moisture data with GPS and mapping technologies, farmers can create detailed spatial maps of soil moisture levels across their fields. This information allows for targeted irrigation, fertilization, and pesticide application, resulting in more efficient resource utilization, improved crop quality, and reduced environmental impact. Furthermore, soil moisture sensors facilitate real-time monitoring and data logging, providing farmers with valuable information for decision-making and trend analysis. By tracking soil moisture levels over time, farmers can identify trends, predict water stress, and optimize irrigation schedules to maximize crop yield while minimizing water usage. soil moisture sensors are essential tools for modern agriculture, enabling farmers to make data-driven decisions, conserve water resources, and enhance productivity and sustainability in the face of changing environmental conditions. Their versatility, accuracy, and affordability make them invaluable assets in the quest for efficient and responsible land management practices.

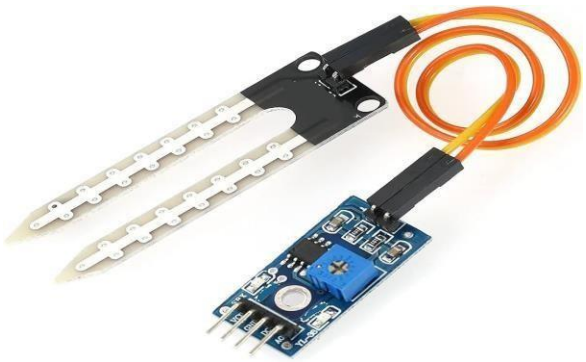

Fig 6 Soil Moisture Sensor

4.2.1 Specifications of soil moisture sensor

- The required voltage for working is 5V
- The required current for working is <20mA
- Type of interface is analog
- The required working temperature of this sensor is 10°C~30°C

4.2.2 Pin configuration of soil moisture sensor

- VCC (Power): This pin is used to supply power to the soil moisture sensor. It is typically connected to the 3.3V or 5V pin of the microcontroller or development board.
- GND (Ground): This pin is connected to the ground (GND) of the microcontroller or development board, completing the circuit.
- Analog Output: This pin provides an analog output voltage proportional to the moisture level detected by the sensor. The voltage level varies depending on the moisture content of the soil.
- Digital Output (Optional): Some soil moisture sensors also feature a digital output pin that provides a binary indication of the soil moisture level. This pin typically outputs a digital HIGH signal when the soil moisture exceeds a certain threshold and LOW otherwise.
- Sensitivity Adjustment (Optional): Certain soil moisture sensors include a sensitivity adjustment potentiometer or jumper. This component allows users to adjust the sensitivity of the sensor to suit different soil types or environmental conditions.
- Heater Control (Optional): In some soil moisture sensor models, especially those designed for outdoor use, there might be a heater control pin. This pin allows for the activation of a heating element to prevent the sensor from being affected by temperature or humidity fluctuations.

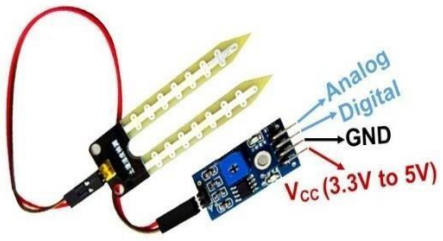

Fig 7 Pin configuration of Soil moisture sensor

4.2.6 Thingspeak cloud

ThingSpeak cloud is a powerful platform designed for IoT (Internet of Things) applications, providing a comprehensive suite of tools and services for collecting, storing, analysing, and visualizing sensor data in real-time. Developed by Math Works, ThingSpeak offers a user-friendly interface that allows developers to quickly deploy IoT solutions without the need for extensive infrastructure setup or programming expertise. With ThingSpeak, users can easily connect their IoT devices, such as sensors and actuators, to the cloud using standard protocols like HTTP, MQTT, or ThingSpeak's own RESTful API. Once connected, ThingSpeak provides secure storage for sensor data, organizing it into channels for easy retrieval and analysis. One of the key features of ThingSpeakis its powerful data analysis and visualization capabilities. Users can create custom MATLAB® code or use built-in MATLAB functions to perform advanced analytics on their sensor data, such as trend analysis, anomaly detection, and predictive modelling. Additionally, ThingSpeak offers a variety of visualization tools, including customizable charts, gauges, and maps, allowing users to create intuitive dashboards for monitoring and analysing their IoT data in real-time. ThingSpeak cloud continues to evolve as a robust platform for IoT applications, offering a myriad of features and capabilities that empower developers to create innovative solutions across diverse domains. One notable aspect of ThingSpeak is its seamless integration with various IoT devices and sensors, enabling effortless data collection and management. Developers can easily connect their devices to ThingSpeak using standard protocols like HTTP, MQTT, or ThingSpeak's RESTful API, facilitating real-time monitoring and control of IoT deployments. Another key strength of ThingSpeak lies in its powerful data analysis and visualization tools, which enable users to derive actionable insights from their IoT data. With built-in support for MATLAB analytics, users can leverage advanced algorithms and machine learning techniques to perform complex data analysis, trend prediction, and anomaly detection. Additionally, ThingSpeak offers customizable visualization components such as charts, gauges, and maps, allowing users to create intuitive dashboards for monitoring and analysing their IoT data in real-time. Moreover, ThingSpeak's flexibility and scalability make it suitable for a wide range of applications, from smart agriculture and environmental monitoring to industrial automation and smart cities. Whether deployed in small-scale hobby projects or large-scale commercial deployments, ThingSpeak can accommodate varying requirements and scale seamlessly to meet the needs of diverse IoT applications.

