VAST AGRICULTURAL LAND AREA MONITORING AND CONTROLLING SYSTEM USING ESP-NOW PROTOCOL

A Thesis in the Partial Fulfilment of the Requirements

for the Award of Bachelor of Computer Science and Engineering (BCSE)

Department of Computer Science and Engineering

College of Engineering and Technology

IUBAT – International University of Business Agriculture and Technology

FALL 2024

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A Thesis in the Partial Fulfilment of the Requirements for the Award of Bachelor of Computer Science and Engineering (BCSE)

The thesis has been examined and approved,

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Prof. Dr. Utpal Kanti Das

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Co-supervisor, Coordinator and Assistant Professor

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Supervisor Name

Supervisor and Designation of the Supervisor

Department of Computer Science and Engineering,

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FALL 2024

Letter of Transmittal

10 march 2025

The Chair

Thesis Defence Committee

Department of Computer Science and Engineering

IUBAT–International University of Business Agriculture and Technology

4 Embankment Drive Road, Sector 10, Uttara Model Town

Dhaka 1230, Bangladesh.

Subject: Letter of Transmittal.

Dear Sir,

As per the requirements of the thesis course, the advocates would like to present the proposal as per your instructions titled "Vast agricultural land area monitoring and controlling system using ESP-NOW protocol".

This thesis paper is an integral part of our academic program in completion of the degree called Bachelor of Computer Science and Engineering. We have tried my level best to collect the relative information as comprehensive as possible in preparing the thesis. During preparation of the report, we have experienced practically a lot that will help us a great in my career.

We hope that this request will merit your approval.

Yours sincerely,

Monirul Islam Nipoon	Symu Alahi Jannat Abonti
ID:20103243	ID: 20103005

Student’s Declaration

This is to certify that the work presented in this thesis paper, titled, “Vast agricultural land area monitoring and controlling system using ESP-NOW protocol” is the outcome of the investigation and research carried out by the following students under the supervision of Md. Asif Hossain, Lecturer, Department of Computer Science and Engineering, International University of Business Agriculture and Technology.

Monirul Islam Nipoon	Symu Alahi Jannat Abonti
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Supervisor's Certification

This thesis paper titled "Vast agricultural land area monitoring and controlling system using ESP-NOW protocol" submitted by the group as mentioned below has been accepted as satisfactory in partial fulfilment of the requirement for the degree of Bachelor of Science in Computer Science and Engineering in Fall 2020.

Md. Asif Hossain

Lecturer

Department of Computer Science and Engineering

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Abstract

Weather monitoring plays a vital role in agricultural management, directly influencing crop health, irrigation planning, and overall productivity. However, small & big-scale farmers often struggle to access accurate and affordable weather data, leading to inefficient farming practices and reduced yields. This research aims to develop a cost-effective weather monitoring system specifically designed for agronomy, equipping farmers with real-time environmental data such as temperature, humidity, soil moisture, and water levels. By addressing the gap in affordable weather monitoring solutions, this system helps farmers make informed decisions, improving resource utilization and crop protection. The core problem this research addresses is the high cost and limited accessibility of traditional weather monitoring stations. Most commercial weather systems are expensive, making them impractical for small, medium & big-scale farmers. This study proposes a more affordable and efficient alternative by utilizing low-cost electronic components such as the NodeMCU microcontroller, DHT11 humidity and temperature sensor, soil moisture sensors, and water level detectors. The system collects real-time data and presents it in an easily accessible format, including Excel sheets and graphical visualizations, enabling farmers to monitor weather conditions effectively. To enhance communication and data transmission, the system employs the ESP-NOW protocol, a low-power, wireless communication method that reduces dependency on expensive network infrastructures. This makes the system highly efficient for rural and remote farming areas where stable internet connectivity may be unavailable. Additionally, to ensure uninterrupted operation without relying on conventional electricity, the system integrates renewable energy sources such as solar panels and wind turbines. These energy solutions provide a self-sustaining power supply, making the system more reliable and environmentally friendly. The research also explores advanced farming techniques, including greenhouse farming and True Potato Seed (TSP) cultivation. Greenhouse systems benefit from real-time weather tracking by allowing precise control over temperature and humidity, ensuring optimal conditions for plant growth. Similarly, TSP, an innovative approach to potato farming, thrives under monitored weather conditions, improving disease resistance and enhancing yield efficiency. By incorporating these technologies, the system supports modern, sustainable agricultural practices that maximize productivity while minimizing environmental risks. The developed prototype was tested in real farming conditions, and the results demonstrated its effectiveness in providing accurate and timely weather data. Compared to conventional methods, this system proved to be more cost-efficient, offering a significant reduction in operational expenses. The ESP-NOW protocol ensured stable wireless communication, while the integration of solar and wind power maintained continuous functionality without external electricity. Farmers using the system reported better irrigation planning, improved crop health monitoring, and reduced water wastage, leading to increased agricultural productivity. This research contributes to sustainable agriculture by offering a practical, affordable, and energy-efficient weather monitoring solution. By leveraging low-cost sensors, renewable energy, and wireless communication, the system empowers small & big-scale farmers with real-time data, enabling them to make precise, informed decisions. The integration of greenhouse monitoring and TSP cultivation further enhances its agricultural value. Overall, this system provides a scalable, eco-friendly approach to weather monitoring, improving food security and economic stability for farmers worldwide.

Keywords: ESP_NOW protocol, Weather monitoring, IoT, NodeMCU, DHT11, 12c display, Soil Moisture Sensor, Dust sensor, Water level sensor, Solar panel, Turban, TSP system.

ACKNOWLEDGEMENT

At first, I am grateful to the Almighty Allah for the good health and wellbeing that were necessary to complete this thesis leading to Bachelor of Computer Science and Engineering (BCSE).

It is a great pleasure to express my deep sense of gratitude, indebtedness appreciation and best regards from my core of heart to my honourable research supervisor ***Md Asif Hossain,*** *Lecturer, Department of Computer Science and Engineering, International University of Business Agriculture and Technology. for his constructive guidance, sincere supervision, valuable advice, cordial behaviours and untiring maintenance throughout the course of this research work.*

I want to express my whole-hearted sense of respect and appreciation to my Co-supervisor ***Shahinur Alam,*** *Coordinator and Associate Professor, Department of Computer Science and Engineering, International University of Business Agriculture and Technology. for his kind co-operation, valuable suggestions, reviewing of the manuscript of the thesis, meticulous corrections and comments in the improvement of this dissertation.*

I wish to state my gratefulness to all of the teachers of the department of Computer Science and Engineering for their nice behaviour, kind help and co-operation during my entire period of study at this department.

I would like to be thankful to all the staff and employees of the department of Computer Science and Engineering, IUBAT for their help and co-operation throughout the research work in the laboratory.

I feel proud to show my deepest acknowledgement and gratitude to my beloved parents for their prayer, inspiration and dedicated efforts to educate me to this level.

Finally, we express our gratitude to our parents for always being motivating and supportive.

The Author

Fall 2024

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LIST OF ABBREVIATIONS

ABBREVIATIONS	ELABORATIONS
✓ ESP-NOW	Espressif Non-Overlapping Wireless.
✓ DHT11	Digital Humidity and Temperature.
✓ NodeMCU	Node Microcontroller Unit.
✓ PPM	Parts Per Million
✓ C	Celsius
✓ LED	Light Emitting Diode
✓ LCD	Liquid Crystal Display.

Chapter 1- Introduction

1.1. Introduction

Weather monitoring plays a crucial role in agricultural management by influencing crop health, irrigation strategies, and overall productivity. However, both small and large-scale farmers often face challenges in accessing accurate and affordable weather data, which leads to inefficient farming practices and decreased yields. This research aims to develop a cost-effective, real-time weather monitoring system tailored for agriculture. By equipping farmers with essential environmental data, including temperature, humidity, soil moisture, and water levels, the system enables informed decision-making. The primary issue addressed is the high cost and limited accessibility of traditional weather stations, which are often impractical for farmers due to their expense. This study proposes an affordable alternative using low-cost components such as NodeMCU microcontrollers, DHT11 sensors, and soil moisture detectors. The system leverages wireless communication via the ESP-NOW protocol and integrates renewable energy sources like solar and wind power, ensuring reliable, eco-friendly operation even in remote areas. There are variations between different theses in different topics, depending on the purpose of the thesis. Most thesis introductions include SOME (but not all) of the stages listed below:

- State the general topic and give some background (a1.)
- Provide a review of the literature related to the topic (a2.)
- Define the terms and scope of the topic (a3.)
- Outline the current situation (b1.)
- Evaluate current situation (advantages/ disadvantages) and identify gap (b2.)
- Identify the importance of the proposed research (c1.)
- State the research problem/ questions (c2.)
- State the research aims and/or research objectives (c3.)
- State the hypotheses (c4.)
- Outline the order of information in the thesis (c5.)
- Outline the methodology (c6.)

Table 1.1 ESPnow usage assessment and energy source and energy consumption assessment

Stage	Sample sentence extracts
a1. Give background about the topic	Agricultural productivity is highly dependent on environmental conditions such as temperature, humidity, soil moisture, and water availability. Traditional monitoring systems are costly and rely on internet connectivity, making them impractical for remote farmlands. Wireless sensor networks and energy-efficient communication protocols like ESP-NOW offer a low-cost alternative for real-time monitoring. By integrating renewable energy sources such as solar panels and wind turbines, modern agricultural monitoring systems can operate efficiently without external power dependency.
b1. Outline current methods	Traditional agricultural monitoring relies on **manual observation** and **expensive weather stations,** which require internet connectivity and high maintenance costs**. IoT-based system**s using Wi-Fi or GSM networks provide automation but face connectivity challenges in remote areas. Recent advancements include **wireless sensor networks (WSNs)** and **ESP-NOW-based low-power communication**, improving affordability and accessibility.
b2. Evaluate current methods	Current weather monitoring methods in agriculture are often expensive and complex, making them inaccessible for small to large-scale farmers. Traditional systems rely on costly infrastructure, limiting their reach. While these methods provide accurate data, they fail to address affordability and accessibility, leaving farmers with inefficient practices. Affordable, real-time weather monitoring

	systems are essential for improving agricultural productivity.
c1. Identify importance of proposed research	The proposed research is crucial as it offers an affordable, efficient, and accessible weather monitoring solution for farmers. By utilizing low-cost sensors, renewable energy, and wireless communication, it empowers farmers with real-time data, improving decision-making, resource utilization, crop protection, and overall agricultural productivity, especially in rural areas with limited connectivity.
c2. State the research problem/ questions	The research problem is the high cost and limited accessibility of traditional weather monitoring systems for farmers, which leads to inefficient farming practices and reduced yields. This study aims to develop an affordable, real-time weather monitoring system that provides essential environmental data to help farmers make informed decisions and improve productivity. 1. What is Internet of Things 2. What is the purpose of IoT? 3. Who will be responsible to monitor the weather condition time to time? 4. Is there a better way? 5. How can affordable weather monitoring systems be developed? 6. What low-cost components can be utilized? 7. How can real-time data be collected efficiently? 8. How to ensure reliable communication in rural areas?

