IMPROVED IOT- BASED WEATHER MONITORING SYSTEM FOR EFFECTIVE FARMING

BY

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CERTIFICATION

This is to certify that this work "**Improved IoT-Based Weather Monitoring System for Effective Farming** was carried out by **Ogbonna, Francisca Chinwendu**, Reg. number (**20204255838**) in partial fulfilment for the award of the degree of M.Sc. in Computer Science in the Department of Computer Science of the Federal University of Technology, Owerri.

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DEDICATION

I dedicate this thesis to my father Martins Ogbonna, for instilling in me the importance of trusting God and hard work since my childhood. Thank you, Dad, for your sacrifices and unwavering belief in me. I also extend my dedication to my beloved husband, Engr. Sylvester Okechukwu who has been my pillar of strength, constant support, and a model of patience throughout this journey. Your boundless love and dedication to me are truly appreciated, and I feel incredibly blessed to have you as my life partner.

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ABSTRACT

Agriculture serves as the backbone of numerous global economies, and its success heavily relies on weather conditions. The conventional weather monitoring systems often involves lack of real-time updates, manual data collection, limited coverage and elevated cost to maintain the infrastructure which hinders their adoption in agricultural settings. These limitations highlight the need for an affordable, automated and efficient weather monitoring solution which leverages IoT technology to assist farmers in mitigating the risks posed by unpredictable and inconsistent weather conditions consequently optimizing resource usage and improving crop yields. This study developed an enhanced Internet of Things (IoT) based weather monitoring system that elevates the efficiency of agricultural operations. The Ignite IoT methodology was adopted in this research. Key components of the system which allowed for real-time weather data collection includes the Digital Temperature and Humidity Sensor (DHT11), Barometric Pressure Sensor (BMP280), Rain Sensor and Light Dependent Resistor (LDR) for light intensity detection. These sensors were integrated with the NodeMCU microcontroller, Wireless Fidelity (Wi-Fi) module, a 9 voltage power supply and a Universal Serial Bus interface (USB) for solar alternative. Real-time weather data transmission to a central server via IoT technology allowing farmers to access crucial weather information through a user-friend mobile application powered by the Blynk IoT platform. The system demonstrated enhanced visualization via a flexible and comprehensible display interface. Extended operational time and more stable power supply through alternative power were also achieved. Compared to conventional methods, the IoT-based weather monitoring system eliminated manual data collection and utilized affordable IoT devices which in turn reduced the overall cost of implementation. By leveraging this IoT-based weather monitoring system, farmers can optimize resource usage, increase crop yields, and mitigate the impact of adverse weather conditions thus providing a cost-effective, reliable and efficient solution for modern agriculture.

Keyword: IoT, Weather monitoring, Effectiveness, Wi-Fi, Blynk application, NodeMCU

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Weather contributes significantly in agricultural production. It has a profound influence on growth, development, and yields of crops and livestock (Tabassum & Hossain, 2018). The quality of crop produce from the field through storage and transport to market depends on weather. Adverse weather affects the quality of produce during transport and the viability of seeds and planting material in storage (Aman, Dipak, Gupta, Ranjan & Badhai, 2021). Therefore, monitoring weather conditions and leveraging weather data are essential for mitigating risks and ensuring sustainable agricultural production in a changing climate. Agriculture is the foundation of human survival and plays a crucial role (Xihai, Zhanyuan & Wenbin, 2022). Agricultural productivity is highly dependent on environmental factors, particularly weather conditions. Climate has a significant impact on crop yield success or failure (Wadne, Walke, Bhandwalkar & Pisal, 2023). Possible changes in rainfall rates and change in temperature are expected to significantly impact crop growth (Aman et al., 2021). Monitoring these weather conditions through offline system can be challenging in the agricultural sector especially during certain hazardous and critical situations, where manual monitoring are really time consuming. This highlights the need for an online system in order to efficiently manage these aspects and safeguard crops and livestock (Hasan, Sipani, Patel, & Upadhyaya, 2020). Moreover, the increasing frequency and intensity of extreme weather events due to climate change necessitates more robust monitoring capabilities to improve preparedness and response strategies (Hasan et al., 2023). Crop yield has to be doubled in 2050 compared to 2009 in order to meet the demand of a growing population while increasing the food quality and reducing production inputs (Fukase and Martin, 2020).

Nowadays, agriculture become incredibly fast, and it is more of a competition now. Farmers now need to grow more crops in a less amount of time to meet the requirements of the people and the market. Atmospheric conditions are a major concern for the farmers because agriculture largely depends on these factors (Aman et al., 2021). Temperature and humidity sensors play a crucial role in agricultural weather monitoring systems allowing farmers to keep track of essential parameters such as temperature and humidity. Understand this ambient conditions in the field is essential for crop growth and development (Rika, 2023).

Farming and agriculture are often used interchangeably and involve the cultivation of crops and the husbandry of livestock primarily for food production. Today, farmers are suffering from low yield of crops. They encounter significant cost when building a weather station for their fields (Amna, Waqar, Roza, Fazal, Ghulam, Sunnia, Muhammed, Ako & Insaf, 2022). The Conventional weather monitoring systems in their field typically involve conventional and bulky machinery with numerous moving parts. These systems rely on a limited number of stationary weather stations, resulting in sparse and sometimes inaccurate data especially in areas with complex terrain or rapidly changing patterns and are also expensive to install and maintain (Balakrishnan & Chikkamadaiah, 2021; Navod, Hayati, Muhammad & Emerolylariffion 2021; Amna et al., 2022)

The field of Internet of Things (IoT) has revolutionized the way we interact with and monitor our environment (Sing, 2022). IoT is a swiftly evolving field that connects everyday objects to the internet, enabling them to collect and transmit data. In agriculture, IoT refers to the application of IoT technology to improve farming practices and efficiency. The IoT makes use of a variety of sensing devices that are connected via the Internet through wired and wireless communication media to coordinate the majority of fieldwork and include a wide range of components with features such as high precision, high accuracy, mobility, and portability which allows faster processing and monitoring capabilities towards mitigating the challenges associated with the growth of crops and having a better crop yield (Navod et al., 2021). Effective farming and IoT are deeply interconnected as productive agriculture relies heavily on weather conditions and require real-time and accurate weather update. IoT technologies provides a range of tools and solutions that empowers farmers with these vital updates enabling them to optimize their operations, increase productivity, and enhance sustainability. IoT technologies play a crucial role in promoting effective farming practices by providing farmers with real-time data and remote monitoring. IoT weather monitoring stations leverages on IoT technology and cloud computing to help collect, analyze and transmit real-time weather information (Kunaka, Mohammed, Shreyash, Digumarti & Yasir, 2023).

IoT enabled weather monitoring system offers several advantages for farmers and other stakeholders in agriculture including real-time data collection, accuracy, remote monitoring, extensive coverage, cost effectiveness, scalability, flexibility, and environmental monitoring. This is just an advancement of precision farming in which sensors collect the relevant data and help the farmer make decisions and take actions based upon analyzed data. One area where IoT has shown tremendous potential is in weather monitoring systems. Additionally, the proliferation of IoT technologies offers an opportunity to revolutionize weather monitoring by enabling the deployment of a dense network of interconnected sensors capable of collecting high-resolution data in real-time. Rasagna, Nivedith, Kumari and Kiran (2023) developed a solar-powered soil and weather monitoring system employing IoT to track various environmental parameters.

Moreover, IoT-based weather monitoring systems provide real-time data updates, enabling prompt and informed decision-making. The collected data is transmitted wirelessly to a central server or cloud platform, where it is processed, analyzed, and made available to users in a user-friendly format (Wadne et al., 2023). This allows farmers, meteorologists, researchers, and the general public to access up-to-date weather information from any device connected to the internet, such as smartphones, tablets, or computers. The development of such a system requires the integration of various technologies and components. This includes the selection and deployment of appropriate sensors capable of measuring different weather parameters accurately. The IoT-based weather monitoring system necessitates the implementation of a reliable and secure communication network. This typically involves using wireless protocols such as Wi-Fi depending on the specific requirements and geographical coverage. The central server or cloud platform plays a vital role in data storage, processing, and analysis (Satpute & Mali, 2022). Data visualization and real-time decision-making are important to IoT (Hurst, Mendoza & Tekinerdogan, 2021)

The first component of an IoT based weather monitoring system is the sensors. These sensors collect different weather factors such as temperature, humidity, pressure, rainfall and light. The type and number of sensors utilized in the system may vary depending on the specific needs and requirements. For example, a basic weather monitoring system may only need a temperature and humidity sensor, while a more advanced system may consists all the aforementioned sensors (Nikita & Nagveni, 2022; Kumtole, Suryawanshi & Pawar, 2022). The next component is the microcontroller, which is the brain and the core component of the system that can be programmed to read data from the sensors and send to the internet. A communication module is required to connect the system to the internet such as Wi-Fi or GSM module. This allows the system to send the collected data to a central server or a cloud-based platform for storage and analysis (Satpute et al., 2022).

Weather stations collect meteorological information about the current situation of a particular region and forecast the weather circumstances in an area. Weather status in Nigeria are declared and analyzed by the Nigerian Meteorological Agency (NiMet) depending on weather factors for a day-and-night period. However, since climate conditions changes constantly, it is necessary to record short term weather update to get accurate results. Data from the meteorological weather monitoring systems is accessible and used for a variety of purposes. Farmers, for example can use the information to mitigate the impact of severe weather events as well as make informed decisions. Weather forecasters can also use the data to improve their predictions and provide more accurate weather forecasts (Balakkrishnan & Chikkamadaiah, 2021). The data can also be used for research purposes, like studying the impacts of climate change.

In this research a simple weather station using IoT technology was developed to enable farmers monitor weather condition of any location at any point in time with the system. The system utilizes a NodeMCU Microcontroller based on ESP8266 along with various IoT sensors to gather weather-related data such as temperature, humidity, rainfall, pressure and light (Nikita et al., 2022; Kumtole et al., 2022). It also integrates the Blynk IoT platform and a smart phone interface. It offers a cutting edge approach to weather monitoring by ensuring real-time data updates and accessibility addressing the need to improve IoT weather monitoring systems. The motivation behind this research stems from recognition of the critical role that weather monitoring plays in agriculture. The goal is to tackle the challenges of getting real-time, accurate weather data and to develop solutions that optimize efficient energy use while minimizing cost.

Thus, this work improves on the existing weather monitoring system methods by leveraging the power of IoT devices, wireless communication, and cloud computing.

1.2 Problem Statement

Conventional weather monitoring systems have suffered several challenges such as lack of real-time and accurate updates, limited coverage and elevated costs associated with infrastructure maintenance (Zhang, Cao & Dong, 2020). Measurements are not saved on the internet for data archiving and essential weather variables such as rainfall and pressure, critical for agricultural purposes and regular planning of activities have not been adequately tackled due to the high power consumption of GSM modules and LCD screens, despite the inculcation of IoT systems (Suleiman, 2022). Economic efficiency, data accuracy, energy sustainability and reliability on the use of IoT enabled smart agriculture for effective monitoring are nothing to write home about (Quy, Hau, Anh,Quy, Ban, Lanza, Randazzo & Muzirafuti, 2022).

Weather forecasting and analysis of data in real-time in meteorology stations has also experienced several setbacks in delivering and determining accurate and real-time weather data collection and dissemination (Suleiman, 2022). In today's rapidly changing climate and unpredictable weather patterns there is a dire need to provide reliable and efficient weather monitoring systems. These systems should provide accurate and real-time weather data collection and dissemination that leverages on the power of IoT sensors, wireless communication and cloud computing. Therefore, the primary objective of this research is to develop an improved IoT-based weather monitoring system that overcomes the problem of real-time data collection, limited coverage, data availability and accessibility associated with the conventional weather monitoring systems.

1.3 Objectives

The main objective of this work is to develop an improved IoT-based weather monitoring system for effective farming.

The specific objectives are to:

1. Design a user friendly IoT- based weather monitoring system.
2. Develop a cloud integration for the IoT-based weather monitoring system for data capture, storage and retrieval.
3. Evaluate the system effectiveness in providing accurate weather information.

1.4 Justification of Study

This research is of immense benefit and significant as it proffers numerous solutions to lack of real-time updates, data archiving, limited coverage and high cost of infrastructure maintenance which has led to unnecessary setbacks in weather farming practices. Additionally, in cases where a weather forecasting system will predict rainfall in the whole of a metropolis or city, whereas, it rains in only a certain percentage of the location, contributes to the unreliability of the system. The improved IoT-based weather monitoring system will, however, predict the weather, covering a smaller distance which will provide better accurate results than that of a weather forecast.
Some other of its benefits includes:

1. Low Power Consumption: The utilization of Wi-Fi module and the Blynk IoT-platform via the smartphone ensured minimal power consumption.
2. Cost-Effective Solution: By incorporating affordable components and interfaces such as the Blynk IoT platform which leverages on existing devices like the smart phone, the overall cost of system implementation is reduced.
3. Improved Accuracy: The integration of 9v battery enhanced the accuracy and precision of data.
4. Improved Energy Sustainability: By optimizing the system battery volts and exploring other power source such as solar, system reliability and energy efficiency is enhanced.

By studying and implementing this IoT-based weather monitoring system, farmers and researchers can harness the power of real-time weather data, optimize resource usage, and enhance the resilience agricultural ecosystems.

1.5 Scope of Study

In this work the focus is on developing an improved IoT based weather monitoring system that provides farmers with quick and accurate weather conditions in real-time while providing a cost-effective solution for those with budget constraints by incorporating affordable IoT devices. The study also involves the design of a user-friendly interface to ensure that farmers with varying levels of technical expertise can easily have access to the system. In addition, it includes developing a cloud integration for capturing, storing and retrieving weather data, enabling farmers to access historical weather information. The research work also tackles optimizing battery voltage for energy efficiency. However, it does not include aspects such as real-time alerts or notifications for particular thresholds, data validation and quality controls or sensor placement and calibration. The System Structured Analysis and Design was adopted for this research work. The coverage range extends to a hectare of land and can be owned by one or more farmers, with a single-farmer ownership being more effective for coverage.

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Framework

Weather describes the atmospheric condition of a place over a short duration of time (Sanjoy, 2018). Weather is defining different variables, such as temperature, humidity, air pressure, and wind. Weather or climatic change plays an important role in human life (Zaw, Theint, Su & Aung, 2019). The concept of monitoring weather conditions did not just begin. It has been in existence. People of old learned to monitor the weather because of its impact on our day-to-day activities. Most especially on our outdoor activities such as travelling, agriculture and other distinct events. Various instruments, over centuries, have been used to predict and monitor weather. These instruments include rain gauge, barometers, anemometers and wind vanes. But the need for systems that can interpret atmospheric conditions with little or no human intervention was required. Weather conditions play a significant role in determining food production. As a result, monitoring these conditions is a key aspect of agricultural management. Devices can now integrate a broad range of environmental data to inform the best use of resources. Devices are also using more advance technology while also using more cost-effective materials, which will enhance the accuracy of forecasts in the face of global climate change (James, 2022).

Weather monitoring systems play a vital role in collecting, analyzing, and disseminating weather data for various applications. The types of weather monitoring stations includes but are not limited to the following:

1. Traditional Weather Stations: Traditional weather stations consist of multiple instruments such as rain gauge, temperature gauge, relative humidity, barometer, and pyrheliometer with solar panels to power the sun tracker and some sensors for measuring weather parameters such as rainfall, temperature, humidity, pressure and sun.
2. Agricultural Weather Stations: Agricultural weather stations are specifically designed to provide the needs of farmers and enable them optimize agricultural practices. These weather stations provides vital information for efficient crop production. They collect data on temperature, humidity, rainfall, pressure and sunlight allowing farmers to make informed decisions.

3. Automated Weather Stations (AWS): An automated weather station is an integrated system of components that are used to measure, record, and often transmit weather parameters such as temperature, humidity, pressure, rainfall and sunlight. Automated weather stations is an automated versions of traditional weather stations equipped with electronic sensors for automated data collection. They involve additional features such as data logging, remote monitoring capabilities, and wireless communication for real-time data transmission. Automated weather stations are mostly used in agriculture, transportation, aviation, and research applications.
4. Weather Radar Systems: Weather radar systems utilizes radio waves to detect precipitation, cloud cover, and severe weather phenomena such as thunderstorms, tornadoes, and hurricanes. Weather radar systems are vital for monitoring and forecasting severe weather events and providing early warnings to the users.
5. Satellite Remote Sensing: Satellite systems provide a unique opportunity to monitor earth-atmosphere system processes and parameters continuously. They provide data in different spatial and temporal resolutions.
6. IoT-Based Weather Station: Systems: The IoT Weather Station involves the development of a sophisticated weather monitoring system powered by Internet of Things (IoT) sensors. This system aims to collect real-time meteorological data, including temperature, humidity, pressure, rainfall and light. The collected data is then displayed on a user-friendly interface or a smartphone, providing users with latest weather information for their location. IoT-based weather monitoring systems leverages on Internet of Things (IoT) technologies, wireless connectivity and cloud computing to collect, transmit, and analyze weather data from a network of interconnected sensors. These systems provides accurate and real-time data updates, localized weather monitoring, scalability and flexibility.

A typical block diagram of IoT-based weather monitoring station is presented in Figure 2.1. This diagram shows how weather parameters including rainfall, wind speed, wind direction, temperature, humidity, light, pressure, smoke and CO_2 are measured using various sensors. These sensors are then processed by an analog or digital unit and transmitted wirelessly via a transceiver and visualized on a monitoring unit. This Figure

2.1 provides a conceptual framework for understanding the essential components and data flow in IoT-based weather monitoring systems. The block diagram is relevant to this work as it highlights the key functional elements of a weather monitoring system which have been adapted and improved upon in the development of the proposed IoT-based weather monitoring system. While the system by (Dipak, Sose & Ajiji, 2018) captures a wide range of weather parameters this study focuses on critical parameters including temperature, humidity, pressure, rainfall and light intensity.

Additionally, the proposed system integrates power optimization strategies and uses cloud integration for real-time data accessibility further enhancing system's efficiency.

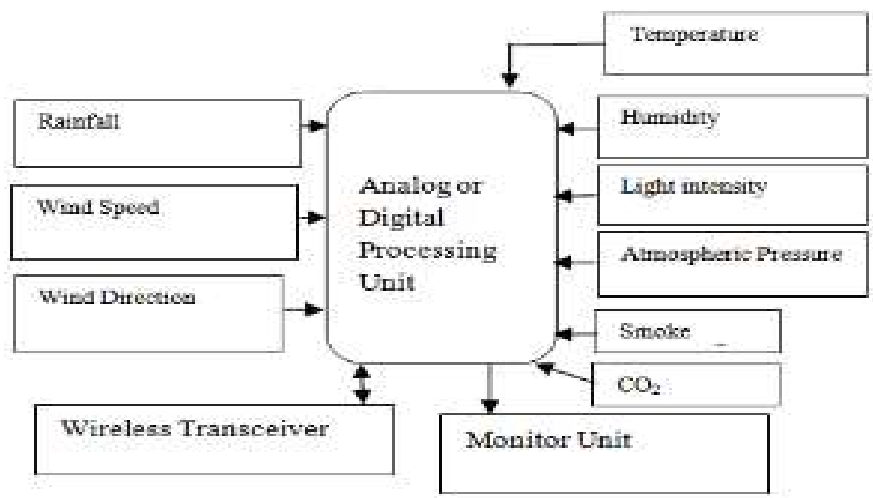

Figure 2.1: Typical block diagram of weather monitoring station (Dipak et al., 2018)

2.1.1 Weather Monitoring and Effective Farming

The concept of effective farming involves the practice of maximizing agricultural productivity, profitability, and sustainability while minimizing environmental impacts and resource use. It leverages real-time, localized data in order to make data-driven decisions, optimize resource use, mitigate risks, and adapt to changing weather conditions. By integrating weather monitoring systems into their operations, farmers can improve productivity, sustainability and resilience in agriculture. Weather monitoring systems play a vital role in effective farming by providing farmers with valuable information about current weather conditions. Effective farming relies heavily on weather monitoring and requires accurate and real-time weather updates in order to optimize agricultural practices and maximize productivity. In developing world countries, the agricultural sector is one of the most essential pillars of national income. Thus, implementing new technologies to enhance the agricultural sector is a significant issue for supporting the national economy in those countries.

The next-generation farming is evolving in a various ways at the same time. However, its main focus is using agricultural technologies to optimize crop yields through adequate planning and smarter management. By promoting more efficient and sustainable farming methods, advanced technology in farming enables farmer's blossom in today's contemporary farming and contribute to the viability of agriculture. Effective farming in weather monitoring is dependent on various factors that contribute to successful farming practices. These includes:

1. Real-time Monitoring: The use of weather monitoring systems which provides real-time weather data allows farmers to stay updated with current weather conditions on their farms. This information is vital for making well-informed decisions such as irrigation, pest management and other farming activities.
2. Localized Data: Weather monitoring systems provides localized data that is specific to the farmer's location. This allows farmers to understand ambient weather conditions within their fields and take necessary actions.
3. Timely Decision-making: Weather monitoring provides farmers with real-time data on temperature, humidity, pressure, rainfall, sunlight and other parameters. This information allows farmers to make timely decisions.
4. Optimized Resource Use: Weather monitoring enables farmers to optimize the use of resources such as water, fertilizer, and pesticides.

2.1.2 IoT Farming

IoT farming typically encompasses the utilization of specialized sensing devices to collect data on environmental factors affecting crops and farming tools. This data is then sent via a data network, allowing for real-time monitoring of farming processes, as well as the tracking and management of agricultural assets according to established data transmission protocols. The primary features of farming in IoT are clear, focusing on comprehensive data collection, intelligent processing, and prompt feedback throughout the agricultural process, from planting to sales. The advent of cloud computing has marked a significant achievement in IoT farming, revolutionizing farm management and operations (Xihai, Zhanyuan & Wenbin, 2022).

The architecture of IoT farming is illustrated in Figure 2.2. This architecture demonstrates the integration of various sensors such as motion detection, pH, soil moisture, soil ingredient, indoor air, ultraviolet, water quality, water level, temperature, air humidity, outdoor air quality and light radiation sensors. Figure 2.2 is relevant to this study as it provides a comprehensive framework for understanding how IoT technology integrate to support agricultural operations. These sensors are interconnected through IoT backhaul infrastructure, data centers and controllers with data accessible via deices like desktops, PDAs and smartphones. These architecture aligns with the objectives of the improved IoT- based weather monitoring system for effective farming by highlighting the importance of sensor integration and real-time data processing to optimize farming operations.

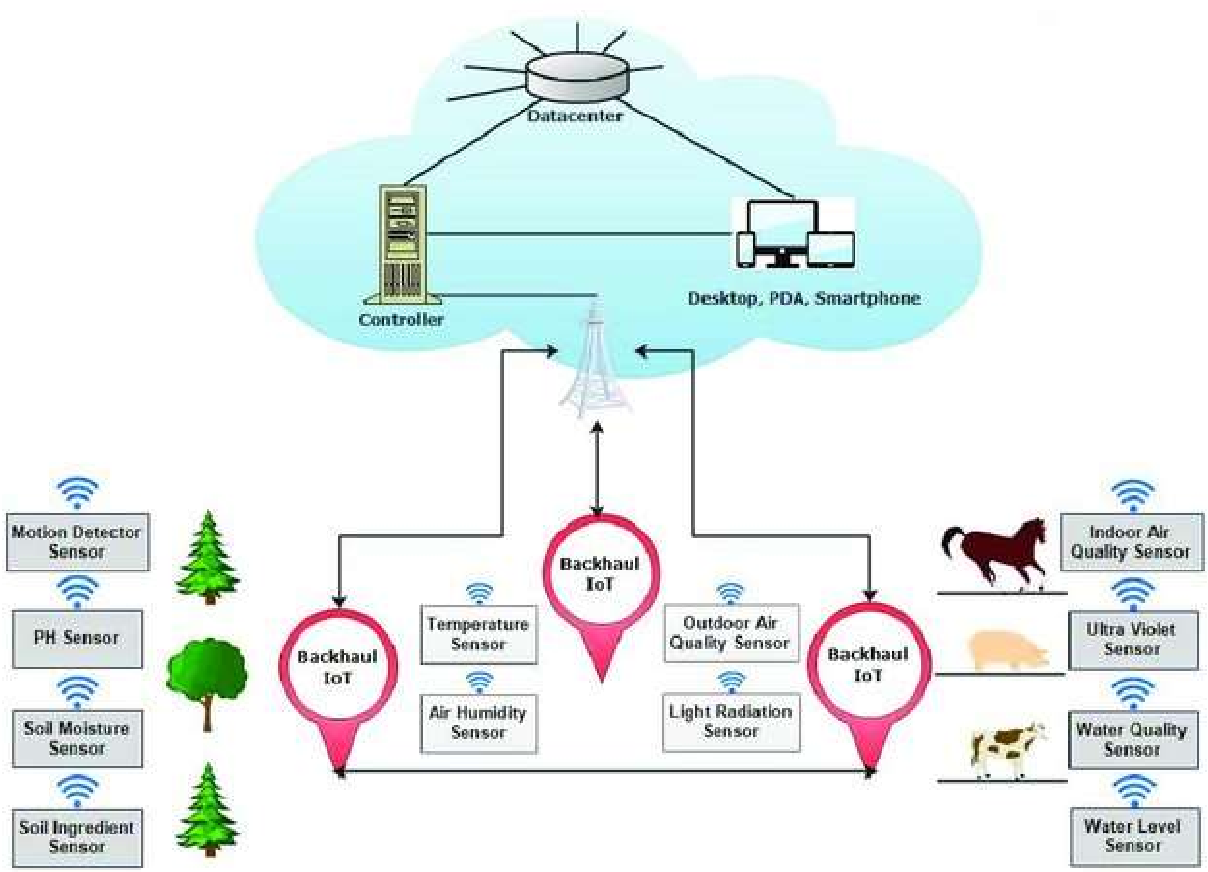

Figure 2.2: Common IoT-based farming topology (Quy et al., 2022)

2.1.3 Role of IoT-Based Weather Monitoring Systems

The IoT-based weather monitoring station represents a comprehensive open-source solution capable of detecting temperature, humidity, pressure and light. The recorded parameters are systematically stored and presented on an open cloud platform (Avines and Safaa, 2023). The Internet of Things (IoT) technology can link various remote sensors such as robots, ground sensors, and drones, as this technology enables devices to be linked together using the internet to be operated automatically (AlMetwally, Hassan & Mourad, 2020). Weather monitoring system that are IoT-based provides the following benefits:

1. Real-Time Data Collection: IoT-based weather monitoring systems integrates IoT sensors to continuously capture weather data including temperature, humidity, rainfall, pressure, and sunlight to provide real-time data on weather conditions.
2. User-Friendly Interface: Allows development of intuitive and accessible user interface that presents weather information in a clear and user-friendly manner.
3. Localized Data: IoT sensors deployed across the farm collects localized weather data, providing more accurate and site-specific information compared to traditional weather stations.
4. Wireless Connectivity: IoT-based systems utilize wireless connectivity, such as Wi-Fi module to transmit weather data to a centralized or cloud-based platform. This eliminates the need for manual data collection and allows farmers to access weather information remotely from any smartphone or computer.
5. Scalability: IoT-based weather monitoring systems can easily be scaled to accommodate the farm as it grows in size, from small-scale operations to large commercial farms. More sensors can be deployed as needed to cover larger areas and to monitor specific conditions.
6. Storage: Cloud-based platforms linked to IoT weather monitoring systems provides data analytics tools that enable farmers to analyze historical weather data, identify trends, and generate actionable insights.

Plate 2.1 depicts monitoring control of IoT devices for smart agriculture.

Plate 2.1: Smart Agriculture with IoT monitoring (Suma, 2021)

2.1.4 Components of an IoT-Based System

a. **IoT Sensors**

The system is composed of various weather sensors that collect data on temperature, humidity, rainfall, wind speed, and solar radiation. These sensors capture data from the environment and push them to an ADC that converts the analogue signals to digital signals that are understandable by computers for processing.

There are different types of sensors which includes:

i. Proximity sensors: These types of sensors are able to detect the presence of nearby objects without any physical contact. The proximity sensor often emits electromagnetic fields or a beam of electromagnetic radiation and looks for changes in the field or return signal. The object being sensed is often referred to as the proximity sensor's target.
ii. Photoelectric sensors: These are electrical devices that sense objects passing within their field of detection, although they are also capable of detecting color, cleanliness, and location if needed (Rasagna et. al 2023). These sensors rely on measuring changes in the light they emit using an emitter and a receiver. They are common in manufacturing and material handling automation for purposes such as counting, robotic picking, and automatic doors and gates.

iii. Pressure Sensors: These are electro-mechanical devices that detect forces per unit area in gases or liquids and provide signals to the inputs of control and display devices. Pressure sensors are used wherever information about the pressure of a gas or liquid is needed for control or measurement. The BMP180 is the new digital barometric pressure sensor of Bosch Sensor Tec, with a very high performance, which enables applications in advanced devices such as smartphones, tablet PCs, and sports devices (Mohit, Deepak, Priya,Anupma, Abhinav & Ankush, 2021). It follows the BMP085 and brings many improvements, like the smaller size and the expansion of digital interfaces. Also, the temperature affects the pressure and so we need temperature compensated pressure reading. To compensate, the BM180 also has good temperature sensor. Figure 2.1 depicts a barometric pressure adapted by (Mohit et al., 2021).

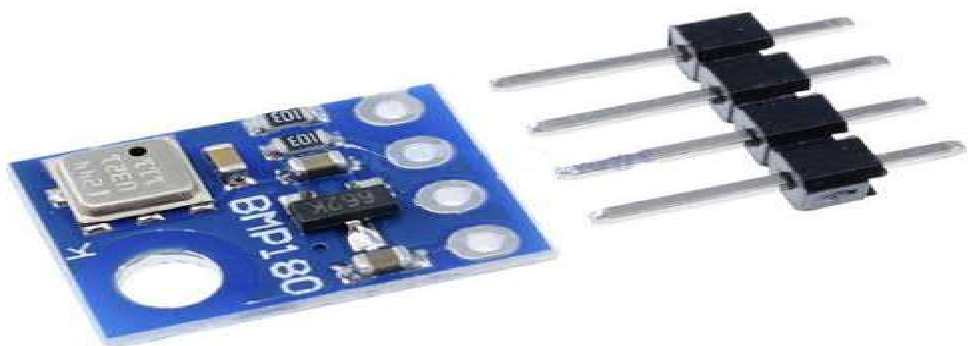

Plate 2.2: BMP180 sensor (Mohit et al., 2021)

iv. Temperature Sensors: These are electronic devices that detect thermal parameters and provide signals to the inputs of control and display devices. A temperature sensor typically relies on an RTD or thermistor to measure temperature and convert it to an output voltage. Temperature sensors are used to measure the thermal characteristics of gases, liquids, and solids in many process industries and are configured for both general- and special-purpose uses (Diarah, Osueke & Adekunle, 2023).

v. Humidity Sensors: These are electronic devices that measure the amount of water in the air and convert these measurements into signals that can be used as inputs to control or display devices. An example is the DHT-11 Digital Temperature and Humidity Sensor. It is a basic, ultra-low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air and spits out a digital signal on the data pin (Diarah et al., 2023). Plate 2.3 depicts a Digital humidity and temperature sensor (DHT11).

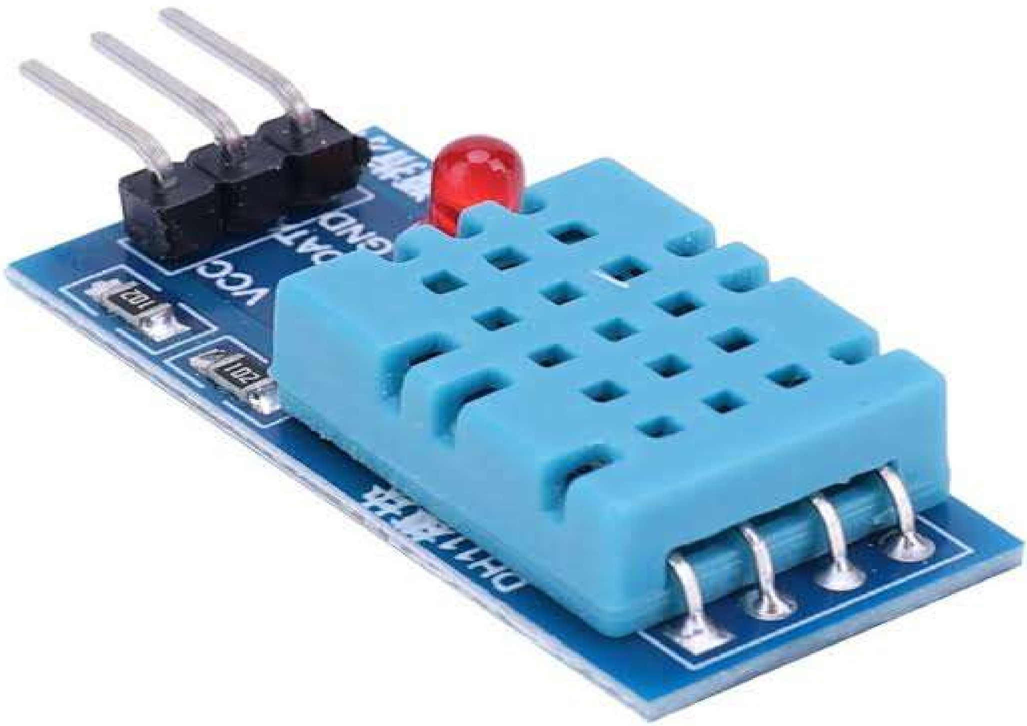

Plate 2.3: DHT11 sensor (Suleiman, 2022)

vi. Rain Sensors: A rain sensor is one kind of switching device which is used to detect rainfall (Mohit et al., 2021). It works like a switch and the working principle of this sensor is, whenever there is rain, the switch will be normally closed. It also consists of a rain sensor module. The rain sensor module/board is shown below. Basically, this board includes nickel coated lines and it works on the resistance principle. This sensor module permits to gauge moisture through analog output pins and it gives a digital output while moisture threshold surpasses. 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. Plate 2.4 depicts a typical rainfall sensor.

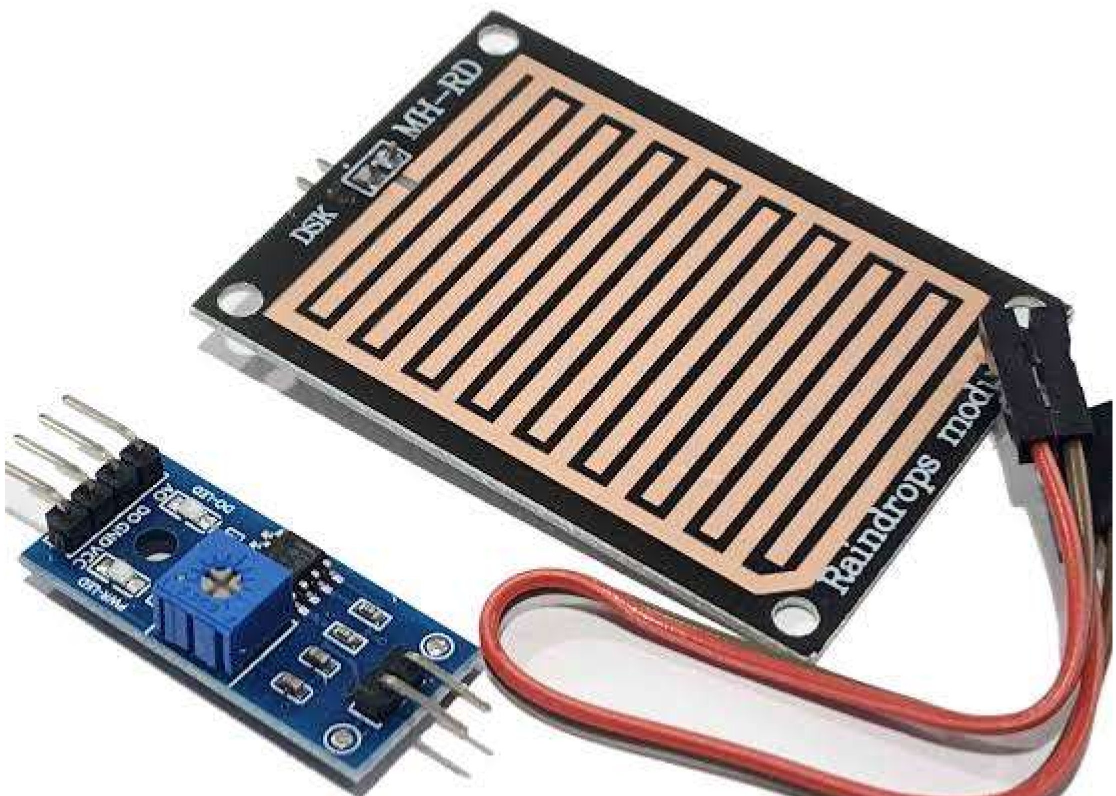

Plate 2.4: Typical rainfall sensor (Mohit et al., 2021)

Figure 2.3 above demonstrates a typical working principle of a sensor. Environmental signals are collected, processed by the sensors and then converted from analog to digital format for analysis.

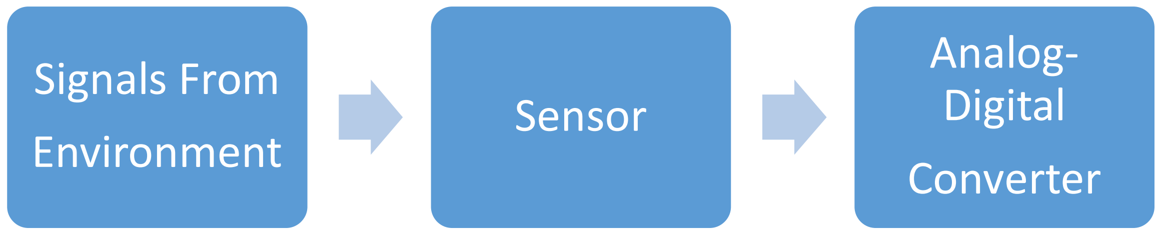

Figure 2.3: Typical sensor working principle

b. Microcontrollers or Single Board Computers (SBMs)

The NodeMCU is an open-source software and hardware development environment built around an inexpensive System-on-a-Chip (SoC) called the ESP8266. The ESP8266, designed and manufactured by Espressif Systems, contains the vital elements of a computer such as CPU, RAM, networking (Wi-Fi), and even a modern operating system and SDK. This makes it an excellent choice for Internet of Things (IoT) applications. The NodeMCU are used to read and process the data captured by sensors. The often run firmware or software that manages data acquisition, storage, and transmission. There are different types of microcontrollers and the one adopted in this work is the Node MCU Microcontroller Unit based on ES8266 as shown in plate 2.5

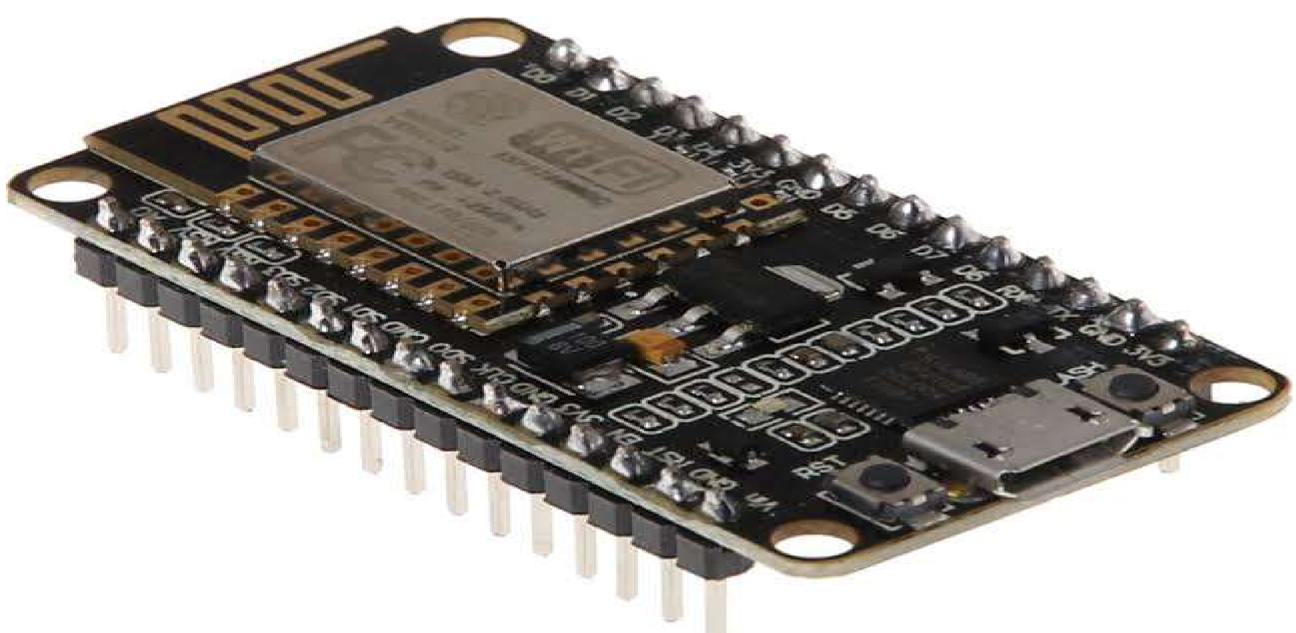

Plate 2.5: NodeMCU ESP8266 unit (Girija, 2018)

c. LCD 16*2

LCD stands for Liquid crystal display and it is one kind of electronic display module used in an extensive range of applications like various circuits & devices like mobile phones, calculators, computers, TV sets, etc. These displays are mainly preferred for multi-segment light-emitting diodes and seven segments. The main benefits of using this module includes inexpensive, simply programmable, animations, and there are no limitations for displaying custom characters, special and even animations, etc. Plate 2.6 shows a 16/2 LCD which is commonly used for real-time visualization. This type of LCD consists of 16 columns and 2 rows.