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FIG 8 Thingspeak cloud

4.2.7 Battery

A 12V battery is a common and versatile power source utilized in a wide range of applications, from automotive vehicles to off-grid solar systems and portable electronic devices. These batteries are designed to provide a stable voltage output of 12 volts, making them compatible with various electrical and electronic equipment requiring this specific voltage level. One of the most widespread applications of 12V batteries is in automotive vehicles, where they serve as the primary energy source for starting the engine, powering onboard electronics, and providing auxiliary power when the engine is not running. Additionally, 12V batteries are extensively used in marine vessels, recreational vehicles (RVs), and motorcycles, providing reliable power for lighting, navigation, communication, and entertainment systems These batteries play a crucial role in enabling renewable energy systems to provide reliable and uninterrupted power for residential, commercial, and industrial applications, reducing reliance on the grid and fossil fuels. In today's increasingly electrified world, 12V batteries stand as essential power sources, powering a wide array of devices and systems across numerous industries. From automotive vehicles and marine vessels to off-grid solar installations and portable electronic devices, these batteries serve as reliable energy reservoirs, providing the stable voltage necessary for sustained operation. In automotive applications, 12V batteries play a central role in starting engines, powering onboard electronics, and providing auxiliary power when engines are not running. Moreover, in marine environments, they ensure the functionality of navigation equipment, lighting systems, and communication devices, contributing to safe and efficient maritime operations. Beyond transportation, 12V batteries are integral to off-grid solar systems, storing energy harvested from solar panels for use during periods of low sunlight or at night. This capability enables individuals and communities to access renewable energy sources and reduce reliance on traditional grid infrastructure. Additionally, 12V batteries power a multitude of portable electronic devices, including camping equipment, power tools, and emergency backup systems, offering a compact and versatile energy storage solution for mobile and remote applications. As technology continues to advance, so too do the capabilities of 12V batteries, with innovations such as lithium-ion and lithium iron phosphate chemistries driving improvements in energy density, durability, and environmental sustainability. With their ubiquitous presence and indispensable role in powering modern society, 12V batteries remain indispensable assets, enabling innovation, mobility, and resilience in an increasingly electrified world.

FIG 9 Battery

4.2.8 Solenoid valve

Solenoid valves are electromechanical devices used to control the flow of fluids or gases in a wide range of applications, from industrial processes to home automation systems. These valves consist of a coil of wire wound around a magnetic core, known as the solenoid, which generates a magnetic field when an electric current is passed through it. This magnetic field attracts an armature or plungerwithin the solenoid, causing it to move and open or close the valve. One of the key advantages of solenoid valves is their fast response time, typically in the range of milliseconds, making them suitable for applications requiring rapid and precise control of fluid flow. Additionally, solenoid valves offer reliable operation and can be easily integrated into automated systems using electrical signals from sensors, timers, or controllers. Solenoid valves are available in various configurations, including two-way, three-way, and four-way valves, with different port sizes, materials, and pressureratings to suit different applications and operating conditions. Two-way solenoid valves have one inlet and one outlet port and are commonly used for on/off control of fluid flow. Three-way solenoidvalves have one inlet and two outlet ports and are often used for diverting or mixing fluids. Four-waysolenoid valves have two inlet and two outlet ports and are commonly used in pneumatic and hydraulic systems for controlling the direction of fluid flow. Applications of solenoid valves span across multiple industries, including HVAC (heating, ventilation, and air conditioning), water and wastewater treatment, oil and gas, automotive, medical devices, and agriculture. In HVAC systems, solenoid valves are used to control the flow of refrigerant or water in heating and cooling systems. Inwater and wastewater treatment plants, solenoid valves are used to control the flow of water, chemicals, and gases in various processes such as filtration, disinfection, and dosing. In automotive applications, solenoid valves are used in fuel systems, transmission systems, and emission control systems. In medical devices, solenoid valves are used in analytical instruments, diagnostic equipment, and therapeutic devices.