	9. Can renewable energy sustain the system? 10. What are the benefits of real-time data for farmers? 11. How can this system improve agricultural productivity and resource management?
c3. State research aims	The research aims to develop a cost-effective, real-time weather monitoring system for farmers, using low-cost sensors and renewable energy sources. It seeks to improve decision-making, resource utilization, and crop productivity while addressing the affordability and accessibility gap in agricultural weather data.
c4. State the hypotheses	The hypothesis is that an affordable, real-time weather monitoring system using low-cost sensors, wireless communication, and renewable energy will improve farming efficiency, resource utilization, and productivity compared to traditional methods.
c5. Outline order of information in the thesis	The thesis will follow this structure: **1.Introduction –** Problem statement, research objectives, and significance. **2.Literature Review –** Overview of current weather monitoring methods and challenges. **3.Methodology –** Design, components, and working of the proposed system. **4.Implementation –** System development, testing, and data collection. **5.Results & Discussion –** Data analysis and performance comparison. **6.Conclusion –** Key findings, contributions, and recommendations for future work.
c6. Outline the methodology	The methodology involves designing a low-cost weather monitoring system using components like

	NodeMCU, DHT11 sensors, and soil moisture detectors. Data will be collected in real-time, transmitted via ESP-NOW protocol, and analyzed through renewable energy sources to ensure sustainable, reliable

Chapter 2 - Literature Review

A literature review provides a comprehensive analysis and critical assessment of the existing research surrounding a specific topic, identifying gaps and highlighting areas where further exploration is necessary. In the context of weather monitoring for agricultural purposes, numerous studies have explored traditional methods of weather data collection, focusing on expensive, stationary stations that provide accurate data but are often inaccessible to small and medium-scale farmers. These systems, while effective, suffer from high initial costs and maintenance expenses, making them impractical for widespread use in developing regions or rural areas.

Several studies have proposed the use of low-cost alternatives, such as sensor-based systems for environmental monitoring. These systems, using inexpensive sensors like temperature, humidity, and soil moisture detectors, have been shown to be both accurate and cost-effective. However, most of these solutions rely heavily on stable internet connections and power sources, which can be unreliable in remote farming areas.

The use of renewable energy sources, such as solar panels and wind turbines, has also been explored in some research as a way to overcome power supply issues. Additionally, wireless communication technologies like ESP-NOW have been proposed as a means of transmitting data in low-power, cost-effective ways, reducing the reliance on expensive network infrastructures.

Despite these advancements, a gap exists in integrating these technologies into a single, cohesive system that is both affordable and accessible for farmers at all scales. This research aims to bridge that gap by developing a comprehensive, real-time weather monitoring solution tailored for agronomy.

Table 2.1 An example to understand how to prepare the literature review chapter

Student's Question	Sample Answer
What is it?	This research develops an affordable, real-time weather monitoring system for farmers, using low-cost sensors and renewable energy to provide critical environmental data, improve agricultural productivity, and bridge the accessibility gap in traditional weather systems.
What is its purpose?	The purpose of this research is to create a cost-effective weather monitoring system for farmers, utilizing low-cost sensors and renewable energy to provide real-time environmental data, improve resource management, and enhance agricultural productivity in remote areas.
What do I need to include?	Based on the abstract, you need to include a detailed description of the system design, components (NodeMCU, sensors, renewable energy sources), data collection methods, communication protocols (ESP-NOW), real-world testing results, and how the system improves agricultural practices and productivity.
How do I organize it?	Organize the research by introducing the problem, explaining the system design and components, describing data collection and communication methods, presenting results and testing, and concluding with the system's impact on agricultural productivity and

	sustainability.
What referencing system should I use?	Based on the abstract, you should use the **(Harvard Referencing)**, which is commonly used in scientific and technical research. It provides clear guidelines for citing sources, ensuring consistency and credibility. This system is suitable for citing research articles, books, and other sources that contribute to your study.
How do I refer to other authors?	Use citation within the text of your thesis report (Harvard Referencing) e.g.: Smith (2020) argues that… according to Smith and Jones (2021)… Smith et al. (2022) proved that… You can find the detail information about referencing in Section 2.6 of this template.
How long should it be?	How long is a piece of string? Use the following as a rough guide: Around 20% of the whole thesis or Your thesis is expected to be 60% your own work. If your literature review is more than 40% of your thesis, it's probably too long. Note: It's better to keep all the chapters with the length of 8-10 pages.
What am I supposed to do in my literature review?	**You are expected to show that:** You can recognize the relevant and important research in your field, you can understand your research by organizing and evaluating it and You can see where there is a gap in the research which your study will attempt to fill.

2.1. Overview of Agricultural Monitoring Systems.

Agricultural monitoring systems help farmers track and manage their land efficiently by using modern technology. These systems collect real-time data on soil moisture, temperature, humidity, and other essential parameters. With the increasing demand for food production, precision agriculture has become crucial for optimizing resources and improving yield. Traditional farming methods rely heavily on manual observations, which can be time-consuming and inaccurate. However, modern agricultural monitoring systems integrate wireless sensors, IoT devices, and automated control mechanisms to provide accurate and timely data. These systems allow farmers to make informed decisions about irrigation, fertilization, and pest control, reducing costs and increasing productivity. By implementing wireless monitoring, large-scale farms can efficiently manage vast agricultural land. The system ensures that crucial farming activities are performed at the right time, preventing losses due to environmental factors. Additionally, remote monitoring eliminates the need for frequent on-site visits, reducing labor costs and improving overall efficiency. Using protocols like ESP-NOW, agricultural monitoring systems can function without internet dependency, making them ideal for rural areas with limited connectivity. These advancements in technology enable sustainable farming practices and promote better resource management, ensuring food security and environmental protection.

2.2. Introduction to ESP-NOW Protocol

ESP-NOW is a low-power, low-latency wireless communication protocol developed by Espressif Systems. It enables direct communication between ESP32 and ESP8266 microcontrollers without requiring a traditional Wi-Fi connection or internet access. This protocol is ideal for real-time data transmission in applications such as agricultural monitoring, industrial automation, and smart home systems. ESP-NOW operates using a peer-to-peer or broadcast communication method, allowing multiple devices to share data efficiently. Unlike traditional Wi-Fi-based IoT systems, ESP-NOW significantly reduces power consumption, making it suitable for battery-powered devices deployed in remote agricultural fields. Additionally, ESP-NOW supports encrypted communication, ensuring data security and integrity. In an agricultural monitoring system, ESP-NOW can be used to transmit sensor data from multiple nodes (such as soil moisture, temperature, humidity sensors, Dust sensor, Water level sensor.) to a central control unit. Since it does not rely on routers or internet infrastructure, the system remains functional even in areas with poor connectivity. The simplicity and efficiency of ESP-NOW make it an excellent choice for vast land monitoring. Its ability to operate over long distances with minimal energy consumption ensures that farmers can collect and analyse essential data without significant maintenance or operational costs.

2.3. Comparison with Other Communication Protocols

ESP-NOW offers several advantages over traditional communication protocols like Wi-Fi, Bluetooth, Zigbee, and LoRa, making it a suitable choice for vast agricultural land monitoring.

- ✓ **Wi-Fi:** While Wi-Fi provides high-speed data transmission, it requires internet connectivity and consumes a lot of power. In large agricultural fields with limited internet access, Wi-Fi-based systems are inefficient and costly to maintain.
- ✓ **Bluetooth:** Bluetooth is energy-efficient and supports direct device-to-device communication, but its short-range connectivity (typically up to 100 meters) makes it unsuitable for vast land monitoring.
- ✓ **Zigbee:** Zigbee is commonly used in wireless sensor networks due to its low power consumption. However, it requires a central coordinator and has limited range, making it less effective in large-scale agricultural applications.
- ✓ **LoRa:** LoRa offers long-range communication with low power consumption, making it a good choice for rural agricultural monitoring. However, it has lower data transmission rates and requires additional infrastructure, such as gateways, for proper implementation.
- ✓ **ESP-NOW:** ESP-NOW balances power efficiency, real-time data transfer, and low operational cost. Unlike LoRa, it does not require gateways, and unlike Wi-Fi, it works without an internet connection. These advantages make ESP-NOW ideal for remote agricultural land monitoring.

2.4. Challenges in Vast Agricultural Land Monitoring

Monitoring vast agricultural land comes with several challenges, including connectivity issues, power supply constraints, environmental factors, and scalability concerns.

- ✓ **Connectivity Issues:** Many large agricultural lands are located in rural areas with poor network coverage. Traditional IoT solutions relying on Wi-Fi or cellular networks may not work efficiently in such regions. Using ESP-NOW helps overcome this limitation by enabling direct communication between devices without requiring internet connectivity.
- ✓ **Power Supply Constraints:** Deploying a large number of wireless sensors requires an efficient power management system. Many remote locations lack a reliable electricity supply, making battery-powered and energy-efficient devices crucial for continuous operation. ESP-NOW's low power consumption helps extend battery life and reduces maintenance efforts.
- ✓ **Environmental Factors:** Weather conditions, soil composition, and vegetation can affect sensor performance and wireless communication. Extreme temperatures, heavy rain, and dust may cause data inaccuracies or system failures. Using durable and weather-resistant sensors is essential to maintaining reliable monitoring.
- ✓ **Scalability and Cost:** Expanding the monitoring system over large areas requires multiple sensors and communication nodes, increasing costs. Traditional solutions like satellite imaging or LoRa-based systems may require expensive infrastructure. ESP-NOW provides a cost-effective alternative by enabling simple peer-to-peer communication with minimal hardware requirements.
- ✓ **Data Management and Analysis:** Large-scale agricultural monitoring generates vast amounts of data. Efficient storage, processing, and real-time decision-making are essential for optimizing farm operations. Integrating ESP-NOW with edge computing and cloud-based analytics can enhance the system's performance and usability.

2.5. Background of IoT

The Internet of Things (IoT) is a network of physical objects, such as gadgets, vehicles, buildings, and goods that are integrated with electronics, software, sensors, and network connectivity to collect and share data. Iot enables remote maintenance and control of devices across the existing network. People all over the world are being affected by the Internet of Things, which is laying the framework for a number of products such as smart health services, smart living, smart education in schools, and automation. Manufacturing, transportation, agriculture, corporate management, and a range of other industries use it economically.