Plate 2.6: LCD 16×2 (Suleiman, 2022)

The 16×2 LCD pinout is shown:

i. Pin1 (Ground/Source Pin): This is a GND pin of display, used to connect the GND terminal of the microcontroller unit or power source.

ii. Pin2 (VCC/Source Pin): This is the voltage supply pin of the display, used to connect the supply pin of the power source.

iii. Pin3 (V0/VEE/Control Pin): This pin regulates the difference of the display, used to connect a changeable POT that can supply 0 to 5V.

iv. Pin4 (Register Select/Control Pin): This pin toggles among command or data register, used to connect a microcontroller unit pin and obtains either 0 or 1(0 = data mode, and 1 = command mode).

v. Pin5 (Read/Write/Control Pin): This pin toggles the display among the read or writes operation, and it is connected to a microcontroller unit pin to get either 0 or 1 (0 = Write Operation, and 1 = Read Operation).

vi. Pin 6 (Enable/Control Pin): This pin should be held high to execute Read/Write process, and it is connected to the microcontroller unit & constantly held high.

vii. Pins 7-14 (Data Pins): These pins are used to send data to the display. These pins are connected in two-wire modes like 4-wire mode and 8-wire mode. In 4-wire mode, only four pins are connected to the microcontroller unit like 0 to 3, whereas in 8-wire mode, 8-pins are connected to microcontroller unit like 0 to 7.

viii. Pin15 (+ve pin of the LED): This pin is connected to +5V

ix. Pin 16 (-ve pin of the LED): This pin is connected to GND.

The diagram in Figure 2.4 demonstrates the pin configuration of a 16x2 LCD. The pin diagram provides a clear representation of how the LCD is interfaced with other components in the system with each pin serving a specific function such as power supply, data transmission and control signals.

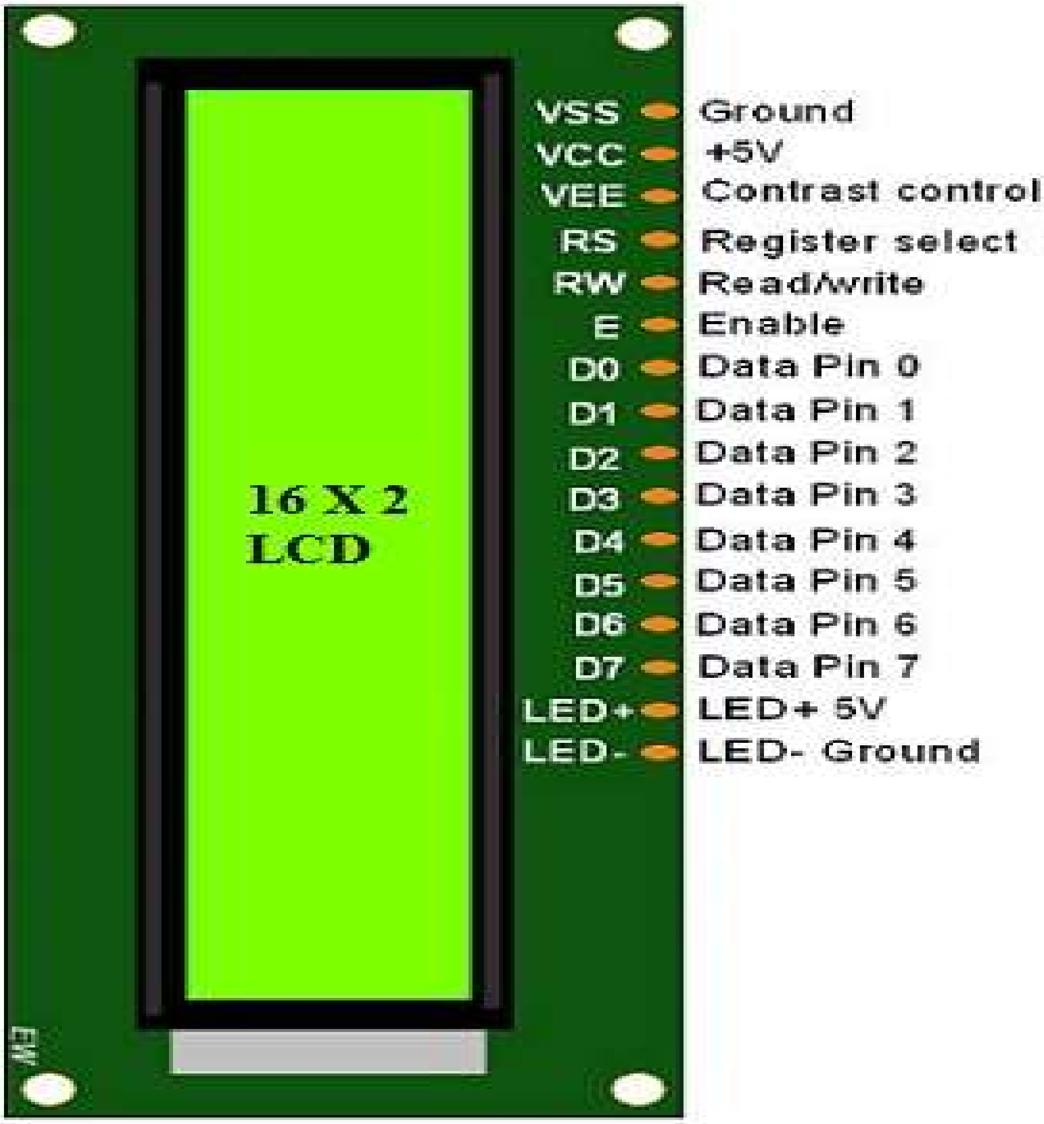

Figure 2.4: LCD 16x2 pin diagram (Suleiman, 2022)

Features of LCD16x2

The features of this LCD mainly include the following:

i. The operating voltage of this LCD is 4.7V-5.3V

ii. It includes two rows where each row can produce 16-characters.

iii. The utilization of current is 1mA with no backlight

iv. Every character can be built with a 5×8 pixel box

v. The alphanumeric LCDs alphabets & numbers

vi. Is display can work on two modes like 4-bit & 8-bit

vii. These are obtainable in Blue & Green Backlight

viii. It displays a few custom generated characters

Registers of LCD

A 16×2 LCD has two registers like data register and command register. The RS (register select) is mainly used to change from one register to another. When the register set is '0', then it is known as command register. Similarly, when the register set is '1', then it is known as data register.

i. Command Register

The main function of the command register is to store the instructions of command which are given to the display. So that predefined tasks can be performed such as clearing the display, initializing, set the cursor place, and display control. Here commands processing can occur within the register.

ii. Data Register

The main function of the data register is to store the information which is to be exhibited on the LCD screen. Here, the ASCII value of the character is the information which is to be exhibited on the screen of LCD. Whenever we send the information to LCD, it transmits to the data register, and then the process will be starting there. When register set =1, then the data register will be selected.

d. Data Communication and Connectivity Modules

IoT weather systems require connectivity to transmit data. A robust network infrastructure has to be established to transmit sensor data securely and reliably. This can be Wi-Fi, GSM or Bluetooth or other communication protocols. Data communication in the Internet of Things (IoT) involves exchange of information between devices, systems, and applications in an IoT ecosystem. IoT devices generate and collect data, which is then transmitted, shared, and processed to enable various functionalities and applications. In IoT, data communication is crucial for enabling the seamless flow of information between devices, cloud services, and applications. It plays a vital role in harnessing the full potential of IoT to drive automation, optimization, and intelligent decision-making in various industries and domains. Some key aspects of data communication in IoT includes:

i. Device-to-Device Communication: IoT devices communicate with each other directly, forming a network of interconnected devices. This can be achieved through wired (e.g., Ethernet) or wireless (e.g., Wi-Fi, Bluetooth, Zigbee) communication protocols. Device-to-device communication allows devices to share data, coordinate actions, and collaborate within an IoT network.

ii. Device-to-Cloud Communication: IoT devices often transmit data to the cloud for storage, analysis, and further processing. This communication typically occurs over the internet using protocols such as HTTP, MQTT (Message Queuing Telemetry Transport), or CoAP (Constrained Application Protocol). Devices send data to cloud servers, where it can be accessed, processed, and utilized by applications or other devices.

iii. Edge Computing: In some IoT scenarios, it is advantageous to process and analyze data closer to the source, at the edge of the network, rather than transmitting it all the way to the cloud. Edge computing enables real-time data processing, reducing latency and network congestion. Edge devices, such as gateways or edge servers, perform local data analysis and make immediate decisions or send relevant data subsets to the cloud for further processing.

iv. Data Formats and Protocols: IoT devices need to adhere to specific data formats and protocols to ensure interoperability and seamless communication. Common protocols include HTTP, MQTT, CoAP, and WebSockets. Data formats such as JSON (JavaScript Object Notation) or XML (eXtensible Markup Language) are commonly used to structure and represent data.

v. Security and Privacy: IoT data communication requires robust security measures to protect the confidentiality, integrity, and availability of the data. Encryption, authentication mechanisms, access controls, and secure communication protocols (e.g., TLS/SSL) are essential to safeguard IoT data. Additionally, privacy considerations should be taken into account when transmitting and storing sensitive user or personal data.

vi. Scalability and Network Infrastructure: IoT deployments often involve a large number of devices, leading to scalability challenges. The underlying network infrastructure should be able to handle the increasing volume of data and support the required bandwidth and latency requirements. Technologies like 5G and LPWAN (Low-Power Wide-Area Network) have emerged to address IoT scalability needs.

e. Data Processing and Storage

The use of cloud-based platforms or local servers enables immediate and efficient processing and storage of the captured data. IoT data processing ans storage includes managing and analyzing the vast amounts of data generated by IoT devices. Efficient data processing and storage are essential components of IoT systems. As IoT deployments continue to grow, efficient data processing and storage mechanisms are vital for extracting meaningful insights, making real-time decisions, and enabling various IoT applications.

f. Visualization and Reporting

The goal of visualization and reporting in an IoT-based weather monitoring system is to provide users with clear, meaningful, and actionable insights from the collected weather data. By presenting data in a visually appealing and interactive manner, users can make informed decisions based on current and historical weather conditions. Visualization and reporting are essential components of an IoT-based weather monitoring system as they enable users to comprehend and interpret the collected weather data effectively. Some considerations for visualization and reporting in IoT systems includes:

i. Real-time Dashboards: Develop interactive dashboards that display real-time weather data collected from IoT weather sensors. The dashboard should present key weather parameters such as temperature, humidity, wind speed, precipitation, and atmospheric pressure in a visually appealing and intuitive manner. Graphs, charts, maps, and gauges can be used to visualize the data dynamically.

ii. Historical Data Analysis: Provide the ability to analyze historical weather data collected over time. Users should be able to select specific time periods and view trends, patterns, and changes in weather conditions. Visualizations such as line charts, heat maps, or histograms can help users identify long-term patterns or seasonal variations in weather data.

iii. Alerts and Notifications: Implement a notification system that can send alerts to users based on predefined weather thresholds or significant weather events. Visual indicators, such as color-coded alerts or warning symbols, can be used to draw attention to critical weather conditions. Users can receive notifications via email, SMS, or push notifications on mobile devices.

iv. Data Comparison: Enable users to compare weather data across different timeframes, locations, or weather stations. Comparative visualizations, such as side-by-side charts or overlaid graphs, can help users identify variations or anomalies in weather conditions. For instance, users can compare current weather data with historical averages or compare weather patterns between different regions.

v. Customizable Reports: Provide the ability to generate customizable reports summarizing weather data. Users should be able to select specific parameters, timeframes, and presentation formats to create tailored reports. Reports can include statistical summaries, graphs, and textual descriptions of weather conditions during a specific period or for a particular location.

vi. Responsive and Accessible Design: Ensure that the visualization and reporting interfaces are responsive, adapting to different devices and screen sizes. The system should be accessible to users with disabilities, adhering to accessibility guidelines and providing alternative text descriptions for visual elements.

g. User Interface

A user-friendly interface accessible via web or mobile applications allows users to interact with the weather monitoring system. The interface provides real-time weather updates, analytics reports, alerts, and notifications, enabling users to make informed decisions.

h. Power Supply

The IoT- based weather monitoring systems can be powered using DC batteries, main electricity, solar panels, or combination of these sources.

2.1.5 Key Features and Functionalities:

1. Real-time Monitoring: The system is designed to provide continuous and up-to-date weather information from the data captured via the sensors.
2. Scalability: The system can be designed to accommodate a large number of sensors and support future expansion.
3. Data Accuracy and Quality: Implementation of calibration mechanisms and data validation techniques to ensure accurate and reliable measurements.
4. Alerts and Notifications: Mechanisms can be developed to send timely alerts and notifications to farmers regarding critical weather conditions.
5. Integration with Farming Practices: The weather monitoring system can be integrated with other farming systems, such as irrigation or crop management, to optimize resource usage.
6. Historical Data Analysis: Allows the storage and analysis of historical weather data to identify long-term patterns, climate changes, and seasonal trends.
7. Decision Support System: Provide farmers with actionable insights and recommendations based on the captured data.
8. Data Security and Privacy: Allows implementation of robust security measures to protect the IoT devices, network infrastructure, and data storage from unauthorized access. It also allows for data encryption during transmission and storage to ensure data confidentiality. However, there's need to comply with relevant data protection regulations and obtain necessary permissions for data collection and storage.
9. Integration with External Data Sources: Integrate the weather monitoring system with external data sources, such as meteorological services or satellite imagery, to enhance accuracy and broaden the scope of information available to farmers.
10. User Interface and Accessibility: Enables the design of a user-friendly interface which can be accessed from various devices, including smartphones, tablets, and computers. There's need to consider farmers with varying levels of technical expertise and provide adequate training and support.

11. Continuous Improvement: Gather feedback from farmers and stakeholders to identify areas for improvement and incorporate new features or technologies as they become available.

2.2 Theoretical Framework

2.2.1 Overview of Frameworks and Platforms

Several research have been conducted to address the design of weather monitoring stations. One significant study introduced a concept for an intelligent weather monitoring station utilizing a peripheral interface microcontroller (PIC) in conjunction with a cloud platform (Djordjevic & Dankovic, 2019). This platform was conceived to offer a straightforward configurational setup and the potential for scalable expansion. However, it is crucial to note that the central control unit powering this platform is a robust PIC microcontroller, which assumes a comprehensive control over the entire system. This microcontroller is equipped with embedded sensors capable of monitoring and measuring environmental conditions or specific locations as necessitated. Furthermore, a pivotal component of this system includes a General Packet Radio Service (GPRS) module, facilitating the seamless transmission of data to the designated cloud platform (Ahuja & Khosla, 2019).

In today's world many monitoring systems are designed by different environmental parameters (Balakrishnan & Chikkamadaiah, 2021). The existing system model presents an IoT-based weather monitoring and reporting system where you can collect, process, analyze, and display your measured data on web server. Wireless sensor network management model consists of devices, router, gateway node and management monitoring center. End device is responsible for collecting wireless sensor network data, and sending them to parent node, the data are sent to gateway node from parent node directly or by router. After receiving the data from wireless sensor network, gateway node extracts data after analyzing and packaging them into Ethernet format data and then sends them to the server. Less formally, any device that runs server software could be considered a server as well. Servers are used to manage network resources. The services or information provided through the internet are connected through LAN and made available for users via smart phones, web browser or other web browser devices to make the system more intelligent, adaptable and efficient.

Recently, the implementation of sensors is now common and has brought with it the era of automated weather monitoring which is done with little or no human intervention at all. These devices have the ability to sense the conditions and real feel of the atmosphere and store the data obtained in a database more accurately without the problem of human errors. An IoT-based farming system can create effective decision-making and avoid undesirable situations (Amna et al., 2022).

Chandini et al. (2020), in their work “IoT based weather monitoring systems for smart agriculture”, buttressed the significant impact of weather and climate in the subject of agriculture. These days’ climate change and pollution has become a serious issue which in turn has increased the importance of weather monitoring. The human activities are responsible to great influence on the climate, and drastic changes over decades. Weather is known to play an important role in agricultural production. Its influence covers crop growth and development, even yields on the incidence of pests and diseases on water needs and on fertilizer requirements (Tabassum & Hossain, 2018) .This can be as a result of differences in nutrient mobilization due to different weather conditions, as well as the timelines and effectiveness of preventive measures and cultural operations with crops. The quality of crop produce during movement from field to storage and transport to market depends on weather. Bad weather affects the quality of produce during transport and the viability of seeds and planting material during storage (Aman et al., 2021).

Weather elements and their observations are essential to agriculture and the environment. Our behavior as humans is driven by the changing weather elements especially our farming operations. The physical elements of climate are observed in order to assist in the evaluation of actual and future land use potentials and of such constraints in agriculture as are caused by the environment. IoT agriculture is a technology that relies on its implementation on the use of AI and IoT in cyber-physical farm management (Bacco, Barsocchi, Ferro, Gotta & Ruggeri, 2019). With respect to the importance of weather conditions in farming, farmers meticulously pay attention to these weather conditions in order to achieve great yield and crop produce. Because the farmer may not be able to fully and efficiently monitor these weather conditions and analyze the data without errors, an IoT based system is required to collect this data, store and analyze them for strategic decision making.

The IoT system comprises of different sensors to collect data on temperature, humidity, atmospheric pressure and amount of rainfall. These sensors will be connected to a microcontroller which is usually Arduino to improve cost-efficiency. It will also have a communication module to transmit the collected data in real-time to cloud or a local server that will process and analyze the data. The entire system will be connected to a power source which will be a DC battery or solar generated. This is because the system is supposed to be a low-cost system affordable by farmers of all financial capacity. The IoT weather station is essentially a data acquisition system remotely able to collect information based on meteorological and ambient parameters and store it in the cloud or database on the webserver (Tabassum & Hossain, 2018). Data acquisition system such as IoT weather station are based on Internet of Things technology. This IoT weather station can be called "IoT" in research related to so-called non-IoT weather stations that do not use Internet of Things technology. Non-IoT weather station use only wired connected media to store measurement results, such as security digital (SD) memory card, flash memory, EEPROM memory, etc.

Main elements of the smart weather station are:

1. Network for communication – wire, cable (Local Area Network (LAN)), wireless.
2. Intelligent control – microcontroller to manage the system.
3. Embedded sensors – products which can be used to observe and measure meteorological/ambient parameters.

There are many different implementations of smart weather stations, which are reflected in the way in which communications and storage media are realized. Most of the implementations use wireless technologies for communication between the sensor part and the main unit. Smart agriculture addresses many issues related to crop production as it allows monitoring of the changes of climate factors (Elsayeed, Belal, Sameh, Mohammed, Gadi & Zahran 2021). The main problem is how to realize a smart weather station that will be as cheap as possible and as safely as possible to store the measured data. Also, how to make a weather station that will help people to automate regular daily activities. For example, store data so that the end-user can easily access them, access the results of the measurement from anywhere, manipulate stored data, etc. Smart weather stations have been developed based on different technologies:

1. Smart weather station based on custom microcontroller and mobile application. Smart weather station uses Bluetooth for communication between the mobile application and the weather station. Limitation of the system like this is Bluetooth range.
2. Smart weather station based on custom microcontroller and computer. Smart weather station uses Radio Frequency (RF) for communication between the computer and weather station. It is based on a computer as entry point for communication between user and smart weather station. Computer is connected using wire to microcontroller.
3. Smart weather station based on NodeMCU running ESP8266 Wi-Fi module and Cloud or database on webserver. WI-Fi Internet is used for communication between weather station and database. Limitation of the system like this is because ESP8266 need to have access to the Internet.
4. Smart weather station based on custom microcontroller and Cloud or database on webserver. Smart weather station uses Global System for Mobile Telecommunications for communication with General Packet Radio Service for communication between weather station and Cloud or database on webserver. Advantage of this system is that the Global System for Mobile Telecommunications does not require Internet access and can be used in difficult accessible locations.

2. 2. 2 Automated Weather Monitoring System

The Internet of Things (IoT) is a revolutionary theory that involves connecting a wide range of devices, objects, and systems over the internet. The devices in the IoT ecosystem consists of sensors, actuators, and software that allow them to collect and transmit data. This information ranges from basic ecological measures to comprehensive information about user behavior and preferences. Various connectivity technologies such as Wi-Fi, Bluetooth, cellular networks, and low-power wide-area networks (LPWANs), allows seamless communication and data sharing between IoT devices. These technologies offer real-time monitoring, control, and automation, which has a wide range of applications. Connected sensors and devices provide for real-time monitoring of devices, allowing for better operations, less downtime, and reduced maintenance costs (AlMetwally et al., 2020).. Thing Speak is a cloud based IoT analytics platform that allows users to gather, store, analyze, and visualize sensor data from connected devices. It has a simple interface and robust features for handling IoT data and developing apps. Thing Speak allows users to create channels to collect data from various sensors and devices. These channels serve as virtual containers for incoming data pieces and timestamps (Kanaka et al., 2023).

2.2.3 Multi culture framework

There are many culture classifications as shown in Figure 2.5. The framework shows the block diagram of multi-culture. For horticulture, floriculture, and viticulture, crop status and pest control can be activated (Chung, Choi, Lee, Kim, Hong & Li, 2022). The profit margin can be estimated for the number of fruits and flowers that can be separately listed from citrus fruits. The organic fertilizer is created by cultivating earthworms named vermiculture. Silviculture is used to establish the control of the composition and quality of land to be evaluated for various growths (Chung et al., 2022).

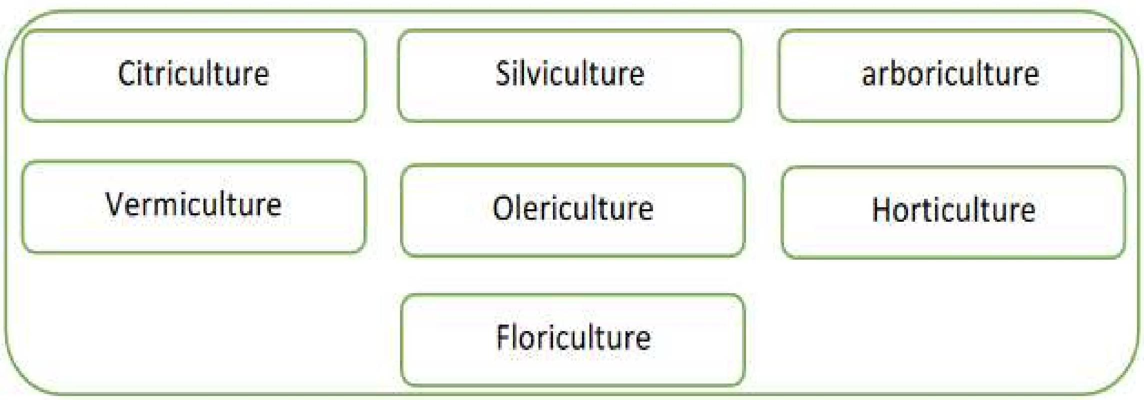

Figure 2.5: Block diagram of classification of multi-culture (Suma, 2021)

2.2.3 Predictive analysis framework

The cloud computing process performs predictive analysis with big data processing from IoT for multi-culture analysis. The probabilistic measures offers increased production in the next monsoon named predictive analysis (Tzounis, Katsoulas, Bartzanas & Kittas, 2017). Conventional agriculture can have ideas about field areas including soil nutrients, temperature, rainfall details, and future climatic conditions with a very experienced farmers' community (Palomino & Miguel, 2015).The predictive analysis framework is performed with many sector data analysis as shown in Figure 2.6 and it is based on the detection capability for predicting the probable situation that occurred (Tzounis et al., 2017). In conventional agriculture, the pest and attack solution trends in the field are based on past data (Pohanish, 2017). An enhanced prediction method is used to predict the scenario before big data analysis. This structure analysis can also predict the use of the vehicle for carrying all plugged goods from the plant product. This structure can have a good profit margin and a positive impact on the sale of goods on the market. This forecast will explain the role of profit or loss that has occurred at present and also in the future. With the support of this predictive system, the farmer will mitigate many risk factors. For the successful functioning of the new age of framing, this system formulates and processes.

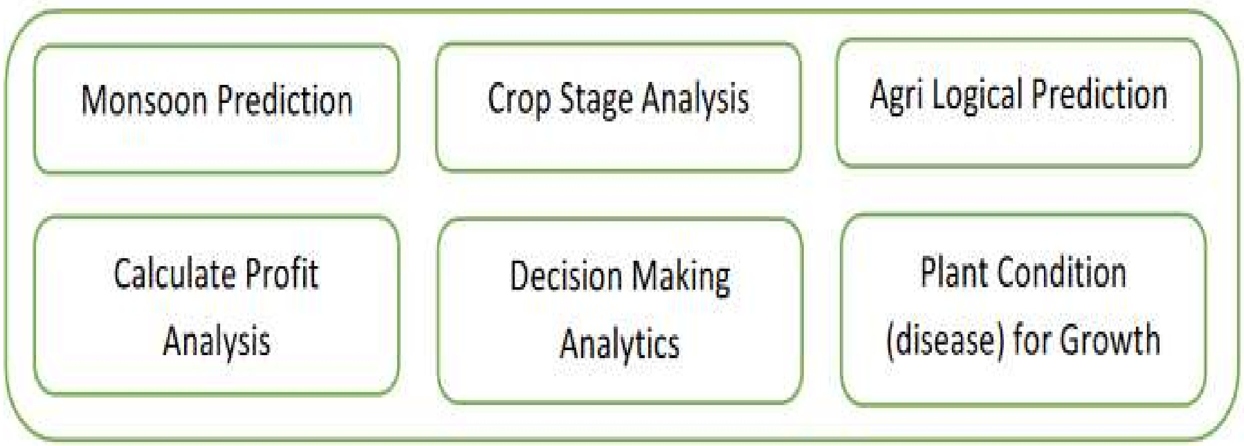

Figure 2.6: Block diagram of prediction analysis (Suma, 2021)

2.2.4 Weather Monitoring and Forecasting using IoT

The system involved monitoring weather and climate changes like temperature, humidity, wind speed, moisture, light intensity, UV radiation and carbon monoxide levels in the air; using multiple sensors. These sensors transmit data to the web page and the sensor data is plotted as graphical statistics. The data uploaded to the web page can easily be accessible from anywhere in the world (Balakrishnan & Chikkamadaiah, 2021). The implemented system utilized Arduino Uno as the main processing unit for the entire system and all the sensor and devices are connected to the microcontroller as shown in Figure 2.7. The microcontroller retrieves the data and processes. The processed data is uploaded and stored in a website to function as a data base using node MCU and Ubi dots.

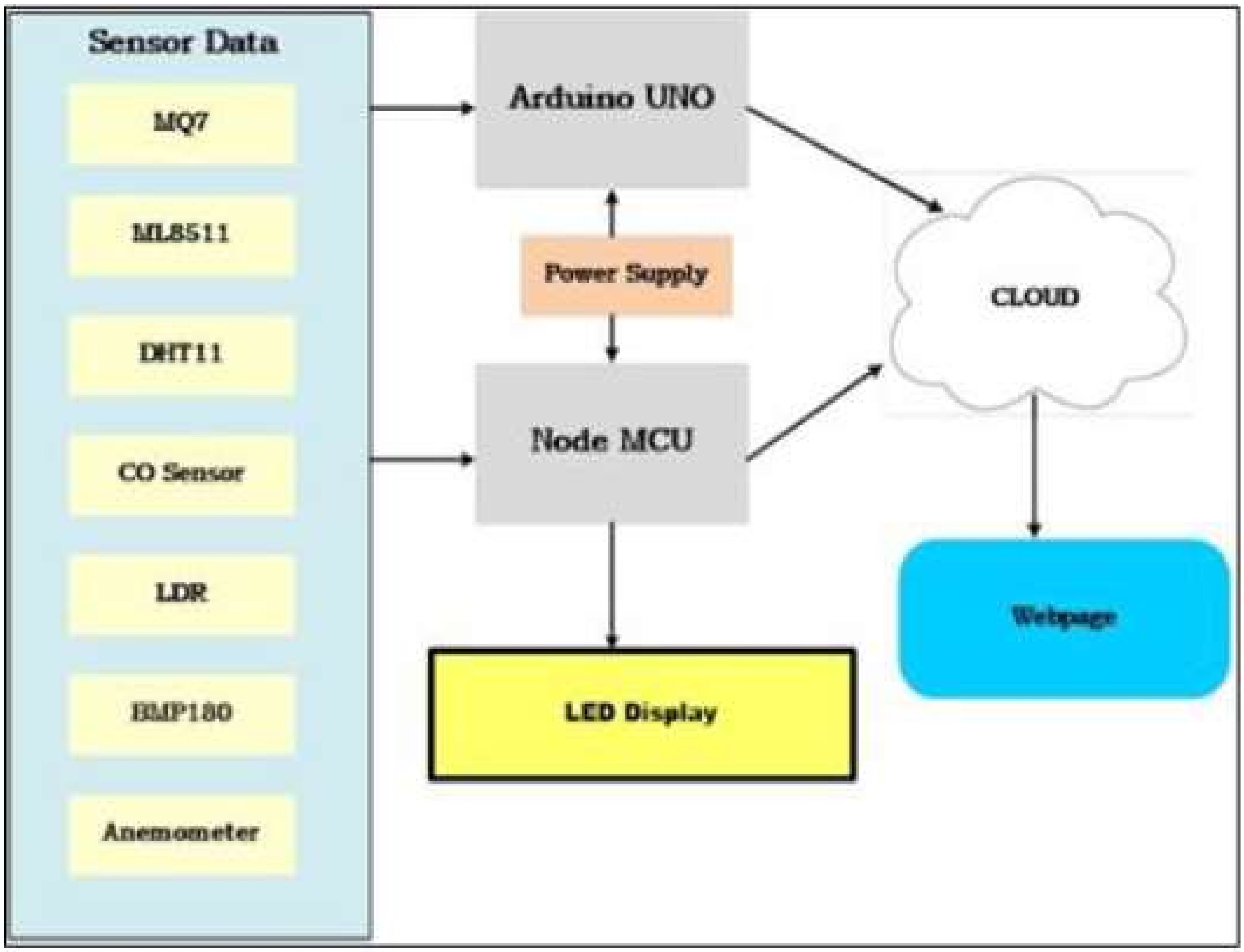

Figure 2.7: Block diagram of system implementation (Balakrishnan & Chikkamadaiah, 2021)

2.2.5 IoT Based Weather Monitoring System for Smart Agriculture

Wadne et al. (2023) developed a weather tracking system for farming. The system monitored key climate parameters in agriculture in real time, such as temperature, humidity, soil moisture, light intensity, and CO2 levels. The system utilized DHT11, BMP 180, Soil moisture and Rain sensors. The NodeMCU board based on ESP32 connects to the MATLAB algorithm development system through the Thingspeak cloud. The sensors' values for temperature, humidity pressure and rainfall are then collected. These values are transmitted to the Thingspeak app through the internet. The values can then be visualization on the screen. The connection diagram of IoT-based weather monitoring system is demonstrated in Figure 2.8.

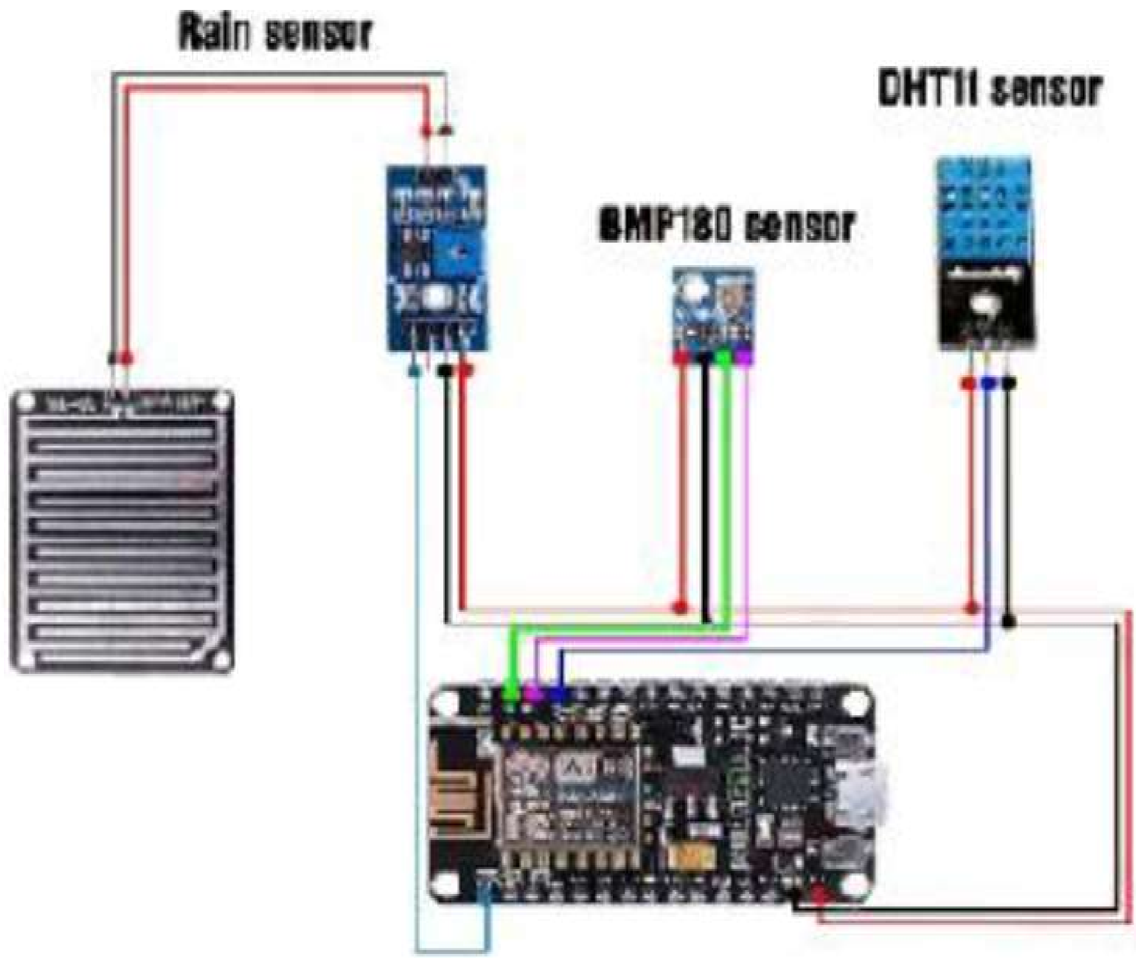

Figure 2.8: Connection Diagram of the IoT-based weather monitoring for smart agriculture (Wadne et al., 2023)

2.2.6 CoAP on NB-IoT Network

Kriddikorn and Kittasil, (2020) in their study, that the weather station is partitioned into two main parts. The Environment Data Acquisitions (EDA) and Master Control Unit (MCU). The process of EDA is to read data from environment including wind speed and direction, humidity and temperature, atmospheric pressure and rainfall and the process of MCU are to measure ozone level, read data from EDA and connect with NB-IoT shield board. The NB-IoT board in MCU will access the NB-IoT network for data transmission. All weather data will be encapsulated using CoAP and transmitted to cloud server (iSYNC). The fetched data is stored in MySQL database. Figure 2.9 shows the framework of the system.

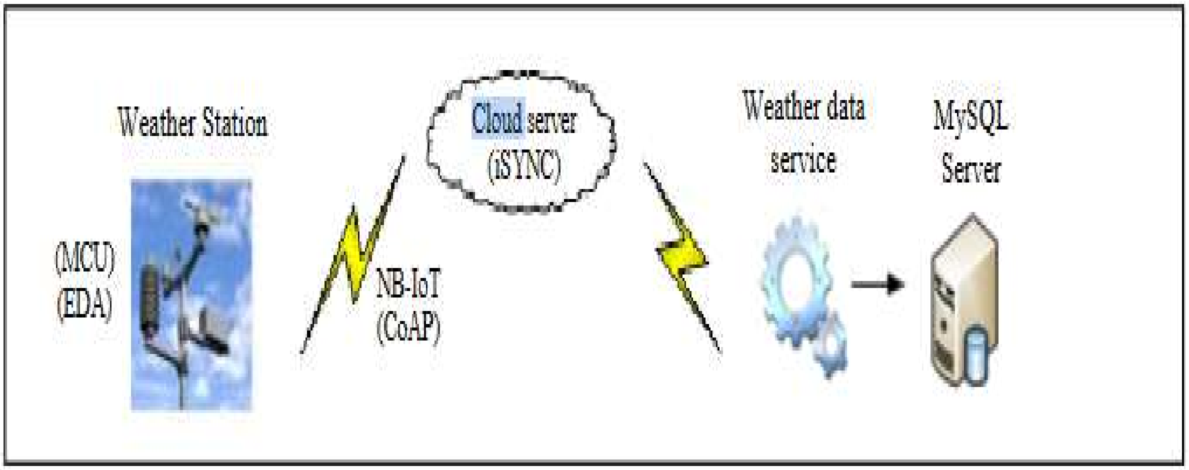

Figure 2.9: Framework system of CoAP on NB-IoT network (Kriddikorn & Kittasil, 2020)

2.2.7 Wireless Weather Station Model

This model consists of various sensors such as temperature, humidity, air pressure, wind speed, and rainfall sensors. The data collected by these sensors is transmitted wirelessly to a central hub or a cloud-based server. Users can access the weather information through a mobile app or a web interface.

Wireless weather monitoring systems are sophisticated setups that utilize Internet of Things (IoT) technology to collect and transmit weather data wirelessly. These systems consist of various sensors that measure different environmental parameters such as temperature, humidity, air pressure, wind speed, and rainfall. The collected data is then transmitted to a central hub or a cloud-based server for storage, analysis, and visualization. Wireless sensor networks (WSNs) are used to collect data from different sensing devices. In addition, cloud services are also essential to be integrated with IoT to analyze and process the remote data that facilitates decision-making to implement the best decisions (Farooq, Riaz, Abid, Umer & Zikria, 2020).

One of the key advantages of wireless weather monitoring systems is their ability to gather real-time and accurate weather information without the need for extensive wiring or manual data collection. The wireless nature of these systems allows for easy installation and scalability, making them suitable for a wide range of applications including agriculture, urban planning, transportation, and outdoor activities.