FIG 10 Solenoid valve

4.2.9 Jumper wires

Jumper wires are essential components in electronics prototyping and circuitry projects, serving as versatile connectors for creating electrical connections between various components on breadboards, development boards, and other electronic modules. Typically made of flexible, insulated wire with connectors at each end, jumper wires come in different lengths, colors, and connector types, offering flexibility and convenience in circuit assembly. One of the primary advantages of jumper wires is their ability to facilitate rapid and temporary connections, allowing users to quickly test circuit configurations, debug circuits, and prototype new designs without soldering. This flexibility enables rapid iteration and experimentation during the development process, saving time and effort. Moreover, jumper wires are commonly used for signal routing, power distribution, and interconnecting different parts of a circuit, such as microcontrollers, sensors, actuators, and power sources. Their versatility makes them indispensable for creating complex circuits and systems in a modular and flexible manner. In addition to their utility in prototyping and experimentation, jumper wires are also used for educational purposes, providing an accessible and hands-on way for students and enthusiasts to learn about electronics and circuitry. By physically connecting components and observing their behavior, learners gain a deeper understanding of fundamental concepts such as voltage, current, resistance, and circuit design. Overall, jumper wires play a crucial role in electronics projects, enabling users to quickly and easily create electrical connections, prototype circuits, and explore new ideas. Their simplicity, versatility, and affordability make them indispensable tools for hobbyists, students, engineers, and makers alike, driving innovation and creativity in the field of electronics.

FIG 11 Jumper wires

4.3 Relay

Creating a relay in an IoT context involves integrating hardware components with software to control the relay remotely. A basic setup typically includes an ESP8266 microcontroller, such as the Node-MCU, and a relay module. The ESP8266 serves as the brain of the IoT device, capable of connecting to Wi-Fi networks and executing code, while the relay module acts as a switch that can be controlled by the microcontroller. The relay module usually consists of an input pin to trigger the relay. Jumper wires are used to connect the components together on a breadboard. In terms of the circuit diagram, the ESP8266 is connected to the relay module via GPIO pins. The code example provided demonstrates how to control the relay using the Arduino IDE and the ESP8266 Arduino core. In the code, the Wi-Fi credentials are first defined, allowing the ESP8266 to connect to the specified Wi-Fi network. The relay pin is then configured as an output. The main loop continuously toggles the relay state every 5 seconds, turning it on and off alternatively. This setup enables remote control of the relay over Wi-Fi, making it suitable for various IoT applications such as home automation, smart appliances, and industrial automation.