2.6. Microcontroller

The NodeMCU (Node MicroController Unit) is an opensource software and hardware development environment that is built around a very inexpensive System-on-a-Chip (SoC) called the ESP8266. The ESP8266, designed and manufactured by Espressif Systems, contains all crucial elements of the modern computer: CPU, RAM, networking (WIFI), and even a modern operating system and SDK.

- ✓ Wi-Fi Module – ESP-12E module similar to ESP-12 module but with 6 extra GPIOs.
- ✓ USB – micro USB port for power, programming and debugging
- ✓ Headers – 2x 2.54 mm 15-pin header with access to GPIOs, SPI, UART, ADC, and power pins
- ✓ Reset & Flash buttons
- ✓ Power: 5V via micro USB port
- ✓ Dimensions: 49 x 24.5 x 13 mm

2.7. Sensors

Oursystemcontainsseveralsensors,includingatemperatureandhumiditysensor,soil moisture sensor, water level sensor, optical dust sensor. We are using a NodeMCU microcontroller for collecting or fetching the values from the sensors. We are using a website and an application to monitor the data. We are also using some wires for connecting the sensors with the NodeMCUmicrocontroller.

2.8. Related Work

- **Suhas Pandurang Nikam and Dr S. M. Kulkarni** presented an IOT-based environmental monitoring system. The proposed system describes an implementation of a wireless sensor network that can be adapted to various applications. And it also adds the necessary adaptability to be negotiated and updated without the need to configure complex infrastructures. The solution is based on small autonomous wireless sensor nodes, small wireless receivers connected to the Internet, and a cloud architecture that enables data storage and delivery to remote clients. The solution enables on-site supervisors not only to monitor the current situation with their smartphones but also to monitor remote locations via the Internet. The proposed system is useful for predicting environmental conditions such as rain, including the measurement of temperature, humidity, and the presence of CO gas. [Nikam et al., 2021]

- In 2014, **P. Susmitha and G. Sowmyabala** presented the Design and Implementation of Weather Monitoring and Controlling System. This paper is to develop an embedded system to design a weather monitoring system that enables the monitoring of weather parameters in an industry. Such a system contains a pair of sensors like temperature, Gas and humidity will be monitored and LPC1768 microcontroller. The data from the sensors are collected by the microcontroller, and also microcontroller sends the sensors data into the LABVIEW by using the Serial Communication. And this module will keep the data on the excel page & also we can get the SMS on the mobile with the help of the GSM module. [Susmitha et al., 2014]

- **Girija C, Harshalatha H, Andreanna Grace Shires, Pushpalatha HP** presented an Internet of Things (IoT) based Weather Monitoring System. The system proposed in this paper deals with monitoring and controlling the environmental conditions like temperature, relative humidity, and CO level with sensors and sends the information to the web page and then plots the sensor data as graphical statistics. But this system uses only three sensors. These are temperature sensor, humidity sensor, and CO level detector sensor. [C et al., 2021]

- **Jeethuri Vasantha & S Mahaboob Basha** presented Weather Monitoring Using Raspberry Pi via Web Application in 2016. This system proposed an environment monitoring system that is also capable of monitoring and control of environmental parameters like temperature, pressure, and humidity. The system uses the Raspberry pi for collecting the information. This system uses Wireless sensor Networks for sensing the environmental parameters in the area under supervision. Sensors Node has been designed to measure the temperature, pressure, and humidity. The Control node has been designed to initiate the control action. The Central Monitoring is based on the ARM11 raspberry pi board. The limitation of this system is, the Raspberry pi is a little expensive. [Vasantha et al., 2016]

- **Anita M. Bhagat, Ashwini G. Thakare, Kajal A. Molke1, Neha S. Muneshwar, and Prof. V. Choudhary** presented IOT Based Weather Monitoring and Reporting System Project in 2019. This system will monitor the temperature, humidity, and moisture of soil and rain levels. Suppose Scientists or nature analysts want to monitor changes in a particular environment like a volcano or a rainforest. And these people are from different places in the world. In this case, SMS based weather monitoring system has some limitations since it sends SMS to too few numbers. And time for sending SMS increases as the number of mobile numbers increases. In order to know the information about Weather of a particular place then they have to visit that particular site. Where everyone can see it. [Bhagat et al., 2019]

Chapter 3 - Research Methodology

3.1. Methods

This research employs a practical, design-based methodology to develop a cost-effective weather monitoring system for agriculture. The approach involves the selection and integration of low-cost electronic components, including the NodeMCU microcontroller, DHT11 humidity and temperature sensors, soil moisture sensors, and water level detectors. These components are chosen for their affordability, reliability, and ability to capture essential environmental data in real-time. The system's data collection process is enhanced by the use of the ESP-NOW protocol, which allows for low-power, wireless communication, ensuring efficient transmission of data even in remote, rural areas where internet connectivity may be limited. To ensure continuous and reliable operation, the system incorporates renewable energy sources, such as solar panels and wind turbines, which provide a self-sustaining power supply, eliminating dependence on conventional electricity. The system is tested in real farming conditions to assess its accuracy, efficiency, and performance. Data gathered from the system is analyzed and presented through visualizations, such as Excel sheets and graphs, enabling farmers to make informed decisions on resource utilization and crop management.

3.2. Proposed System:

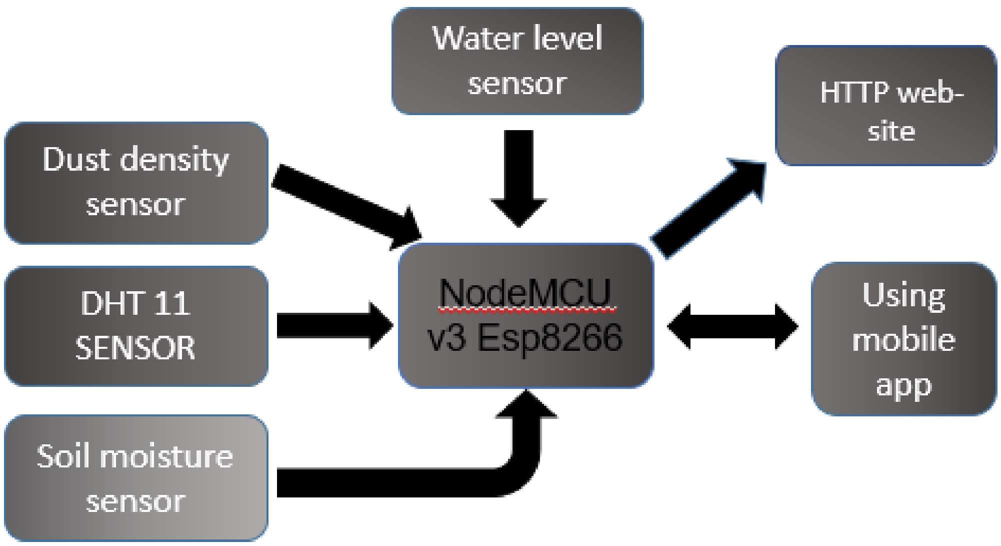


Figure 3.2.1: Overview of System

Figure 3.2.1. provides an overview of the research process and summarizes the methods used in this study. This paper reports on two interrelated efforts:

The development and validation of a weather monitoring system that is easy to use and beneficial to the farmers. And comparing the performance against other proven and/or traditional weather monitoring system. It can reduce the cost and easy touse.

3.3. Constructing the System

Elements:

- ✓ NodeMCUESP8266
- ✓ DHT11 (Temperature and Humidity sensor)
- ✓ Soil- Moisture Sensor
- ✓ Waterproof temperature sensor [DS18B20]
- ✓ Breadboard
- ✓ Water level sensor
- ✓ Connecting wires
- ✓ Mq3
- ✓ Liquid crystal display
- ✓ I2c driver
- ✓ Jumper wire
- ✓ Solar system
- ✓ Turbine
- ✓ Greenhouse system
- ✓ LEB light

3.3.1. Node MCU

NodeMCU is an IoT platform which is open-source program and by using this we can reduce the cost. There are two terms node and MCU (micro-controller-unit). It is a firmware that uses a language which is Lua scripting. Express if Systems' ESP8266 Wi-Fi SoC need a software and as well as ESP-12 module need a hardware and this NodeMCU provide this. For choosing this micro-controller there are a main reason that it is cheap and by using this we can make a Wi-Fi module. NodeMCU is related with Arduino. NodeMCU can work when an Arduino IDE is presence. NodeMCU has some Input and Output pins those make a link to external devices and we can use this pin ten different purpose. A standard NodeMCU, complete with pin numbers.

Figure 3.3.1: NodeMcu ESP8266

3.3.2. Temperature & Humidity Sensor:

DHT11 offers extremely high reliability and excellent long-term durability. The DHT11 features a capacitive moisture sensor and temperature sensing element connected to a powerful 8-bit microcontroller which can provide excellent quality, ultra-fast response time, powerful anti-interference capabilities, and cost-effectiveness.

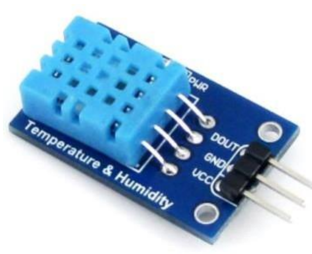


Figure 3.3.2: Temperature and Humidity sensor

3.3.3. Soil Moisture Sensor:

The Soil Moisture Sensor is a sensor which is for measuring the moisture content of soil and other similar materials. It can measure the amount of water in the soil. It is easy to set up and operate the soil moisture sensor. It can measure so many things such as electrical resistance, dielectric constant, or interaction with neutrons, as a proxy for the moisture content. The soil moisture sensor is a sensor which can measure the volumetric water content. There are two types of sensors, one is stationary another is portable. Stationary sensors are placed in that type of placed which is predetermined and depths in the field, whereas portable soil moisture can measure or works at several locations.

Specifications:

- ✓ Working voltage:5V
- ✓ Working current: <20mA
- ✓ Interface: Analog

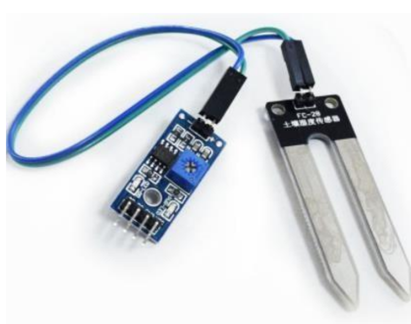


Figure 3.3.3: Soil moisture sensor

3.3.4. Waterproof temperature sensor [DS18B20]

A waterproof temperature sensor measures temperature in wet or submerged conditions without damage. It works by using a temperature-sensitive element, like a thermistor or RTD, enclosed in a waterproof casing made of materials like stainless steel or plastic. This casing protects the internal components from water, dust, and corrosion. The sensor detects temperature changes, converting them into electrical signals sent to a connected device or system for monitoring. Waterproof sensors are commonly used in pools, aquariums, industrial processes, and outdoor environments. They are designed to withstand high pressure and harsh conditions, ensuring accurate readings even when fully submerged. Proper installation and calibration are essential for reliable performance.