In a typical wireless weather monitoring system, the sensors are strategically placed in different locations to capture environmental variations across an area of interest. These sensors are often battery-powered or equipped with energy-harvesting mechanisms to ensure continuous operation. They communicate with a central hub or gateway using wireless communication protocols such as Wi-Fi, Bluetooth, or LoRaWAN (Kohila & Raja, 2019). The central hub acts as a data aggregator, receiving the sensor readings and relaying them to a cloud-based server or a local storage device. This hub may also perform data preprocessing tasks, such as data filtering, calibration, and time stamping. The collected data is then transmitted to the cloud server using cellular networks, Ethernet, or other wireless technologies.

Once the weather data is stored in the cloud server, it can be accessed and analyzed by authorized users through various interfaces. These interfaces can include web-based dashboards, mobile applications, or APIs (Application Programming Interfaces) that allow integration with other systems or services. Users can monitor real-time weather conditions, view historical trends, set up alerts based on specific thresholds, and generate reports for further analysis. The data collected by wireless weather monitoring systems can be used for a wide range of applications. For example, in agriculture, farmers can leverage this data to optimize irrigation schedules, determine optimal planting times, and prevent crop diseases. In urban planning, city officials can utilize the data to monitor air quality, predict microclimates, and make informed decisions about infrastructure development. Transportation systems can benefit from real-time weather data to manage road conditions and improve safety.

Furthermore, wireless weather monitoring systems can be integrated with machine learning algorithms and predictive analytics to provide more accurate weather forecasts and early warning systems for severe weather events. By analyzing historical data and leveraging advanced modeling techniques, these systems can enhance prediction accuracy, enabling individuals and organizations to take proactive measures and mitigate potential risks.

Generally, wireless weather monitoring systems have revolutionized the way we collect, analyze, and utilize weather data (Farooq et al., 2020). They provide a cost-effective, scalable, and efficient solution for monitoring environmental conditions in real-time. As technology continues to advance, further enhancements in sensor capabilities, communication protocols, and data analytics can be expected, enabling even more sophisticated weather monitoring systems in the future. Figure 2.10 adopted from (Kumar, Mishra, Gupta, & Dutta, 2021), illustrates the configuration of automated wireless smarts sensors highlighting their ability to collect and transmit data seamlessly for real-time monitoring and analysis.

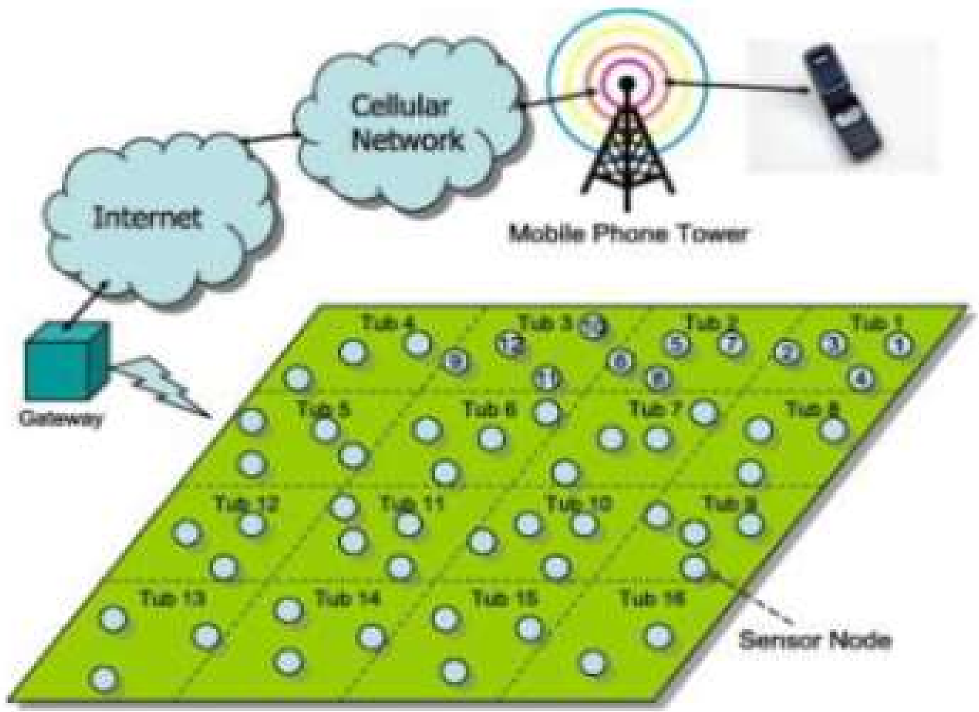

Figure 2.10: Automated wireless smart sensors (Kumar et al., 2021).

2.2.8 Agricultural Weather Monitoring System Model

This model is specifically designed for monitoring weather conditions in agricultural settings. It includes sensors for measuring temperature, humidity, soil moisture, and sunlight intensity. The data collected by these sensors is used to optimize irrigation schedules, predict crop diseases, and make informed decisions regarding agricultural practices.

Agricultural weather monitoring systems are specialized setups that utilize Internet of Things (IoT) technology to collect and analyze weather data specifically tailored for agricultural applications (Rasagna et al., 2023). These systems consist of a network of sensors strategically placed in agricultural fields to monitor various environmental parameters such as temperature, humidity, soil moisture, sunlight intensity, and precipitation. The collected data is then used to optimize irrigation schedules, predict crop diseases, and make informed decisions regarding agricultural practices.

One of the primary objectives of agricultural weather monitoring systems is to provide farmers with accurate and real-time weather information relevant to their specific crop and location. By continuously monitoring environmental conditions, farmers can gain valuable insights into the state of their crops, make data-driven decisions, and implement precision agriculture techniques (Dayananda, Narmilan & Pirapuraj, 2023).

Temperature and humidity sensors play a crucial role in agricultural weather monitoring systems. They help farmers understand the ambient conditions in the field, which is essential for crop growth and development. Monitoring temperature allows farmers to track frost events, heatwaves, and growing degree days, enabling them to adjust planting schedules and optimize crop selection accordingly. Humidity data provides insights into the moisture levels in the air, helping farmers manage irrigation and prevent diseases caused by excessive moisture or humidity (Raja, Gupta, Chamola, Elhence, Garg, Atiquzzaman & Niyato, 2021).

Soil moisture sensors are another integral component of agricultural weather monitoring systems. These sensors are installed in the soil at different depths to measure the water content. By monitoring soil moisture levels, farmers can determine the optimal timing and amount of irrigation required, preventing both over-irrigation and under-irrigation. This data-driven approach helps conserve water resources, enhance crop yield, and promote sustainable agricultural practices.

Sunlight intensity sensors are employed to measure the amount of sunlight reaching the crops. This information aids in understanding the light requirements of different crops and optimizing planting locations accordingly. By monitoring sunlight intensity, farmers can identify areas with insufficient sunlight and take appropriate actions such as pruning neighboring trees or adjusting crop spacing.

Precipitation sensors are used to measure rainfall or the amount of water received by the crops. This data is critical for managing irrigation schedules and avoiding water stress. By integrating precipitation data with soil moisture measurements, farmers can determine the ideal irrigation frequency and duration, preventing waterlogging or drought conditions.

Agricultural weather monitoring systems typically consist of a network of sensors interconnected through a wireless communication protocol such as LoRaWAN or cellular networks (Raja et al, 2019). These sensors transmit the collected data to a central gateway or a cloud-based server for storage, analysis, and visualization. Farmers can access the weather data through user-friendly interfaces such as mobile applications or web-based dashboards, allowing them to monitor real-time conditions, view historical trends, and receive alerts based on specific thresholds (Rasagna et al., 2023).

The capabilities of the agricultural weather monitoring system model can be enhanced by application of advanced analytics techniques to the collected data. Machine learning algorithms can be utilized to predict crop diseases based on historical weather patterns and identify optimal conditions for crop growth. By integrating weather data with crop models and pest prediction models, farmers can make informed decisions regarding pest control measures, fertilizer application, and planting strategies (Dayananda et al., 2023).

2.2.9 Urban Weather Monitoring Network Model

This model involves deploying a network of weather monitoring devices across a city or urban area. These devices are equipped with sensors to measure temperature, humidity, air quality, and pollution levels. The collected data is aggregated and analyzed to provide real-time weather updates, air quality index, and environmental insights to the residents of the city.

An urban weather monitoring network is a comprehensive system that employs Internet of Things (IoT) technology to gather and analyze weather data specifically tailored for urban areas. It involves the deployment of a network of sensors strategically placed across a city or urban environment to monitor various weather parameters such as temperature, humidity, air quality, rainfall, wind speed, and pollution levels. The collected data is then analyzed and utilized to provide real-time weather updates, air quality index, and environmental insights to residents, city planners, and other stakeholders (Chodorek & Yastrebov, 2023).

The primary objective of an urban weather monitoring network is to provide accurate and localized weather information within an urban setting. Urban areas often exhibit microclimates, where weather conditions can vary significantly from one location to another due to factors such as buildings, pavement, and urban heat island effects. By deploying a network of sensors across the city, the system can capture these microclimatic variations and provide more precise and relevant weather information.

Temperature and humidity sensors play a crucial role in urban weather monitoring networks. They help monitor ambient conditions within the city, enabling residents and city officials to understand the urban heat island effect, which refers to the phenomenon where urban areas are significantly warmer than surrounding rural areas. By monitoring temperature and humidity levels, the system can provide information on heatwave events, heat stress risks, and the overall thermal comfort of urban areas. This data is crucial for individuals with respiratory conditions, urban planning decisions, and public health initiatives (Girija, 2018).

Rainfall sensors are employed to measure precipitation within urban areas. Understanding rainfall patterns and intensities can help manage storm water runoff, flood prediction, and infrastructure planning. By monitoring rainfall in real-time, the system can provide alerts and warnings during heavy rainfall events, enabling residents and emergency management teams to take appropriate actions. Wind speed sensors are utilized to monitor wind conditions within the urban environment. This information is crucial for urban planning, building design, and wind energy applications. By measuring wind speed, the system can provide insights into wind patterns, identify areas prone to strong winds, and assist in optimizing wind energy generation (Chodorek et al., 2023)

An urban weather monitoring network typically consists of a distributed network of sensors placed at various locations throughout the city. These sensors are often connected wirelessly to a central hub or gateway, which acts as a data aggregator. The hub collects the data from the sensors and transmits it to a cloud-based server or local storage for further analysis and visualization. The collected weather data can be accessed by residents, city officials, and other stakeholders through user-friendly interfaces such as mobile applications, websites, or public displays. These interfaces provide real-time weather updates, forecasts, air quality information, and other relevant environmental insights. Users can customize their preferences, set up alerts for specific weather conditions, and make informed decisions based on the provided data. In order to enhance the capabilities of urban weather monitoring networks, advanced data analytics and machine learning techniques can be applied. These techniques can be used to identify patterns, correlations, and trends in the collected data, enabling more accurate weather predictions, early warning systems for severe weather events, and customized forecasts for specific areas within the city.

2.2.10 Temperature Prediction Model

This model uses historical temperature data and other relevant variables such as time of day, season, and geographical location to predict future temperatures. It can employ techniques such as regression analysis, time series analysis, or machine learning algorithms to forecast temperature patterns over specific time intervals. Regression analysis is a statistical technique used to model the relationship between a dependent variable and one or more independent variables. The mathematical expression of a simple linear regression model can be written as Equation 2.1

$$Y = \beta_0 + \beta_1 * X + \varepsilon \quad (2.1)$$

Where:

Y is the dependent variable (the variable we are trying to predict or explain),

X is the independent variable (the variable used to predict or explain Y),

$\beta 0$ is the y-intercept or the constant term,

$\beta 1$ is the coefficient or slope of the independent variable,

ε is the error term representing the variability or random fluctuations in the relationship between X and Y.

This expression represents a simple linear regression model, where there is a linear relationship between the independent variable X and the dependent variable Y. The goal of regression analysis is to estimate the values of the coefficients $\beta 0$ and $\beta 1$ that minimize the sum of squared differences between the observed Y values and the predicted Y values (also known as the least squares method). Once the coefficients are estimated, the regression equation can be used to predict the value of Y for a given value of X.

2.11 Rainfall Estimation Model

This model utilizes various factors such as humidity, atmospheric pressure, wind speed, and historical rainfall data to estimate the amount of rainfall in a given area. It can incorporate statistical methods, such as multiple linear regression or artificial neural networks, to predict rainfall based on the input variables.

In multiple linear regression, there are multiple independent variables used to predict or explain the dependent variable. The mathematical expression of multiple linear regression can be written as Equation 2.2

$$Y = \beta_0 + \beta_1\chi_1 + \beta_2\chi_2 + ... + \beta_n{*}\chi_n + \varepsilon \quad (2.2)$$

Where:

Y is the dependent variable,

χ_1, χ_2... χ_n are the independent variables,

β_0 is the y-intercept or the constant term,

β_1, β_2... β_n are the coefficients or slopes associated with each independent variable,

ε is the error term representing the variability or random fluctuations in the relationship between the independent variables and the dependent variable.

The goal of multiple linear regression is to estimate the values of the coefficients β_0, β_1, β_2, ..., β_n that minimize the sum of squared differences between the observed Y values and the predicted Y values using all the independent variables. The regression equation can then be used to predict the value of Y for a given set of values for the independent variables.

2.2.12 Intelligent Farm Machinery and Crop Management

Complex mathematical models called “deep learning” are modelled to resemble the structure and operation of the human brain. These neural networks are trained on enormous datasets and can learn and make predictions or judgments based on the data. Additionally, deep learning may be utilized to create autonomous agricultural equipment that can plant, weed, and harvest crops autonomously, without human assistance. This may lower labour expenses and boost overall effectiveness. Deep learning algorithms may be used to train autonomous farm machinery to navigate and operate in complex agricultural situations while making judgments based on the information obtained from sensors and other sources.

Numerous challenges remain, such as the shortage of workers in the agricultural sector and the increased demand for newer high-tech advanced machinery. New technologies within autonomous robotics are expanding in the agricultural industry. Huge investments are being made to develop autonomous agricultural mobility robots; as a result, modern farms have high prospects for increased productivity.

2.2.13 Impact of IoT on Effective Farming

The Internet of Things (IoT) has had a significant impact on effective farming practices and in turn revolutionizing the agriculture industry (Verma, 2022). By integrating IoT technologies into farming operations, farmers can enhance efficiency, improve productivity, reduce costs, conserve resources, and make more informed decisions (Navod et al., 2021. Some of the key ways IoT has influenced effective farming includes:

1. Precision agriculture: IoT devices such as sensors, drones, and satellite imagery enable farmers to gather real-time data on soil moisture, temperature, humidity, and nutrient levels. This information helps farmers optimize irrigation, fertilization, and pesticide application, resulting in precise and targeted usage, reduced waste, and improved crop yields.
2. Automated farming operations: IoT-powered automation streamlines various farming tasks, saving time and labor. Automated systems can control irrigation, adjust climate conditions in greenhouses, operate machinery, and monitor inventory levels. By automating routine operations, farmers can focus on more strategic activities, improving overall productivity.
3. Crop and field monitoring: IoT devices enable continuous monitoring of crop growth, pests, and disease outbreaks. Farmers can deploy sensor networks, drones, and imaging technologies to identify crop stress, optimize harvest timing, and take preventive measures against potential crop losses. This proactive approach helps farmers make timely interventions and reduce crop damage.
4. Data-driven decision-making: IoT generates vast amounts of data, which can be analyzed to extract valuable insights. Farmers can leverage data analytics, machine learning, and predictive modeling to optimize crop management, improve resource allocation, and enhance overall farm efficiency. Data-driven decision-making enables farmers to respond promptly to changing conditions and make informed choices for improved outcomes.

5. Livestock monitoring: IoT solutions allow farmers to remotely monitor the health, behavior, and location of livestock. Smart collars, ear tags, and sensors can track vital signs, detect disease outbreaks, and optimize feeding schedules. This proactive monitoring helps farmers identify issues early, prevent disease spread, and ensure proper animal care.

For better understanding, typical procedures in IoT-powered smart agriculture are depicted in Figure 2.11 adapted from (Wan-Soo, Won-Susk & Yong-Joo, 2020).

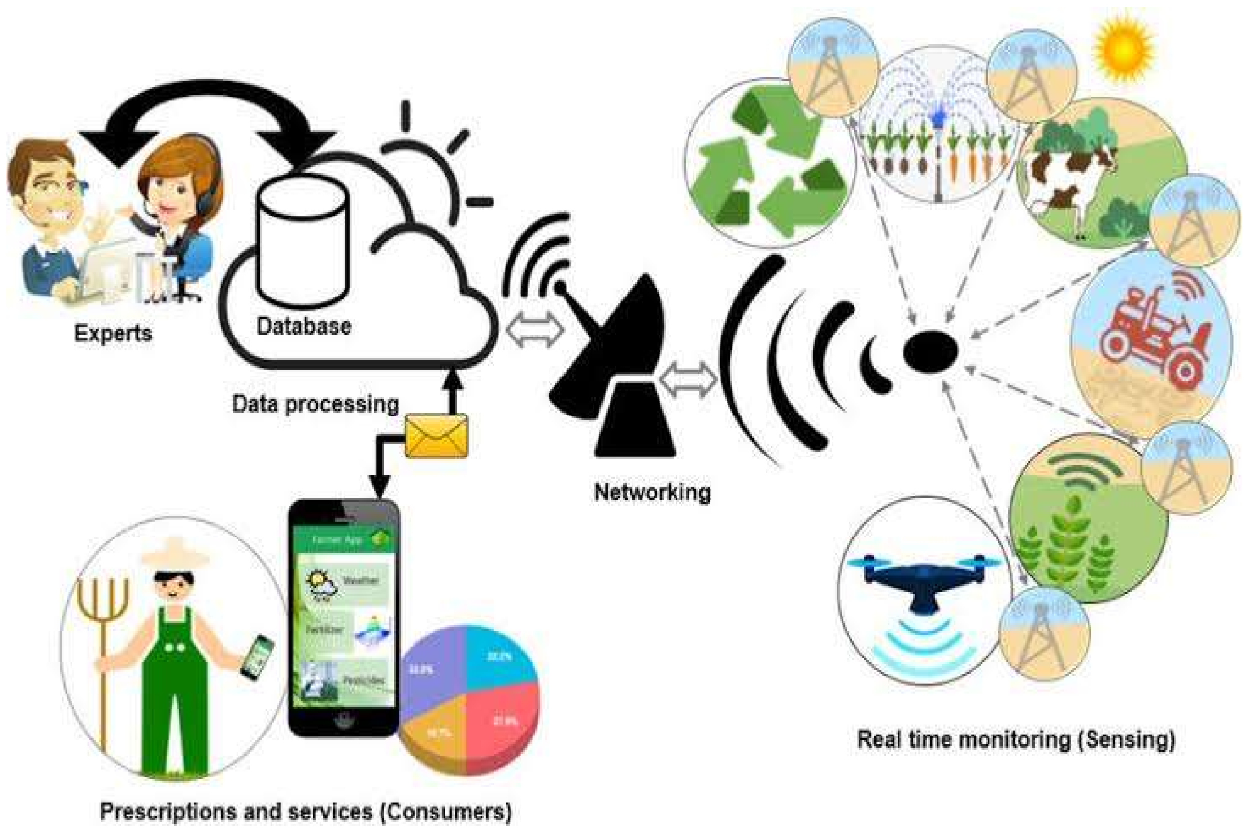

Figure 2.11: Procedures in IoT smart agriculture (Wan-Soo et al., 2020)

2.2.14 IoT Frameworks for Smart Agriculture

Internet of Things (IoT) frameworks for smart agriculture are designed to leverage technology and data to optimize agricultural practices, improve productivity, and enhance resource efficiency. These frameworks integrate various IoT devices, sensors, and data analytics to provide real-time insights and automation for farm management. IoT frameworks are grounded in engineering, networking, and data processing concepts but they do not rely on theorems in the mathematical sense. Instead, they draw on a combination of technologies and design principles to create effective solutions for smart agriculture. Smart agriculture technology based on the Internet of Things (IoT) technologies has many advantages related to all agricultural processes and practices in real-time, which include irrigation and plant protection, improving product quality, fertilization process control, and disease prediction, etc. (Adamides, Kalatzis, Stylianou, Marianos, Chatzipapadopoulos, Giannakopoulou, Papadavid, Vassiliou & Neocleous, 2020). Some of the key components and principles that underpin these IoT frameworks includes:

1. Low Power Wide Area Network (LPWAN): LPWAN technologies like LoRaWAN and Sigfox are designed to enable long-range communication with low-power consumption. They use spread spectrum modulation techniques to achieve reliable communication over distances, making them suitable for applications in agriculture where devices need to operate on battery power for extended periods
2. Sensor Networks: IoT frameworks rely on sensor networks to collect data from the physical environment. These sensors can measure various parameters such as soil moisture, temperature, humidity, light intensity, and more. The data collected by these sensors is crucial for making data-driven decisions in precision agriculture.
3. Cloud Computing and Data Analytics: Cloud-based platforms, such as Microsoft Azure, Google Cloud, and IBM Watson, provide the computational power and storage necessary to process and analyze the massive amounts of data generated by IoT devices. Data analytics and machine learning algorithms can help identify patterns, correlations, and anomalies in the data to provide valuable insights for farmers.
4. Internet Protocols: IoT frameworks use various internet protocols to facilitate communication between devices and cloud platforms. Common protocols include HTTP, MQTT (Message Queuing Telemetry Transport), CoAP (Constrained Application Protocol), and AMQP (Advanced Message Queuing Protocol).
5. Security and Encryption: Since IoT involves transmitting sensitive data, security is a critical consideration. IoT frameworks implement encryption and authentication mechanisms to secure data transmission and prevent unauthorized access to the devices and cloud resources.
6. Edge Computing: Edge computing is the concept of performing data processing and analysis at the edge of the network, closer to the IoT devices, rather than sending all the

data to the cloud. This approach reduces latency, conserves bandwidth, and allows for real-time decision-making in the field.

7. APIs and Integration: IoT frameworks often provide Application Programming Interfaces (APIs) to allow seamless integration with other software systems, such as farm management applications, agricultural databases, or third-party services (Adamides et al., 2020).
8. Modularity and Scalability: IoT frameworks are designed to be modular and scalable, allowing farmers to start with a small set of sensors and gradually expand the system as needed. This flexibility enables farmers to tailor the technology to their specific requirements and budget.

Figure 2.12 illustrates the various applications of IoT across different domains including its relevance in smart agriculture. Said, Abdelazi, Sameh & Mohammed (2021) emphasized how IoT technologies enhance agricultural operations by enabling real-time monitoring, data-driven decision making and improved resource management.

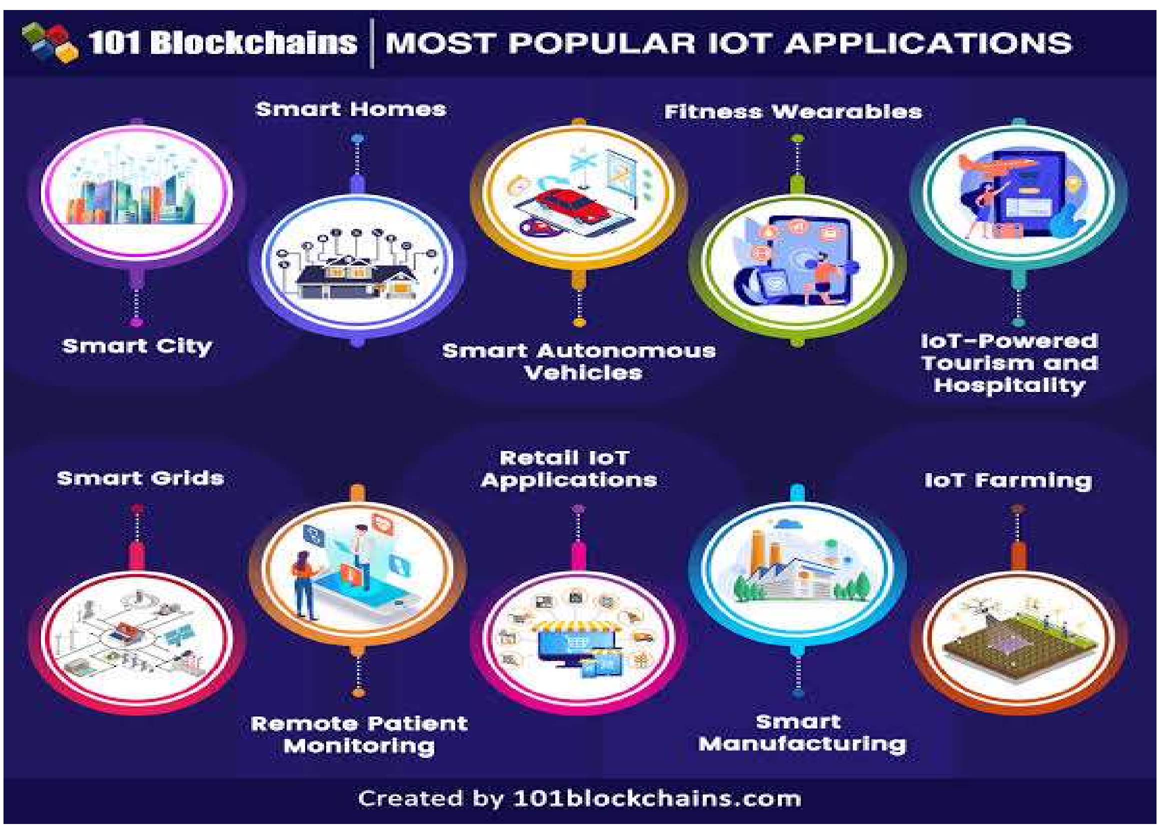

Figure 2.12: Application of IoT in different areas (James, 2023)

2.2.15 IoT-Based Smart Agriculture

The IoT is reshaping the agriculture sector by providing farmers with a diverse set of tools to address several challenges faced by them on the field (James, Saji, & Joseph, 2019). Farmers can connect to their farm from almost anywhere and at any time using IoT-enabled technologies. Sensors and actuators are used to regulate farming processes, while wireless sensor networks are being used to monitor the farm. Wireless cameras and sensors were used to remotely monitor the farm and collect data in the form of videos and different IoT sensors and sensor networks being used for making the agriculture sector smart. A sensor is indeed a device that monitors several parameters, such as pressure, light, moisture level, and so on. Most of the time, the sensor output is an electrical signal, which is sent to a micro-controller for the further analysis on a network. The development of simple to advanced sensors represents a transformation in the way we gather information. The success of smart systems depends on high-speed internet, advanced mobile devices, and satellites to provide (images and positioning) (James et al., 2019). In the agricultural field, IoT technology has made significant development in agricultural management. This technology allows all agricultural devices and equipment is to be linked together to make the appropriate decision in irrigation and fertilizer supply (Kumar & Periasamy, 2021). Figure 2.13 illustrates IoT applications for smart agriculture.

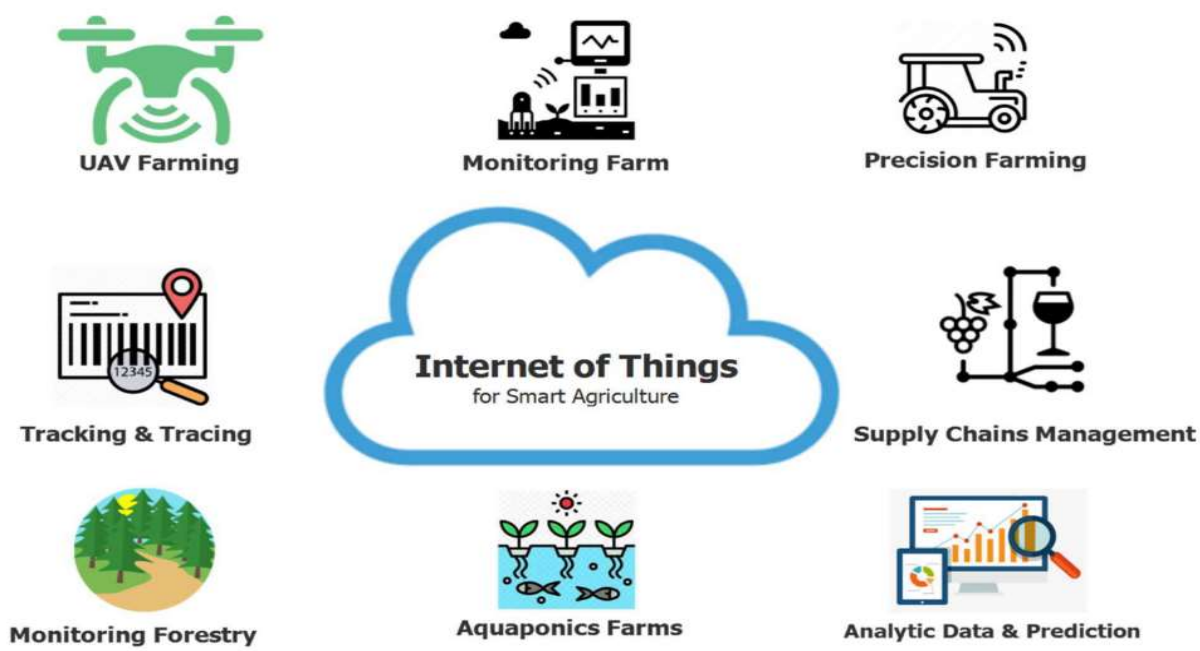

Figure 2.13: An illustration of IoT applications for smart agriculture (Quy et al., 2022)

According to the United Nations statistics, the world population is estimated to grow to 10 billion by 2050 (on. News-prospect., 2021). As a consequence, the requirements of agricultural products are continually increasing. However, farmlands are declining, natural resources are increasingly depleted, and the rise of unpredictable nature challenges, such as global warming, salinization, and flooding, make food security the most concerning problem for all nations worldwide.

In recent years, with the aim of increasing agricultural production, new solutions and technologies have been introduced in the agriculture sector (Yang, shu, chen & Ferrag, 2021). An emerging trend is the application of the IoT and big data. A significant number of studies have been focused on research, experiments, and applications (Ayaz, Ammad, Sharif & Mansour, 2019; Alfred, Obit, Chin & Haviluddin, 2021). According to the Cisco forecast, over 500 billion IoT devices will be connected to the Internet by 2030 (Zikria, Ali & Afzai, 2021). The use of IoT and big data will enable smart agriculture and is expected to enhance efficiency and productivity (Kour & Arora, 2020).

Over the years, wireless sensor networks (WSN) have been strongly applied in the agricultural sector, building the foundation for developing smart agriculture (Saad, Benyamina & Gamatié, 2020). The unique characteristics of WSN, such as the ability to self-organize, self-configure, self-establish, and self-recover, make it suitable for smart agriculture (Tyagi et al., 2020). The sensor device consists of a radio frequency (RF) transceiver, sensor, microcontroller, and battery power The WSN focuses on applications such as environmental monitoring, machine control automation, and traceability (Gopalakrishnan, Waimin, Raghunathan, Bagchi, Shakouri & Rahimi, 2021; Udutalapally, et al., 2020).

Along with the development of science and technology, the urgent requirement for breakthrough solutions and technologies aiming at improving productivity and efficiency in the agriculture sector has led to adoption of the IoT. The primary motivation for their applications is the breakthrough progress of smart agriculture and its inevitable role as the future of smart and sustainable environment management. IoT integrates a series of existing solutions and technologies, such as WSN, cognitive radio, ad hoc networks, cloud computing, and end-user applications (Friha, Ferrag, Shu, Maglaras & Wang, 2021). In the smart agricultural sector, automation solutions and technologies, mechanical machines, knowledge, decision-making tools, services, and software are integrated seamlessly to help farmers improve productivity, product quality, and profitability. Faroog et al. (2019) in their work conducted "A comprehensive survey of IoT applications for smart agriculture". An analysis of 135 relevant works published between 2017 and 2022 was conducted. Firstly, relevant 550 papers published in the period of (2017–2022) were retrieved from major scientific databases, namely IEEE Xplore Digital Library, Science Direct, MDPI, and Springer, by using keywords such as IoT-enabled smart agriculture, smart agriculture, Internet of Things, aquaponics, monitoring forestry based on IoT, tracking and tracing, smart precision farming, greenhouse production, Sigfox, LoRa, Wi-Fi, LoRaWAN, and IoT ecosystems).

2.2.16 IoT Ecosystem Architecture for Smart Agriculture

In this section, we present a common framework of an IoT ecosystem for smart agriculture based on three main components, including (1) IoT devices, (2) communication technologies, and (3) data process and storage solutions. An illustration of the IoT ecosystem for smart agriculture is presented in Figure 2.14

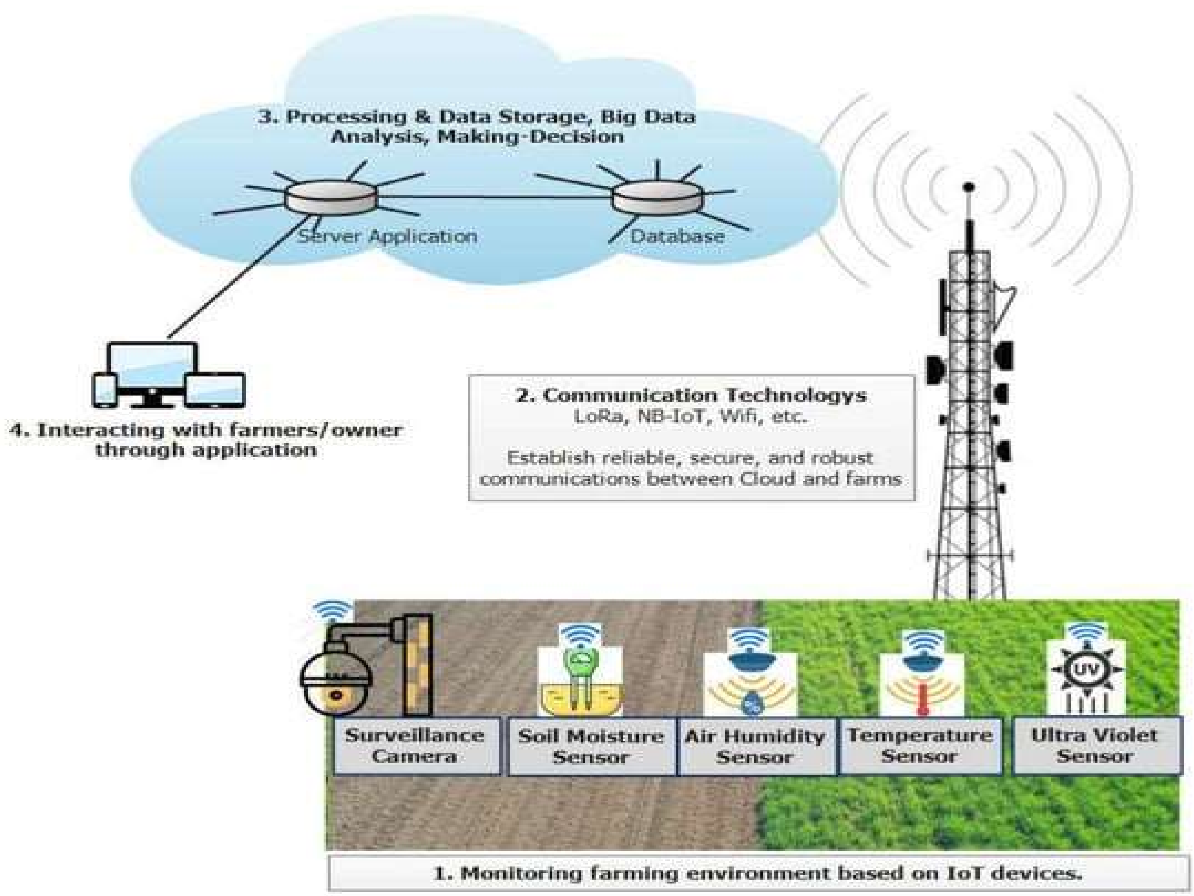

Figure 2.14: IoT ecosystems' architecture for smart agriculture (Quy et al., 2022).

IoT Devices

The common architecture of an IoT device consists of sensors to collect information from the environment, actuators based on wired or wireless connections, and an embedded system that has a processor, memory, communication modules, input–output interfaces, and battery power (Said et al., 2021). Embedded systems are programmable interactive modules, namely FPGAs (field programmable gate arrays). Sensor devices are specially designed to operate in open environments, in nature, in soil, water, and air to measure and collect environmental parameters that affect production, such as soil nutrients, humidity, temperature, etc. Smart farming solutions are agricultural operations that are often deployed on large farmlands, outdoors, so the devices that support solutions need some unique characteristics, such as the ability to withstand the effects of weather, humidity, and temperature instability throughout their service lifecycle. Some of their main features, as shown in Figure 2.15 make IoT devices suitable for smart agriculture solutions (El-Basioni, Balami & El-Kader, 2020).

The common architecture of a typical IoT device for smart agriculture is shown in Figure 2.15

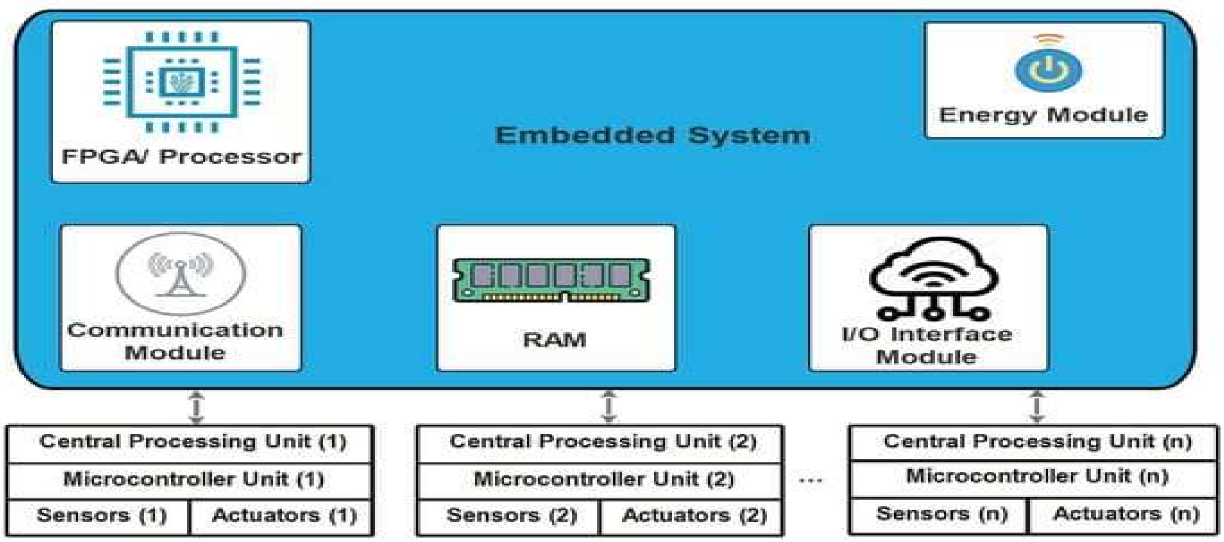

Figure 2.15: Common architecture of an IoT device (El-Basioni et al. 2020)

2.2.17 Smart Precision Farming

The advent of the GPS (global positioning system) has created breakthrough advances in many fields of science and technology. The GPS provides the most important parameters for locating a device, such as location and time. GPS systems have been successfully deployed in many fields, such as smartphones, vehicles, and IoT ecosystems. However, GPS is only good support for outdoor systems and the sky. Meanwhile, the demand for the locating and navigating systems in the home and on the streets of smart cities is growing rapidly. Based on GPS and GNSS systems, suitable farming maps have been established for fields and farms. As a result, agricultural machinery and equipment can be operated autonomously. Figure 2.16 adapted from (Zhou, Meng, He, Hou & Li, 2020) presents an illustration of the typical cloud-assisted, IoT-based precision agriculture platform.