Fig 12 Relay

4.3.1 ESP-NOW Protocol

It's designed for low-power, peer-to-peer communication between ESP8266 and ESP32 chips, enabling them to exchange data without the need for a Wi-Fi network. ESP-NOW is a communication protocol developed by Espress if Systems, the company behind the ESP8266 and ESP32 series of microcontrollers. It operates with a range of 2.4 GHz frequency band and can achieve relatively long-range communication. One of the key advantages of ESP-NOW is its low power consumption, which is crucial for battery-operated devices.The range of ESP-NOW is up to 480 meters when using the ESP-NOW protocol for bridging between multiple Nodemcus.The ESP-NOW protocol, an integral component of the ESP8266 and ESP32 microcontroller series, revolutionizes wireless communication in IoT and sensor networks. Designed by Espressif Systems, ESP-NOW operates onthe principle of peer-to-peer communication, facilitating direct data exchange between ESP8266 or ESP32 devices without the need for Wi-Fi access points or routers. This protocol leverages the low- power capabilities of these microcontrollers, making it ideal for battery-operated devices andapplications requiring energy efficiency. With its simple yet robust architecture, ESP-NOW enablesfast and reliable communication with minimal overhead, achieving high throughput and low latency. Additionally, ESP-NOW supports secure data transmission through encryption and authentication mechanisms, ensuring data integrity and confidentiality in IoT deployments. Its versatility extends to both unicast and multicast communication modes, catering to diverse networking requirements. By providing a lightweight and efficient communication solution, ESP-NOW empowers developers to create scalable and resilient IoT systems, unlocking new possibilities in smart home automation, industrial monitoring, environmental sensing, and beyond. The ESP-NOW protocol's effectiveness lies in its streamlined operation, optimized for scenarios where traditional Wi-Fi connections might be impractical or unnecessary. This protocol boasts a simple API, enabling developers to easily integrate it into their projects with minimal configuration overhead. By bypassing the complexities of Wi-Fi setup and connection management, ESP-NOW reduces latency and power consumption, enhancing the responsiveness and energy efficiency of IoT applications. Moreover, its peer-to-peer architecture eliminates the reliance on centralized infrastructure, increasing the robustness and resilience of the network to failures or interference. This decentralized approach also enhances privacy and security, as data is transmitted directly between trusted devices without passing through external servers or gateways. Furthermore, ESP-NOW's support for custom payloads and user-defined protocols enables tailored communication solutions, accommodating a wide range of application requirements and data formats. Whether deployed in remote sensor networks, mesh networks, or ad-hoc communication scenarios, ESP-NOW empowers developers to build scalable, low-latency IoT systems that deliver real-time insights and actionable intelligence. As the IoT ecosystem continues to evolve, ESP-NOW stands as a foundational technology driving innovation and unlocking new possibilities for connected devices and smart environments. ESP-NOW stands as a remarkable communication protocol crafted by Espressif Systems explicitly tailored for ESP8266 and ESP32 microcontroller-based devices. This innovative protocol facilitates direct peer-to-peer communication between ESP8266 and ESP32 devices, eliminating the necessity for intermediary Wi-Fi access points or routers. Its design prioritizes efficiency, boasting a lightweight protocol stack optimized for low-power microcontrollers while operating within the 2.4 GHz frequency band, leveraging IEEE 802.11 Wi-Fi technology. Setting up communication via ESP-NOW is relatively straightforward, requiring the exchange of unique identifiers known as MAC addresses to establish secure connections between sender and receiver. Furthermore, ESP-NOW offers both peer-to-peer

and broadcast communication modes, catering to diverse communication scenarios ranging from sensor networks to home automation systems. Notably, ESP-NOW excels in power efficiency, making it suitable for battery-powered devices with its ability to enter low-power sleep modes when idle. Despite its low-power design, ESP-NOW delivers high data transfer rates, ensuring seamless real-time data streaming and robust communication. Its robust error-checking mechanisms enhance data integrity and reliability, automatically handling transmission errors or packet loss. Native support for ESP8266 and ESP32 microcontroller platforms ensures easy integration into projects, offering a convenient solution for IoT developers seeking to establish direct device-to-device communication. In essence, ESP-NOW stands as a testament to Espressif's commitment to innovation, empowering IoT developers with an efficient, reliable, and scalable communication protocol for their wireless networking needs. ESP-NOW protocol offers a myriad of advantages for IoT applications, primarily due to its ability to establish direct peer-to-peer communication between ESP8266 and ESP32 devices. One significant advantage is its versatility in supporting various communication modes, including unicast, multicast, and broadcast. This flexibility allows for the implementation of diverse network topologies, such as point-to-point links, star networks, and mesh networks, depending on the specific requirements of the application. Additionally, ESP-NOW's support for multicast and broadcast communication enables efficient data dissemination to multiple devices simultaneously, making it ideal for scenarios like firmware updates, group commands, or status notifications across an IoT network. Furthermore, ESP-NOW's low latency and high-speed communication capabilities make it suitable for real-time applications, such as remote control, monitoring, and automation, where timely data exchange is critical. Overall, the versatility and performance of ESP-NOW protocol position it as a powerful tool for building robust and efficient wireless IoT networks, capable of supporting a wide range of applications and use cases with ease.