Figure 3.3.4: Waterproof temperature sensor [DS18B20]

3.3.5. Breadboard

A breadboard, also known as a protoboard, is a fundamental tool for building and prototyping electronic circuits. It consists of a plastic board with a grid of holes, internally connected by metal clips, allowing components like resistors, capacitors, and ICs to be inserted and connected without soldering. This makes it ideal for creating temporary circuits, testing designs, and experimenting with electronics. Breadboards are reusable, enabling quick modifications and troubleshooting. They are commonly used by students, hobbyists, and engineers to develop and refine circuit designs before finalizing them on a permanent PCB (printed circuit board).

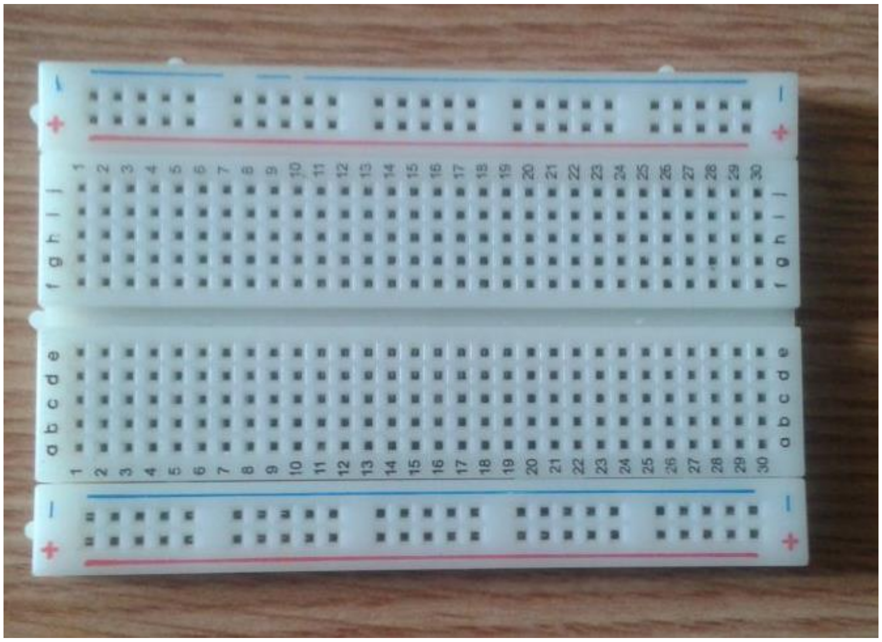


Figure 3.3.5. Breadboard

3.3.6. Water Level Sensor:

A water level indicator is a system that relays information back to a control panel to indicate whether a body of water has a high or low water level. Some water level indicators use a combination of probe sensors or float switches to sense water levels. “The Water Level Indicator employs a simple mechanism to detect and indicate the water level in an overhead tank or any other water container.”

Figure 3.3.6: Water level sensor

3.3.7. Connecting wires

Connecting wires are essential in electrical circuits, serving as pathways for electricity to flow between components. Made of conductive materials like copper, they ensure efficient current transfer from sources (e.g., batteries) to devices (e.g., light bulbs). Insulated coatings prevent short circuits and ensure safety. Wires come in various sizes and types, depending on current capacity and application. Properly connecting wires is crucial for circuit functionality, enabling devices to operate as intended. Without wires, electrical circuits cannot function, making them a fundamental part of any electrical system.

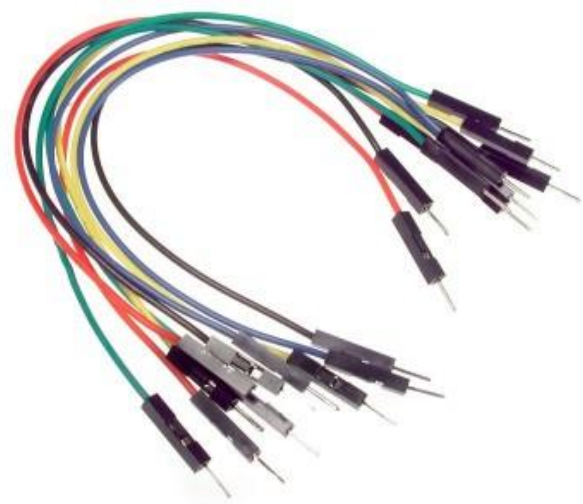


Figure 3.3.7. Connecting wires

3.3.8. Mq3

The MQ3 gas sensor module, while primarily used for detecting gases like alcohol, benzene, CH4, hexane, LPG, and CO in safety applications, can also be adapted for agricultural purposes. In agriculture, it can monitor gases emitted during fermentation processes in silage or compost production, ensuring optimal conditions for decomposition. Additionally, the sensor can be integrated into automated systems using microcontrollers like Arduino or Raspberry Pi for real-time monitoring and alerts. Its adjustable sensitivity via a potentiometer allows customization for specific agricultural environments. However, proper calibration and preheating are essential for accurate performance. Overall, the MQ3 is a versatile tool that can enhance safety and efficiency in agricultural settings.

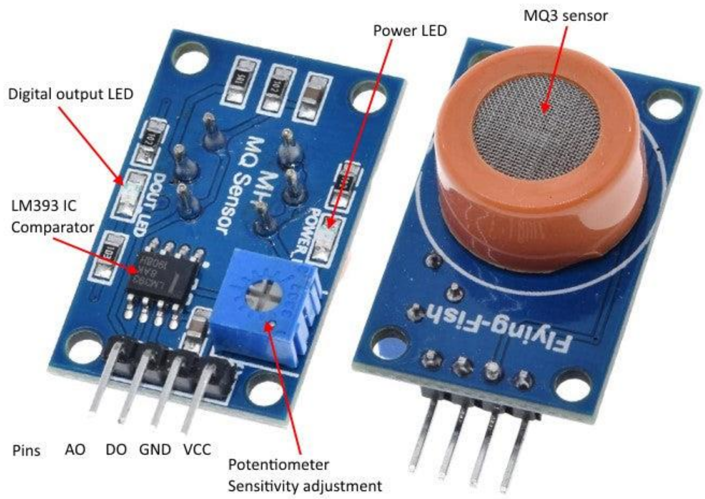


Figure 3.3.8. Mq3

3.3.9 Liquid crystal display

A liquid crystal display (LCD) is a versatile tool that can be used in agriculture for monitoring and displaying critical data. Integrated into agricultural systems, LCDs can show real-time information such as soil moisture levels, temperature, humidity, gas concentrations (e.g., CO2, methane), and irrigation status. These displays are often connected to sensors and microcontrollers (like Arduino or Raspberry Pi) to provide farmers with actionable insights for precision farming. LCDs are energy-efficient, easy to read in various lighting conditions, and durable, making them suitable for both indoor and outdoor agricultural applications. They help optimize crop management, reduce resource waste, and improve overall farm productivity.

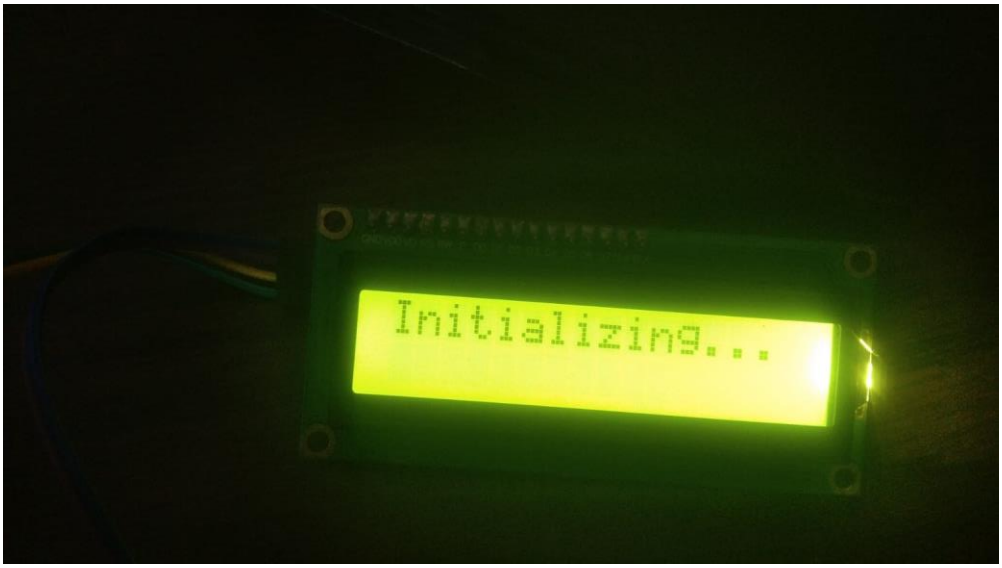


Figure 3.3.9 Liquid crystal display

3.3.10 I2c driver

The I2C (Inter-Integrated Circuit) driver is a crucial component in modern agricultural systems, enabling efficient communication between multiple devices over the I2C bus. This protocol is widely used in precision farming to connect sensors, microcontrollers, and displays, ensuring seamless data exchange. The I2C driver supports master and slave modes, allowing devices like soil moisture sensors, temperature sensors, and gas detectors to communicate with a central controller (e.g., Arduino or Raspberry Pi). In master mode, the driver can read and write bytes, enabling the controller to collect data from sensors or send commands to actuators. For example, it can read soil moisture levels or control irrigation systems. In slave mode, devices like LCD displays or environmental monitors can respond to requests from the master, providing real-time updates on farm conditions. Additionally, the I2C driver supports register-based communication, where sensors store data in registers that the master can access. This feature is particularly useful for monitoring parameters like humidity, temperature, or gas concentrations in greenhouses or livestock barns. The I2C bus's simplicity, low power consumption, and ability to connect multiple devices with just two wires make it ideal for agricultural applications, enhancing automation, resource efficiency, and crop yield.