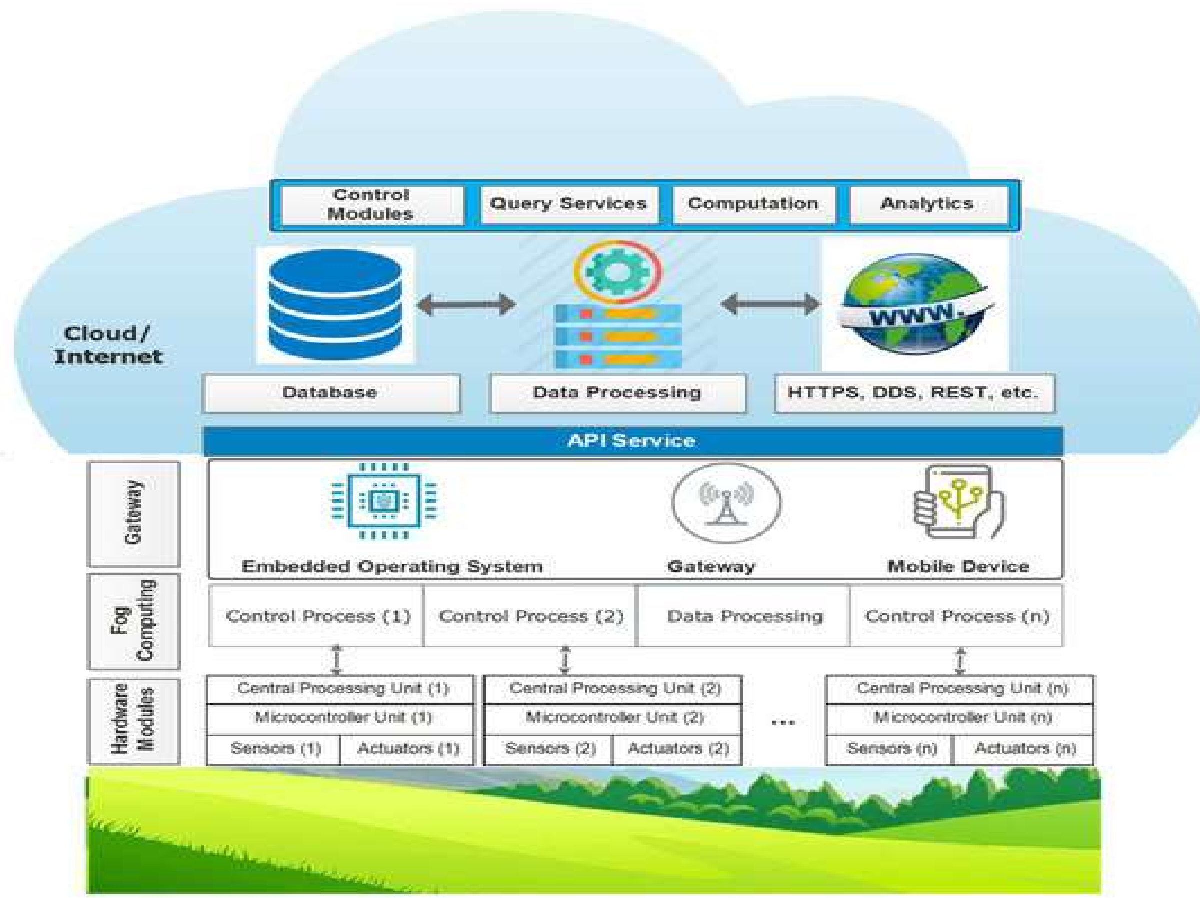

Figure 2.16: Cloud-assisted IoT-based precision agriculture platform (Zhou et al., 2020)

In smart precision farming, one of the most important applications is the use of drones in monitoring farming activities. Some common farming tasks using UAVs include spraying pesticides, fertilizing, sowing seeds, evaluating and mapping, and monitoring crop growth (Kim, Kim, Ju & Son, 2019). Kim et al. (2019) presented a detailed survey of drone applications for smart agriculture, including applications, control technology, and future trends of the UAV application for smart agriculture. Zhou et al. (2020) designed an automatic agricultural product classification system based on camera systems, image processing algorithms, and mechanical actuators. The experimental results for agriculture products such as oranges and tomatoes present a classification success rate of over 95%, and the sorting time for each product is less than 1(s). This solution can be adapted and applied to the classification of different agricultural products. Many survey studies have shown that smart precision agricultural equipment, such as irrigation systems, unmanned aerial vehicles (UAV), and smart agricultural equipment, etc., are configurable in an autonomous-control mode based on certain conditions or can be controlled remotely by the farmer via the Internet (Zhou et al., 2020; Faveza et al., 2019). Smart precision farming helps to improve productivity and production efficiency and is suitable for large-scale farms (Udutalapally et al., 2020). Nowadays, suppliers of precision agricultural equipment have IoT modules built into their machines, allowing machines to operate autonomously and remotely via the internet (Friha et al., 2021).

2.2.18 The Things Network (TTN)

The Things Network (TTN) is an open, community-driven, and decentralized Internet of Things (IoT) network infrastructure based on the LoRaWAN (Low Power Wide Area Network) technology. TTN is designed to provide low-cost and long-range communication capabilities for IoT devices, making it well-suited for various applications, including smart agriculture, smart cities, environmental monitoring, and more. The Things Network provides a powerful and accessible infrastructure for IoT applications, fostering innovation and collaboration among its global community of users and contributors. It empowers developers and farmers to create scalable, cost-effective, and sustainable IoT solutions for various agricultural challenges and beyond (Olivier et al 2020).

TTN operates as a global, decentralized network, where anyone can set up and deploy their own LoRaWAN gateway. The network is supported and expanded by a large community of developers, enthusiasts, and businesses. This community-driven approach encourages innovation, collaboration, and knowledge sharing. TTN uses the LoRaWAN protocol to enable long-range communication between IoT devices and gateways. LoRaWAN is designed to support low-power, low-data-rate applications over long distances, making it ideal for connecting remote sensors and devices in areas where traditional cellular or Wi-Fi connectivity is not feasible. IoT devices or nodes equipped with LoRaWAN transceivers connect to the TTN network through nearby gateways. Nodes can be sensors, actuators, or other embedded devices that collect data or perform actions in the physical environment.

The TTN Console is a web-based management interface that allows users to manage their IoT devices, gateways, and applications. It provides features like device registration, monitoring of network traffic, data visualization, and integration with third-party platform (Ouni & Saleem, 2020). TTN emphasizes security and employs various measures to protect data and devices such as using AES encryption to secure communications between nodes and gateways. The TTN network also supports over-the-air activation (OTAA) and activation by personalization (ABP) methods to securely provision devices on the network.

TTN provides APIs and integration options to allow developers to build applications and services that interact with the network and IoT devices. This flexibility allows seamless integration with various cloud platforms, analytics tools, and other software services (Ouni et al., 2020).

TTN operates under an open-source model, encouraging the sharing of knowledge, code, and best practices. The data transmitted through the TTN network is considered open data, which means it can be accessed and used by the community for research and other non-commercial purposes.

2.2.19 Sigfox

Sigfox is a Low Power Wide Area Network (LPWAN) technology designed for the Internet of Things (IoT). It provides long-range, low-power communication capabilities for IoT devices, making it ideal for connecting a large number of low-energy devices over vast areas. Sigfox is optimized for simple, low-bandwidth applications and is used in a variety of industries, including agriculture, logistics, asset tracking, smart cities, and more (Levchenko, Alqahtani, Munir & Eltawil, 2022). Sigfox's LPWAN technology offers a cost-effective, low-power, and long-range solution for IoT applications, especially those that require simple and periodic data transmission. Its global network coverage, security features, and ease of deployment have made it a popular choice for a wide range of industries seeking to leverage IoT for enhanced operational efficiency and improved decision-making (Levchenko et al., 2022).

Sigfox operates in the unlicensed Industrial, Scientific, and Medical (ISM) radio bands, primarily using sub-GHz frequencies (e.g., 868 MHz in Europe and 902 MHz in the USA). This frequency range allows for excellent penetration through walls and objects, making it suitable for indoor and outdoor deployments. Sigfox uses ultra-narrow-band modulation, which means it uses very narrow frequency bands for data transmission. This approach enables long-range communication and better resistance to interference, but it also limits the data rate to 100 bits per second (bps) uplink and 600 bps downlink. (Levchenko et al., 2022) Sigfox devices have a unidirectional communication model, meaning they can only transmit data to the network (uplink). Downlink communication from the network to the device is limited, primarily used for acknowledgments and configuration updates.

2.2.20 IBM Watson IoT Platform

IBM's IoT platform provides solutions for various industries, including agriculture. It provides data analytics, machine learning, and AI capabilities to enable farmers make data-driven decisions, optimize irrigation, manage crop health, and predict weather patterns. IBM Watson IoT Platform is a rich and scalable IoT solution that empowers businesses and industries to harness the full potential of IoT data. Its advanced analytics, AI integration, and edge computing capabilities enable organizations to drive innovation, enhance efficiency, and make data-driven decisions to transform their operations.

2.2.21 AgSense

Agsense is a comprehensive Internet of Things (IoT) platform developed by Lindsay Corporation, a leading company in the agricultural irrigation industry. Agsense is specifically designed to provide smart irrigation management solutions for farmers and agricultural businesses. The platform integrates various IoT devices, sensors, and data analytics to help farmers optimize their irrigation practices, conserve water resources, and increase crop yields (Diego, Alvaro, Jimenez-Bravoa, Mendesa & Valderi, 2021). The core functionality of Agsense revolves around irrigation management. It allows farmers to remotely monitor and control their irrigation systems, providing them with real-time insights into the status of their fields and water usage.

Agsense supports a wide range of IoT devices and sensors, such as soil moisture sensors, weather stations, flow meters, and pressure sensors. These devices collect crucial data on soil conditions, weather patterns, and water flow, enabling farmers to make data-driven decisions. The platform offers integration with other agricultural management platforms and software. This integration allows farmers to consolidate data from multiple sources, facilitating better decision-making and resource management.

Agsense enables automated control of irrigation systems based on pre-defined parameters and schedules. Farmers can set up precise irrigation plans, taking into account factors like soil moisture levels and weather forecasts, to optimize water usage (Diego et al., 2021). Farmers can access Agsense through a web-based or mobile app interface. This remote monitoring capability allows them to keep track of their irrigation equipment and field conditions from anywhere, improving efficiency and convenience.

2.2.22 FarmBeats

FarmBeats is an innovative Internet of Things (IoT) platform developed by Microsoft Research with a focus on agriculture. It leverages a combination of cutting-edge technologies, including IoT, artificial intelligence (AI), and cloud computing, to provide data-driven insights and solutions for precision agriculture. FarmBeats is designed to help farmers make informed decisions, optimize resource utilization, and improve crop productivity. (Deepak, Zerina, Jong-ho, Xinxin, Ranveer, Ashish, Sudipta & Madhusudhan, 2017). FarmBeats collects data from various sources using IoT sensors. These sensors are deployed in the field to measure parameters such as soil moisture, temperature, humidity, weather conditions, and even plant health. The data collected from these sensors forms the foundation for data-driven agricultural insights. This framework incorporates edge computing, where data processing and analysis are performed at the edge of the network, close to the IoT sensors. This approach reduces latency and bandwidth requirements and enables real-time decision-making in the field (Deepak et al., 2017).

FarmBeats utilizes AI and machine learning algorithms to analyze the collected data and generate valuable insights. AI models can predict crop health, disease outbreaks, and optimize irrigation schedules based on historical and real-time data. FarmBeats leverages satellite imagery and remote sensing technologies to gain a broader perspective of crop conditions over large areas. The combination of satellite data and ground-level sensor data provides a comprehensive view of the agricultural landscape. The platform is designed to be user-friendly and accessible to farmers with varying levels of technical expertise. It aims to bridge the gap between traditional farming practices and modern IoT technologies.

2.2.23 Impact Evaluation of weather data decisions that could benefit local farmers.

Table 2.1, Table 2.2 and Table 2.3 and Table 2.4 respectively demonstrates how local farmers make management decisions based on key weather parameters such as rainfall, temperature relative humidity and light intensity. Each table highlights the critical role of these factors in guiding agricultural operations.

Table 2.1: Rainfall management decisions by local farmers (Alok, 2022)

Dry season / Below normal rainfall (0 - 49)	**Wet season / Normal to above normal rainfall (50 -100)**
Ensure land is cultivated in a timely fashion prior to drier conditions.	Ensure land is cultivated in a timely fashion prior to the onset of good rainfall events.
Order inputs (seedlings, sees and fertilizer) prior to engaging in planting.	Order inputs (seedlings, sees and fertilizer) prior to engaging in planting.
Minimize planting density by at least 25%-50% ha^{-1}	Introduce normal to higher planting density ha^{-1}
Minimize labour and other input use	Ensure there is sufficient labour and apply fertilizer.
Plant just before the expected onset of the 1st rainfall event.	Adopt sequential planting and intercropping.
Adopt drought tolerant crops such as sorghum, millet and cassava.	Plant crop varieties (diversify).
Control weeds frequently.	Control weeds more frequently.
Introduce water conservation methods such as using different types of mulch.	Strengthen the use of terraces and ridges/dykes to reduce erosion and surface run-off.
Minimize the area under cultivation.	Enlarge the area under cultivation.
Adopt water conservation measures.	Store water to apply in the occurrence of long dry spells.

Table 2.2: Temperature management decisions by local farmers (Balakrishnan & Chikkamadaiah, 2021).

High Temperature (Above 50^{o}c)	**Low Temperature(Below 20^{o}c)**
Yield reduction	Reduced Plant growth and death
Decreased enzyme activity	Abnormal curling, lobbing, and crinkling of leaves
Increased oxidative Stress	Loss of Vigor
Reduced Antioxidants activity	Internal Discoloration (Vascular browning)
Hormonal Changes	Changes in membrane structure
Transcriptional Change	Prototyplsmic streaming and electrolyte leakage
Water Loss and sterility in plants formation of abnormal seeds	Surface lesions on leaves and fruits
Reduction in plant growth	Photosynthesis inhibition
Reduced Photosynthetic activity	Cellular leakage of electrolytes
Scorching of leaves and stem, leaf abscission and senescence DNA Damage	Chlorophyll degradation

Table 2.3: Relative humidity management decisions by local farmers (Balakrishnan & Chikkamadaiah, 2021).

Very High RH (Above 70)	**Moderately High Humidity (60 -70)**	**Too Low Relative Humidity**
Reduces evapotranspiration	Is beneficial	Increase evapotranspiration
Incident of pest and disease is high	Easy germination	Water deficits in plants
Increases heat loads of plants		Lower leafs drop off
Reduced CO2 intake		Longer time to obtain saleable size

Photosynthesis & plant growth is slowed		Drip tip burn
Wilting and Stunted plants		Increased folia disease
Leaf curl		Nutrient deficiencies
Increased infestation of spider mites		Increased root disease

Table 2.4: Light management decisions by local farmers (Alok, 2022).

Artificial Light	**Natural Sunlight**
Allows for year –round growth and quick production	The intensity and nutrients natural sunlight gives can never truly be duplicated
Gives food and energy to plants through photosynthesis	Gives food and energy to plants through photosynthesis
Allows you to manipulate the growing environment and produce at a more rapid space	Provides the energy plants need to convert carbon dioxide and water into carbohydrates and oxygen.

2.3 Empirical Framework

In IoT enabled weather monitoring system research, Arduino Uno measures weather parameters using the four respective sensors. These sensors are a temperature sensor, humidity sensor, light sensor, and rainfall sensor (Gopalakrishnan, Waimin, Raghunathan, Bagchi, Shakouri & Rahimi, 2021). These four sensors are directly connected to Arduino Uno since it has an inbuilt Analog to digital converter. The weather monitoring system gives high accuracy and reliability for weather monitoring and climate changing. It can also use the renewable energy source like solar panel for charging the connected battery. Through the web, it accesses real time weather information and data. This system can be communicated over general packet radio service (GPRS) network. Low maintenance is required for end users. It is capable for storing data and providing it to the users as required. The implemented system consists of a microcontroller (ESP8266) as a main processing unit for the entire system and all the sensor and devices can be connected with the microcontroller. The sensors can be operated by the microcontroller to retrieve the data from them and it processes the analysis with the sensor data and updates it to the internet through Wi-Fi module connected with an app then we can measure temperature, humidity, pressure and rainfall (Gopalakrishnan et al., 2021).

Rasagna et al. (2023) in their research work 'Solar Powered Soil and Weather Monitoring System Using IoT focused on the design of IoT based system to monitor the environmental conditions such as temperature, humidity, soil moisture, rain level and light intensity in order to monitor the conditions of agricultural farm land. The study entails the use of solar- powered soil and weather monitoring system using IoT sensors to collect data on soil and weather conditions, which is then processed by a microcontroller and sent to a cloud platform for storage and analysis.

Dayananda et al. (2023) in their paper 'An IoT based Low-cost Weather Monitoring System for Smart Farming' proposed a system that monitors weather manually and automatically. The system can reliably monitor the weather and deliver real time weather information to the user, in this case, which are the farmers. The system was able to monitor real-time weather conditions such as temperature and humidity, pressure, rain, light intensity, CO_2 level, wind speed and wind direction. The project's main objective was to create a modular and cost-effective mechanism to monitor real-time weather conditions and improve farming using low power.

Apurva et al. (2022) proposed a WSN based system that helps in real-time monitoring of the agricultural field. The research focused on the fact that the yield rate in agriculture has become stagnant and hence they have included additional agricultural parameters that have to be monitored. In addition to the conventional parameters like humidity, temperature and soil moisture, their research focuses on the water level, flood, wind direction, wind speed, weather, etc. Agricultural projects usually use wired communication which has various problems and hence this paper points on the use of the wireless network.

Suleiman (2022) constructed an IoT Wireless Weather Monitoring System using Global System of Mobile (GSM). The system uses an ATMEGA-328 Microcontroller, SIM 800 GSM Module, LCD, sensors, and a regulated 5V, 500mA power supply. The microcontroller converts analog data from the sensors to digital data using built-in ADC. When an abnormal weather condition occurs, the system detects it and sends a message to assigned mobile phone numbers via the GSM module. Users can log the data at any time by sending a data request SMS. The data is displayed on the LCD, which serves as a user interface. The system allows supervisors and operators to monitor the weather station from anywhere in the world with GSM network coverage.

Rajinder, Kumar and Dharwadkar (2021) proposed an IoT-Based Real-Time Local Weather Station for Precision Agriculture in India. The authors aim to provide farmers with a means of automating their agricultural practices such as irrigation, fertilization, and harvesting, at the right time using this system. The paper describes a low-cost weather station that monitors weather parameters like temperature, humidity, air pressure, rainfall, and soil moisture using an IoT platform. The authors also propose an artificial neural network-based smart weather prediction system that can predict weather conditions in advance to aid farmers in decision making. The study is significant in that it addresses the challenges faced by farmers in India due to unpredictable weather conditions and the high cost of conventional weather monitoring systems.

Tanmay et al. (2021) in their research work "Weather Monitoring System Using Wi-Fi" designed a weather monitoring system for monitoring parameters such as temperature, pressure, humidity, rainfall, wind speed and direction. All the necessary parameters that were to be monitored are sensed using various sensors. For temperature pressure and humidity measurement, available sensors like the DHT11 and BMP180 have been used whereas wind-speed, wind-direction and rainfall have been measured using rotary encoder, opt-coupler, tipping bucket technique respectively. The measured data is processed using microcontroller-based system and made available wirelessly on the server for storage and access continuously. The system is totally automatic thus minimizing human error. In their work, the various sensors such as temperature sensor, pressure sensor, humidity sensor reads the atmospheric temperature, pressure and humidity respectively. For every tip one pulse is send to the pin of the microcontroller. The number of pulses is measured by the microcontroller. The anemometer is used to sense wind speed and wind direction. The signal conditioning block is required for getting accurate wind velocity. The signal conditioning consists of an opt coupler. This output is given to a Schmitt trigger which is a bi-stable circuit. In this circuit when the input rises above a certain threshold, the output increases to a steady maximum and decreases to almost 0 when the input voltage falls below another threshold value. All the sensor outputs are received by the controller and processed in necessary format. These are then transmitted using Wi-Fi to main server. The databases of all these sensed parameters are maintained on main server and are routed and displayed continuously on the website with a refreshing rate of 10 seconds.

Dhawan (2021) presented a weather monitoring system that utilizes an IoT approach to provide real-time monitoring of temperature and humidity. The system was implemented using an Arduino UNO microcontroller and a DHT11 sensor to measure temperature and humidity. The study aimed to create an efficient, low-cost system with different models to monitor the environment in real-time and provide alerts. The data collected by the system was statistically analyzed, and the results showed no significant difference between the study groups.

Dabhi & Jethva (2021) presented a system for monitoring various environmental parameters such as temperature, humidity, air quality index, CO concentrations, rain, and light using custom-designed, energy-efficient sensors. The system utilizes an ESP8266 Wi-Fi module to transmit data to Thing Speak, which analyzes and presents the collected data in graphical and tabular forms. The system includes a mobile application and web application for data monitoring, storage, and visualization. The implementation of the E-Sense system is cost-efficient, compact, user-friendly and can work without human intervention.

Sai et al. (2021) presented a solution for monitoring weather conditions in real-time using IoT technology and implemented a system that uses multiple sensors to collect weather data, which is then transmitted to a central hub for processing and analysis. The system is based on the Message Queuing Telemetry Transport (MQTT) technology, which enables easy communication between heterogeneous Relational Database Management Systems (RDBMS). The paper also described the hardware and software components used in the system, as well as the communication protocols and data transmission methods.

Abdulkadir et al. (2019) designed, 'Implementation and Evaluation of Remote Weather Monitoring System'. The study presented an automated weather monitoring system. The system was designed, implemented and evaluated using electronic sensors. The proposed system can monitor and measure temperature, humidity, wind speed, wind direction, solar illumination and rainfall at near real-time. Remote monitoring was made possible by XBee modules at the transmitting and receiving units. Upon receiving weather parameters, a data logger saves the values on a PC. The system was evaluated using existing monitors. In their work, a weather station that monitored temperature, humidity, sun intensity, rainfall, wind speed and direction was designed, implemented and evaluated using existing systems. To achieve the implementation, sensors to measure temperature, humidity, wind speed, wind direction, rainfall and light intensity were used. The sensors were interfaced to an Arduino board which also served as the processing unit. XBee modules were used to transmit and receive the sensors' data which were saved to a database via a data logger. To enhance the reliability of the system and allow it to run independently and at a remote location, a solar based power supply was used. The power supply charged a battery that both supplied the required power to the system and saved some for use during no-sun periods.

Varghese et al. (2019) proposed an IoT-based climate forecast system that uses a Raspberry Pi 3 Model B, some sensors, and a weather forecast algorithm to predict weather. The system monitors temperature and air pressure to forecast the weather. The paper describes the system's design, implementation, and testing, and presents the results of the system's accuracy in weather forecasting.

Girija et al. (2018) in their work 'Internet of Things (IoT) based Weather Monitoring System' proposed an advanced solution for monitoring the weather conditions at a particular place and make the information visible anywhere in the world. The technology behind this is Internet of Things (IoT), which is an advanced and efficient solution for connecting the things to the internet and to connect the entire world of things in a network. Here things might be whatever like electronic gadgets, sensors and automotive electronic equipment. The system deals with monitoring and controlling the environmental conditions like temperature, relative humidity and CO level with sensors and send the information to the web page and then plot the sensor data as graphical statistics. The data updated from the implemented system can be accessible in the internet from anywhere in the world.

Abdulkareem (2018) presented the 'Design & Construction of a Wireless Weather Monitoring System Based on GSM' detailing the implementation of sensors which accurately acquire analog or digital data passed to a microcontroller for the storage and processing of these data. This system is focused on the construction of wireless weather monitoring system able to sense temperature, humidity and light intensity for normal use by regular users, application in agriculture, science laboratories, industries and creation of weather app.

The literature on the "Wireless Weather Monitoring System using Arduino DUE and GSM Technology", uses an Arduino UNO microcontroller, the core of the system connected to the major components and the sensors via the ADC (Mohammed & Dave, 2018). It measures temperature, humidity, rain, light intensity, carbon dioxide, pressure and wind with their corresponding sensors. It allows the user to gain control over the system remotely with the implementation of the GSM module in the system. The user is able to call the weather station which the GSM module receives as a notification and further retrieves the data on weather based parameters and transmits to the user as an SMS (Mohammed & Dave, 2018).

In IoT-based Temperature and Humidity Monitoring System for Agriculture, Akash and Birwal (2017) analyzed weather monitoring system based on Raspberry Pi and ThingSpeak. They used Raspberry Pi 3 model B, it has a 1.2 GHz 64-bit quad core ARMv8 CPU, and RAM of 1GB. It also has 40 GPIO pins, Full HDMI port, 4 USB ports, Ethernet port, 802.11n wireless LAN connectivity, etc. Operating voltage of system is 5V. For measuring temperature and humidity authors used DHT11 sensor with 8-bit microcontroller. DHT11 sensor offer temperature measuring in range from 0ºC to 55ºC, and relative humidity in range from 20% to 90%. In compared with sensor used in this manuscript BME280, DHT11 provides weaker range of temperature and humidity measurement. Authors used Local Area Network wired Internet connectivity for send data of measured temperature and humidity to ThingSpeak.

Baste and Dighe (2017) in their work "Low Cost Weather Monitoring Station Using Raspberry XPI" planned, developed and verified a little cost weather station using raspberry pi. It monitors the weather information, as well as wind direction, air speed, air temperature, atmospheric pressure, humidity, solar radiation and rain. Weather information are sent to a database server and is stored in memory card via Wi-Fi network. For visualization of the weather information of a remote place, a web application interface is used. This system provides real-time weather updates like other expensive weather station. It is very small in size, little in price, reliable and relaxed to use which can be effectively used in different applications.

2.3.1 Numerical Weather Prediction Models

Numerical weather prediction (NWP) models are sophisticated computer simulations that use mathematical equations to simulate atmospheric conditions. These models take into account various factors like air pressure, humidity, wind speed, and solar radiation to predict future temperatures. NWP models are typically run by meteorological agencies and are used for weather forecasting on regional or global scales. Numerical weather prediction (NWP) models use complex mathematical equations to simulate and predict atmospheric conditions. These equations are derived from fundamental principles of physics, including the laws of motion, conservation of mass, and thermodynamics. The mathematical expression for NWP models involves a set of partial differential equations that describe the evolution of atmospheric variables over time and space.

A commonly used set of equations in NWP is the primitive equations, which are based on the equations of fluid dynamics. The primitive equations represent the three-dimensional motion of the atmosphere and can be written as follows:

1. The continuity equation: $\partial \rho/\partial t + \nabla \cdot (\rho V) = 0$ (2.3)
2. The momentum equations: $\partial(\rho V)/\partial t + \nabla \cdot (\rho V \otimes V) = -\nabla p + \rho g + F$ (2.4)
3. The thermodynamic equation: $\partial \theta/\partial t + V \cdot \nabla \theta = Q$ (2.5)

In these equations:

ρ is the air density,

t represents time,

V is the wind vector (u, v, w) representing the three-dimensional wind components,

∇ is the Del operator, which represents the spatial gradient,

p is the pressure,

g is the acceleration due to gravity,

θ is the potential temperature,

Q represents heating or cooling sources.

These equations are solved numerically using computational techniques, such as finite difference, finite element, or spectral methods. NWP models also incorporate additional parameterizations to account for processes that occur at smaller scales and are not resolved by the model grid, such as turbulence, radiation, and surface interactions.

The mathematical expression of an NWP model is much more complex and involves numerous additional equations and parameterizations to represent different atmospheric processes and interactions. These models are implemented on high-performance computers and run using vast amounts of observational data to provide weather forecasts for specific regions and time periods.

2.4 Research Gap

Though, several researches have been made on IoT and its applications in agricultural sector. There are still gap that exist especially on economy efficiency which has to do with the upfront costs of implementing these systems, slowing down the deployment of IoT application in agriculture.

There's also need for research into optimizing power efficiency and data transmission protocols in IoT-based weather monitoring systems, especially for remote or off-grid locations where energy sources may be limited.

Another gap is the lack of real-time updates and the integration of advanced sensor technologies to enhance the accuracy and specificity of weather measurements.

2.5 Summary of Literature Review

Table 2.5 provides a concise summary of the literature reviewed. It highlights the key contributions, materials and methods as well as findings of various studies relevant to this work. This summary identifies the gaps and establishes the foundation for this research.

Table 2.5: Summary of literature review

Authors	Title	Method	Contribution	Gap
Suleiman, (2022)	Construction of a Wireless Weather Monitoring System Using GSM Module	Utilized Atmeg32 microcontroller as the central processing unit, DHT11 sensor for temperature and humidity, light sensor, GSM module (Sim 800) for wireless transmission and LCD for data visualization.	Detected weather characteristics such as temperature, humidity and light.	Reliance on DC batteries. Lack of data archiving. High power consumption. Inability to measure rainfall and pressure.
Rasagna et al., (2023)	Solar Powered Soil and Weather Monitoring System Using IoT	Used DHT11 sensor, soil moisture, rain drop sensor and LDR sensor	Monitored field parameters such as temperature, humidity, soil moisture, rain level and light Intensity.	Accuracy and reliability of the data collected is affected by environmental factors. High cost of hardware and cloud-based server.
Abdulkadir et al., (2019)	Design, Implementation and Evaluation	Implemented XBee modules at the transmitting	Monitored temperature, humidity, wind	Lack of real-time updates.

	of Remote Weather Monitoring System	and receiving units for remote monitoring. A data logger saves the values on a PC after receiving weather Parameters. The system was evaluated using existing monitors.	speed, wind direction, solar illumination and rainfall at near real-time Used solar power to run the system and constantly monitored its level of charge remotely.	High cost of implementation. Complexity issues.
Tanmay et al., (2021)	Weather Monitoring System Using Wi-Fi	Used tipping bucket technique for rain gauge. Anemometer is used to sense wind speed and wind direction. The transmitter section included the controller, various sensors and Wi-Fi module whereas receiving section included router, webserver and website	Monitored weather parameters accurately over a wide area. Provides a cheap, easy, and real time solution to monitor weather parameters	No satellite images is included to give a more accurate weather forecast. Inability to assist farmers find the best time for each crop and specific conditions for appropriate pest control.

Dayananda et al., (2021)	An IoT based Low- cost Weather Monitoring System for Smart Farming.	Utilized various sensors to measure real-time weather parameters. The user receive this data through a GSM network. Arduino Uno microcontroller, liquid crystal display and GSM900A module was used as a hardware requirement.	Monitored conditions such as temperature, humidity, light, pressure, CO2 level, wind speed and direction in a specific region. The system had three main unit; power, sensing and output unit.	Lack of user-friendly interface. Need for installation of more sensors to detect solar radiation and moisture, rain intensity etc.
Apurva Pusatkar et al., (2021)	A Wireless Sensor Network Based System for Real Time monitoring of Agriculture	Sensors captured various parameters. The ATMEGA microcontroller reads and transmits it to the GSM mobile for users to access. LCD screen was also utilized for visualization	Allowed cultivation in places with water scarcity. The internet link allowed supervision through mobile telecommunication devices.	Inability to detect a particular disease on the plant and the curative measures on it. Unable to communicate with the nearer weather station through satellite communication
Kanaka et al., (2023)	Developing a Sustainable	Communicates data to the IOTA	Tracked temperature,	Need for advanced sensor

	IoT-based Smart Weather Station for Real Time Weather Monitoring and Forecasting	network via a Wi-Fi module. The ESP32 microcontroller is used to track local weather condition. Machine learning algorithm is use to analyze the collected data	humidity, wind speed, and send the data to the IOTA network via a Wi-Fi module	technology and machine learning algorithm. Need for edge computing capabilities
Tabassum,& Hossain, (2018)	Design and Development of Weather Monitoring and Controlling System for a Smart Agro (Farm)	Uses temperature and humidity sensor to send digital value and soil moisture sensor and rain detector sensor to send analog value to Arduino. Arduino UNO send data to Raspberry Pi for processing and stores in local database system. Users can access	Designed and developed a weather monitoring and controlling system for a smart agro farm. Detected temperature, humidity, soil moisture, rain detector	Need to add sensor for more effective result. Need to develop mobile application for forecasting weather from anywhere in the world.

		with laptop or smartphone.		
Suma, (2021)	Internet-of-Things (IoT) based Smart Agriculture in India.	Used predictive analysis, Internet of Things (IoT) devices, sensor module, agri robot with cloud management, security units for multi-culture.	Provided irrigation data for different sensors like moisture, temperature, humidity. Once it reaches the threshold level, the device provides appropriate action to the fieldwork robot.	Cost of hardware and software cost with compromising precision system output. Complexity due to many devices interlinked through a web server. Need for deep learning analysis to increase the production of IoT farming
Balakrishnan and Chikkamadaiah (2021)	Weather monitoring and forecasting system using IoT	Utilized Arduino Uno as the main processing unit for the entire system. The sensor and devices is connected to the microcontroller. The sensors are operated by the microcontroller	Displayed the SMS regarding the current weather statistics on user's cell phone. Forecasted weather based on the current and previous data.	Need to power the device using solar panels. Exterior cover to protect the system from harsh weather conditions.

		to retrieve the data from them and The processed data is uploaded and stored in a website using node MCU and Ubi dots.		

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Preamble

This chapter presents the methodology adopted in this work, focusing on the step-by step approach employed to achieve the objectives of this research; to develop improved IoT based weather monitoring system for effective farming. The methodology provides a framework for designing, implementing and evaluating the system, ensuring it is efficient, offers a user- friendly experience and is capable of providing accurate real-time weather information.

The Ignite IoT Methodology was adopted for this research. This methodology was chosen due to its structured and innovative approach to IoT system development. It allows for seamless integration of hardware and software components, cloud-based data management and user-friendly interfaces. The chapter discusses each phase of the methodology and how it helped to achieve the research objectives.

3.1.1 Ignite IoT Methodology

1. Ideation and Requirement Analysis

   A feasibility study was conducted during this phase to assess the system's technical, economic and operational viability. Farmer's needs were identified focusing on their requirements for accurate and real-time weather data. Weather data critical for agricultural productivity including temperature, humidity, pressure, rainfall and sunlight were identified in this phase. The expected system functionality such as real-time monitoring, cloud integration and a user-friendly interface were also outlined during this phase.

2. Use Case Definition

   Use cases were developed to define the desired outcomes and functionalities of the system such as allowing farmers to access real-time weather data via mobile applications. This phase also helped in selecting the system features and components.

3. Solution Blueprint

   During this phase, the system architecture was designed to address farmers' requirements identified during the analysis. The hardware components including DHT11, BMP280, rain, LDR sensors, and the NodeMCU microcontrollers were defined for data collection and processing. The software architecture involved data processing algorithms and a mobile application interface which is powered by the Blynk Cloud API for data visualization and integration.

4. Hardware Design

   This phase focused on selecting and integrating sensors and the microcontroller. The NodeMCU microcontroller was chosen due to its low-power consumption, high processing power and computational capabilities and IoT compatibility. Sensors were selected for their adequate accuracy, low power consumption, simplicity and ability to measure the identified weather parameters. Energy efficiency and connectivity were prioritized to ensure reliable data collection and transmission.

5. Software Development

   This phase played a crucial role in the successful implementation of the IoT based weather monitoring system as it focused on designing, coding and testing the software components required to collect, process and transmit weather data in real-time. The system's core logic was developed using Arduino language which is basically C++. This language was chosen for its simplicity and compatibility with the NodeMCU microcontroller, the core hardware component of the system. The programming aspect involved configuring the sensors to read real-time weather data. Blynk API was integrated into the Arduino code, allowing the system to send packets to the Blynk cloud and a smartphone interface was created to enhance user interaction with the system.

6. Integration

   The hardware and software components were integrated to form a cohesive system. Sensors were configured to interact with the NodeMCU microcontroller and the Blynk IoT platform was installed on the mobile application. This integration allowed the weather data collected to be transmitted to a central server through IoT technology.

7. Deployment

   The integrated system was deployed on the farm. The cloud-based platform was activated to store and retrieve data and the mobile application was made accessible to farmers for real-time weather data monitoring and visualization.

8. Testing

   Functional and performance testing was carried out during this phase to validate the system's operations. Discrepancies were identified and resolved. The system's ability to provide accurate real-time weather data was thoroughly evaluated ensuring it met the research objective.

9. Monitoring and Feedback

   During this phase, the deployed system was continuously monitored and feedback was collected from users (farmers). This feedback helped to refine the system to improve usability, accuracy and performance.

10. Scalability and Maintenance

    The system was designed to scale and cover wider agricultural areas as it grows. The cloud infrastructure allowed for updates and improvements ensuring the system's adaptability to future needs.

3.2 Analysis of the Existing System

Several studies have been done on IoT-based weather monitoring systems by scholars and IoT developers worldwide. Earlier advancements involved combining the ATmega328P microcontroller with a GSM module, connecting it to a network of sensors. The setup allowed for uploading and displaying collected data on a 16/2 LCD display as well as utilizing Things view app (Rasagna, 2023).

The conventional weather monitoring systems rely on weather stations equipped with various instruments like thermometers, barometers, rain gauges, and wind vanes to measure weather and climate changes. These instruments typically utilize analog technology and the data is manually recorded and stored in a database. Subsequently, this information is transmitted to news and radio stations for weather reporting purposes (Anita et al., 2019).

Another group of developers designed and implemented a weather monitoring system capable of manual and automatic operation. This system effectively provides real-time weather data, specifically tailored for farmers. It monitors various weather parameters including temperature, humidity, pressure, rain, light intensity, CO_2 level, and wind speed/direction.

Other researchers have built a wireless weather monitoring systems that incorporated a GSM module. Suleiman (2022) utilized an ATmega32 microcontroller connected to various sensors, including those for temperature, humidity and light.

The main objective of this work is to develop a modular and cost-efficient system for monitoring real-time weather conditions, aiming to enhance agricultural practices while minimizing low power.

3.2.1 Architecture of Existing Study

The selected existing system architecture, which this research aim to enhance, was constructed using the Arduino Uno board and ATMEGA 32 microcontroller featuring a microprocessor. Sensors are linked to the microcontroller's pins, and the LCD screen is likewise connected. Real-time data transmission occurs, with the information displayed on the screen. Moreover, the system incorporates the SIM 800 module to enable wireless SMS transmission to a mobile device.

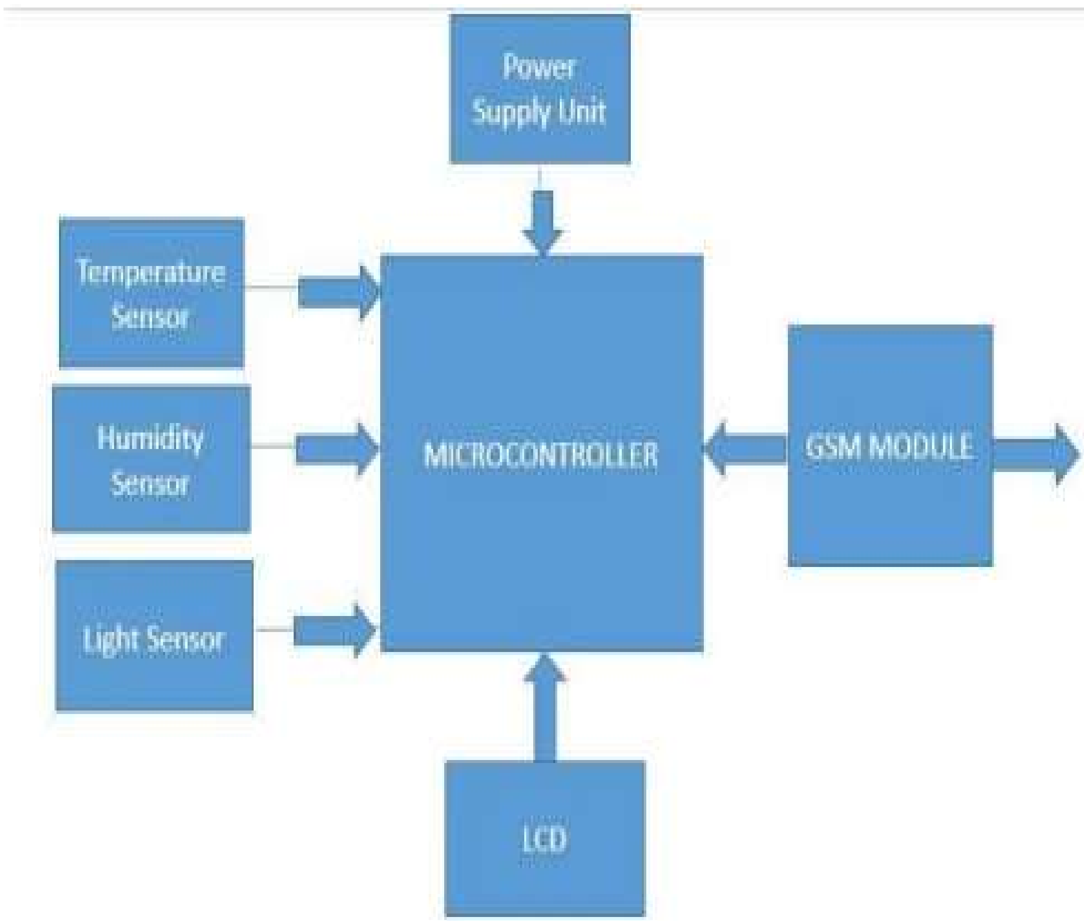

Figure 3.1: Architecture of weather monitoring system using a GSM module (Suleiman, 2022)

The wireless weather monitoring system depicted in Figure 3.1 illustrates the effectiveness in providing real-time weather updates to mobile users regardless of their location. The system detects temperature, humidity and light, sending SMS alerts with current weather data. It is cost-effective and applicable in research, industry and agriculture for weather monitoring and analysis. The adaptable prototype integrates multiple sensors and utilizes GSM technology for remote access, comprising sensors linked to a microcontroller for meteorological data generation.