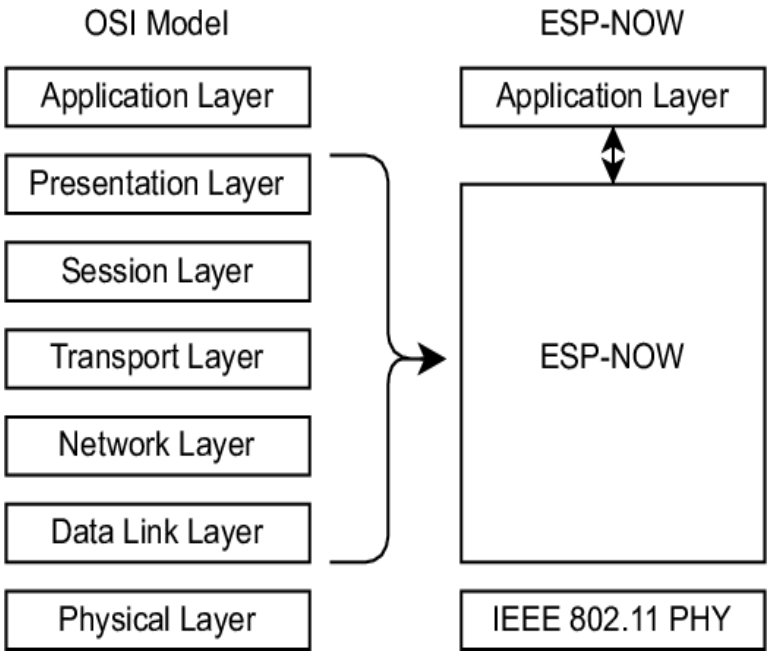


FIG 13 ESP-NOW Protocol

In the ESP-NOW protocol, a "master" device typically acts as a central coordinator or controller, responsible for managing and orchestrating communication with one or more "slave" devices. The master device initiates communication and often controls the overall operation of the network. It may send commands or data to the slave devices and receive responses or data from them. On the other hand, "slave" devices are usually peripheral devices or nodes within the network that respond to commands or requests from the master device. They may perform specific tasks or functions based on the instructions received from the master device. Slave devices often operate in a more passive role compared to the master, waiting for commands or data and responding accordingly. One of the key advantages of the master-slave architecture in ESP-NOW is its simplicity and efficiency. By designating specific devices as masters and slaves, the network can be organized in a hierarchical manner, streamlining communication and reducing overhead. This is particularly useful in scenarios where one device needs to control or coordinate the actions of multiple peripheral devices. Furthermore, the master-slave model facilitates scalability, allowing additional slave devices to be easily added to the network without significantly impacting the overall system architecture. Each slave device can be uniquely identified and addressed by the master, enabling targeted communication and coordination. Overall, the master-slave architecture in the ESP-NOW protocol provides a flexible and efficient framework for building IoT applications, enabling seamless communication and coordination between devices while simplifying network management and scalability.

4.3.2 Arduino IDE

The Arduino Integrated Development Environment (IDE) is a versatile and user-friendly software platform designed for programming Arduino microcontroller boards. Developed by Arduino LLC, the IDE provides a comprehensive set of tools and features that streamline the process of writing, compiling, and uploading code to Arduino boards. At its core is a powerful code editor equipped with syntax highlighting and auto-completion capabilities, facilitating efficient code writing and editing. Additionally, the IDE includes a Library Manager, enabling users to easily install and manage libraries of pre-written code for various components and functionalities. The Serial Monitor tool allows for communication with Arduino boards via the serial port, facilitating debugging and troubleshooting. Furthermore, the IDE's Board Manager simplifies the selection and installation of board definitions and drivers, supporting a wide range of Arduino-compatible boards. With its built-in examples, compiler, and uploader, the Arduino IDE provides a seamless development environment for beginners and experienced developers alike, fostering innovation and creativity in the Arduino ecosystem. The Arduino IDE serves as a central hub for Arduino development, offering a plethora of features tailored to the needs of both novice and seasoned users. Beyond its intuitive code editor and Library Manager, the IDE boasts a vibrant ecosystem supported by an active community of developers and enthusiasts. This community-driven approach ensures that users have access to a wealth of resources, including tutorials, forums, and project documentation, fostering collaboration and knowledge sharing. Moreover, the Arduino IDE is platform-independent, compatible with Windows, macOS, and Linux operating systems, ensuring accessibility to a wide range of users. Its open-source nature also allows for customization and extension, empowering users to tailor the IDE to their specific requirements and preferences. With its rich feature set, robust ecosystem, and user-friendly interface, the Arduino IDE continues to be the go-to tool for Arduino development, inspiring countless makers, educators, and inventors to bring their ideas to life. The Arduino Integrated Development Environment (IDE) stands as a cornerstone in the world of microcontroller programming, providing a user-friendly platform for both beginners and experienced users alike. With its intuitive interface and cross-platform compatibility, the Arduino IDE simplifies the process of writing, compiling, and uploading code to Arduino boards, enabling users to focus on their projects rather than navigating complex development environments. Its code editor offers essential features such as syntax highlighting and auto-indentation, enhancing the coding experience. Furthermore, the IDE's built-in library manager streamlines the integration of additional functionality through easily accessible libraries, while its collection of built-in examples serves as invaluable resources for learning and project development. The Arduino IDE's ability to compile sketches, upload code to boards, and monitor serial data exchange via the built-in serial monitor facilitates seamless development and debugging.