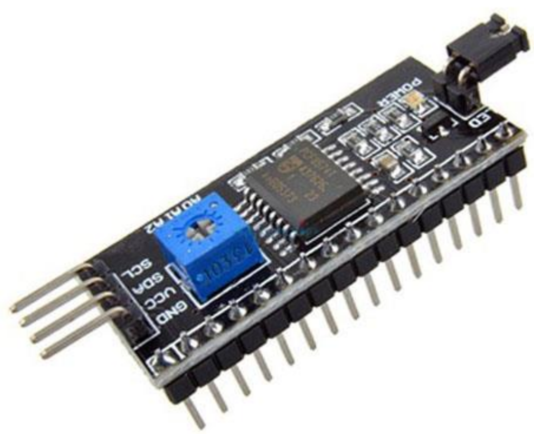


Figure 3.3.10 I2c driver

3.3.11 Solar System

A solar system with a solar panel and battery is designed to capture and store solar energy for later use. The solar panel converts sunlight into electricity through photovoltaic cells, generating **direct current (DC)** power. This energy is then stored in a battery, typically a deep-cycle type, designed to withstand repeated charging and discharging cycles. The battery acts as a storage unit, allowing power to be used during periods of low sunlight or at night. The energy stored can be used to power devices or systems, ensuring continuous operation. This setup is particularly beneficial in off-grid areas, providing a sustainable and reliable energy source.

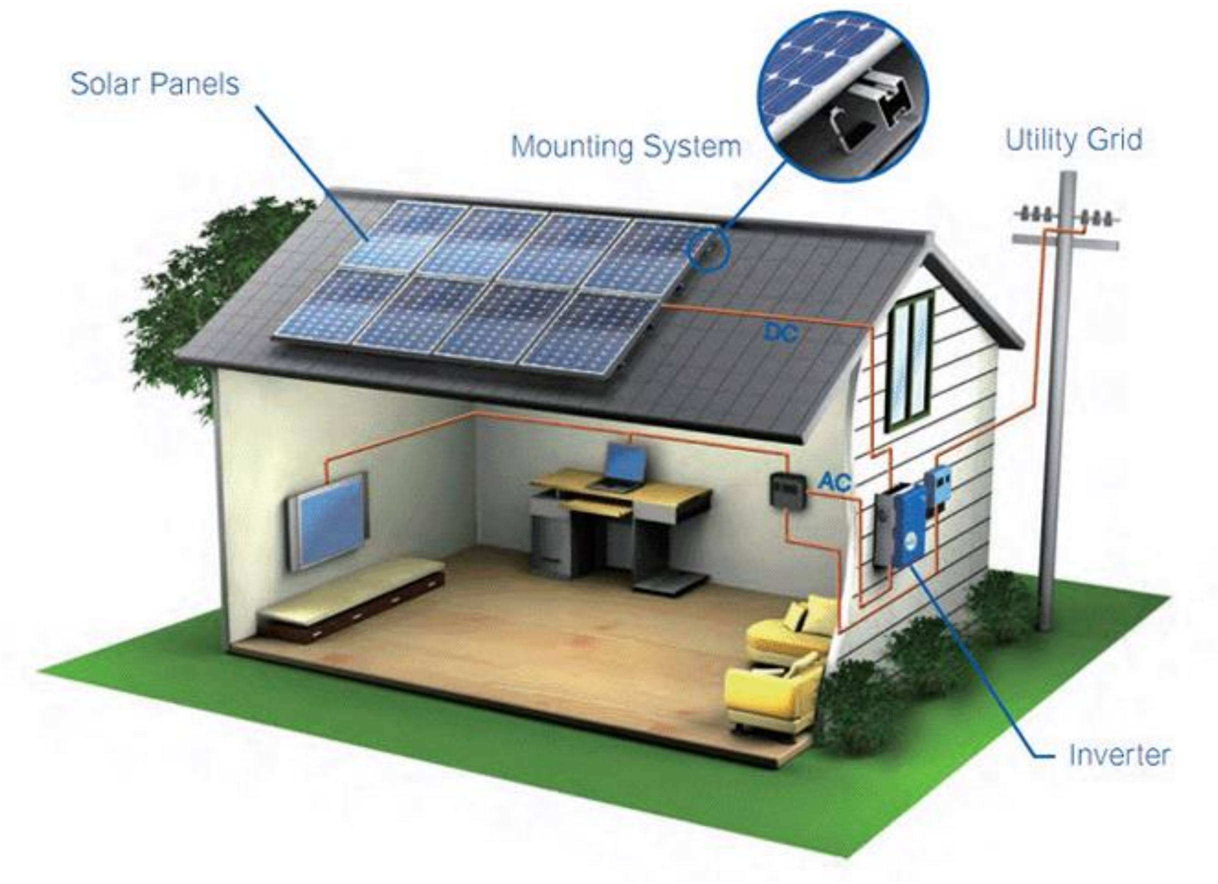


Fig: 3.3.11 Solar System

3.3.12 Turbine

A turbine is a mechanical device that converts fluid energy, such as wind, water, or steam, into mechanical energy. It consists of blades or rotors that rotate when the fluid flows over them. The rotating blades drive a generator or other machinery to produce electricity or mechanical power. There are several types of turbines, including wind turbines, which harness wind energy to generate electricity, and hydroelectric turbines, which use water flow from rivers or dams to produce power. Steam turbines are commonly used in power plants, where steam produced from boiling water drives the turbine blades. Turbines are efficient and widely used in renewable energy generation, helping to reduce dependence on fossil fuels and providing an eco-friendly source of power.

Figure: 3.3.12 Turbine

3.3.13 Greenhouse System

A greenhouse with a lighting system is designed to create an optimal environment for plant growth by controlling temperature, humidity, and light. The structure of the greenhouse typically consists of transparent materials like glass or plastic, allowing natural sunlight to enter. However, to extend growing hours, especially in regions with limited sunlight, a lighting system is integrated. This system uses artificial lights, such as LED or fluorescent lights, to supplement natural light during cloudy days or night-time. The light spectrum is carefully selected to promote photosynthesis and plant growth, with some systems offering adjustable settings for different plant stages. Additionally, automated systems control the intensity and timing of the lighting to ensure energy efficiency. The combination of natural and artificial light helps maintain ideal growing conditions, enhancing crop yield, and improving overall productivity, especially in greenhouse farming.

3.4. Proposed Model Flowchart:

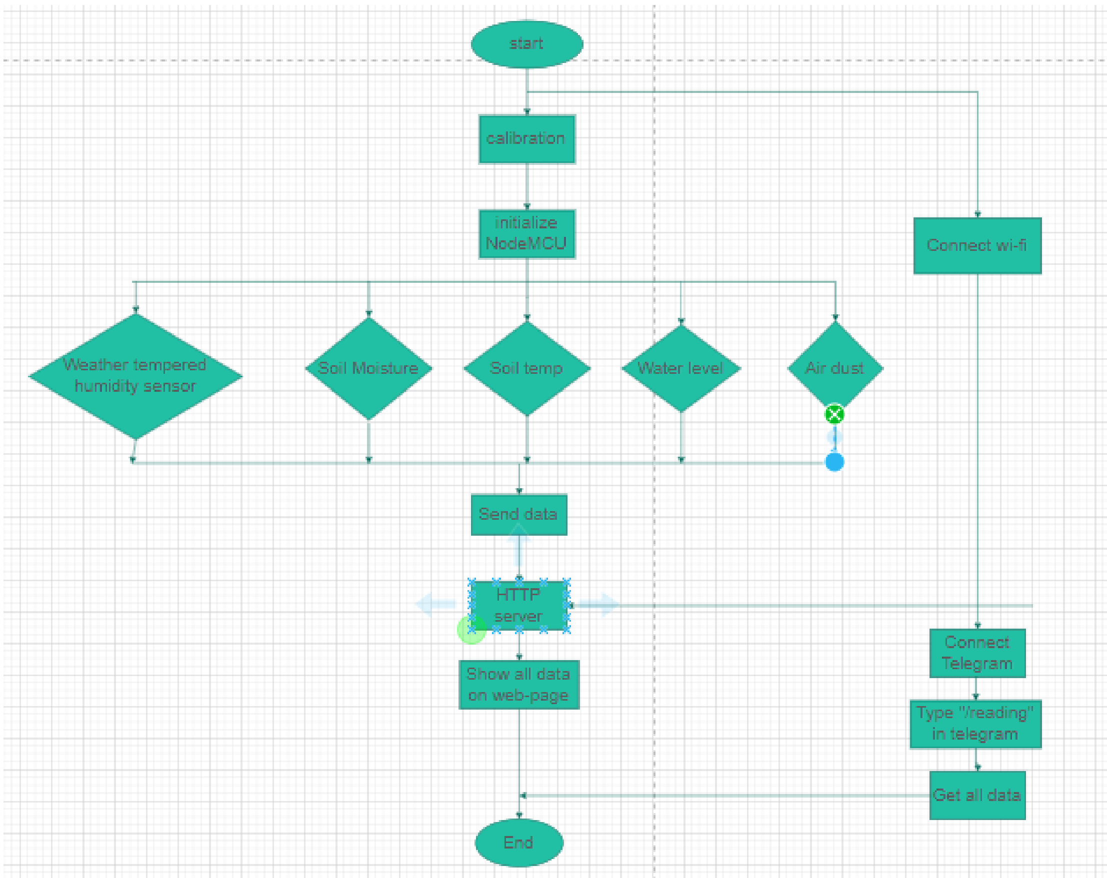
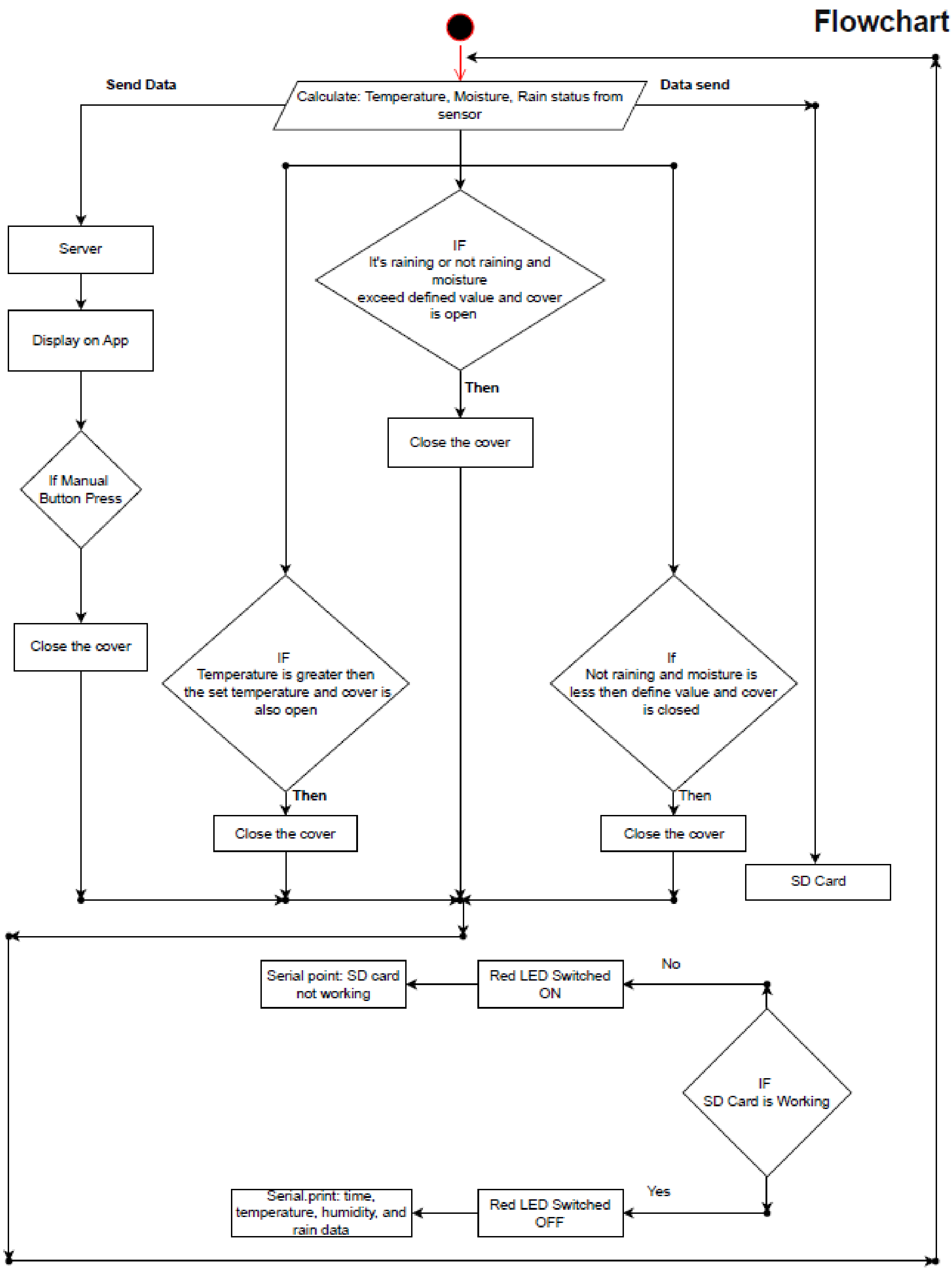