3.2.2 Limitations of the Existing Study

Some of the limitations of the existing study were:

1. The prototype relied sorely on DC batteries which drain quickly due to the high power consumption of the GSM module and LCD screen. Weather variables such as rainfall and pressure, which are critical for agricultural purposes can not measured. Additionally, measurements cannot be saved on the internet for data archiving (Suleiman 2022).
2. Most IoT-based weather monitoring system developed lacks real-time updates which affects the accuracy, usefulness and effectiveness of the system (Zhang et al., 2020).
3. Existing weather monitoring systems that are used in the field generally consist of unconventional and heavy machinery that consists of numerous moving parts that require constant maintenance and need to be manually monitored and changed frequently which adds up to the cost of installation and maintenance (Balakrishnan et al., 2021).
4. Cost is also a limiting factor for adopting and deploying IoT-based weather monitoring systems in farming operations, especially for resource-constrained farmers (Quy et al., 2022).
5. Some existing systems have challenges in terms of scalability, making it difficult to accommodate additional sensors as farming operations grow.

3.3 Analysis of the Proposed System

The system proposed is an advanced solution for weather monitoring that uses IoT to make its real time data easily accessible over a very wide range. The proposed system consists of network of sensors and actuators sensing and capturing data from the environment. The system utilizes NodeMCU ESP8266 Microcontroller at each sensor node to collect, process, and transmit data and also Wi-Fi for communication within the farm. The system leverages cloud-based platform for storing, processing and analyzing weather data collected from the farm, and the user accesses weather data through their smartphone. The architecture of IoT comprises three layers: the perception layer, which is made out of the physical devices, the network layer for data transmission, and finally the application layer for providing services. (Navod et al., 2021; Ullo et al., 2021).

3.3.1 Architecture of the Proposed System

The architecture of the proposed system is shown in Figure 3.2

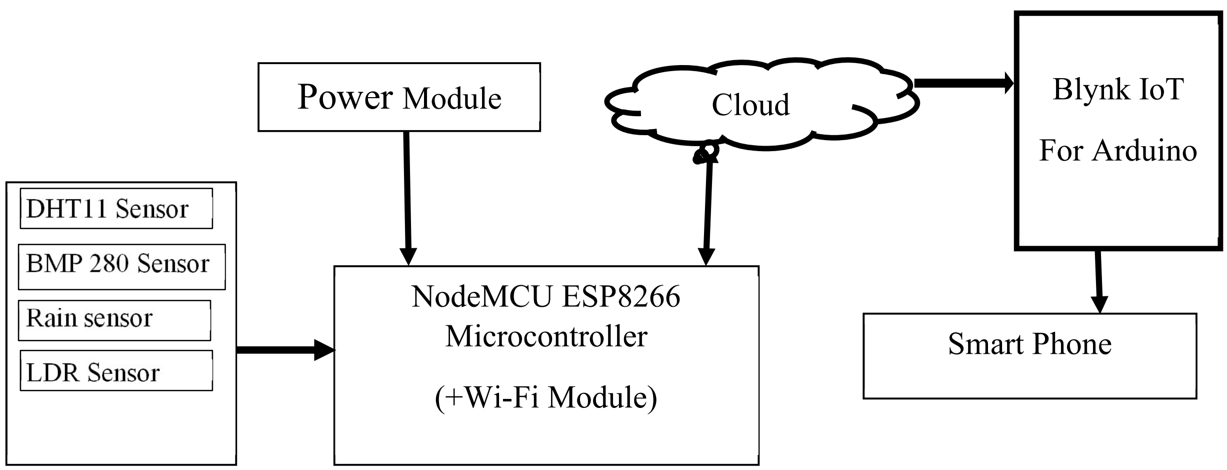

Figure 3.2: IoT- based weather monitoring system

As shown in Figure 3.2 above, the interaction between each of the components in the proposed system architecture is discussed below:

1. **DHT11 Sensor:** The DHT11 sensor captures temperature and humidity data. It is connected to the NodeMCU microcontroller via digital pins. The NodeMCU reads the temperature and humidity data from the DHT11 sensor periodically. The DHT11 sensor is a popular choice for IoT-based weather monitoring due to the following reasons:
   i. Cost- effectiveness: The DHT11 sensor is affordable than and many other sensor used for weather monitoring such as DHT22 sensors making it accessible for research with budget constraints.
   ii. Adequate accuracy: DHT11 sensor provides sufficient accuracy for IoT-based weather monitoring systems.
   iii. Simplicity: The DHT11 sensor allows easy integration into various IoT devices without taking up much space.

iv. Low power consumption: The DHT11 sensor is designed to consume minimal power, making it suitable for battery-powered IoT devices where energy efficiency is relevant.

2. **BMP280 Sensor:** BMP280 sensor captures atmospheric pressure. The NodeMCU reads the pressure data from the BMP280 sensor periodically. The existing study utilized BMP180 for pressure measurement (Wadne et al., 2023). BMP 280 sensor was chosen in this study as it offers several advantages over the BMP180 sensor in IoT-based weather monitoring systems. Typically, it provides higher accuracy and precision in pressure measurements which is crucial for accurate weather monitoring. The BMP 280 sensor provides a faster response time allowing it to capture rapid changes in atmospheric pressure more quickly than the BMP180 sensor. Additionally, BMP 280 sensor is designed to operate efficiently with low power consumption which allows it to extend the battery life of weather monitoring systems as well as reducing the need for frequent battery replacements or recharging. More also, BMP 280 sensor is typically smaller and more compact than the BMP180 sensor, making it easier to integrate into IoT-devices.
3. **Rain Sensor:** The rain sensor detects the presence of rainfall or rain drops and outputs a digital signal to the NodeMCU microcontroller. The signal indicates the occurrence of a rainfall or rain drops and triggers an interrupt or a polling mechanism on the microcontroller. The NodeMCU microcontroller responds to the signal from the rain sensor by either handling an interrupt generated by the sensor or periodically polling the sensor's output pin to check for changes in rainfall status. The rainfall data collected by the NodeMCU microcontroller is integrated with other weather data, such as temperature, humidity, and barometric pressure, to provide a comprehensive view of weather conditions in the monitored area. The NodeMCU microcontroller handles the power supply to the rain sensor, ensuring that it receives sufficient power to operate properly.
4. **LDR Sensor**: The LDR (Light Dependent Resistor) sensor measures ambient light levels. It is connected to the NodeMCU microcontroller. The light sensor senses light just like a thermometer senses the temperature and a speedometer senses speed. The moment a flashlight is turned on, the light sensor detects surrounding ambient light and shines bright and if the light disappears it automatically turns off.

5. **NodeMCU Microcontroller based on ESP8266:** The NodeMCU microcontroller servers as the central processing unit of the IoT-based weather monitoring system. It reads data from the sensors (DHT11, BMP280, rain, and LDR) and processes it. The existing system architecture utilized ATMEGA-32 microcontroller. However, NodeMCU microcontrollers based on ESP 8266 was chosen for this study over ATmegaA-32 microcontroller due to the fact that it comes with built-in Wi-Fi connectivity, allowing them to connect directly to Wi-Fi networks without the need for additional WiFi-modules. This allows for easy setup, enabling seamless integration with IoT platforms and cloud services for data transmission and remote monitoring. NodeMCU microcontrollers provides higher processing power and computational capabilities compared to ATmega-32 microcontrollers. Additionally, NodeMCU microcontrollers are designed to operate efficiently, consuming low power during normal operation and stand mode which is advantageous for battery-powered. NodeMCU microcontrollers are compatible with popular IoT platforms and cloud services including Blynk and Thing Speak.
6. **Blynk IoT Platform**: The Blynk IoT platform is responsible for linking the NodeMCU microcontroller to the internet.The NodeMCU delivers weather data to the Blynk IoT platform using the Blynk library and APIs over Wi-Fi. The Blynk platform stores the data and allows users to access it from anywhere using a smartphone. The Blynk platform provides a cloud-based infrastructure for connecting IoT devices and creating user interfaces. Blynk IoT platform was chosen in this research due to the following reasons:
   i. User-Friendly Interface: Blynk IoT platform provides a more intuitive and interactive interface, making it easier for farmers and developers to create, customize, and mange IoT operations.
   ii. Scalability and Flexibility: Blynk IoT platform provides scalable and flexible pricing plans. Farmers can start with a free plan and upgrade to premium plans as their weather monitoring systems grow in scale and complexity in the long term
   iii. Mobile App Support: Blynk IoT is compactible for both iOs and Android platforms, allowing farmers to access and monitor weather directly from their smartphones or tablets. This mobile support provides convenience and accessibility, enabling farmers to stay connected to their weather monitoring systems whether in or outside the field.

7. **Smartphone**: The smartphone provides the user interface for accessing weather data collected by the IoT-based monitoring system. Users can install the Blynk app on their smartphones. The app displays real-time weather data, such as temperature, humidity, pressure, rain, and light intensity. Smartphones is chosen over LCD displays used in the existing system (Suleiman, 2022) for displaying weather data because smartphones are portable devices that farmers typically carry with them, allowing them to access weather data from anywhere on the farm. Unlike smartphones, LCDs are static and requires physical access in order to view weather information. Smartphones feature a high-resolution graphical user interface (GUI) that can display weather data in a visually appealing and interactive manner. LCD has limited interactive options such as meus and buttons and as a result does not provide rich user experience. Although LCD displays may be suitable for displaying weather data in a centralized monitoring station, smartphones offer greater flexibility, accessibility, and functionality for the on-the-go monitoring of weather conditions.
8. **The power module:** The proposed system utilized a 9 volts battery along with a USB port to accommodate alternative light sources such as a solar panel unlike the existing system that relied only on a 5 volts battery. A 5 volts battery typically refers to a battery that provides a nominal voltage output of 5 volts. A 9 volts battery, on the other hand provides a higher nominal voltage output of 9 volts. A 9v battery typically has a higher energy capacity compared to a 5v battery of similar size. This result in longer battery life and extended operation eliminating the need for battery replacements or charges. The power module supplies electrical power to the NodeMCU microcontroller. The power module regulates the voltage and current supplied to the NodeMCU microcontroller to ensure stable and consistent operation. When the power module is activated or powered on, it provides electrical power to the NodeMCU microcontroller.

Generally, the interaction between the components in the proposed system architecture involves the collection of weather data from available sensors by the NodeMCU microcontroller, transmission of the data to the Blynk IoT platform over Wi-Fi, storage and visualization of the data on the Blynk platform, and access to the data by users through the Blynk app on their smartphones.

Mathematical representation of the proposed system:

Let's denote:

i. $\boldsymbol{T}$ as the temperature measured by the DHT11 sensor in Celsius (°C).
ii. $\boldsymbol{P}$ as the pressure measured by the BMP280 sensor in hectopascals (hPa).
iii. $\boldsymbol{R}$ as the rainfall measured by the rain sensor in millimeters (mm).
iv. L as the light intensity measured by the LDR sensor in lux (lx).

The system components are:

i. NodeMCU Microcontroller: Responsible for data acquisition, processing, and communication.
ii. DHT11 Sensor: Measures temperature $\boldsymbol{T}$ **(**humidity not included in this mathematical representation)
iii. BMP280 Sensor: Measures pressure $\boldsymbol{P}$
iv. Rain Sensor: Measures rainfall $\boldsymbol{R}$
v. LDR Sensor: Measures light intensity $\boldsymbol{L}$
vi. Blynk IoT Platform: Cloud-based platform for data storage, visualization, and remote access.
vii. Smartphone Interface: Interface for accessing real-time data from the Blynk IoT platform.

Mathematically, the system can be represented as follows:

1. Data Acquisition:
   - Temperature reading $\boldsymbol{T}$ from DHT11 sensor.
   - Pressure reading $\boldsymbol{P}$ from BMP280 sensor.
   - Rainfall reading $\boldsymbol{R}$ from rain sensor.
   - Light intensity reading $\boldsymbol{L}$ from LDR sensor.
2. Data Processing:
   - Processed data for transmission to Blynk platform: $\boldsymbol{Tavg}$, $\boldsymbol{Pavg}$, $\boldsymbol{Rtotal}$, $\boldsymbol{Lavg}$.
   - $\boldsymbol{Tavg}$: Average temperature over a specific time interval.
   - $\boldsymbol{Pavg}$: Average pressure over the same interval
   - $\boldsymbol{Rtotal}$: Total rainfall accumulated over time

- $Lavg$: Average light intensity during the interval.

3. Data Transmission to Blynk:
   - Transmission of processed data ($\boldsymbol{T}avg$, $\boldsymbol{P}avg, \boldsymbol{R}total, \boldsymbol{L}avg$.)

Mathematically, the data processing and transmission steps can be represented as functions or algorithms within the NodeMCU microcontroller code. The smartphone interface interacts with the Blynk platform to access and visualize the real-time which is not explicitly represented in this mathematical model but is part of the system functionality. This mathematical representation provides a conceptual overview of how data is collected, processed, and transmitted in the Improved IoT-based Weather Monitoring system using the specified components and platform.

3.3.2 Connection Diagram of the Proposed System

These diagram illustrates the electrical connections and components involved in the system, such as sensors and microcontrollers. As shown in Figure 3.3, NodeMCU microcontroller serves as the microcontroller, which control and coordinates the activities of the ESP8266 embedded on it, the DHT11 and BMP280, rain and LDR sensors were the main components used in this research. The connection diagram of the proposed system provides a visual representation of how the various components are interconnected and work together to collect, process, and transmit weather data for monitoring and analysis.

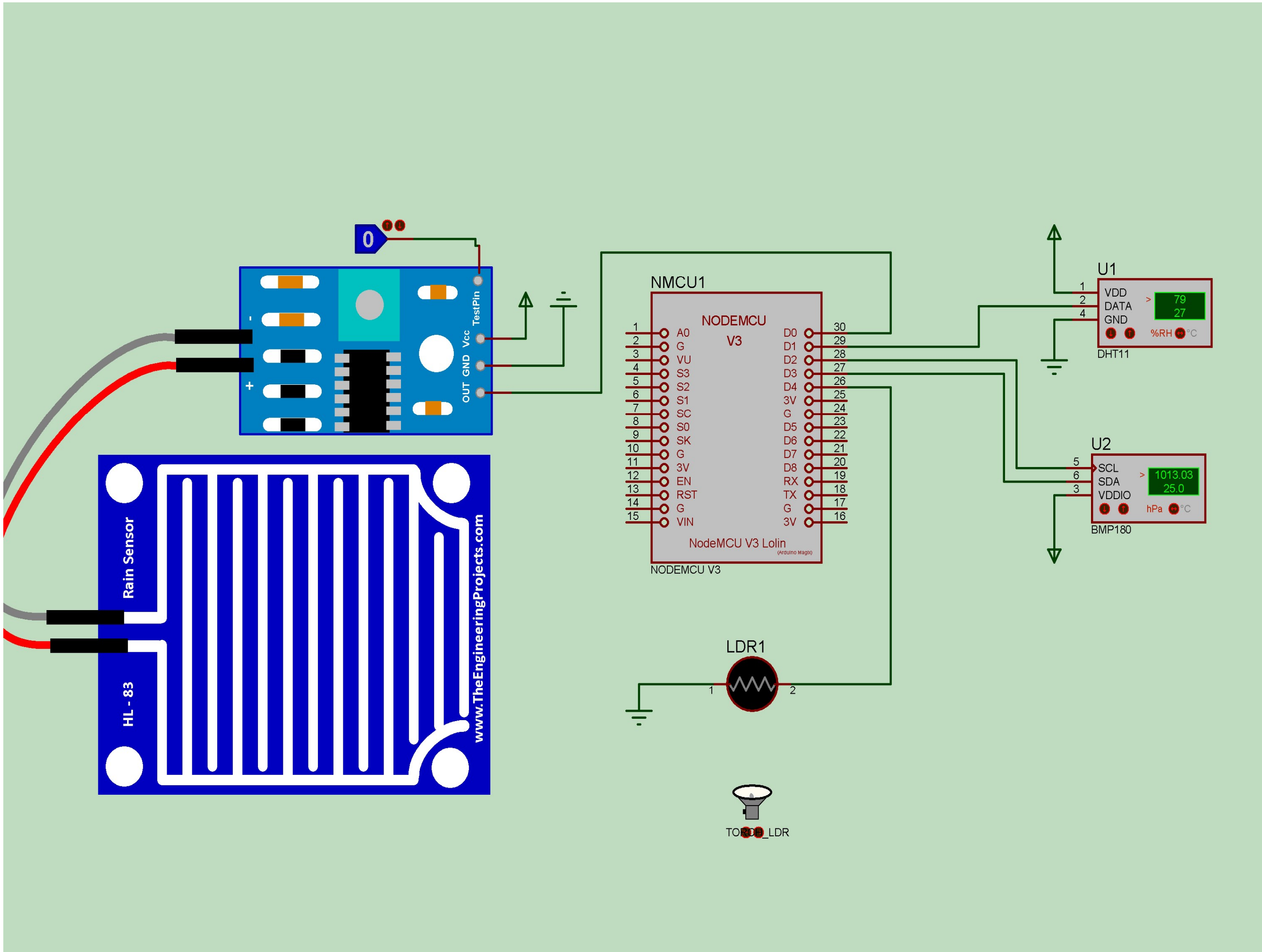

Figure 3.3: Connection diagram of the system

3.3.3 Virtual Model of the Proposed System

The virtual model mimics the components, connections, and functionality of the real world weather monitoring system allowing users to design, simulate, and test the system without the need for physical hardware. This virtual model illustrates the basic components and their connections. The actual implementation may involve additional components or features.

In creating a virtual model for the proposed system, Proteus software was used for the schematic design and Fritzing software for virtual implementation. This software's aided the implementation of the system as it made it possible to ascertain the best connections that will setup a fully functional detection unit. This research work uses NodeMCU as the microcontroller which acts as the main board connecting every sensor used and will be connected virtually by Blynk IoT application. Figure 3.4 shows the virtual model of the proposed system.

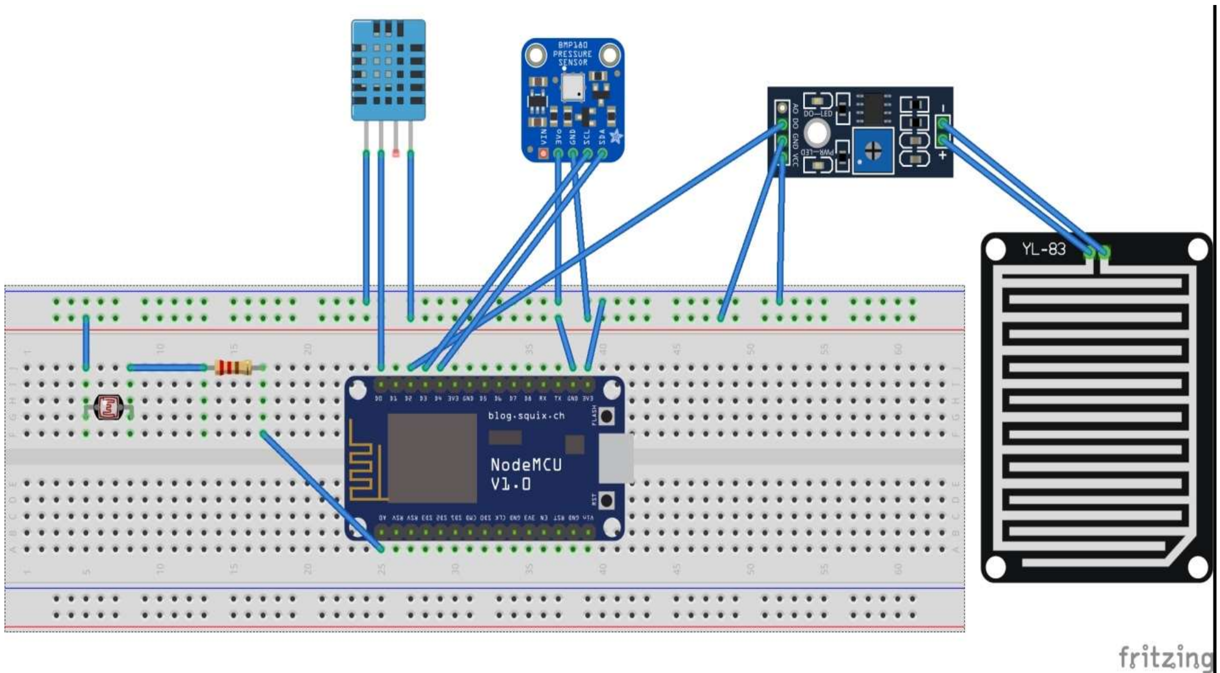

Figure 3.4: Virtual model of the proposed system

Creating the virtual model using Proteus and fritzing software involves several steps:

1. Schematic Design in Proteus:
   i. Start by designing the schematic diagram of the IoT-based weather monitoring system using Proteus.
   ii. Add components such as (DHT11, BMP280, rain, and LDR sensors), NodeMCU ESP8266, power supply, and communication to the schematic.
   iii. Connect components according to their electrical connections, ensuring proper power and data connections between the components.
2. Component selection:
   i. Choose the appropriate components from the Proteus library for each sensor, microcontroller, and other peripherals in the system.
   ii. Ensure that the selected components match the specifications and pin configurations of the actual hardware components.
3. Wiring and Connections:
   i. Use the wiring tools in Proteus to create electrical connections between the components.
   ii. Pay attention to proper wiring and connection routing to avoid signal interference, short circuits, or other electrical issues.

4. Simulations:
    i. Perform simulations in Proteus to verify the functionality of the weather monitoring system.
    ii. Test sensor readings, data transmission, and communication between the microcontroller and the external devices or cloud platforms.
    iii. Debug any issues or errors encountered during simulation and make necessary adjustments to the schematic design.
5. Export Schematic:
    i. Once the schematic design is complete and verified, export the schematic diagram from Proteus in a compatible file format such as PDF or image for further use.
6. Virtual Implementation in Fritzing:
    i. Import the exported schematic diagram into fritzing for virtual implementation.
    ii. Use Fritzing's breadboard view to visually assemble the components and create a virtual prototype of the weather monitoring system.
    iii. Add virtual wires and connections between the components to replicate the wiring layout from the Proteus schematic.
7. Testing and Validation:
    i. Test the virtual implementation in Fritzing to ensure that all the components are properly connected and functioning as intended.
    ii. Verify sensor readings, data transmission and communication with external devices or cloud platforms in the virtual environment.
    iii. Address any discrepancies or issues identified during testing and make necessary adjustments to the virtual prototype.
8. Documentation and Presentation:
    i. Document the virtual model of the weather monitoring system, including component specifications, wiring diagrams, and simulation results.
    ii. Prepare a presentation or report showcasing the virtual model, its features, and functionality using screenshots, diagrams, and descriptions.

As shown in Figure 3.5 and Figure 3.6 respectively, the Proteus and Fritzing software were used to design the IoT-based weather station system. This software provides models for most of the components used in building and modeling circuits. It was used to model the interfacing of various component parts of the System.

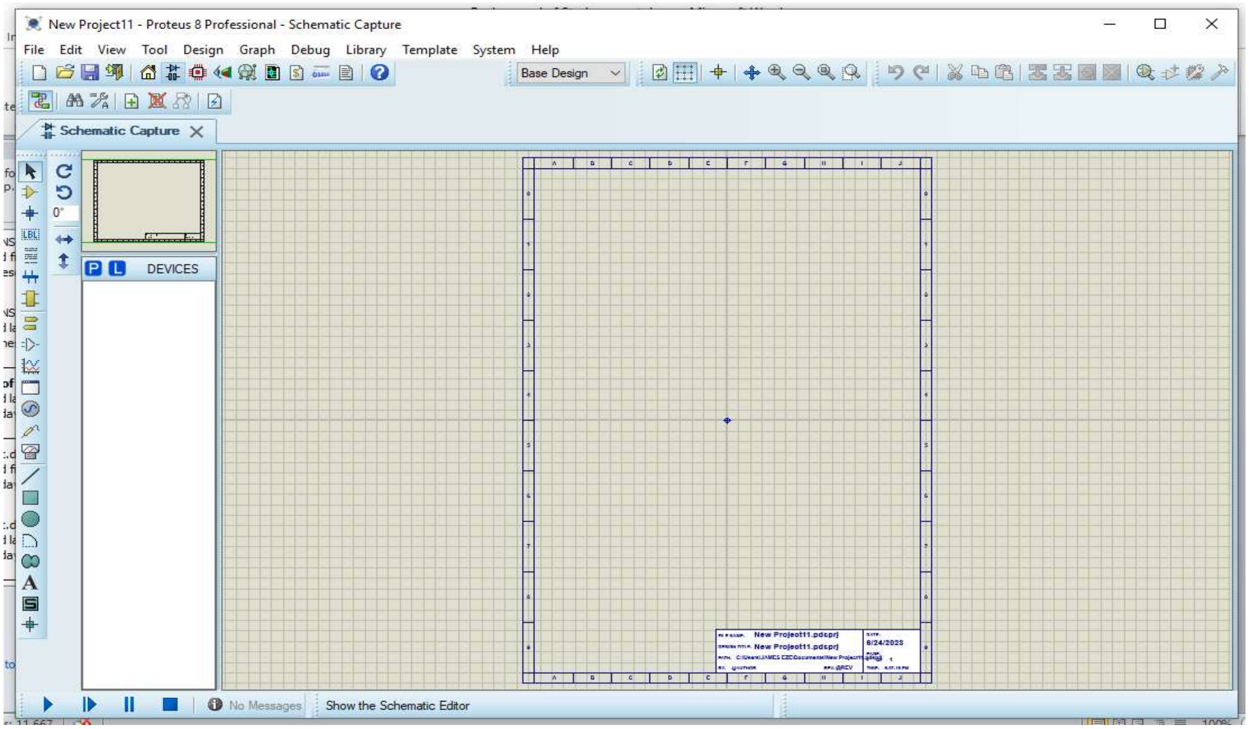

Figure 3.5: Proteus software interface

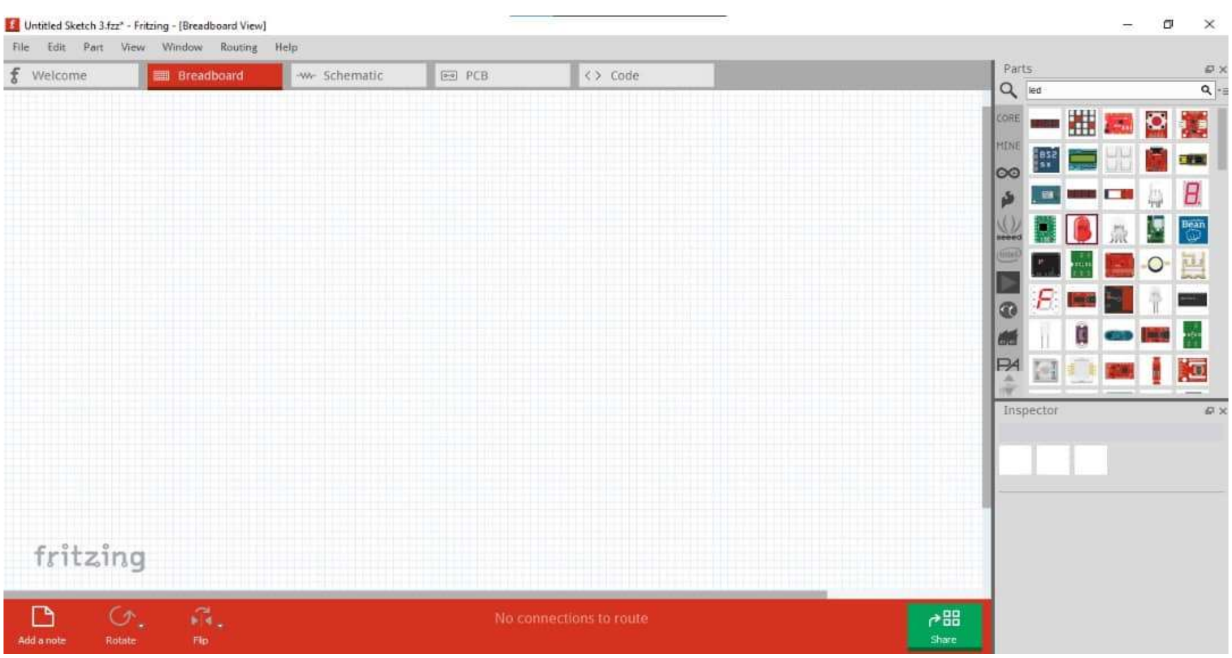

Figure 3.6: Fritzing software interface

3.3.4 Operational Procedure of the Proposed System

Step 1:

a. Initialize the Node MCU ESP 8266 microcontroller and set up the Blynk app integration.
b. Configure pins for connecting the DHT11 sensor, BMP 280 sensor, Rain Sensor, and LDR sensor
c. Establish communication between the Node MCU ESP 8266 and the Blynk cloud platform.

Step 2:

a. Continuously poll the DHT11 sensor to collect temperature and humidity data.
b. Monitor the Rain Sensor to detect rain presence or absence.
c. Retrieve atmospheric pressure data from the BMP280 pressure sensor.

Step 3:

a. Preprocess the collected sensor data to ensure accuracy and reliability.
b. Calculate the dew point from temperature and humidity readings.
c. Aggregate the data from all sensors into a cohesive dataset.

Step 4:

a. Analyze the rain sensor output to determine if it's currently raining or not.
b. Process the pressure sensor data to understand changes in atmospheric pressure.

Step 5:

a. Store cleaned and processed data on the Blynk cloud platform for historical reference.
b. Utilize Blynk's data logging and storage capabilities for efficient historical data storage.

Step 6:

a. Create a Blynk app dashboard with widgets for temperature, humidity, rain status, and pressure.
b. Use Blynk's Virtual Pins to update the dashboard with real-time data.

Step 7:

a. Set up threshold values for rain intensity and pressure changes on the Blynk app.

b. Trigger Blynk notifications (push, email) when thresholds are exceeded.

Step 8:

a. Regularly check sensor readings for anomalies or outliers and report to the Blynk app.
b. Implement error handling to address sensor malfunctions or communication issues.

Step 9:

a. Encourage users to provide feedback through the Blynk app interface.
b. Use user feedback to enhance the Blynk app interface and system functionality.

3.3.5 Algorithm

This algorithm outlines the processes involved in capturing sensor data, transmitting it to the Blynk server for real-time visualization, storing it locally for backup and historical analysis, and implementing error-handling mechanisms to ensure data integrity. It provides a structured approach for implementing an IoT-based weather monitoring system tailored for effective farming practices.

Inputs:

a. Initialize ESP8266 WiFi module and connect to the local WiFi network
b. Configure sensor pins (DHT11, BMP280, LDR sensor, Rain sensor) on NodeMCU microcontroller
c. Set up Blynk IoT platform for data visualization and remote monitoring
d. Define sampling intervals for sensor readings
e. Specify data storage parameters (e.g., database structure, storage location)

Processes:

1. Initialize system:

a. Power on the NodeMCU microcontroller and ESP8266 module
b. Connect to the WiFi network
c. Connect to the Blynk IoT platform

2. Read sensor data:

   a. Read temperature and humidity data from DHT11 sensor
   b. Read atmospheric pressure data from BMP280 sensor
   c. Read light intensity data from LDR sensor
   d. Read rainfall data from Rain sensor

3. Send data to Blynk server:

   a. Transmit sensor data (temperature, humidity, pressure, light intensity, rainfall) to the Blynk server for real-time visualization

4. Store data locally:

   a. Save sensor data (timestamped) to a local storage device (e.g., SD card, EEPROM) on the NodeMCU microcontroller

5. Retrieve stored data:

   a. Implement mechanisms to retrieve historical sensor data from local storage when requested

Output:

a. Real-time visualization of weather data (temperature, humidity, pressure, light intensity, rainfall) on the Blynk IoT platform
b. Ability to retrieve 3months sensor data from local storage when requested

3.3.6 Data Flow Diagram of the Proposed System

A Data Flow Diagram (DFD) is a graphical representation of how data flows within a system. In the context of an IoT-Based weather monitoring system, here how the system can be represented using a basic DFD with a two processes and external entities.
External Entity 1: Represents a source of input data, such as weather sensors or data providers.
External Entity 2: Represents a destination for output data which is cloud storage. External Entity 3: Represents the users and a display interface from where the user can interact with the system and retrieve weather data from the database.

Process 1: This is the core of the weather monitoring system where data is processed and flows through.

Process 2: This process entails weather information retrieval from the storage

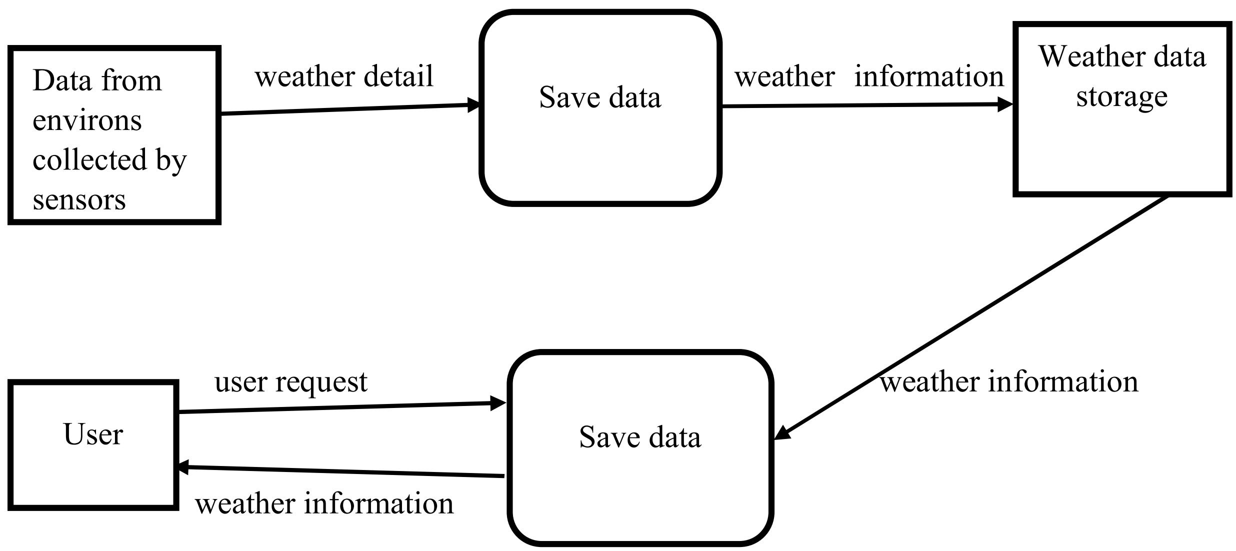

Figure 3.7: Dataflow diagram of the proposed system

3.3.7 Use Case Diagram of the Proposed System

A use case diagram is a visual representation of the functional requirements of a system, showcasing how different actors (users, external systems, or other entities) interact with the system to accomplish specific tasks or goals.

In this system design, the use case is quite simple consisting of just few use cases, an actor and their relationships. Figure 3.8 shows the use case diagram for the proposed system design. It includes:

1. **Weather monitoring System:** Represents the main system being modeled.
2. **User:** An actor interacting with the system. They can perform various tasks like requesting for weather information and viewing weather information.
3. **Use cases:** This represents the actions the user is allowed to take in the system.
4. **Associations**: The lines connecting actors and use cases represent associations, showing that actors interact with the system through these use cases.

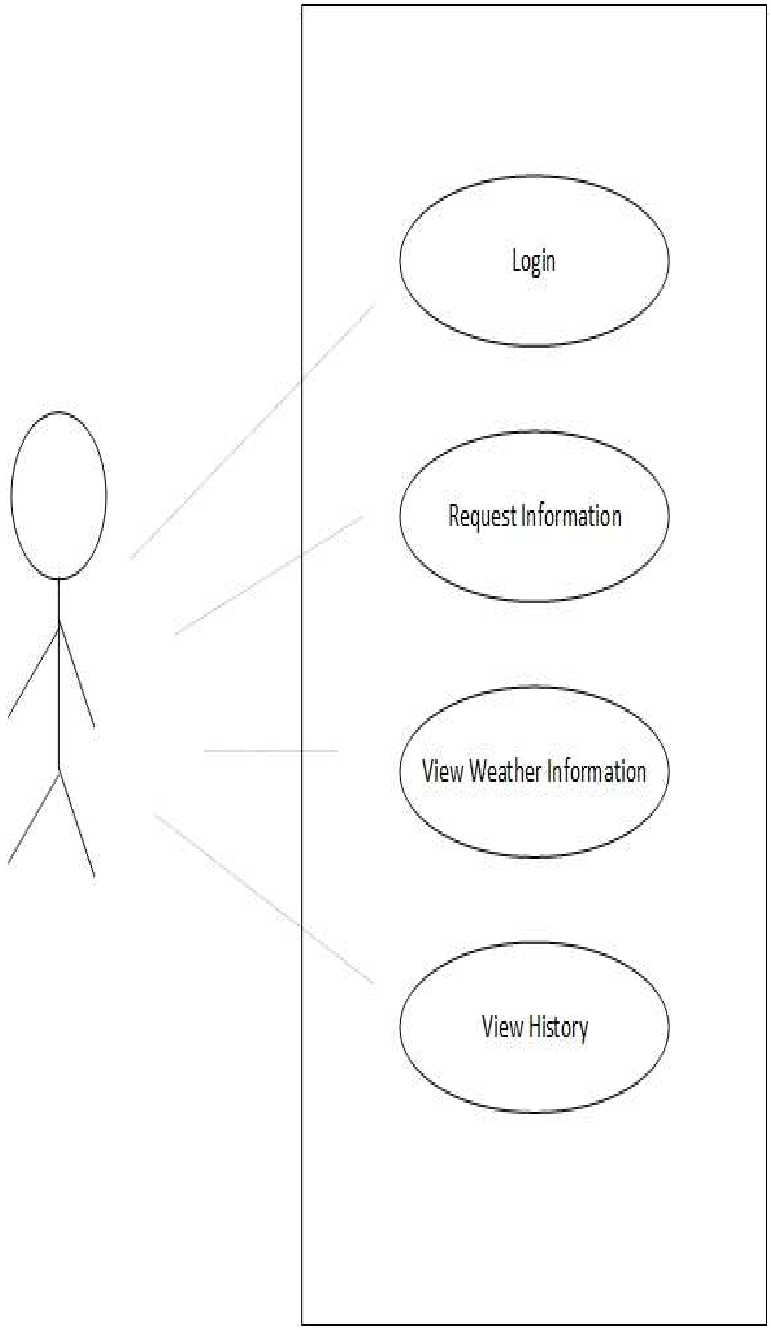

Figure 3.8: Use Case diagram for the proposed system

3.3.8 Flowchart for the Proposed System

Figure 3.9 depicts the flowchart for the proposed system. It starts by initializing the system which comprises of connecting to the Blynk and Wi-Fi. Then, the readings are taken by the sensors for some seconds and sent to the Blynk Platform and displayed on the Phone through the Blynk app.