Fig 14 Arduino IDE

4.3.3 Airtel 4G Hotspot

The Airtel 4G hotspot is a portable wireless router device that allows users to create a high-speed Wi-Fi hotspot wherever they go, providing seamless internet connectivity on-the-go. Developed by Airtel, one of India's leading telecommunications companies, the Airtel 4G hotspot leverages the latest 4G LTE technology to deliver fast and reliable internet access to users' devices, including smartphones, tablets, laptops, and smart TVs. The Airtel 4G hotspot is compact, lightweight, and easyto carry, making it an ideal travel companion for individuals who need internet access while on the move. With its built-in rechargeable battery, the hotspot can provide several hours of continuous usage on a single charge, ensuring uninterrupted connectivity even in areas with limited access to power outlets. Setting up the Airtel 4G hotspot is simple and straightforward. Users can activate the device by inserting an Airtel 4G SIM card and powering it on. Once activated, the hotspot automatically establishes a high-speed 4G LTE connection with the Airtel network, allowing users toconnect their devices to the hotspot's Wi-Fi network using the provided SSID and password. The Airtel 4G hotspot offers fast download and upload speeds, enabling users to stream HD videos, browse the web, play online games, and video conference with ease. Additionally, the hotspot supports multiple user connections simultaneously, allowing users to share their internet connection with family members, friends, or colleagues. One of the key advantages of the Airtel 4G hotspot is its affordability and flexibility. Users can choose from a variety of prepaid and postpaid data plans offered by Airtel, allowing them to customize their internet usage based on their needs and budget. Moreover, the hotspot's pay-as-you-go model ensures that users only pay for the data they use, with no long-term contracts or commitments required. Overall, the Airtel 4G hotspot is a convenient and reliable solution for staying connected to the internet while on-the-go. Its fast and stable internet connectivity, combined with its compact and portable design, makes it an essential tool for travelers,remote workers, students, and anyone else who requires reliable internet access outside of traditionalhome or office environments.

FIG 15 Airtel 4G Hotspot

4.3.4 Advantages

- ESP-NOW facilitates real-time data transmission from sensors deployed across the agricultural field to a central monitoring system. This enables farmers to continuously monitor crucial parameters such as soil moisture, temperature, humidity, and crop health, allowing for timely interventions and optimized decision-making.
- **Efficient Resource Management**: By precisely monitoring environmental conditions and crop needs, precision agriculture minimizes resource wastage. ESP-NOW enables targeted irrigation, fertilization, and pesticide application, reducing water usage, fertilizer runoff, and chemical usage while maximizing crop yield and quality.
- **Cost Reduction**: Precision agriculture helps farmers save costs by optimizing resource usage and minimizing manual labour. By automating tasks such as irrigation scheduling and pest control, farmers can reduce labour expenses and improve overall operational efficiency.
- **Increased Crop Yield and Quality**: By providing precise control over environmental variables, ESP-NOW-enabled precision agriculture systems can significantly improve crop yield and quality. By ensuring optimal growing conditions and timely interventions, farmers can minimize crop stress, disease outbreaks, and yield losses.
- **Environmental Sustainability**: Precision agriculture promotes sustainable farming practices by minimizing the environmental impact of agricultural activities. By reducing chemical usage, water consumption, and soil erosion, precision agriculture helps preserve natural resources and biodiversity, mitigating the negative effects of conventional farming on the environment.
- **Data-driven Decision Making**: ESP-NOW protocol facilitates the collection of vast amounts of data from sensors deployed throughout the agricultural field. This data can be analysed using advanced analytics tools to gain valuable insights into crop performance, soil health, and environmental conditions, empowering farmers to make data-driven decisions and optimize their farming practices.
- **Scalability and Flexibility**: ESP-NOW protocol offers scalability and flexibility, allowing precision agriculture systems to be tailored to the specific needs of different crops, soil types, and growing conditions. Farmers can easily expand or modify their precision agriculture systems as needed, adapting to changing environmental conditions and crop requirements.