Figure 3.4.1: Flowchart of the proposed weather monitoring system.

Our system uses NodeMCU to monitor weather parameters, including several sensors such as temperature and humidity sensors, water level sensors, air dust detectors, soil temperature and soil moisture sensors. Here we use a Node MCU, which is an inexpensive microcontroller for retrieving data from the sensor. Add 5 sensors to your system. Soil moisture sensor and water level sensor are added to the temperature and humidity sensor. All of these parameters are very useful for monitoring weather conditions in the agricultural sector. Knowing real-time weather conditions such as temperature, precipitation, and humidity is the best way to protect plants and ensure high quality yields. As you know, soil is the most important part of farmland. Therefore, as long as the farmer knows the exact soil moisture value, less or more water can be used to grow the crop. And by knowing the water level, farmers can maintain soil water for better production. Farmers can also find out about the water level in their fields. Therefore, when the water level rises, he can take the necessary measures for his crop. Farmers can also use Telegram to monitor their fields from anywhere by connecting through Telegram App.

Figure 3.4.3: System Flow Chart



3.5 Smart Weather monitoring System Circuit Diagram:

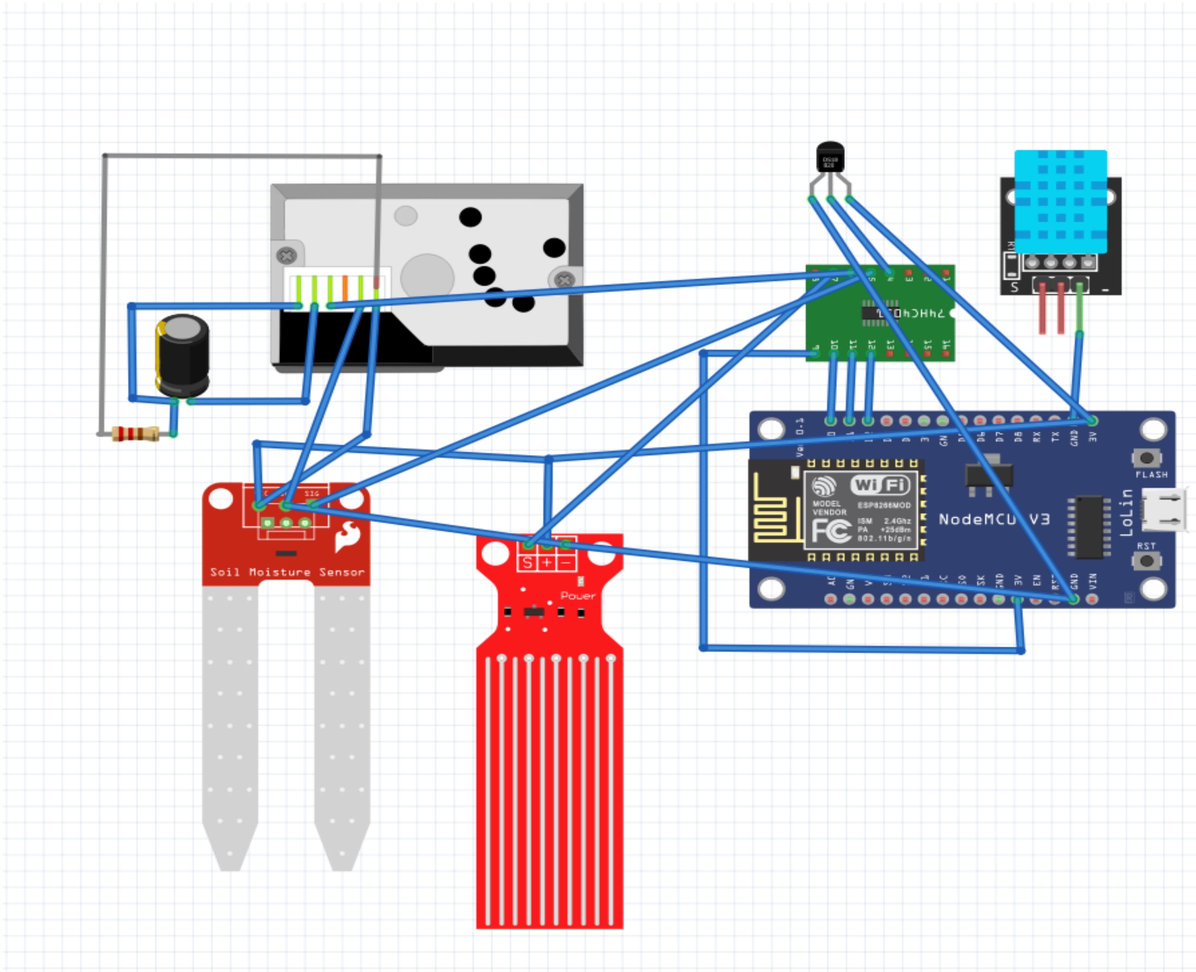


Figure 3.5.1: Circuit Diagram of weather monitoring system.

Chapter 4 - System Design and Architecture

4.1 System Overview

This system is designed to monitor and control vast agricultural lands using IoT and the ESP-NOW protocol. It enables real-time data collection from wireless sensors placed across large fields, transmitting crucial information such as soil moisture, temperature, and humidity to a central hub. Farmers can access this data remotely via a mobile app, allowing them to make informed decisions about irrigation, fertilization, and climate control.

One of the key features of this system is automation. Based on sensor readings, actuators such as water pumps, fans, and irrigation systems operate automatically to maintain optimal crop conditions. ESP-NOW ensures efficient communication between devices without requiring Wi-Fi or internet connectivity, making it ideal for remote agricultural areas.

By reducing water and energy waste while improving crop yield, this system enhances precision farming. It provides a cost-effective, low-power solution for large-scale agricultural monitoring, increasing productivity and sustainability.

4.3 Hardware Components

4.3.1 ESP32 Microcontroller

The ESP32 serves as the core of the system, enabling wireless communication via ESP-NOW. It collects data from sensors, processes it, and controls actuators. Its low power consumption and dual-core processor make it ideal for large-scale deployments.

4.3.2 Sensors

- ✓ **Soil Moisture Sensor:** Measures water content in the soil.
- ✓ **Temperature and Humidity Sensor:** Monitors ambient conditions.
- ✓ **Dust Sensor:** Detects air quality.
- ✓ **Water Level Sensor:** Tracks water availability in storage tanks.
- ✓ **Solar System**
- ✓ **Turbine**
- ✓ **Greenhouse**

4.3.3 Actuators

- ✓ **Water Pumps:** Automate irrigation based on soil moisture levels.
- ✓ **Fans:** Regulate temperature and humidity in greenhouses.
- ✓ **Power supply**
- ✓ **Power generates**
- ✓ **Greenhouse support**

4.3.4 Power Supply

Solar panels or batteries provide sustainable power to sensor nodes and the central hub, ensuring continuous operation in remote areas.

4.4 Software Components

4.4.1 ESP-NOW Protocol Implementation

ESP-NOW enables peer-to-peer communication between ESP8266 devices without Wi-Fi. It ensures fast, reliable data transmission over long distances, making it suitable for large farms.

4.4.2 Data Collection and Transmission

Sensor data is collected periodically and transmitted to the central ESP8266 hub via ESP-NOW. The hub aggregates and processes the data for analysis and control.

4.4.3 Control Algorithms

The system uses algorithms to analyse sensor data and trigger actuators. For example, if soil moisture is low, the algorithm activates the water pump for irrigation.

4.5 System Workflow

- ✓ Sensors deployed across the field collect environmental data.
- ✓ Data is transmitted to the central ESP8266 hub using ESP-NOW.
- ✓ The hub processes the data and sends it to the mobile app for real-time monitoring.
- ✓ Based on predefined thresholds, the system activates actuators (e.g., pumps, fans) to maintain optimal conditions.
- ✓ Farmers can override automated controls manually via the mobile app.

Chapter 5 - ESP-NOW Protocol

5.1. Overview of ESP-NOW

ESP-NOW is a wireless communication protocol developed by Espressif for ESP8266 microcontrollers, enabling direct, peer-to-peer data transmission without requiring Wi-Fi or internet access. Designed for low-power, low-latency communication, it is ideal for IoT applications such as agricultural monitoring, where real-time data collection and control are essential.