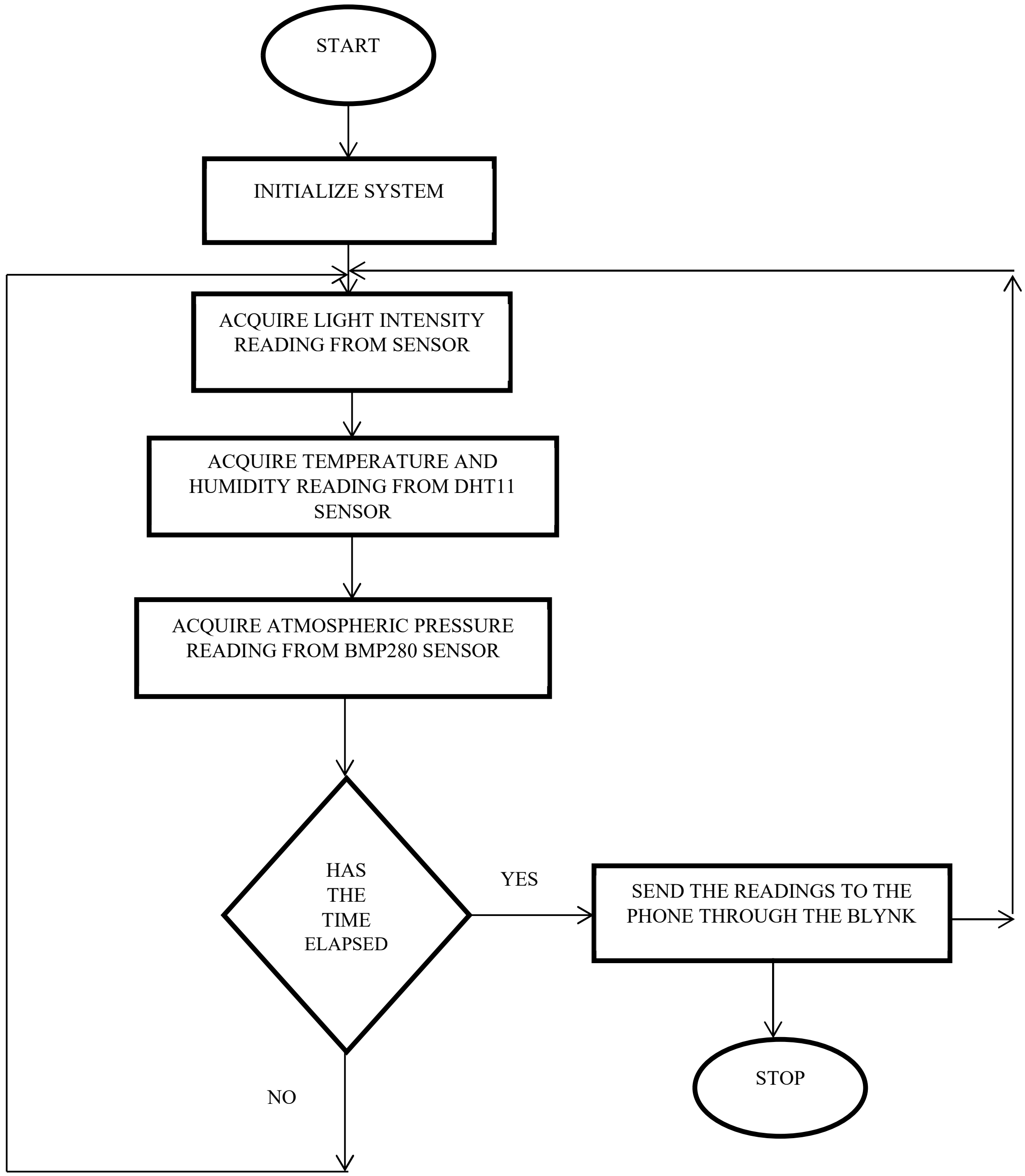

Figure 3.9: Flowchart for the proposed system

3.3.9 Evaluation Method

The evaluation method employed allows stakeholders to assess the effectiveness, reliability, scalability and usability of the IoT-based weather monitoring system for capturing, storing, and retrieving data, ultimately ensuring its value in supporting farming operations.

1. **Data Accuracy Evaluation:**

Evaluated the precision and consistency of the weather parameters. Compared the captured weather data with data from conventional weather stations.

2. **Data Storage and Retrieval Performance:**

Ensured access and retrieval of past weather data from the Blynk Cloud IoT platform.

3. **Data Integrity and Security:**

Assessed the system's ability to maintain data integrity, ensuring that captured data is not corrupted or lost during storage or retrieval processes. Evaluated the security measures implemented to protect sensitive weather data from unauthorized access.

4. **System Reliability and Availability:**

Tested the system's reliability by simulating various failure scenarios such as network outages and power failure.

5. **User Experience Evaluation:**

Evaluated the user interface for ease of navigation, clarity of displayed data, and accessibility.

3.3.10 Proposed system Assumption

During the design of the system, the following assumption was considered, combing DHT11 sensor for temperature and humidity, BMP280 for pressure measurement, and a 9v battery will enhance the capabilities of the improved IoT-based weather monitoring system by providing accurate weather data and potentially improving system performance. Consequently, careful consideration of sensor accuracy, energy efficiency, system design, and environmental factors is necessary to optimize the system’s functionality and reliability.

3.4 Requirements of the Proposed System

A requirement is simply a statement of what the system must do or what characteristics it needs to have.

3.4.1 Functional Requirement

The International Institute of Business Analysis (IIBA) defines functional requirements as “the product capabilities, or things that a product must do for its users. They are as follows;

1. This system must be able to connect to the smartphone.
2. This system must be able to send data from the Node Microcontroller to the Blynk Platform.
3. The Phone must be able to display the data received from the Blynk Platform for the users.

3.4 .2 Non-functional requirements

The nonfunctional requirements describe a variety of system characteristics: operational, performance and security. These characteristics do not describe business processes or information, but they are very important in understanding what the final system should be like. They are as follows:

Operational: The system can run on embedded devices

Performance: The system should be available for use 24 hours per day, 365 day per year.

Security: Only registered phones can have direct access to the data from the weather station.

3.5 Hardware Specifications

The hardware comprises of the computer devices that we can feel and touch, including the monitor and mouse. The hardware requirements are the specifications of the hardware systems required to use the system.

1. NodeMCU
2. DHT11
3. BMP 280
4. Rain Sensor
5. Light Dependent Resistor (LDR)
6. Breadboard
7. Jumper wires
8. Copper Wires
9. Smart Phone

General list of the hardware components and the quantity used to develop this system is shown in Table 3.1

Table 3.1: List of components required for the proposed system

S/N	Name	Quantity
1.	Node MCU	1 piece

2.	DHT11	1 piece
3.	BMP 280	1 piece
4.	Rain Sensor	1 piece
5.	LDR Sensor	1 piece
6.	Breadboard	1 piece
7.	Jumper Wires	8 pieces
8.	Wiring and Miscellaneous	

Table 3.2: NodeMCU specifications

Microcontroller	ESP-8266 32-bit
NodeMCU Model	Clone LoLin
NodeMCU Size	58mm x 32mm
Pin Spacing	1.1" (27.94mm)
Clock Speed	80 MHz
USB **to Serial**	CH340G
USB Connector	Micro USB
Operating Voltage	3.3V
Input Voltage	4.5V-10V
Flash Memory/SRAM	64GB /5MB
Digital I/O Pins	11
Analog In Pins	1
ADC Range	0-3.3V

UART/SPI/I2C	1 / 1 / 1
WiFi Built-In	802.11 b/g/n
Temperature Range	-40C - 125C

Table 3.3: BMP 280 module specification

Specifications		**BMP 280 Module Specification**	
Operating Voltage	3.5V – 5.5V	**Operating Voltage**	1.3v-3.6v
Operating Current	0.3 mA	**Input Voltage**	3.3v-5.0v
Output	Serial data	**Peak Current**	1000uA
Temperature Range	0° - 50° C	**Operating Temperature**	40ºc to +80ºc
Humidity Range	20 – 90%	**Consumes standby**	0.1µA
Resolution	16-bit	**Maximum Voltage at SDA, SCL**	VCC +0.3v
Accuracy	±1% and ±1°C		

3.6 Relevant Technology and Tools for Implementation

These tools and technologies work together to create a robust and efficient IoT-based weather monitoring system capable of collecting, storing, retrieving and visualizing weather data for effective farming practices.

-The following tools and technology were useful in the design and implementation of this research:

1. **Blynk:**

Blynk is a platform with iOS and Android apps to control Arduino, Raspberry Pi and the likes over the Internet. It's a digital dashboard where you can build a graphic interface for your project by simply dragging and dropping widgets. It's really simple to set everything up and you'll start tinkering in less than 5mins. Blynk is not tied to some specific board or shield. Instead, it's supporting hardware of your choice. Whether your Arduino is linked to the Internet over Wi-Fi, Ethernet or this new ESP8266 chip, Blynk will get you online and ready for the Internet of Things. Figure 3.10 depicts an overview of the Blynk IoT plaform.

Figure 3.10: Blynk app overview

Blynk was designed for the Internet of Things. It can control hardware remotely, it can display sensor data, and it can store data, visualize it and do many other cool things. There are three major components in the platform:

i. **Blynk App:** – It allows you to create amazing interfaces for your projects using various widgets which are provided.

ii. **Blynk Server:** – It is responsible for all the communications between the smartphone and hardware. You can use the Blynk Cloud or run your private Blynk server locally.

iii. **Blynk Libraries:** – It enables communication, for all the popular hardware platforms, with the server and process all the incoming and out coming commands.

Every time you press a button in the Blynk app, the message travels to the Blynk Cloud, where it magically finds its way to your hardware. It works the same in the opposite direction and everything happens in a blink of an eye. Figure 3.11 depicts the architecture of the Blynk cloud.

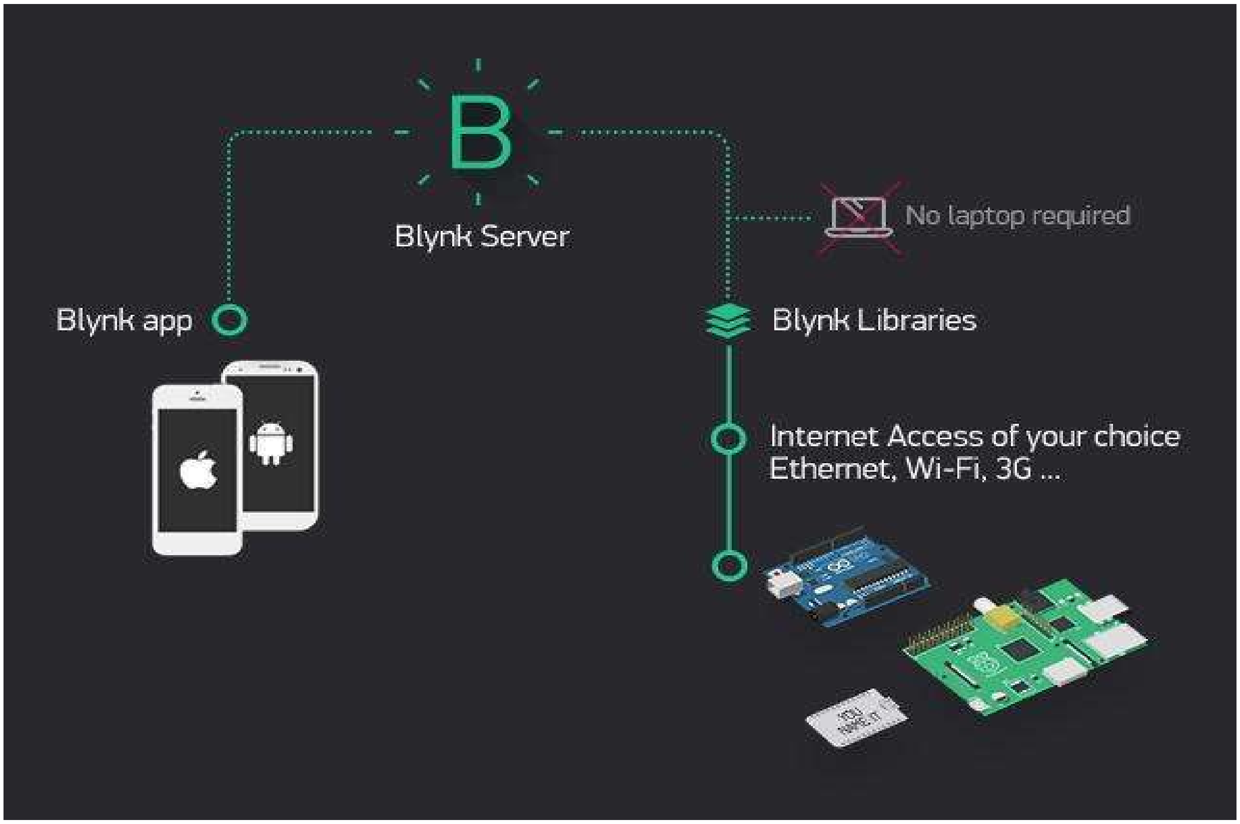

Figure 3.11: Blynk cloud architecture

Characteristics of Blynk are:

i. Similar API & UI for all supported hardware & devices.
ii. Connection to the cloud can be done using Ethernet, Wi-Fi, Bluetooth, BLE and USB (Serial)
iii. Set of easy-to-use Widgets.
iv. Direct pin manipulation with no code writing
v. Easy to integrate and add new functionality using virtual pins
vi. History data monitoring via History Graph widget
vii. Device-to-Device communication using Bridge Widget
viii. Sending emails, tweets, push notifications, etc.

2. **Wi-Fi Technology:**

Wifi is short for "wireless fidelity", Wi-Fi is one of the most popular wireless communication standards on the market. It allows devices to connect to a local area network (LAN) wirelessly. Wi-Fi technology enables communication between devices such as computers, smartphones, tablets, IoT devices, and other hardware within the coverage area of a Wi-Fi network. Figure 3.12 depicts a framework of Wi-Fi technology.

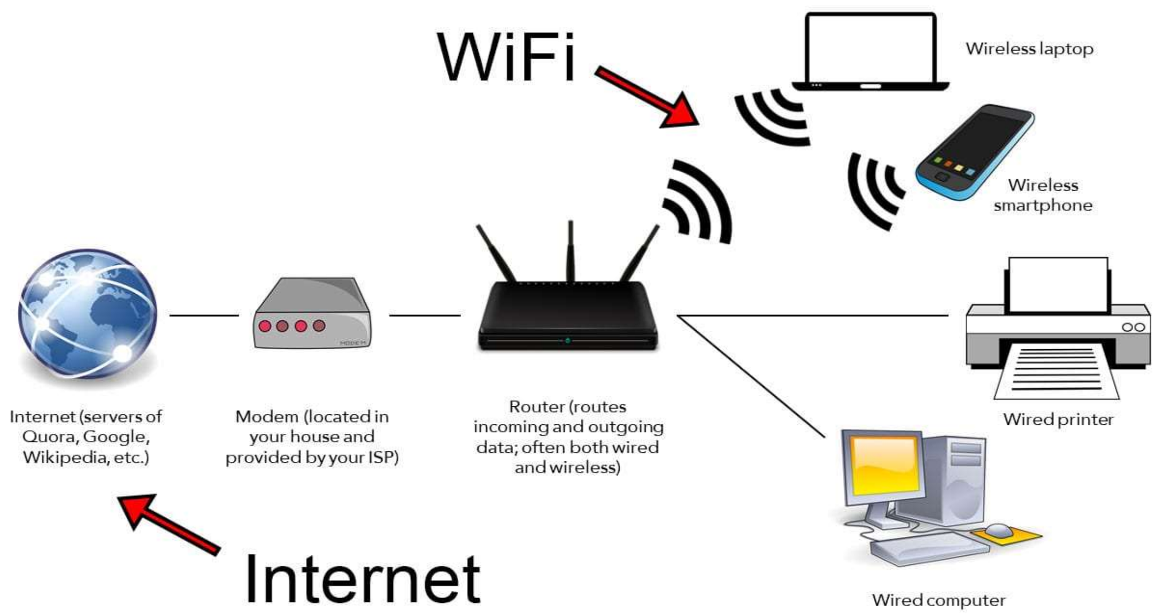

Figure 3.12: Wi-Fi source: https://www.hellotech.com/blog/what-is-the-difference-between-bluetooth-and-wifi

Advantages: The Wi-Fi technology have many advantages and some of them are:

i. Unparalleled mobility and flexibility
ii. Quick, easy setup
iii. Fast data transfer rates
iv. Flexibility to connect Wi-Fi camera with PC and Arduino.
v. Quick, easy setup, do not need complex configuration to connect devices. Fast data transfer rates, that we need it specially to transfer lifetime video from Wi-Fi to PC camera immediately.

3. **Arduino Integrated Development Environment (IDE)**

The Arduino integrated development environment (IDE) is a cross-platform written in Java, whereas the programs are written in C or C++ as shown in Figure 3.13. The platform comes with a software library along with the code editor with features such as syntax highlighting, brace matching and automatic indentation. Arduino is simple and can be easily learned by beginners. Arduino can run on any platform, including Windows, Linux Operating System, and Macintosh, unlike other microcontrollers, which run only on Windows. The Arduino can be used to develop an interactive interface, get inputs from a diverse collection of switches and sensors, and simultaneously control the output from various physical devices, including lights and other appliances. Arduino is focused on an environment that needs to be programmed with a language executed via wiring: a physical computing platform.

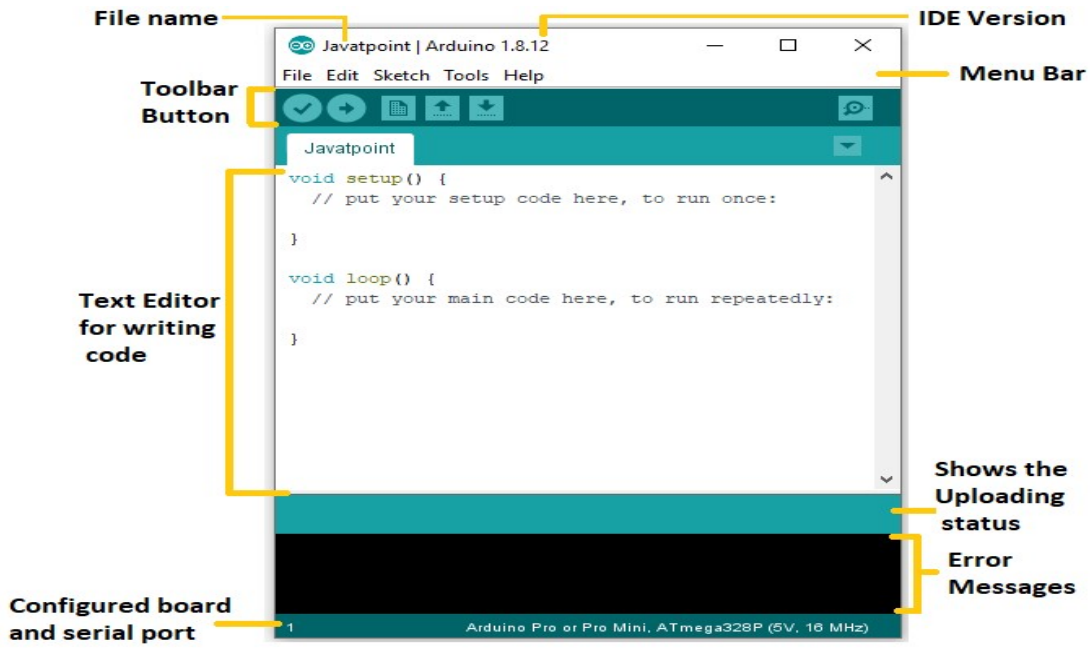

Figure 3.13: Arduino IDE source: https://www.javatpoint.com/arduino-ide

4. **Smartphone**

   Smartphones are uniquely suited to IoT because it is going to be everywhere since everyone carries a smartphone at all times. Smartphone is an IoT devices that can sense, control and communicate with other smart objects. With your smartphone you can control many IoT devices through the Blynk app installed on the smart phone as shown in Plate 3.1.

Plate 3. 1: Smartphone

5. **NodeMCU:**

The term "Node MCU" is derived from the combination of "node" and "MCU" (microcontroller unit). It represents an open-source firmware and development kit designed to facilitate the swift prototyping of IoT products through the use of concise Lua scripts. The platform is centered on an economical System-on-a-Chip (SoC) known as the esp8266. The NodeMCU microcontroller is depicted in Plate 3.2.

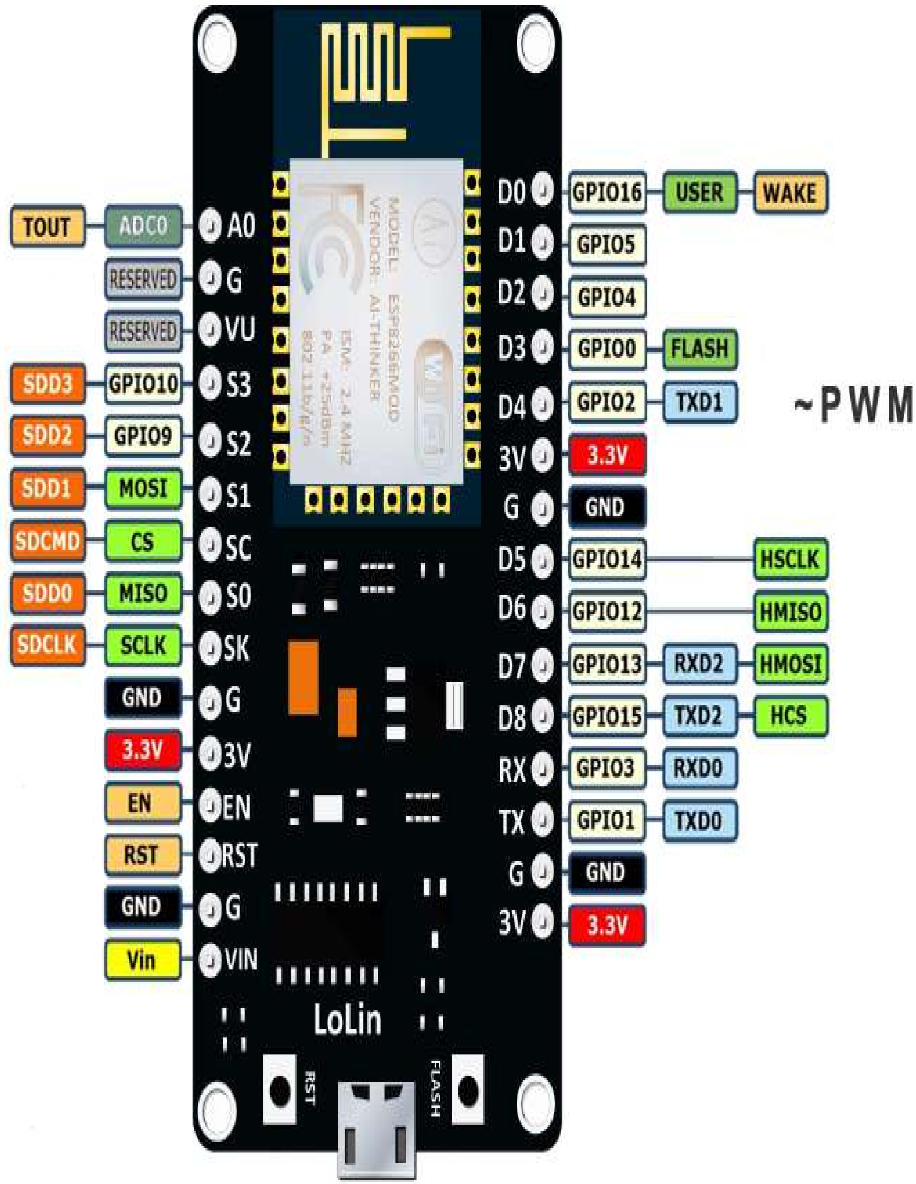

Plate 3.2: NodeMCU source: https://www.teachmemicro.com/nodemcu-pinout/

6. **DHT11 Humidity Sensor:** The DHT11 humidity and temperature sensor is used for monitoring of humidity and temperature in this research. It is a reliable, inexpensive and low power consuming device. It acquires digital signal values making it highly reliable and giving it long term stability. The sensor has 4 pins and makes use of resistive type humidity component with an 8-bit microcontroller to output values of humidity data serially. It is able to measure humidity in the range of 20-90% precisely with ±1% accuracy [Mouser Electronics].

DHT 11 Specifications

The specifications of the DHT11 are as follows:

i. Operating voltage: 3.5V – 5.5V
ii. Operating Current: 0.3 mA (measuring) 60 µA
iii. Output: serial data
iv. Temperature range: 0° - 50° C
v. Humidity range: 20 – 90%
vi. Resolution: 16-bit
vii. Accuracy: ±1% and ±1°C

The DHT11 sensor is depicted in Plate 3.3

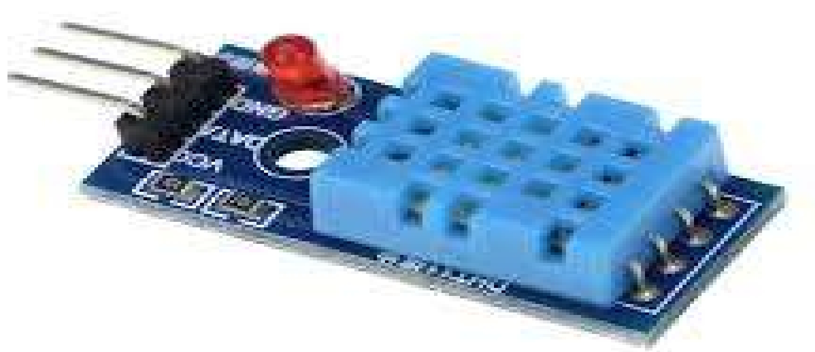

Plate 3.3: DHT11 sensor

7. **BMP 280:** BMP 280 is one sensor of BMP series. They are designed to measure atmosphere pressure. It is a high precision sensor designed for consumer applications. Barometric pressure is nothing but weight of air applied on everything. The air has weight and wherever there is air its pressure is felt. Plate 3.4 depicts the BMP280 sensor

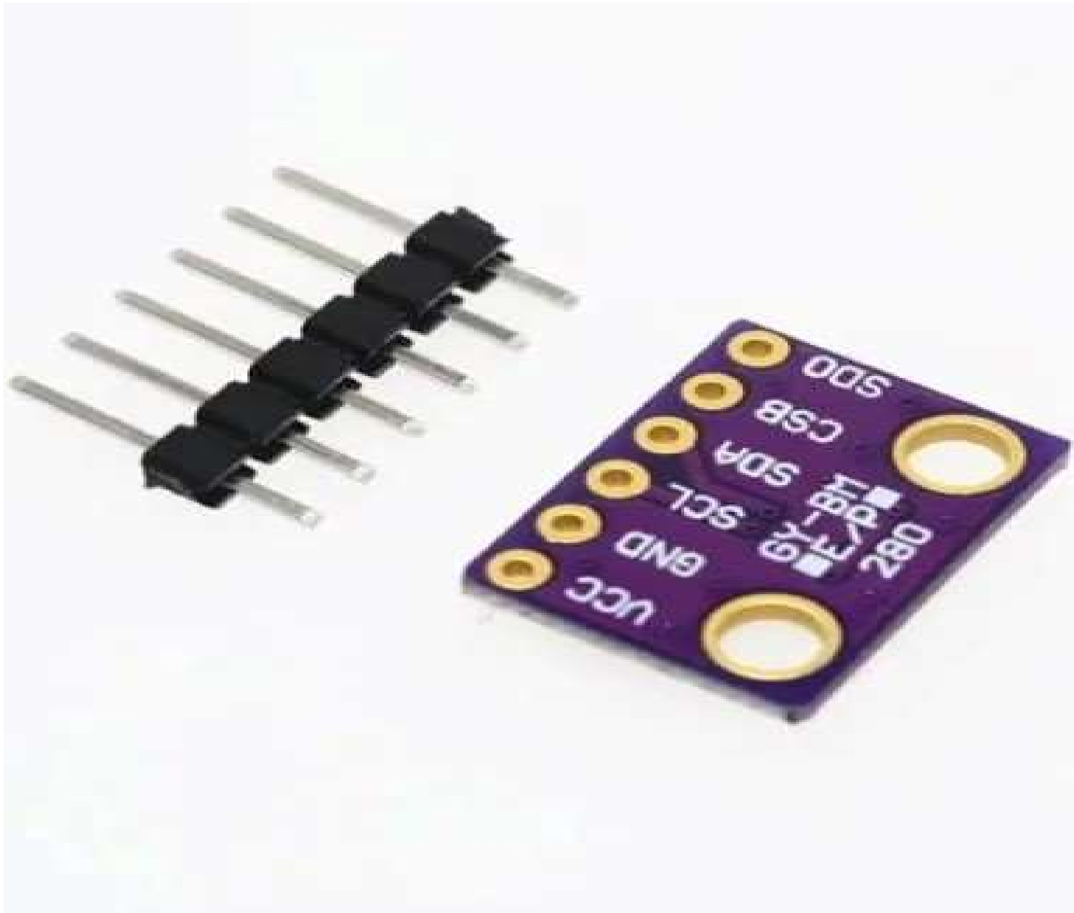

Plate 3.4: BMP280 sensor

8. **Rain Sensor:** A rain sensor is one kind of switching device which is used to detect the rainfall. The sensor is a resistive dipole, and based on the moisture only it shows more resistance when it is dry and show less when it is wet.

Rain Sensor Specification

i. This sensor module uses good quality of double-sided material.
ii. Anti-conductivity & oxidation with long time use.
iii. The area of this sensor includes 5cm x 4cm and can be built with a nickel plate on the side.
iv. The sensitivity can be adjusted by a potentiometer.
v. The required voltage is 5v.

The rainfall sensor is displayed in Plate 3.5

Plate 3.5: Rain sensor

3.7 Program Development

This consists of all the processes involved in the design of the proposed system. These processes include:

I. **The Planning Phase:** is the process of understanding why a system should be built and determining how the system should be built. It has two steps: system initiation and system approval.

II. **Analysis Phase:** The analysis phase determines and defines who the system's user would be, what the system will do, when and where it would be used. During this phase, an investigation is carried out to identify any other system and identify improvements.

III. **Design Phase:** The design phase decides the system's operation in terms of hardware, software and network infrastructure that will be in place, the user interface, forms and reports that will be used, and the specific programs, databases, and files needed. Although most of the strategic decisions about the system are made in the development concept during the analysis phase, the steps in the design phase determine exactly how the system will operate.

IV. **Implementation Phase:** In this phase, the designed system is implemented by coding the design and deploying the proposed system, after which maintenance is carried out.

3.7.1 Choice of Programming Language

The implementation of this proposed system was done using C/C++ Programming language. The main component of the IoT Weather Monitoring System is programmed in the Node MCU Microcontroller. The code (sketch) is written in C/C++, verified (Compiled) and finally uploaded to the chip for all control. It is a general-purpose, object-oriented programming language.

3.8 System Testing

The testing of the system took place in many stages, however there were two major phases. The first phase was in-development" testing which took place throughout the development stage. At each minor and major version, the newly implemented features were tested to ensure that they worked according to specifications. This testing method correctly identified most of the errors and bugs which existed in the system, ensuring it is rectified quickly before they had the possibility of escalating. Our final testing phase was after development had been completed. This stage tested all major and minor aspects of the application to ensure they worked in all instances. This phase provided some very useful results to check the effectiveness of the application.

3.8 1 Component Testing

In this case, tests were carried out on different components that make up the system. The components were tested individually to ensure they were all functional and they worked perfectly well.

3.8.2 Integration Testing

Integration testing is a logical extension of component testing. In a simplest form, two units that have already been tested are combined into a component and the interface between them is tested. A component in this sense refers to an integrated aggregate of more than one unit. In a realistic scenario, many units are combined into the components which are in turn aggregated into larger parts of the system. In this research, lower level components were tested first and the output was then used to facilitate the testing of the higher level components in the system. This process was repeated until the component at the top of the hierarchy is tested. The integration test result for the system in this research was satisfactory.

3.8.3 User Acceptance Testing

User acceptance of a system is the key factor for the success of any system. The system under consideration is tested for user acceptance by constantly keeping in touch with the system users at time of developing and making changes whenever required.

3.8.4 System Integration

Integration deals with the process of combining smaller components of the system to become a larger module. In this research, multiple individual sub-systems or sub-components are combined into one all-encompassing larger system thereby allowing the sub-systems to function together. The symbiosis created through system integration allows the main system to achieve the overarching functionality required of the system. The use of system integration is to improve efficiency, productivity and quality of the operations of the system.

3.9 Weather Data API

A weather data API is an Application Programming Interface for querying weather information. Weather APIs provide easy access to large forecast databases. Weather data API displays meteorological information on web application and provides access to current and historical weather data.

The weather API plays a critical role in enhancing the functionality, reliability, and effectiveness of the Improved IoT-based weather monitoring system developed on the Blynk IoT platform. The weather API contributes in the following ways:

1. **Data Acquisition:** The weather API serves as the primary source of weather data for the IoT system. It retrieves information such as temperature, humidity, atmospheric pressure from external weather data providers in real-time.
2. **Environmental Monitoring:** The weather data obtained from the API is integrated into the IoT system to monitor environmental conditions both indoors and outdoors. This allows for comprehensive monitoring of weather parameters that are relevant to specific applications such as agriculture.
3. **Decision Support:** Real-time weather data provided by API enable informed decision-making for various stakeholders.
4. **User Interface Enhancement:** Weather data obtained from the API can be displayed on the user interface of IoT applications developed using the Blynk platform. Visual re

presentations such as graphs, charts, or weather icons provide users with intuitive and informative displays of current weather conditions, enhancing the overall user experience.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

The improved IoT-based weather monitoring system for effective farming has shown promising results in capturing, storing, and retrieving weather data accurately and efficiently. Farmers can now access real-time weather information crucial for making informed decisions. The following results are displayed in this section; the power on test result, the result of usability test presented in a table, the various interfaces and modules of the system developed, table of system evaluation as well as plots depicting weather monitoring responses.

4.1.1 Power on Test Result

The system was powered on by pressing the ON/OFF switch on the right side of the casing. Once the switch was pressed, the 9v battery in the casing supplied the required voltages to all the system components. Alternatively the system was powered on by inserting or plugging the USB cable to the USB port provided and directly to solar power. The LED attached to the side of the casing blinked to indicate that the system was booting. It took about 5seconds for the system to power on.

4.1.2 Functionality Test

The system was tested while in operation. After booting, the user gets alerted on the application that the system is connected and signal is been sent to the system through the Blynk platform, and immediately the Node MCU receives the data signal, the relay closes or opens to control the appliance according to the instruction gotten from the Node MCU. Table 4.1 describes the various events done during testing of each module of the system, the processes involved, the outputs and result, as well as the remark obtained.

Table 4.1: Functional validation test

Event	Process	Output/Result	Remark
Power the system	All components should receive specified input voltage to power on	All components were powered by a 9v battery used.	Satisfactorily
User connects Wi-Fi Module to Hotspot	The Blynk Platform indicates that the device is connected.	The Blynk indicated that the Wi-Fi Module is connected.	Satisfactorily
The microcontroller sends the data gotten from the sensor the Blynk Platform.	The Wi-Fi Module (esp8266) should send data across to the Blynk Platform,	There is transfer of data from the esp8266 to the IoT Platform that is the Blynk Platform.	Satisfactorily
The Blynk App displays the data gotten from the Blynk Platform for the user to see.	The user should see the readings from the Smart weather station.	The user gets real time weather data on his/her mobile phone.	Satisfactorily
The Blynk App receives signal again	The process should repeat	The process was repeated	Satisfactorily

4.1.3 Interfaces and Modules

The IoT system results on weather parameter monitoring was carried out in phases. The system typically consists of several interfaces and modules to facilitate data collection, processing, analysis, and dissemination. The interfaces and modules includes:

1. **Home Screen**

The home screen is the first page that displays when the user clicks on the Blynk app installed on their smartphone as shown in figure 4.1. This page welcome the users to the IoT weather monitoring system. To continue using the application, the user is expected to login if already signed up or sign up as a new user.