4.3.5 Applications

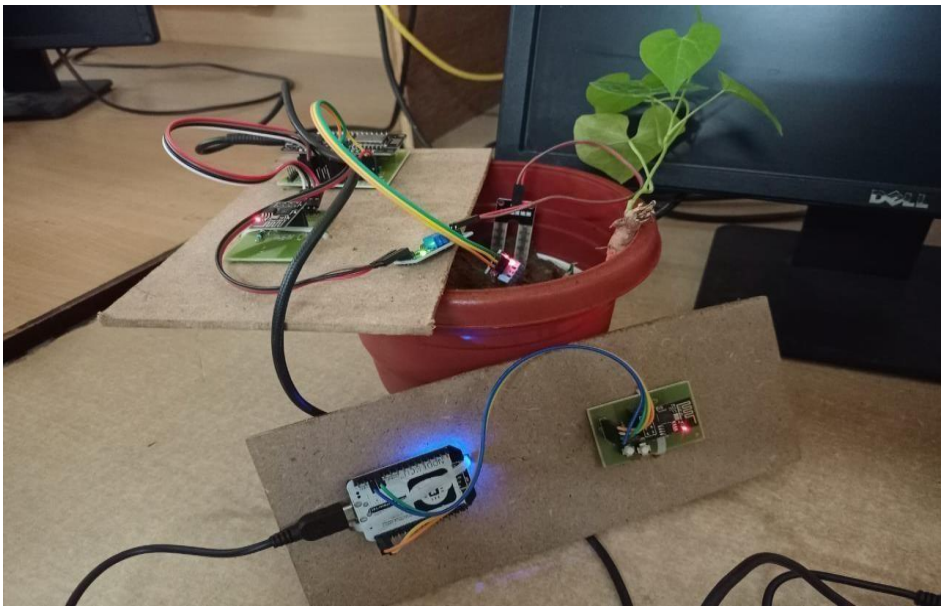
- **Soil Moisture Monitoring**: ESP-NOW-enabled soil moisture sensors can be deployed throughout a field to monitor moisture levels in real-time. This data can then be used to precisely schedule irrigation, ensuring that crops receive the optimal amount of water, thus preventing both water wastage and water stress in plants.
- **Crop Health Monitoring**: Sensors equipped with ESP-NOW can collect data on various environmental factors such as temperature, humidity, and light intensity. This information can be used to assess crop health and detect early signs of stress or disease. With precise data, farmers can take timely actions such as adjusting fertilization, applying pesticides, or modifying cultivation practices.
- **Livestock Tracking**: In addition to crop monitoring, ESP-NOW can be used for tracking livestock within a farm. Tags or collars equipped with ESP-NOW transmitters can relay location data to a central hub, allowing farmers to monitor the movement patterns of their animals. This data can be valuable for optimizing grazing patterns, preventing theft, and ensuring the overall well-being of the livestock.
- **Environmental Monitoring**: ESP-NOW-enabled sensors can be deployed to monitor environmental parameters such as air quality, pollution levels, and weather conditions. This data can help farmers make informed decisions regarding crop selection, planting times, and pest management strategies based on local environmental conditions.
- **Equipment Monitoring and Control**: ESP-NOW can also be utilized for monitoring and controlling agricultural machinery such as tractors, irrigation systems, and drones. By integrating ESP-NOW modules into these devices, farmers can remotely monitor their operation, schedule maintenance tasks, and even automate certain processes, leading to increased efficiency and reduced labour costs.
- **Data Aggregation and Analysis**: ESP-NOW can facilitate the transmission of data from multiple sensors distributed across a farm to a centralized data management system. This allows farmers to aggregate and analyse data from various sources, gaining insights into trends and patterns that can inform decision-making and improve overall farm management practices.
- **Energy Efficiency**: ESP-NOW's low-power capabilities make it suitable for use in battery-operated devices, allowing for extended deployment without frequent battery replacements. This energy efficiency is particularly beneficial in remote or off-grid agricultural settings where access to power sources may be limited.