The protocol allows multiple devices to communicate within a single network, ensuring seamless data exchange between sensors and a central hub. This makes it highly efficient for monitoring vast agricultural lands, where traditional network-based solutions may be impractical due to connectivity issues.

Unlike Wi-Fi, ESP-NOW does not require complex pairing or authentication processes, simplifying deployment and reducing power consumption. It also supports encrypted communication, enhancing security. With its ability to work in remote areas and support battery-operated devices, ESP-NOW provides a reliable, cost-effective solution for precision agriculture, enabling farmers to optimize resources and improve crop productivity.

5.2. Advantages of ESP-NOW for Agricultural Monitoring

ESP-NOW offers several advantages for agricultural monitoring, making it an efficient and reliable choice for vast farmland management.

- ✓ **Low Power Consumption:** One of its key benefits is energy efficiency. ESP-NOW operates on low power, extending the battery life of sensor nodes deployed in remote fields, reducing maintenance needs.
- ✓ **Long Range Communication:** The protocol supports long-distance data transmission, ensuring effective monitoring across large agricultural areas without requiring additional infrastructure like repeaters or gateways.
- ✓ **Fast Data Transmission:** ESP-NOW enables real-time data transfer with minimal latency, allowing farmers to receive immediate updates on soil moisture, temperature, and humidity, leading to timely decision-making.
- ✓ **No Wi-Fi Dependency:** Unlike traditional IoT solutions, ESP-NOW does not rely on Wi-Fi or internet connectivity. This makes it highly effective in rural areas where network coverage is limited or unavailable.
- ✓ **Scalability:** ESP-NOW supports communication between multiple ESP8266 devices, making it ideal for large-scale monitoring. Farmers can easily expand their system by adding more sensors and devices without complex network configurations.

5.3. Implementation Details

Implementing ESP-NOW for agricultural monitoring involves setting up a network of ESP8266 devices for seamless data transmission.

First, configure one ESP8266 as a sender (sensor node) and another as a receiver (central hub). The sender collects real-time data from sensors measuring soil moisture, temperature, and humidity. It then transmits this data wirelessly to the receiver using ESP-NOW.

The receiver processes the incoming data and can either display it on a local interface, send it to a mobile app, or store it on a cloud platform for remote access. Each device in the network is identified using its unique MAC address, ensuring secure and organized communication.

To maintain data accuracy, implement error-checking mechanisms such as acknowledgment packets and data validation techniques. ESP-NOW's low power consumption and fast transmission make it ideal for large-scale agricultural monitoring, enabling real-time decision-making and automation without relying on Wi-Fi or internet connectivity.

5.4. Network Topology

The network topology for ESP-NOW in agricultural monitoring is primarily a star configuration, where a central hub communicates directly with multiple sensor nodes spread across the field.

- ✓ **Central Hub:** A single ESP8266 functions as the main receiver, collecting real-time data from all sensor nodes. It processes the information and forwards it to a mobile app or cloud platform for remote monitoring.
- ✓ **Sensor Nodes:** Multiple ESP8266 devices act as sensor nodes, each gathering data on soil moisture, temperature, and humidity. These nodes transmit their readings directly to the central hub using ESP-NOW's efficient communication protocol.
- ✓ **Mesh Option:** For larger agricultural areas where direct communication with the hub is difficult, a mesh topology can be implemented. In this setup, sensor nodes relay data to nearby nodes, which then pass the information along until it reaches the central hub. This ensures extended coverage without additional infrastructure.

This flexible topology enhances scalability, allowing farmers to efficiently monitor vast farmlands while maintaining low power consumption and reliable communication.

5.5. Security Considerations

In the development of the weather monitoring system, several security measures were considered to protect both the system and the data it collects. The wireless communication method, using the ESP-NOW protocol, ensures that data transmission is secure by reducing the risk of interference or unauthorized access, especially in rural areas with limited internet connectivity. Additionally, the system integrates encrypted data protocols to safeguard the transmission of sensitive environmental information. Secure access control is implemented for data visualization platforms, ensuring only authorized users, such as farmers or designated personnel, can access real-time data and system settings. Power security is also a concern, particularly for systems relying on renewable energy sources. The integration of backup power solutions, like batteries, ensures continuous operation during periods of low sunlight or wind, reducing the risk of system downtime. Regular software updates and system checks are performed to address vulnerabilities and ensure the system remains secure and efficient over time. Ensuring security in an ESP-NOW-based agricultural monitoring system is crucial to protect data integrity and prevent unauthorized access.

- ✓ **Encryption:** ESP-NOW supports AES encryption, securing data transmission between sensor nodes and the central hub. This prevents interception or tampering by unauthorized devices.
- ✓ **MAC Address Filtering:** To restrict communication to trusted devices, MAC address filtering can be implemented, allowing only whitelisted ESP8266 devices to exchange data within the network.
- ✓ **Data Integrity:** To detect and prevent data corruption, use checksums or Cyclic Redundancy Check (CRC) mechanisms. These ensure that transmitted data remains accurate and unaltered.
- ✓ **Firmware Updates:** Regularly update ESP32 firmware to fix security vulnerabilities, enhance encryption capabilities, and improve overall system performance. Keeping devices updated reduces the risk of exploitation.
- ✓ **Physical Security:** Protect sensor nodes and the central hub from tampering or environmental damage by placing them in weatherproof, tamper-resistant enclosures. This prevents unauthorized physical access and ensures long-term reliability.

By implementing these security measures, ESP-NOW-based agricultural systems remain resilient against cyber threats and physical risks.

Chapter 6 – Implementation

6.1. Hardware Setup

The hardware setup for an ESP-NOW-based agricultural monitoring system involves deploying multiple ESP32 microcontrollers and sensors across the field to collect environmental data.

- ✓ **Sensor Nodes:** Each node consists of an ESP8266 connected to sensors such as soil moisture, temperature, humidity, and water level sensors. These sensors continuously gather data and transmit it wirelessly to the central hub using the ESP-NOW protocol.
- ✓ **Central Hub:** A dedicated ESP8266 hub receives data from all sensor nodes and controls actuators like water pumps, irrigation systems, and fans based on sensor readings.
- ✓ **Power Supply:** The system operates on solar panels or rechargeable batteries to ensure continuous functionality, especially in remote areas without grid electricity.
- ✓ **Installation & Protection:** The central hub is strategically placed for optimal connectivity, and sensor nodes are distributed evenly across the field. Components are housed in waterproof, dustproof enclosures to prevent damage from rain, dust, and extreme temperatures, ensuring long-term reliability.

6.2. Sensor Integration

Integrating sensors with the ESP8266 microcontroller is essential for collecting accurate environmental data in an agricultural monitoring system. Each sensor is carefully selected and connected to the ESP8266 based on its communication protocol and data requirements.

- ✓ **Soil Moisture Sensor:** This sensor measures the water content in the soil and is connected to the ESP8266’s analog pin. It provides voltage readings that correspond to soil moisture levels, helping automate irrigation.
- ✓ **Temperature and Humidity Sensor (e.g., DHT22, SHT31):** These sensors use I2C or digital pins for data transmission. They measure air temperature and humidity, providing crucial information for optimizing crop growth conditions.

- ✓ **Water Level Sensor:** Installed in water storage tanks, this sensor detects water levels and is connected to the ESP8266 to manage water resources efficiently.
- ✓ **Soil Moisture Sensor:** Connected to the analog pin of NodeMCU, this sensor detects soil water content, helping automate irrigation and prevent water wastage.
- ✓ **Dust Sensor:** The dust sensor (e.g., GP2Y1010AU0F) measures air pollution levels by detecting dust particles. It uses an analog interface to provide real-time air quality data.

Each sensor undergoes calibration to ensure precise measurements. The ESP8266 reads sensor data at regular intervals, processes it, and prepares it for transmission using ESP-NOW. Data integrity techniques, such as averaging multiple readings, are applied to minimize errors. This seamless integration ensures real-time monitoring and automation, enabling farmers to make data-driven decisions for improved crop management and resource efficiency.

6.3. ESP-NOW Configuration

Configuring ESP-NOW for agricultural monitoring involves setting up one ESP8266 as a sender (sensor node) and another as a receiver (central hub). The sender is programmed to collect data from connected sensors such as soil moisture, temperature, and humidity sensors. This data is then transmitted wirelessly to the receiver using the receiver's MAC address for identification. The receiver listens for incoming data and processes it for further analysis or forwarding to a mobile app or cloud platform. To ensure secure communication, encryption is enabled using AES (Advanced Encryption Standard), protecting the transmitted data from unauthorized access. The ESP-NOW protocol allows fast and reliable communication between devices without the need for a Wi-Fi network, making it ideal for remote agricultural environments where connectivity may be limited. This configuration ensures seamless data transmission, low power consumption, and real-time monitoring of environmental conditions in agricultural fields.

6.4. Data Transmission and Reception

Data transmission in an ESP-NOW-based system involves sending sensor readings from the sender (sensor node) to the receiver (central hub). The sender packages the data—such as soil moisture, temperature, and humidity readings—into a structured format (e.g., JSON), ensuring easy interpretation and processing. This data is then transmitted wirelessly using the ESP-NOW protocol, which allows for fast and reliable communication without the need for Wi-Fi. The receiver collects the incoming data, verifies its integrity through checksums or CRC mechanisms, and processes it accordingly. If any errors are detected, the data transmission is reattempted. Once the data is processed, the central hub can store it locally or forward it to a mobile app or cloud platform for real-time monitoring. This enables farmers to remotely track environmental conditions and make informed decisions about irrigation, crop management, and resource allocation. The entire system is optimized for low power consumption, ensuring long-term operation even in remote areas.

6.5. Control Mechanism Implementation

The control mechanism uses sensor data to automate actuators like water pumps and fans. For example:

- ✓ If soil moisture is low, the ESP8266 activates the water pump for irrigation.
- ✓ If temperature is high, it turns on fans to cool the area.

These actions are based on predefined thresholds programmed into the ESP8266. Farmers can also manually control actuators via the mobile app, overriding automated decisions if needed.

6.6. Testing and Calibration

Testing involves verifying the functionality of each component:

- ✓ **Sensor Calibration:** Ensure sensors provide accurate readings by comparing them with manual measurements.
- ✓ **ESP-NOW Communication:** Test data transmission between sender and receiver to ensure reliability.

- ✓ **Actuator Control:** Verify that actuators respond correctly to sensor data and manual commands.
- ✓ **Power Supply:** Check the stability of the power supply under different conditions.
- ✓ **Field Testing:** Deploy the system in a small area first to identify and fix any issues before scaling up.