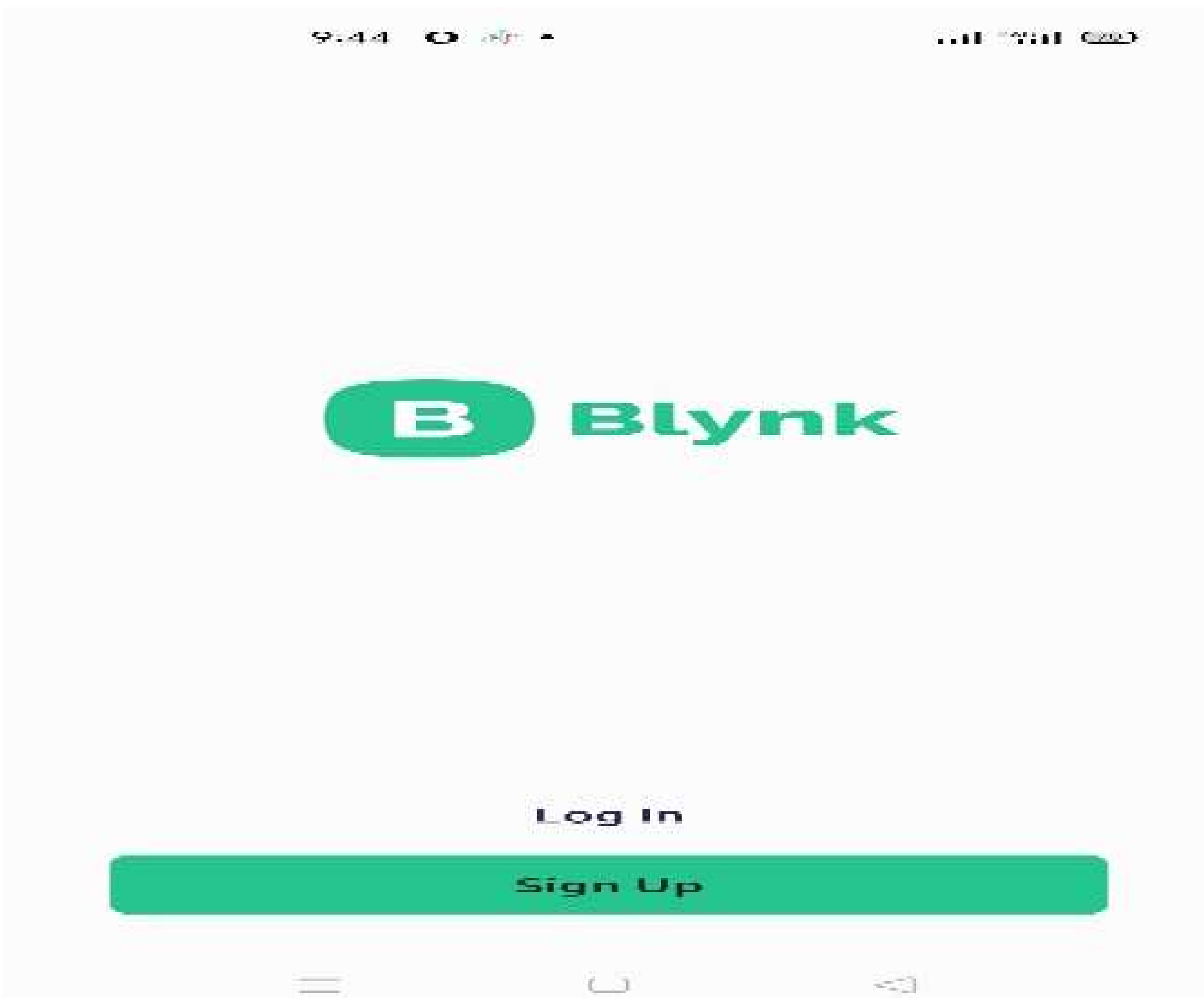

Figure 4.1: Home screen

2. **Official Login Page**

In this module, the system provides the user of the system already signed up with the opportunity to provide their email address and password as login criteria while the system validates and authenticates each user. If validation and authentication is true, the system checks for the particular user and redirects the user to the main menu accordingly or click on forgot password to recover password. The official page is shown in Figure 4.2

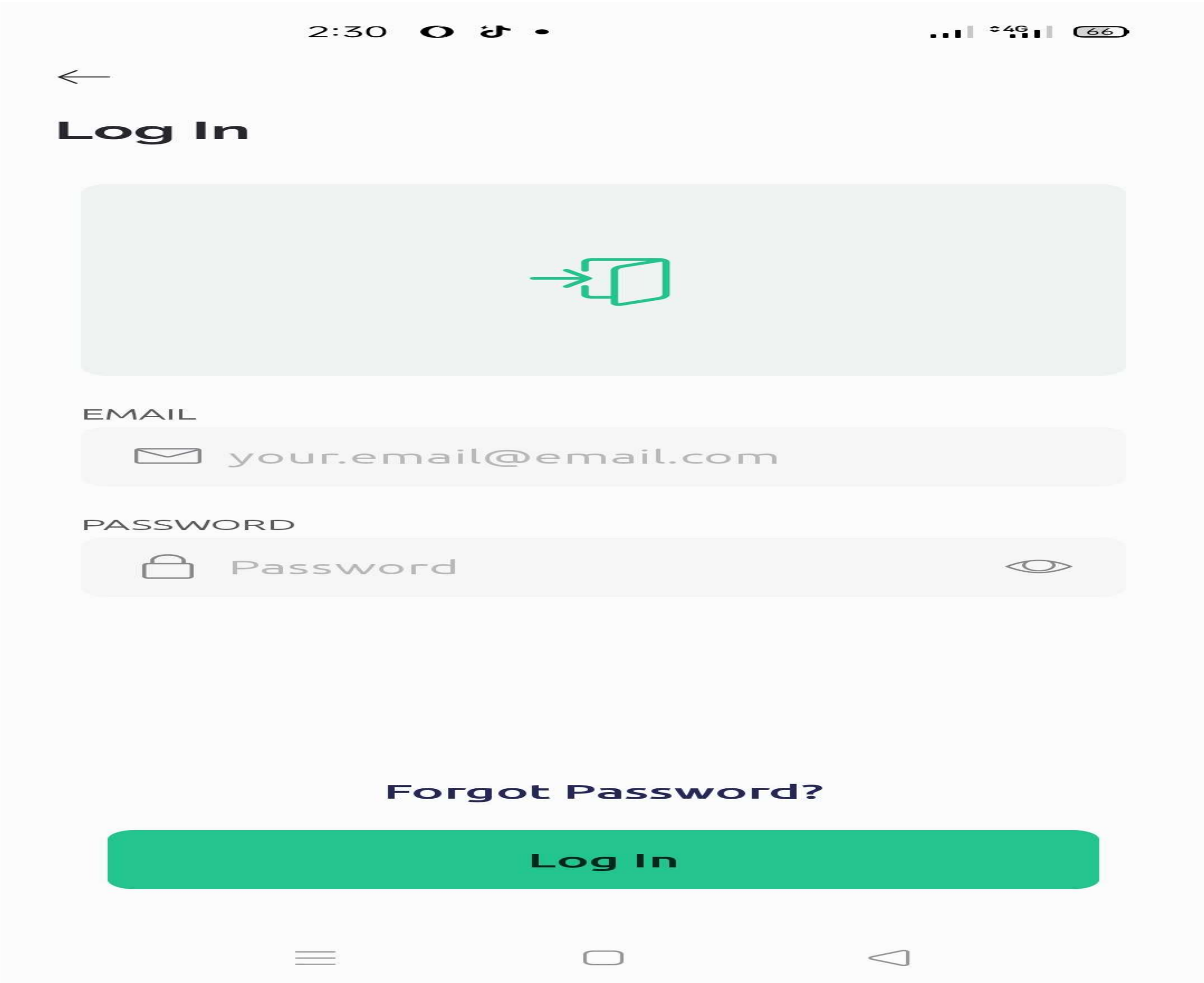

Figure 4.2: Official login

3. **Signup Page**

Figure 4.3 depicts the signup page for the new user to access the system. The signup form requires an email address and following , an account activation link will be sent to the email address provided to validate the account. The user must also agree to term and condition before he/she can continue to sign up.

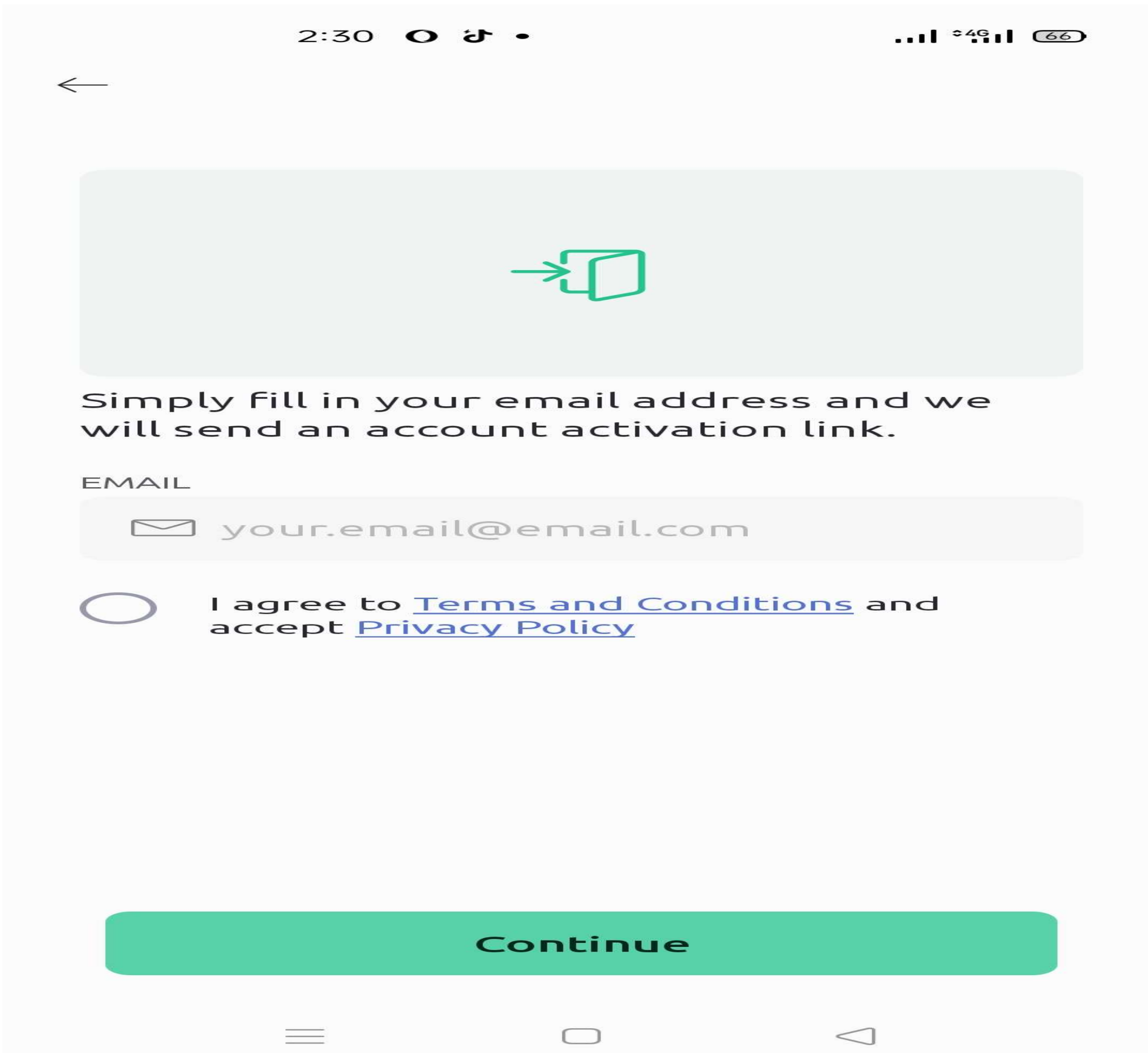

Figure 4.3: Signup page

4. **Offline IoT Weather Monitoring System**

Firstly, the IoT system application (Blynk IoT app) was applied without internet connectivity to the weather station. This interface displays after successful login. It was observed that the IoT application was un-enable to launch due the fact most of the components of the system required internet connectivity to function in order to generate results from the Weather Station**.** As seen in Figure 4.4 the Wi-Fi logo is showing offline, and to enable online, then Wi-Fi module of the IoT system must be linked to a hotspot of your smartphone.

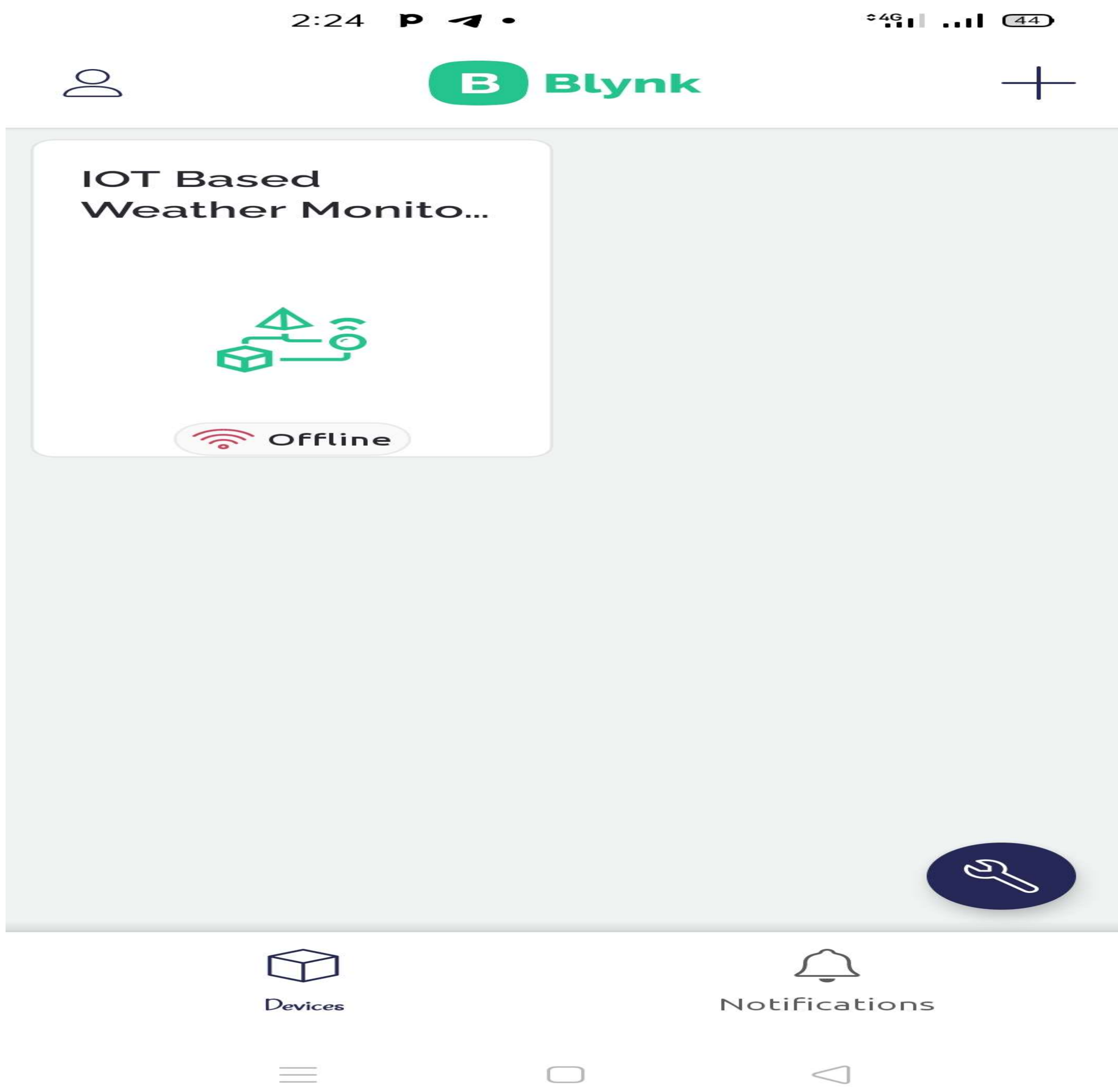

Figure 4.4: Offline IoT weather monitoring system

5. **Online Weather Monitoring System**

In similar manner the IoT-based weather monitoring system was then connected to an internet access and upon successful connections the weather monitoring system becomes enabled to access the weather station. As shown in Figure 4.5, is the online weather monitoring system which displays after successful connectivity of the IoT weather station to the hotspot of your device. Therefore from any part of the world you can automatically link up with your IoT weather monitoring system.

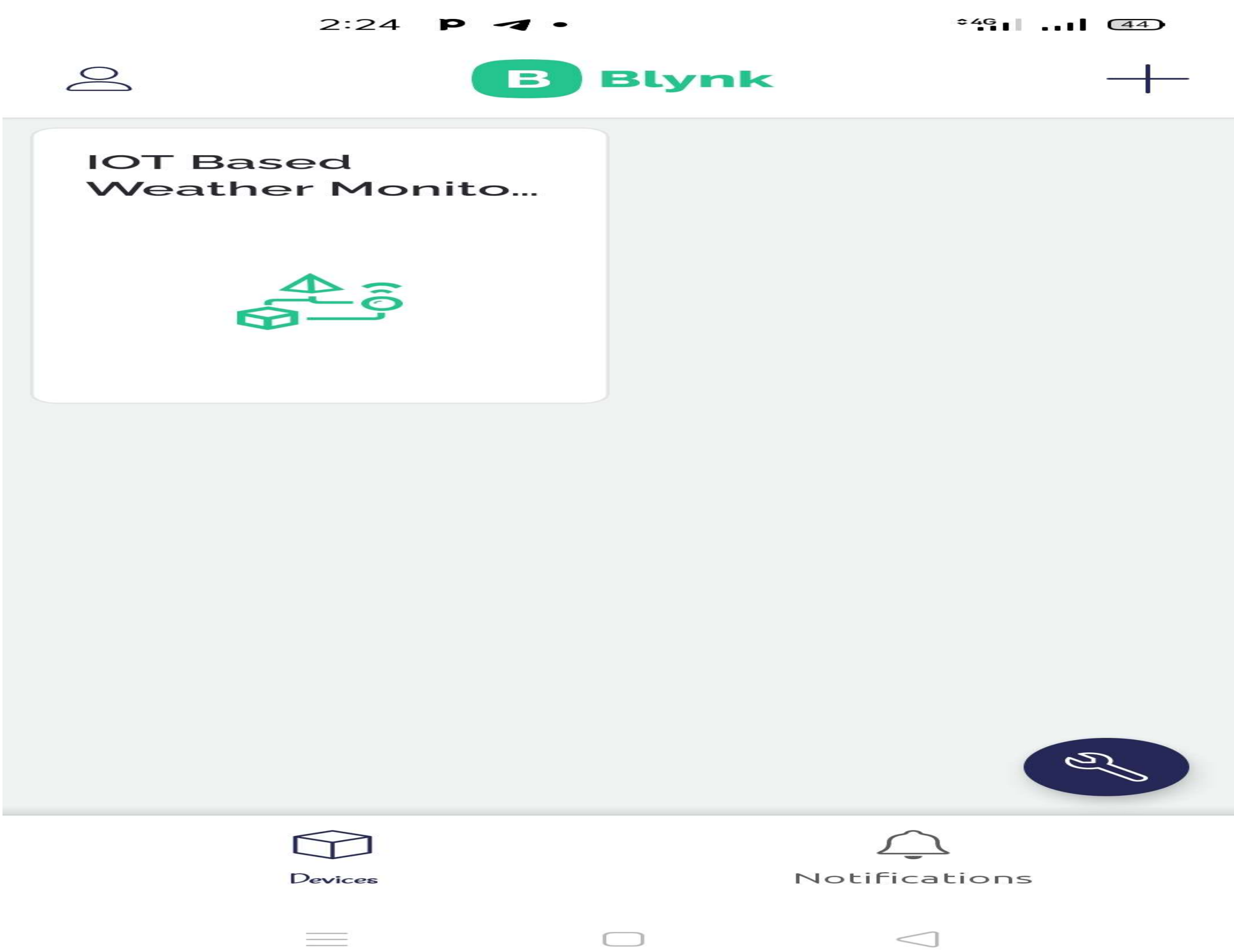

Figure 4.5: Online weather monitoring system

6. **Display Storage of Weather Data Parameter**

Figure 4.6 shows where the total reading of all-weather parameters are stored for every complete testing and references, this weather logged data may be retrieved by farmers for use and research purposes. The proposed system displays observations generated by the system, with weather conditions detected by the sensors thereby enabling the real-time visualization of weather parameters of temperature, humidity, pressure, rain and light as seen in Figure 4.6. In this module, the web dashboard and the mobile dash board can be accessed from any part of the world, displaying the values of temperature, humidity, pressure, rain and light of the current geographical location of the place. The results are stored on the web console of the Blynk as seen in the interface. It keeps record from last week, month until three months.

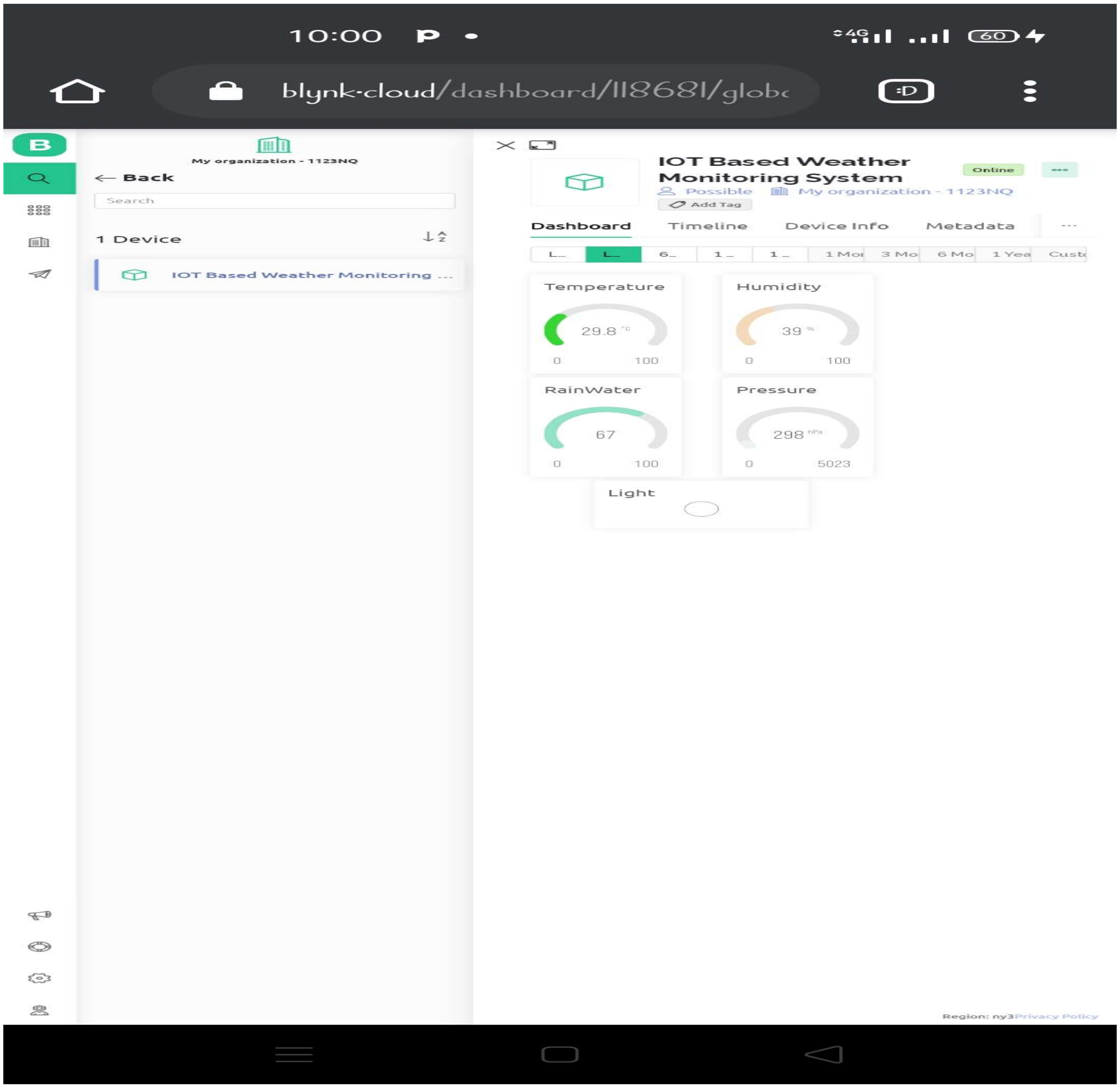

Figure 4.6: Display storage of weather data parameter

7. Speedometer Readings of Weather Parameters in the Absence of Rain and Light

Figure 4.7(a), 4.7(b) and 4.7(c) respectively depicts the speedometer readings of the various parameters including temperature, humidity, pressure, rainfall and light intensity under conditions where no rainfall or water droplets were detected by the rain sensor. The system was tested at different time intervals to evaluate the accuracy and reliability of weather conditions essential for farming operations. Although, the IoT- based application was designed as mobile- based solution to enable easier mobility and access, additional testing was conducted to determine the most suitable weather conditions for farming specifically under scenarios without rainfall. These figures 4.7(a), 4.7(b) and 4.7(c) further demonstrate the responses obtained from monitoring weather condition in the absence of rainfall. It was observed that the reading of the system at different time frame reads temperature 31.1^0 C, 30.9^0C and 31.1^0C respectively; humidity levels were measured as 35.5%, 35.7% and 35.6% respectively and pressure reading as 311^{hpa}, 309^{hpa} and 311^{hpa} respectively. The sensor didn't perceive any light and as a result the light sensor remained off or was neutral when it didn't perceive or recognize the presence of light. For example, if a flashlight shines on the LDR sensor, it senses the reflection of light and shines bright.

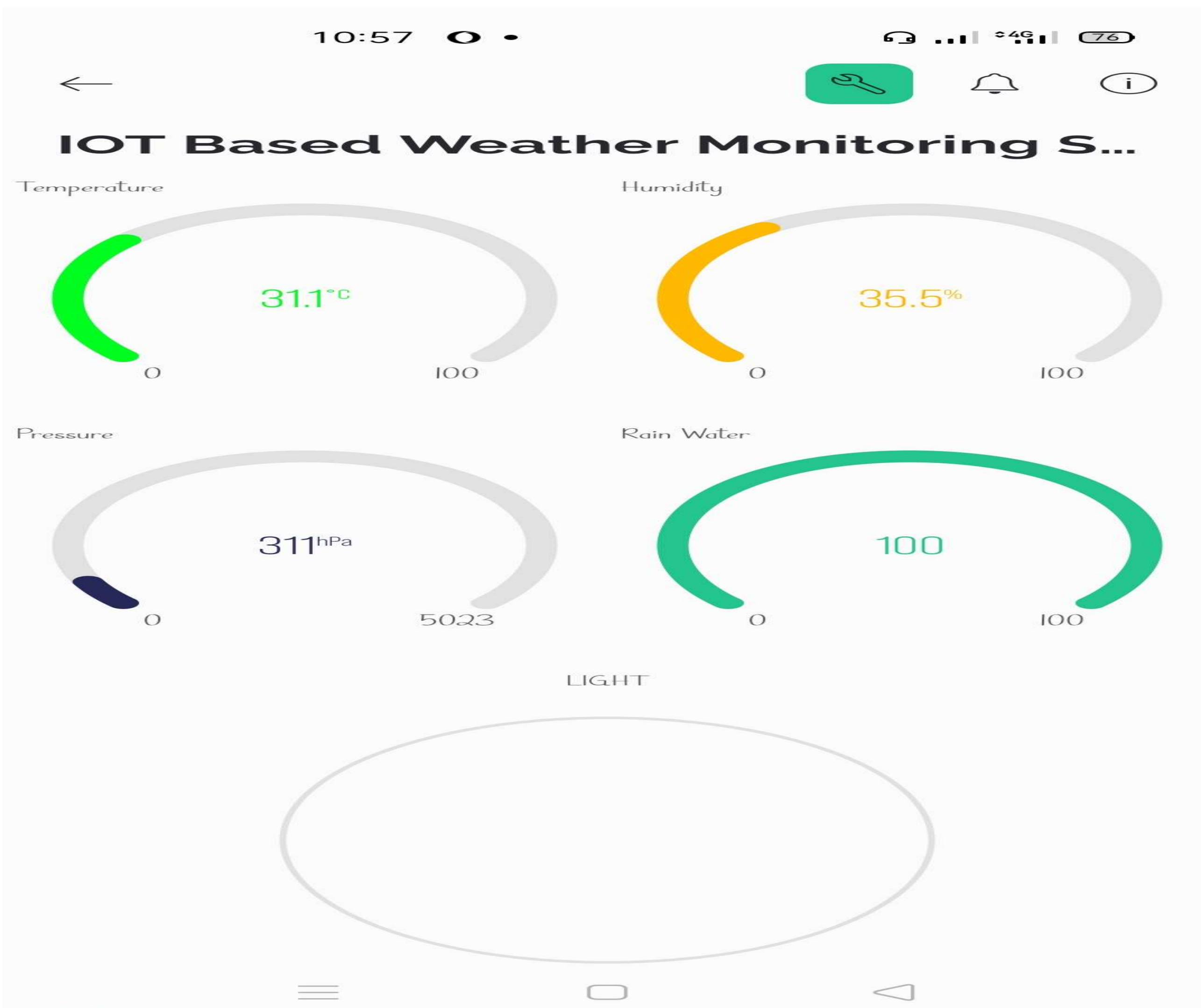

Figure 4.7(a): Speedometer readings of weather parameters in the absence of light and rain

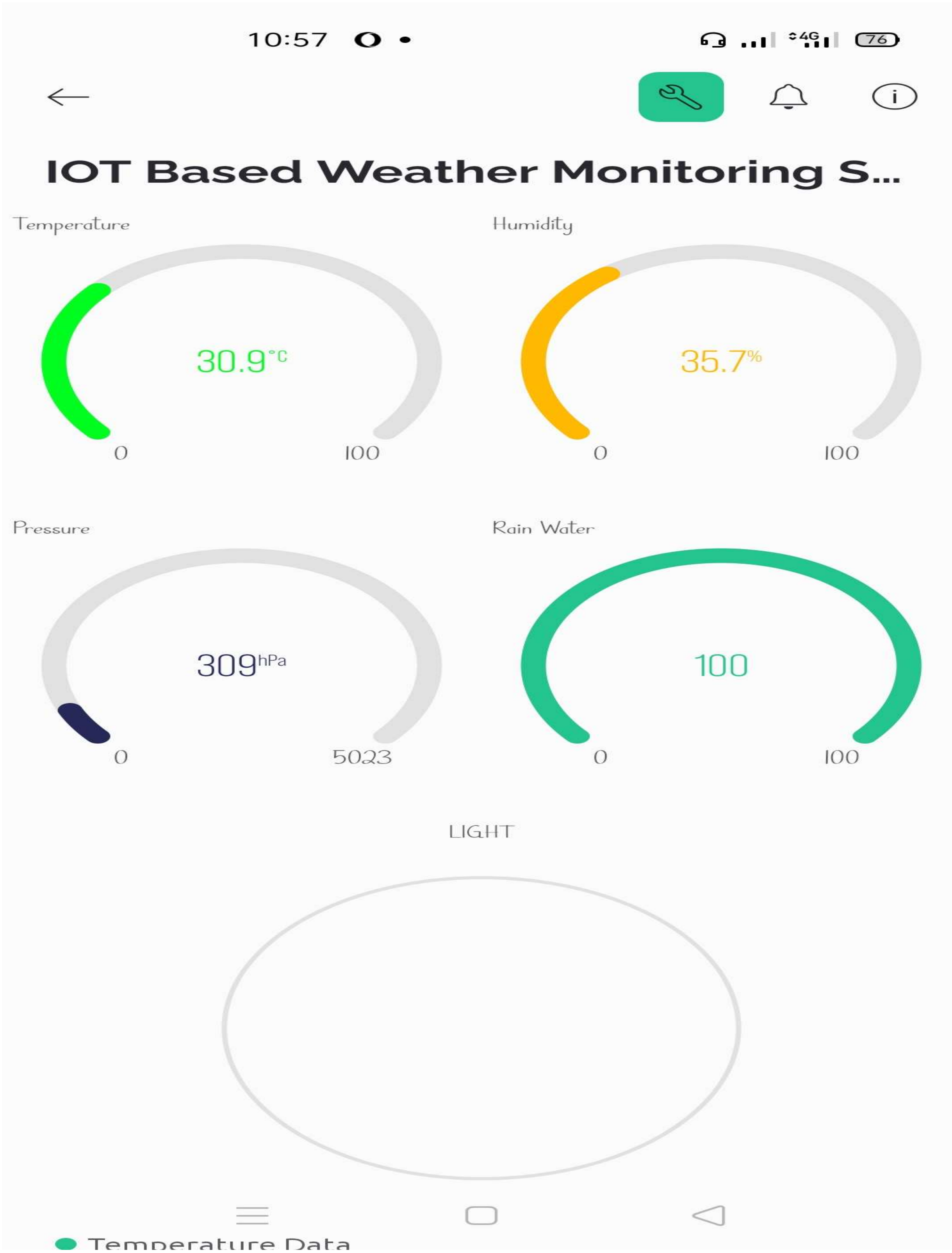

Figure 4.7(b): Speedometer readings of weather parameters in the absence of light and rain

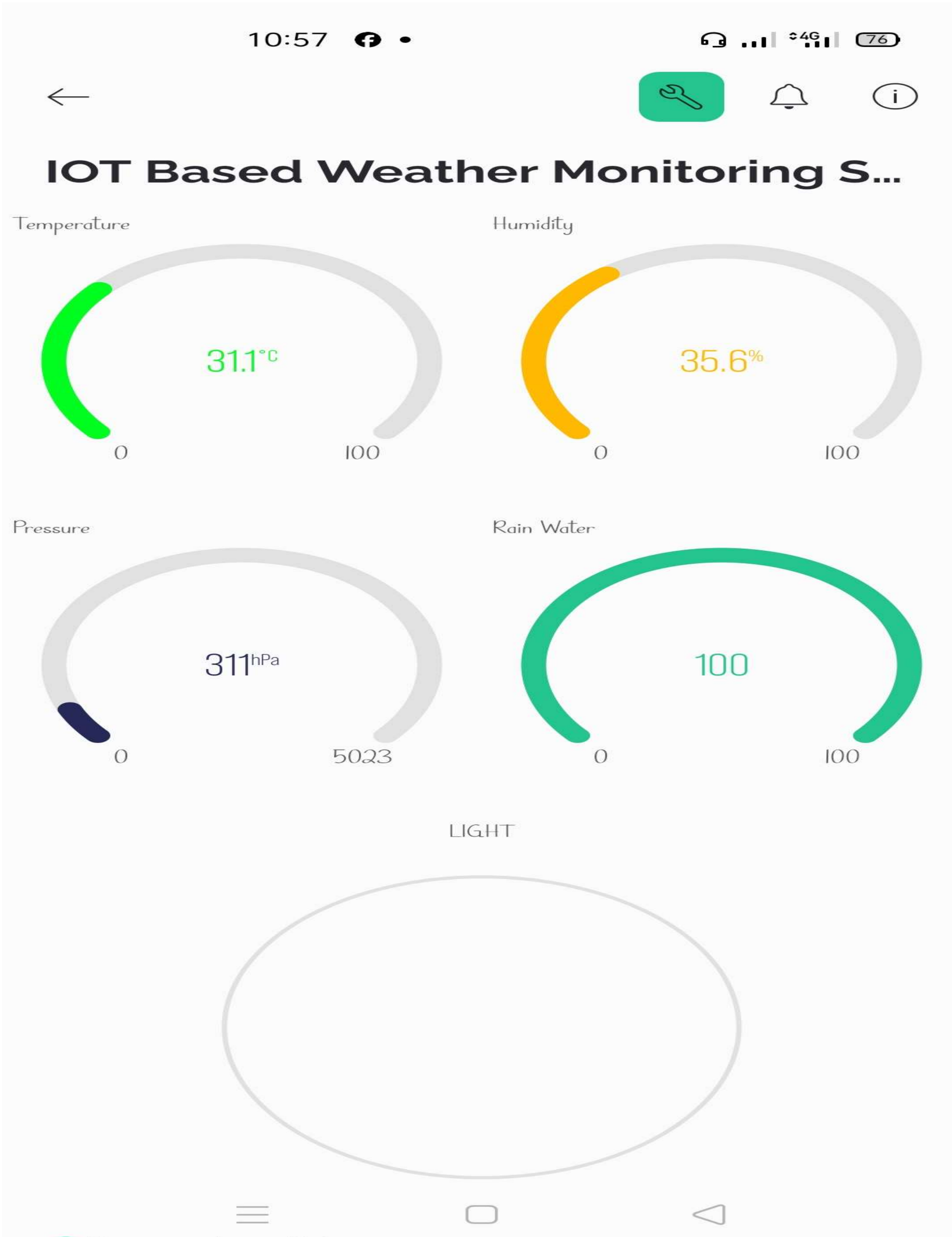

Figure 4.7(c): Speedometer readings of weather parameters in the absence of light and rain

8. **Speedometers Readings of Weather Parameters with rainfall and absence of light**

Figure 4.8(a) and Figure 4.8 (b) respectively presents the speedometer readings of weather parameters under two distinct conditions. Figure 4.8(a) illustrates the readings when raindrops were detected by the rain sensor, indicating active rain. Conversely, Figure 4.8(b) shows the readings when there was no light reflection detected by the LDR sensor, representing a low light environment. There was rain drop on the rain sensor and no light reflection on the LDR sensor.

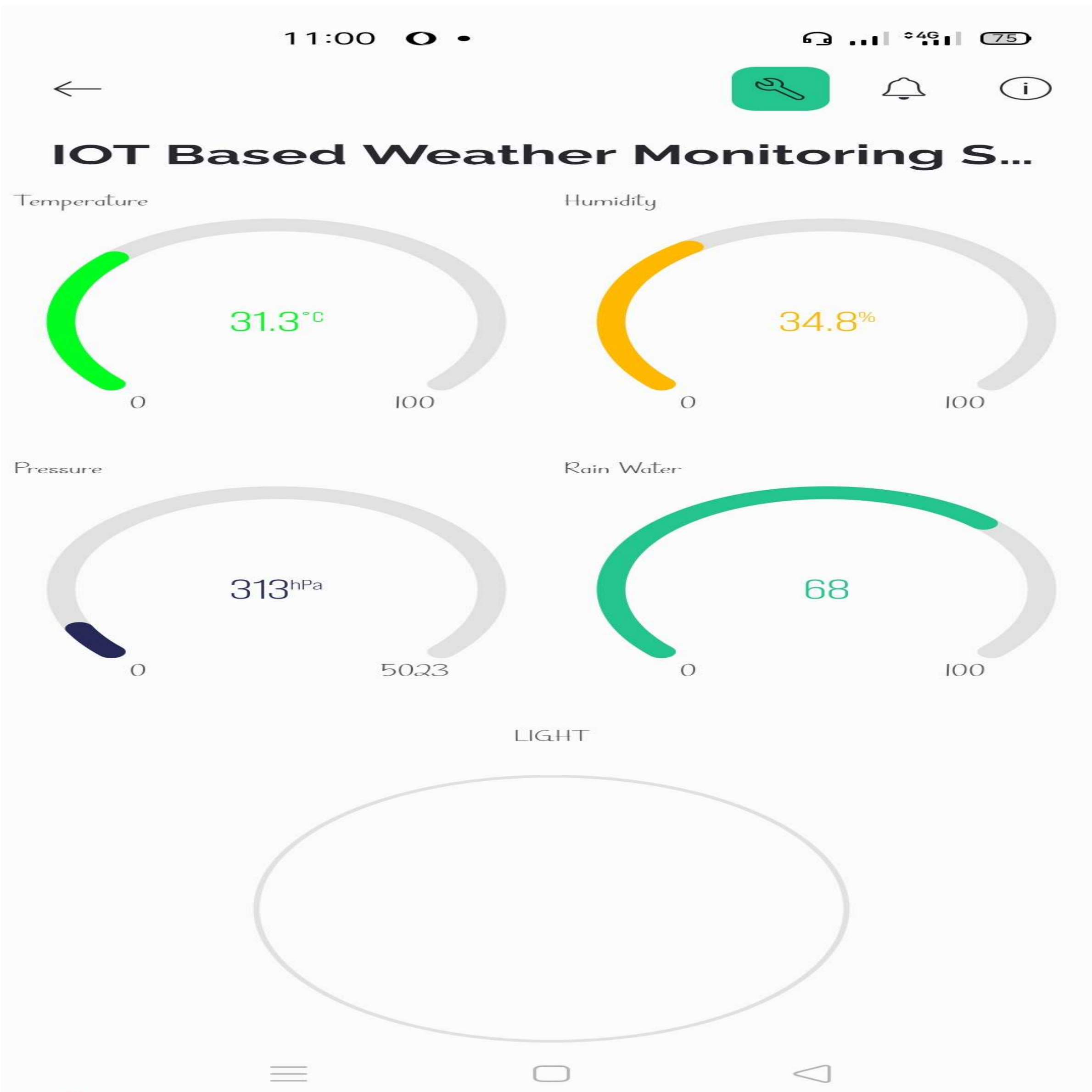

Figure 4.8(a): Readings of the Parameters in the absence of light and presence of rainfall

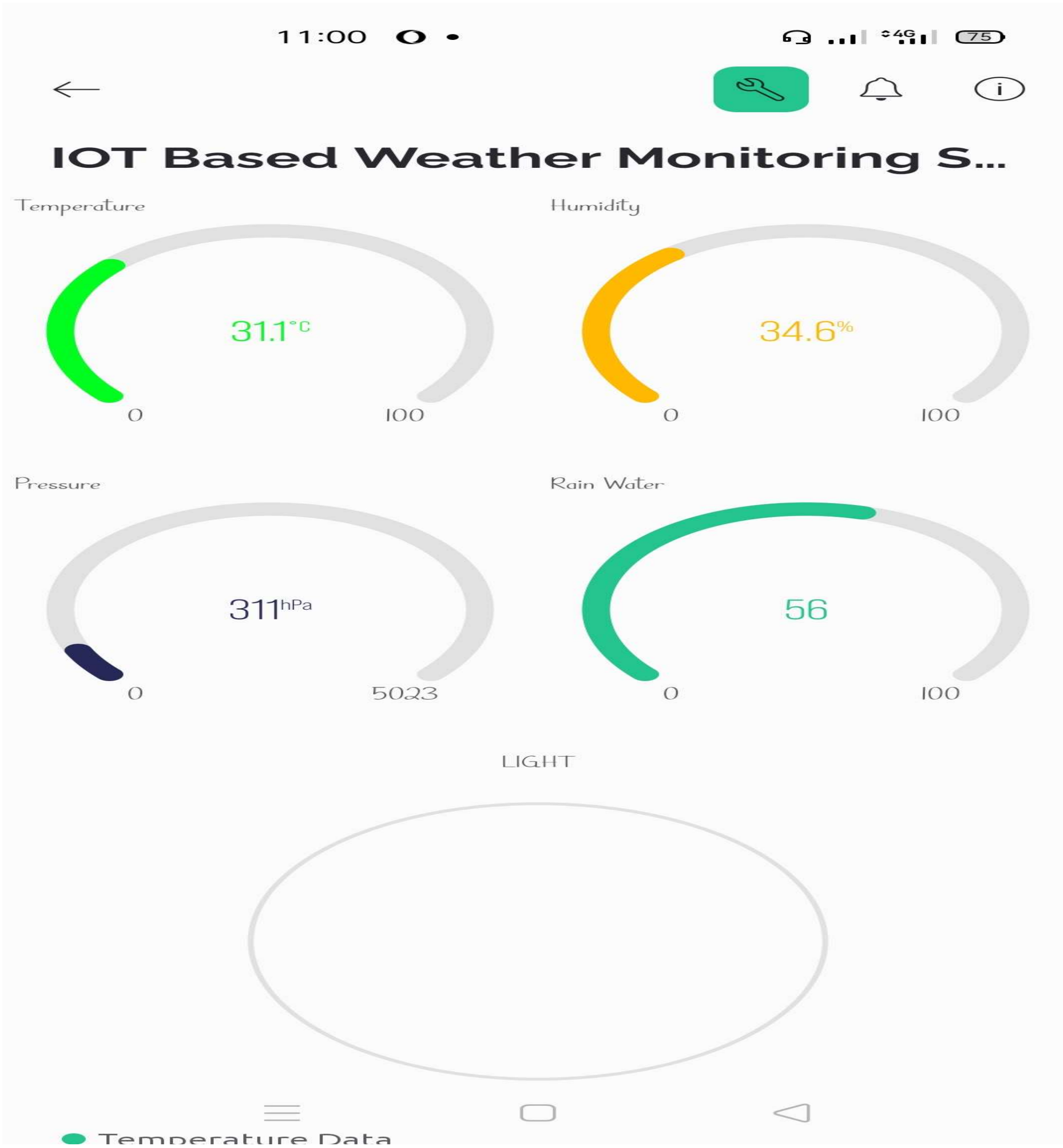

Figure 4.8(b): Readings of the parameters in the absence of light and presence of rainfall

9. **Readings of Weather Parameters in the Presence of Light and Absence of rain**

Figure 4.9(a) and 4.9(b) displays the speedometer readings of weather parameters at different timestamp when there was a reflection of light on the sensor and absence of rainfall. The rain water value is 100 by default. This means that there was no rain at the time the reading was taken or there was no drop of water on the sensor. The light sensor senses light just like a thermometer senses the temperature and a speedometer senses speed. The moment a flashlight is turned on, the light sensor detects surrounding ambient light and if the light disappears it automatically turns off. Moreover, the research related the results obtained for this reading to weather forecasting parameter and observed that the relative temperature suitable for planting in the Sub Sahara Africa is that plants grow well in moderate temperatures between 21°-29° C. Both higher and lower temperatures slow the plants rate of metabolism and growth. Plants grow fastest when the temperature during the lit period is kept between 22°-26°C. Most seeds prefer a relative humidity level between 50^0 C and 60^0 C, but this can vary depending on the type of seed. In figure 4.9(a) and 4.9(b) the responses obtained in the system without rain water, it was observed that temperature reading was 30.1^0 C, humidity 36. 9%, and 37.3%, atmospheric pressure of 301^{hpa}.