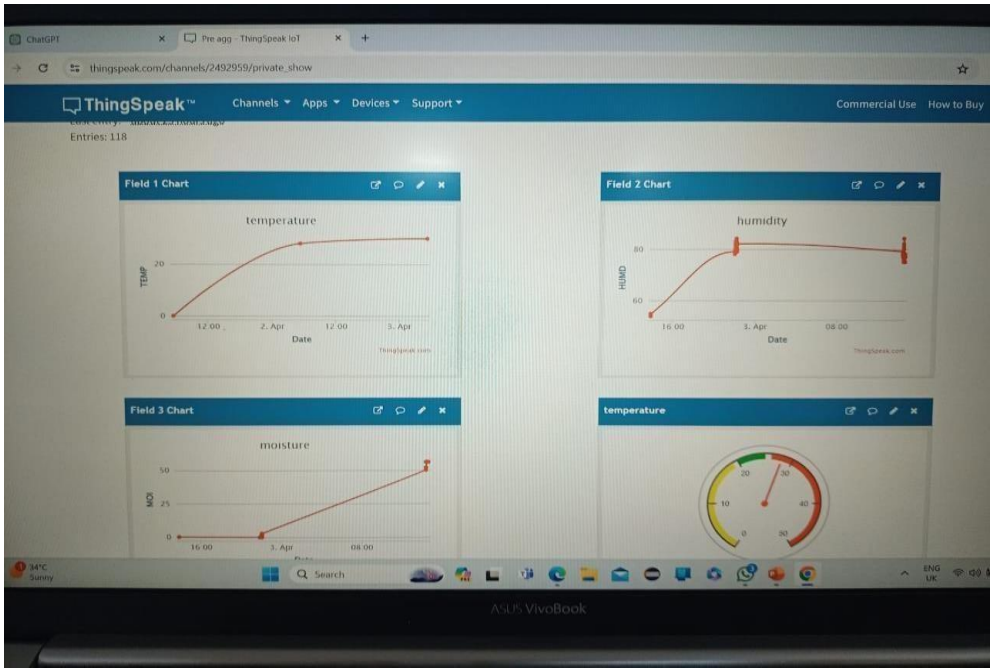
4.3.6 Expected Results

- Providing better mineral resources and water to get good yield to farmers.
- Using IoT monitoring technologies, site managers can update farmers regarding the state of the field in real time, track their performance, and exchange insights and approaches that teams in separate fields use. IoT for precision agriculture improves the farm.

CHAPTER-5

OUTPUT AND ANALYSIS





CHAPTER-6

6.1 Conclusion

The adoption of ESP-NOW protocol in precision agriculture signifies a paradigm shift towards data-driven farming practices. With its ability to seamlessly connect sensors, devices, and machinery across vast agricultural landscapes, ESP-NOW empowers farmers to optimize every aspect of their operations. By leveraging real-time data insights, farmers can make proactive decisions that improve crop quality, reduce input wastage, and mitigate risks associated with environmental variability. Moreover, the energy-efficient nature of ESP-NOW ensures prolonged deployment of monitoring systems, even in remote or off-grid areas. As the agricultural sector continues to evolve, precision agriculture using ESP-NOW protocol stands poised to revolutionize farming practices, driving towards greater productivity, sustainability, and resilience in the face of global challenges. The integration of ESP-NOW protocol in precision agriculture offers a multifaceted approach to optimizing farming practices. Through real-time monitoring, efficient data transmission, and remote control capabilities, ESP-NOW enables farmers to make informed decisions that enhance crop yields, conserve resources, and promote sustainability. By harnessing the power of wireless communication, precision agriculture using ESP-NOW protocol not only increases operational efficiency but also facilitates the transition towards smarter and more resilient farming systems.

CHAPTER-7

Future Scope

In the future, precision agriculture utilizing ESP-NOW protocol is poised to undergo significant advancements, promising a transformative impact on farming practices. With the integration of AI and machine learning technologies, ESP-NOW-enabled systems will evolve to offer predictive analytics and decision support, empowering farmers with actionable insights derived from real-time data. Moreover, the expansion of the IoT ecosystem will lead to the seamless integration of ESP-NOW with a wider array of sensors, actuators, and agricultural equipment, enabling comprehensive monitoring and control within smart farming systems. Advancements in telecommunications infrastructure will enhance remote monitoring and control capabilities, extending the reach of ESP-NOW-enabled devices to even the most remote agricultural areas. Standardization efforts will ensure interoperability across different platforms, while customization and scalability features will cater to the diverse needs of various agricultural operations. Furthermore, ongoing developments in data security and privacy mechanisms will address concerns surrounding the confidentiality and integrity of agricultural data. Through collaborative research and innovation efforts, stakeholders can collectively drive the development and adoption of ESP-NOW-enabled solutions, paving the way for more efficient, resilient, and sustainable farming practices in the future.

CHAPTER-8

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