By thoroughly testing and calibrating the system, it ensures reliable performance in real-world agricultural environments.

Chapter 7 - Applications and Future Scope

7.1. Applications in Precision Agriculture

The weather monitoring system developed in this research plays a pivotal role in **precision agriculture** by providing real-time, localized environmental data. This data enables farmers to make informed decisions about irrigation, pest control, and crop management, significantly improving resource utilization. The system's ability to monitor temperature, humidity, soil moisture, and water levels helps optimize irrigation schedules, preventing overuse of water and ensuring crops receive the necessary moisture at the right time.

Furthermore, the system supports the adoption of advanced farming techniques like **greenhouse farming** and **True Potato Seed (TSP)** cultivation. In greenhouse environments, real-time data helps control temperature and humidity, ensuring optimal growth conditions and improving crop yields. For TSP farming, the system enhances disease resistance and improves yield efficiency by monitoring environmental factors that influence plant growth.

By integrating this weather monitoring system, precision agriculture can minimize environmental risks, reduce costs, and enhance overall productivity, contributing to sustainable farming practices.

7.2. Scalability of the System

The weather monitoring system is designed with scalability in mind, making it adaptable for use across various agricultural scales, from smallholder farms to large commercial operations. Its modular design allows additional sensors or units to be added based on specific farming needs, enabling farmers to expand the system as their operations grow. The low-cost, efficient components—such as the NodeMCU microcontroller, renewable energy sources, and wireless communication protocol—ensure that the system can be implemented in diverse environments without significant increases in cost.

Moreover, the use of **solar panels** and **wind turbines** for energy generation ensures the system can operate in remote areas without relying on external power sources, making it particularly suitable for rural regions. As technology advances, the system can also be upgraded with newer sensors or communication technologies, ensuring long-term relevance. This adaptability and low-cost infrastructure make the system an ideal solution for scalable implementation in global agricultural practices.

7.3. Integration with IoT and Cloud Platforms

The weather monitoring system is designed to integrate seamlessly with **Internet of Things (IoT) technologies** and **cloud platforms**, enhancing its functionality and accessibility. By connecting sensors and microcontrollers to IoT networks, real-time environmental data is continuously collected and transmitted for analysis. This data can then be uploaded to cloud platforms, where it is securely stored and processed for further use.

Through cloud integration, farmers can access the system’s data remotely via smartphones or computers, enabling them to monitor weather conditions and make timely decisions even from distant locations. The cloud platform also allows for data visualization, trend analysis, and predictive analytics, helping farmers optimize irrigation schedules, crop management, and resource utilization.

The IoT-based design facilitates easy scalability, as additional sensors or devices can be integrated into the system without major infrastructure changes. Overall, this integration improves the efficiency, accessibility, and effectiveness of the weather monitoring system, supporting smarter, data-driven farming practices.

7.4. Future Enhancements

Future enhancements to the weather monitoring system can focus on increasing its accuracy, efficiency, and adaptability to meet evolving agricultural needs. One potential improvement is the integration of **advanced sensors** such as soil pH sensors, light intensity sensors, and multi-spectral cameras for more comprehensive environmental monitoring. These sensors can provide a deeper understanding of soil health, plant growth, and pest conditions, further optimizing farming decisions.

Another key enhancement could involve the integration of **artificial intelligence (AI)** and **machine learning (ML)** algorithms. These technologies could analyze the collected data to predict weather patterns, detect potential crop diseases, and suggest preventive measures based on historical trends and real-time inputs.

Additionally, the system could incorporate **smart irrigation** capabilities, using automated decision-making tools to adjust irrigation schedules dynamically based on real-time weather and soil moisture data. Expansion to a larger network, connecting multiple farms or agricultural regions, could provide broader insights into regional climate trends.

Improving user interfaces, enhancing data security, and increasing integration with global agricultural platforms are also areas for future development, ensuring the system remains scalable and relevant to modern farming practices.

Chapter 8 - Result and Discussion

8.1. Evaluation and Experimental Result

The effectiveness of our system is measured using readings from the following sensors

- ✓ 1.Weather Temperature and Humidity Sensor [DHT11]
- ✓ 2.Soil Temperature Sensor
- ✓ 3. Soil Moisture Sensor
- ✓ 4.Water Level Sensor
- ✓ 5.Optical Air Dust Sensor [GP2Y1014AU0F]

According to these readings we will able for keep track on the real time weather monitor from anywhere by using the weather monitoring webpage or via Telegram App. The system can measure the Soil moisture, Temperature, Humidity and Water Level by all the sensors. So, the system is working perfectly.

Table 8.1.1: Test Result

Sensors	Morning	Afternoon
Weather Temperature	29˚C	36˚C
Weather Humidity	65%	72%
Soil Temperature	21˚C	25˚C
Soil Moisture	60%	32%
Air Dust	0.73 ppm	1.37 ppm

8.2. Tested Results display on the webpage

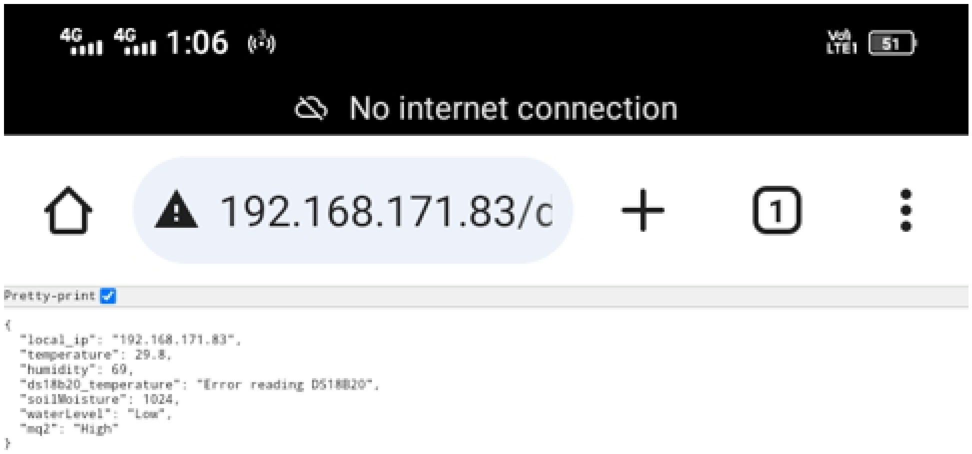


Figure 8.2.1: Tested Results display on the webpage

Here we can see the webpage of our project weather monitoring system. All the sensors are giving a real time data by measuring from the weather and soil. The data can be changed base on changing weather condition.

“local_ip”: “192.168.171.83”,

“Temperature”: 29.8,

“Humidity”: 69,

“Ds18b20 _temperature”: 25,

“SoilMoisture”: 1024,

“WetherLevel”: “Low”,

“mq2”: “High”,

According to the real time weather data from the webpage our farmer will able to know about the weather and soil condition of his crops field. Whenever the temperature rises that time soil temperature also rise and the soil moisture and water level of the crops field decrease. Our farmer can easily notify this by following this weather monitoring system.

8.3. Comparison with Similar Works

Here is the comparison between similar research based on different hardware.

P. Susmitha and G. Sowmyabala presented the Design with built in display and LPC1768 microcontroller which only can be monitor within a small range.

Jeethuri Vasantha & S Mahaboob Basha presented Weather Monitoring by using Rapsberry Pi and Wireless sensor Networks for sensing the environmental parameters. But Rapsberry Pi is too expensive for a farmer to afford.

But here we are you using NodeMCU as microcontroller and display the results by a weather monitoring webpage. Additionally, the user can also monitor the crops field weather condition by using Telegram App from anywhere in world.

Name of Papers	Communication Interface	Controller	Used Interface	Sensors Used	Benefits
Design and Implementation of Weather Monitoring and Controlling System(P. Susmitha and G. Sowmyabala)	GSM Module	Arduino UNO	GSM Based	Temperature, Gas and humidity.	Control relay from the mobile.
Weather Monitoring Using Raspberry Pi via Web Application (Jeethuri Vasantha & S Mahaboob Basha)	Web Server	Raspberry Pi	Cloud Based	Temperature, pressure, and humidity	Controlling all relay and get data from sensor to Server.
Weather monitoring system using Iot (Mehedi Hasan & Samim Al Masud)	Wireless LAN	NodeMCU	Smartphone Application Based	Soil moisture, temperature and humidity, dust sensor, water level	Get data from sensor to the HTTP website & Mobile Application.

Table8.3.1: Comparison with similar works

8.4. Discussion

This discussion part explains why the proposed system is superior to existing systems.

- ✓ This system is less costly as compared to the existing one. Because in the existing system, they use a Raspberry pi or Arduino Uno microcontroller. But here we use NodeMCU microcontroller. As we know, Raspberry pi is expensive and not so available in our country and Arduino Uno is less updated then NodeMCU, so we can say that this system is less costly and but more effective.
- ✓ This device is more accurate than previous systems. We have used top notch materials so that we can maintain the data accuracy and it works.
- ✓ The user can get weather update from anywhere in the world by using Telegram App.

Chapter 9 - Conclusion

9.1. Conclusion

This research presents an innovative, cost-effective weather monitoring system tailored for agricultural use, addressing the challenges faced by small and large-scale farmers in accessing affordable, accurate environmental data. By leveraging low-cost sensors, renewable energy sources, and efficient wireless communication, the system offers real-time monitoring of crucial parameters such as temperature, humidity, soil moisture, and water levels. The integration of IoT and cloud platforms ensures easy access to data, supporting informed decision-making and optimized resource management. The system's scalability, adaptability, and energy efficiency make it a practical solution for diverse farming environments, promoting sustainability and improving agricultural productivity. Future enhancements, such as AI integration and advanced sensors, promise further advancements in precision agriculture, contributing to smarter farming practices and long-term food security.

9.2. Limitation

The limitation of this weather monitoring system is mentioned below:

- ✓ **Weather Variability:** Environmental conditions such as extreme weather events may impact the performance or accuracy of the sensors, particularly in harsh climates.
- ✓ **Maintenance and Calibration:** Sensors require regular maintenance and calibration, which could incur costs and time, particularly in large-scale applications.
- ✓ **Initial Setup Cost:** Though the system is cost-effective, the initial setup, including solar panels, batteries, and other infrastructure, may be a financial barrier for small-scale farmers.
- ✓ This system is developed or designed for a small area.
- ✓ If the internet connect is lost then the device will unable to provide data through Telegram.

9.3. Future Scope

In the future, we will develop this project further, and it can also give more effective results in real-life applications.

- ✓ Adding more sensors for getting more effective output.
- ✓ For forecasting weather from anywhere in the world, we can develop a mobile application.

Chapter 10 - References

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