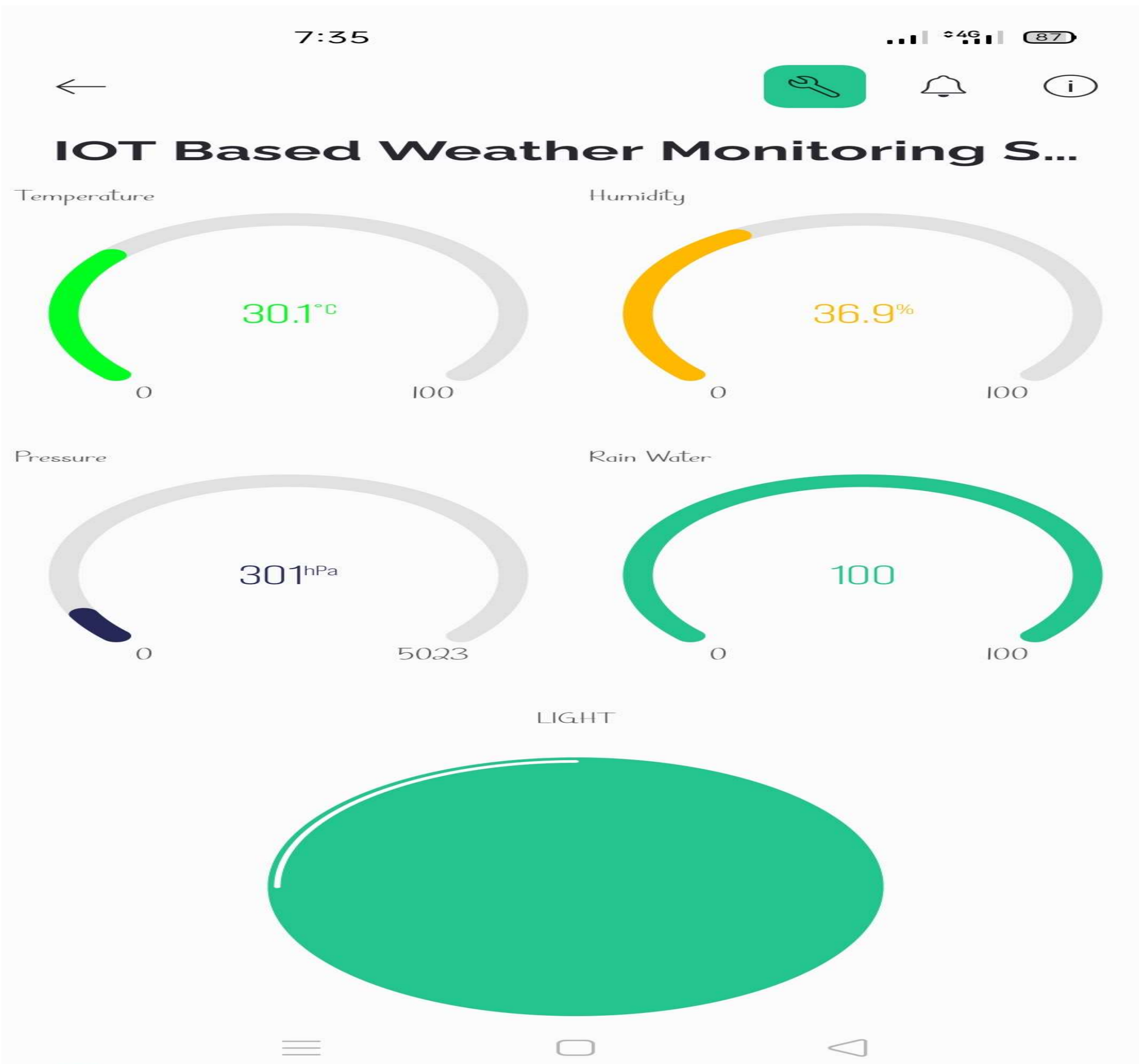

Figure 4.9(a): Readings of the parameters in the presence of light and absence of rain

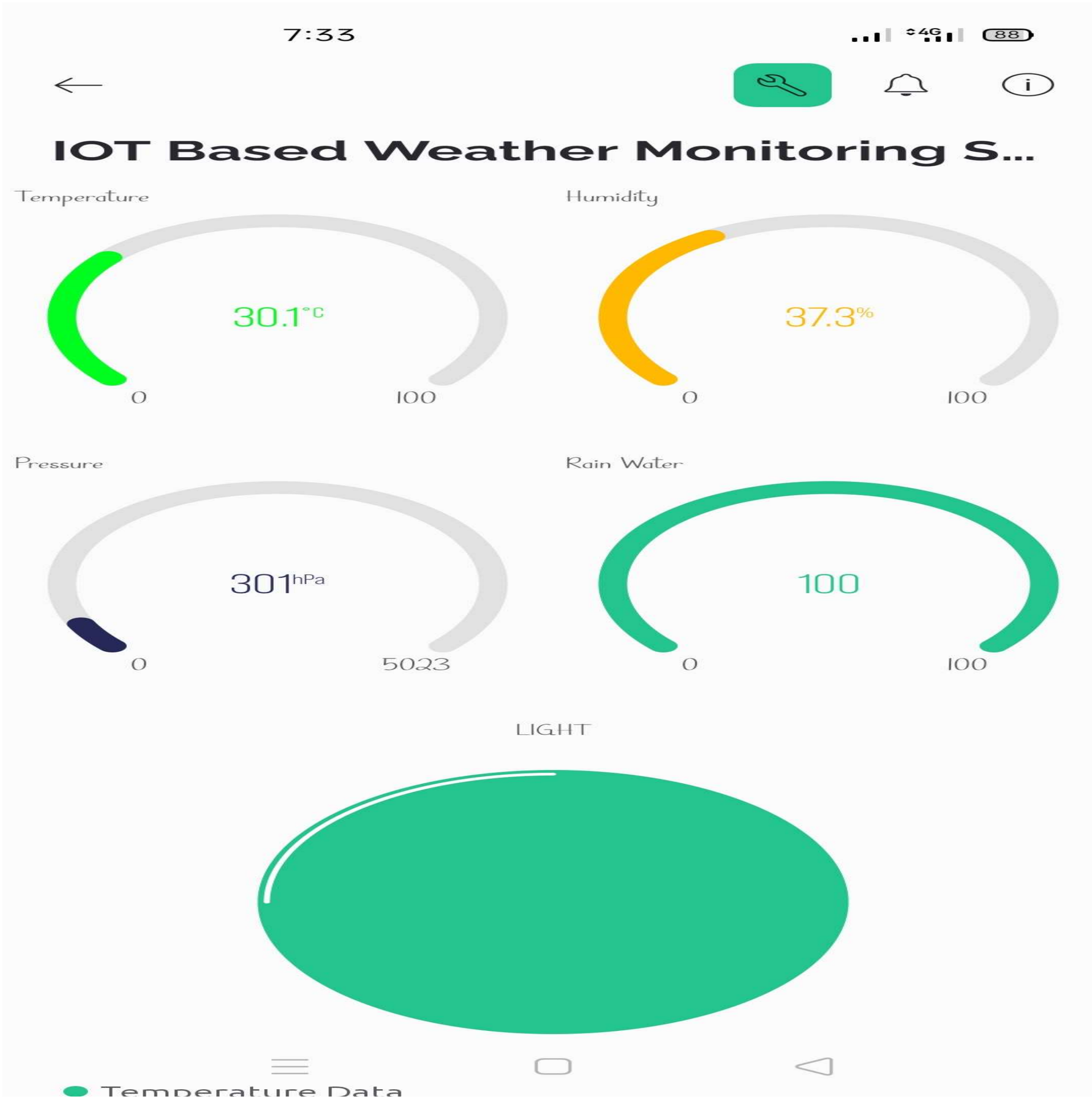

Figure 4.9(b): Readings of the parameters in the presence of light and absence of rain

10. Readings of Weather Parameters in the Presence of Light and Rainfall

However, figure 4.10(a) and 4.10(b) displays the speedometer readings of the various sensors including temperature, humidity and pressure from the weather station when there was sensation of light as well as rain drop on the rain sensor at different time frame.

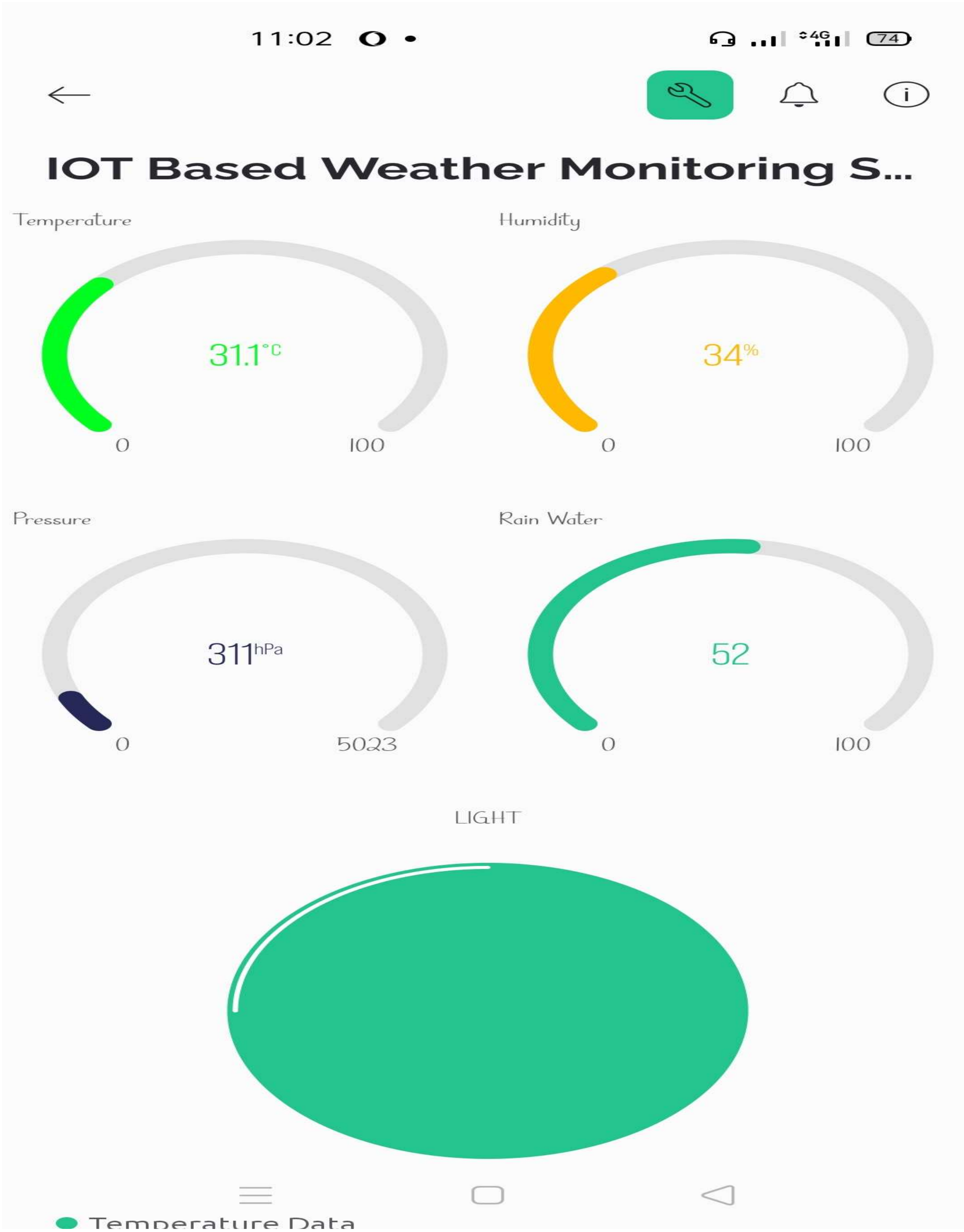

Figure 4.10(a): Readings of weather parameters in the presence of light and rainfall

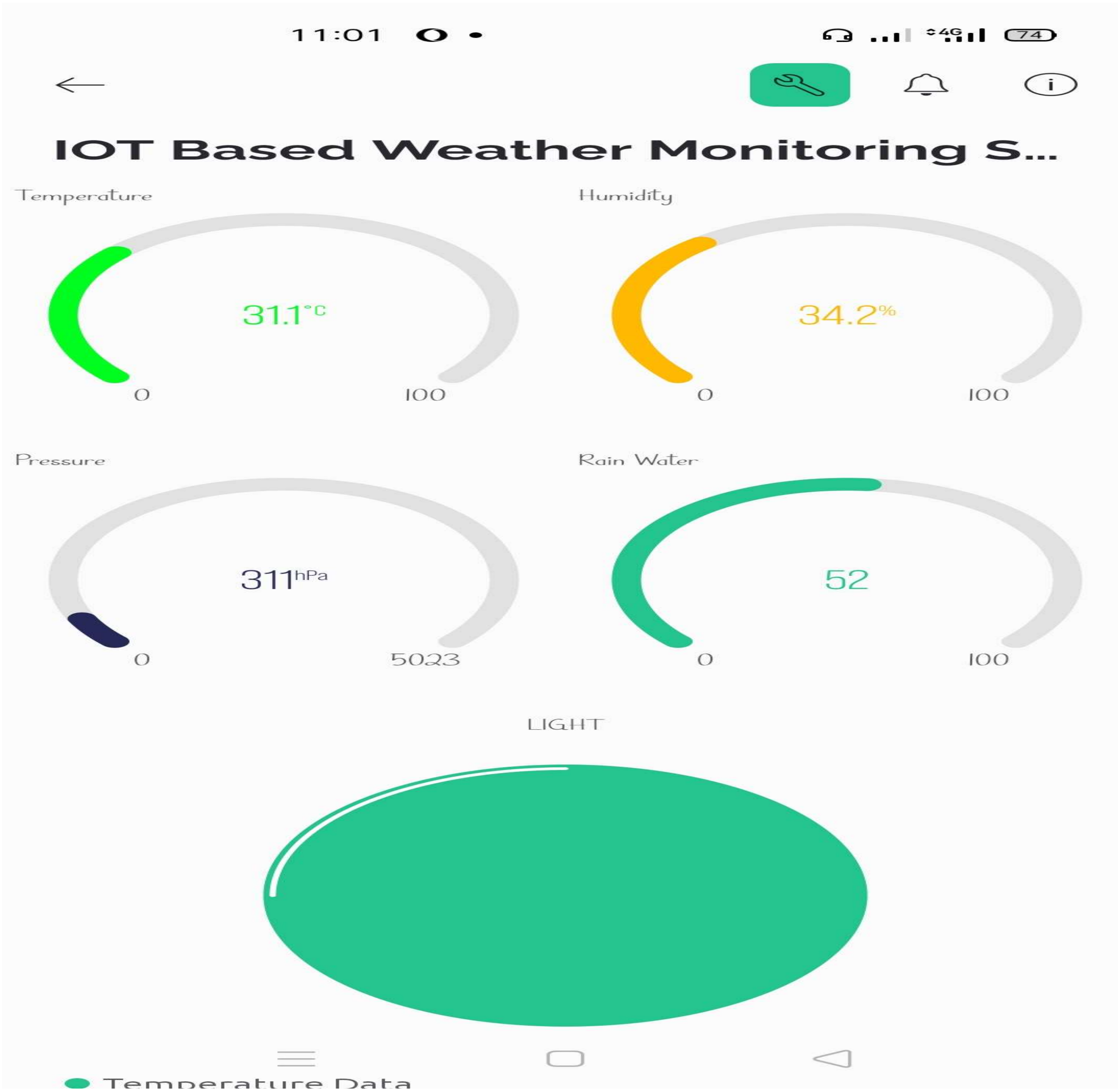

Figure 4.10(b): Readings of weather parameters in the presence of light and rainfall

4.1.4 Evaluation Results

The proposed system displays the real-time visualization of weather parameters of temperature, humidity, pressure, rainfall and light intensity of a geographical location in which the system is being used. Evaluation testing continued, and at this time we obtained real live weather data on the IoT-based system at various time interval for minutes, hours and weeks for the weather parameters as showed in Figure 4. 11(a) and 4.11(b) respectively. The results are stored on the web console of the Blynk as seen in the interface. It keeps record from last week, month until three months.

Figure 4.11(a): Real-time weather monitoring of temperature, humidity and rain

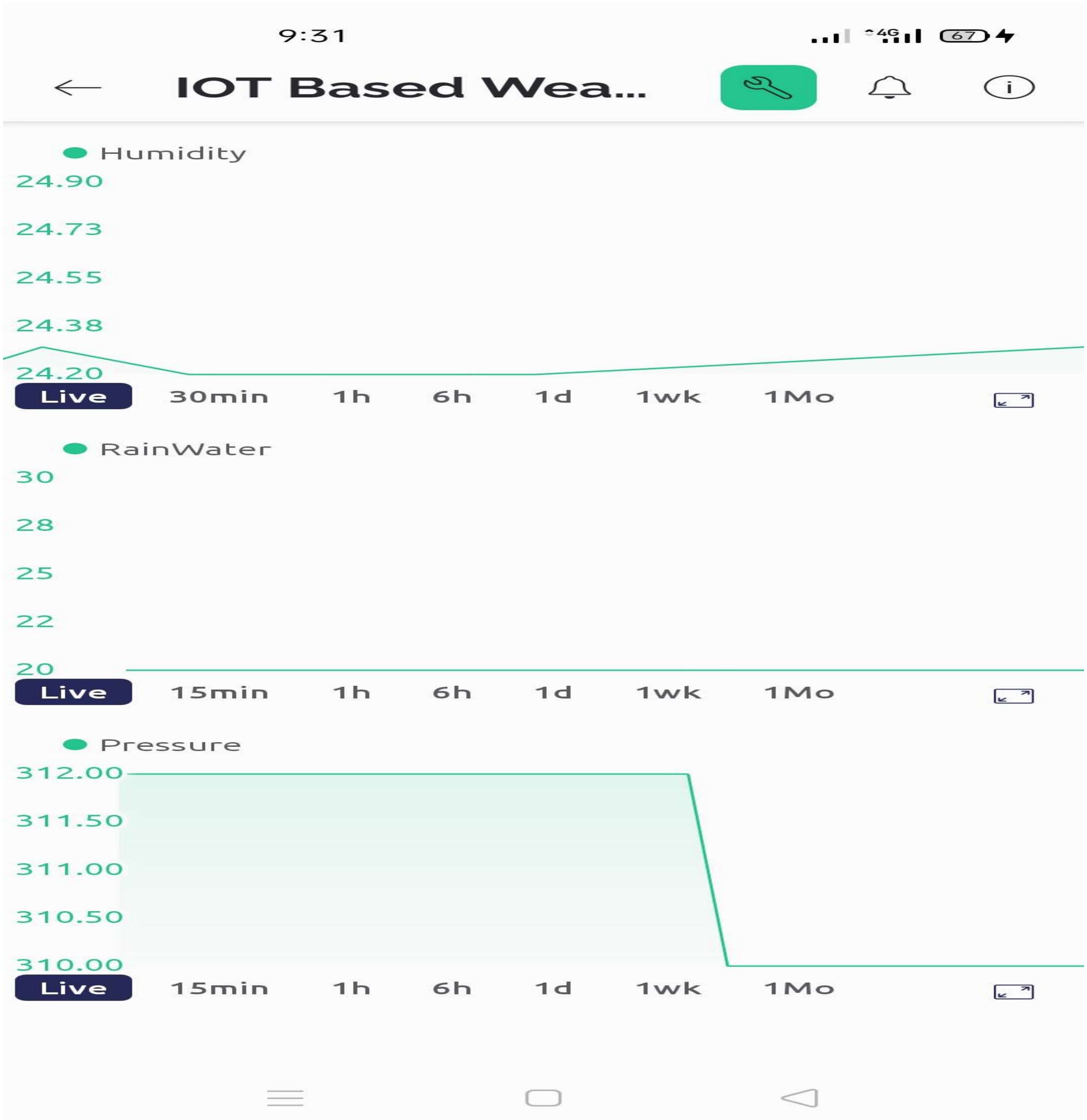

Figure 4.11(b): Real -Time weather monitoring of temperature, humidity and rain

4.1.5 Evaluation of Weather Parameters on IoT Weather Monitoring System

The readings obtained on the IoT-based weather monitoring system was on real-time. Table 4.2 shows the weather monitoring data log for weather parameters such as temperature, humidity and rainfall on Thursday 23rd November, 2023. The monitoring was carried out at various time intervals.

Table 4.2: Weather reading for Thursday 23rd November, 2023

Timestamp	Temperature Readings	Humidity Readings	Rainfall
6:00 AM	31.36	35.87	0
7:00 AM	31.82	35.76	0
8:00 AM	31.77	36.18	0
9:00 AM	31.5	34.61	0
10:00 AM	31.6	33.79	0
11:00 AM	32.07	28.59	0
12:00 PM	31.55	30.28	0
1:00 PM	31.44	34.46	0

The results were also analyzed in Figure 4.12 to show the responses between the parameters at given time stamps on weather data log.

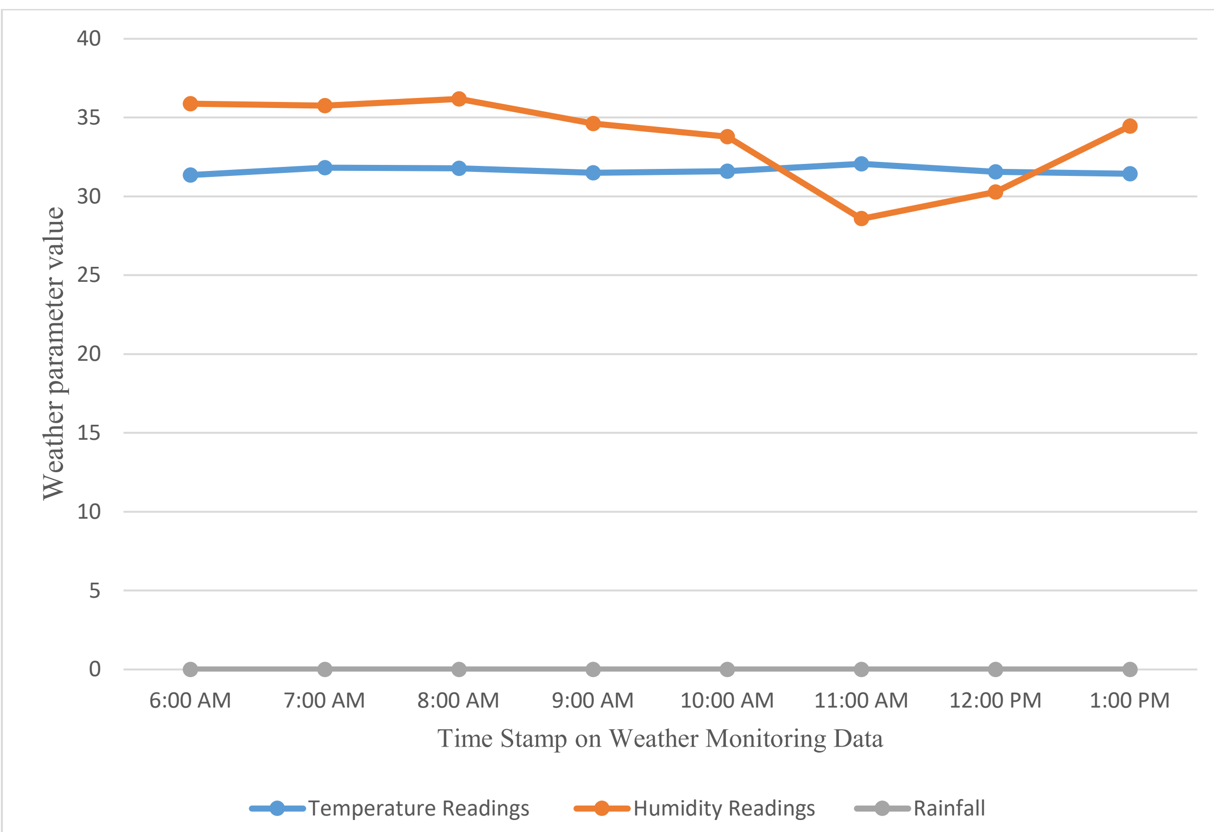

Figure 4.12: Responses on Temperature, Humidity and Rainfall on 23/11/2023

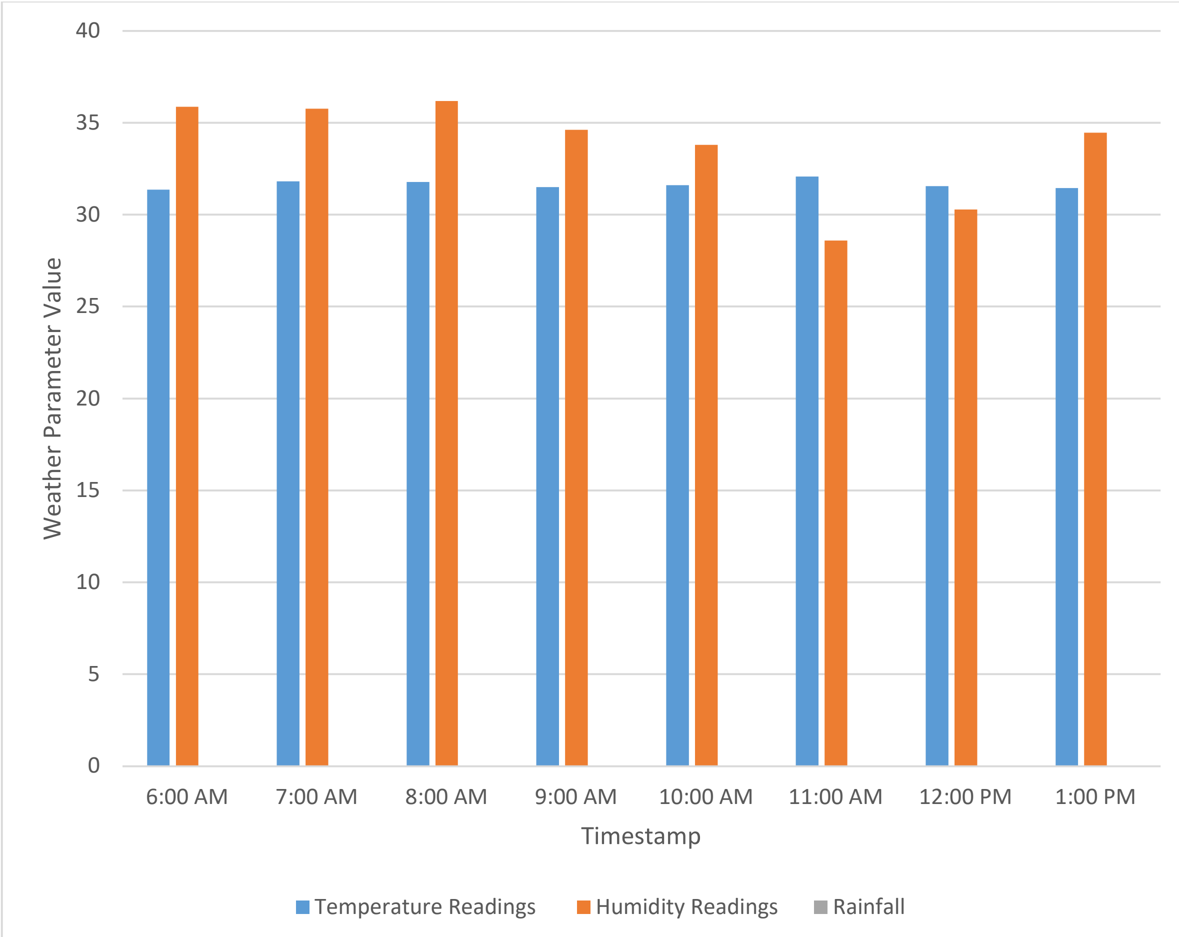

Figure 4.13: Bar chart Representation of temperature, humidity and rainfall on 23/11/2023

Figure 4.13 represents Thursday, 23rd November, 2023 weather report for temperature, humidity and rainfall parameters. It shows that at 6am the temperature was 31.36^0 C, humidity of 35.87%, with 0^0 rainfall, at 7am the report obtained was that temperature was 31.82^0 C, humidity of 35.76%, at with 0^0 rainfall, 8:0am the temperature was 31.77^0 C, humidity of 36.18%, with 0^0 rainfall, by 9am the temperature reading was 31.5^0 C, humidity of 34.61% with 0^0 rainfall. At 10am the temperature was 31.6^0 C and humidity of 33.79%, furthermore, by 11am the temperature was 32.07^0 C, humidity of 28.59%, again, at 12pm, the temperature raised to 31.55^0 C, humidity was 30.28%, and finally, at 1pm temperature was 31.44^0 C, and humidity was 34.46%with 0^0 rainfall in all.

Table 4.3 shows the weather monitoring data log on Thursday 24th November, 2023, the monitoring was done on various time intervals 6:00 AM, 7:00 AM, 8:00 AM, 9:00 AM, 10:00 AM, 11:00 AM, 12:00 PM and 1:00 PM.

Table 4.3: Weather monitoring reading for Friday, 24th November, 2023

Timestamp	Temperature Readings	Humidity Readings	Rainfall Readings
6:00 AM	30.66	37.25	0
7:00 AM	32.95	23.75	0
8:00 AM	32.4	26.63	0
9:00 AM	31.87	27.87	0
10:00 AM	31.75	33.18	60
11:00 AM	31.51	36.02	0
12:00 PM	31.55	34.58	0
1:00 PM	31.71	34.03	0

The results were also analyzed in Figure 4.14 to show the responses between the weather parameters at given time stamps on weather data log**.**

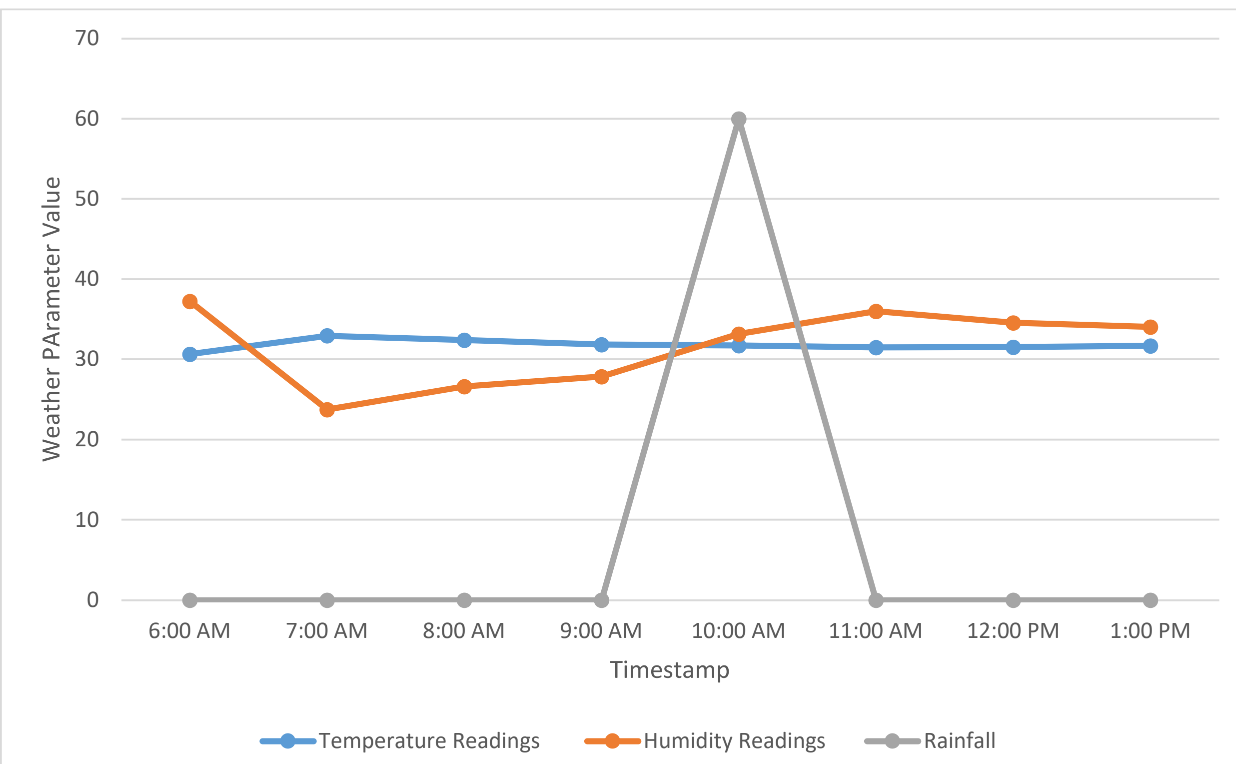

Figure 4.14: Relative responses of weather parameters on Friday, 24th November, 2023

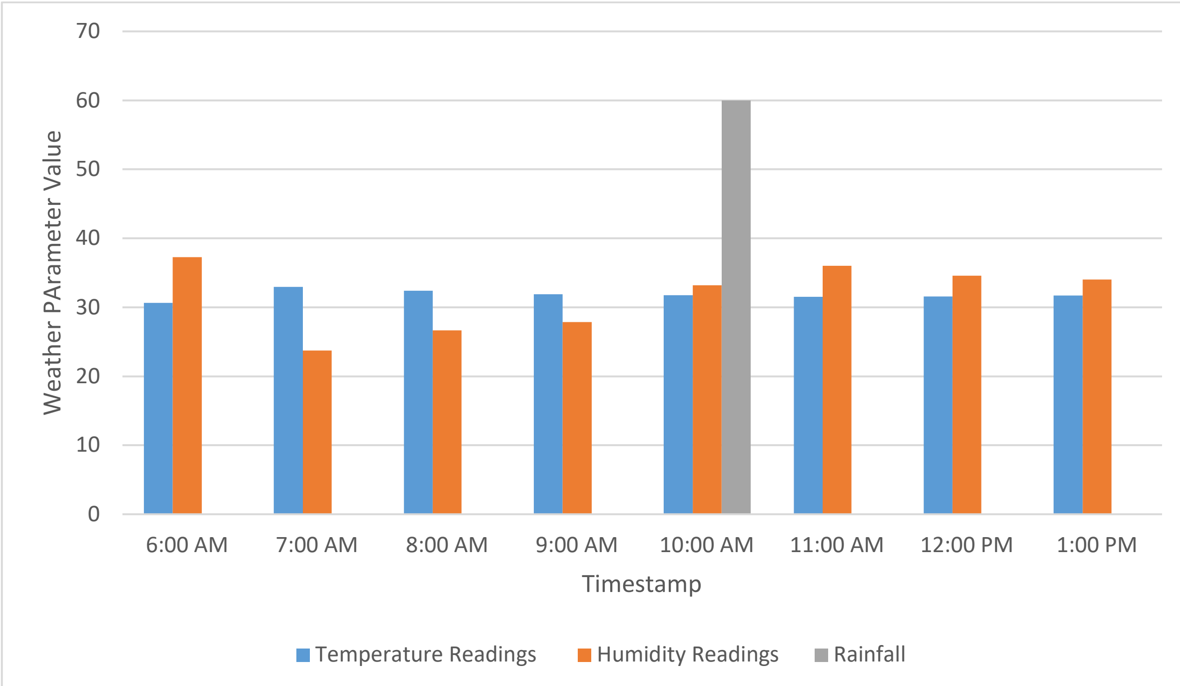

Figure 4.15: Bar chart of Temperature, Humidity and Rainfall on 24/11/2023

Table 4.4 shows the weather monitoring data log on Saturday 25th November, 2023, the monitoring was done on various time intervals as well.

Table 4.4: Weather monitoring reading for Saturday November 25th, 2023

Time	Temperature	Humidity	Rainfall
6:00 AM	32.2	26.84	0
7:00 AM	32.44	26.41	0
8:00 AM	31.78	27.15	0
9:00 AM	32.29	30.69	0
10:00 AM	32.15	35.7	0
11:00 AM	31.85	36.91	0
12:00 PM	31.82	36.13	0
1:00 PM	31.85	35.37	0

Figure 4.16 represents Saturday, November 25th, 2023 weather report for temperature, humidity and rainfall parameters it shows that at 6am the temperature was 33.26^{0c}, humidity of 25.84%, with 0^0 rainfall, at 7am the report obtained was that temperature was 313.82^{0c}, humidity of $25.96^{0,}$ at with 0^0 rainfall, 8:0am the temperature was 35.12^0, humidity of 35.88^0, with 0^0 rainfall, by 9am

the temperature reading was 34.45^0, humidity of 34.61^0 with 0^0 rainfall. At 10am the temperature was 31.6^0 and humidity of 33.79^0, furthermore, by 11am the temperature was 32.07^0, humidity of 28.59, again, at 12pm, the temperature raised to 32.15^0, humidity was 35.28^0, and finally, at 1pm the 32.14 and humidity was 35.10^0 with 0^0 rainfalls in all.

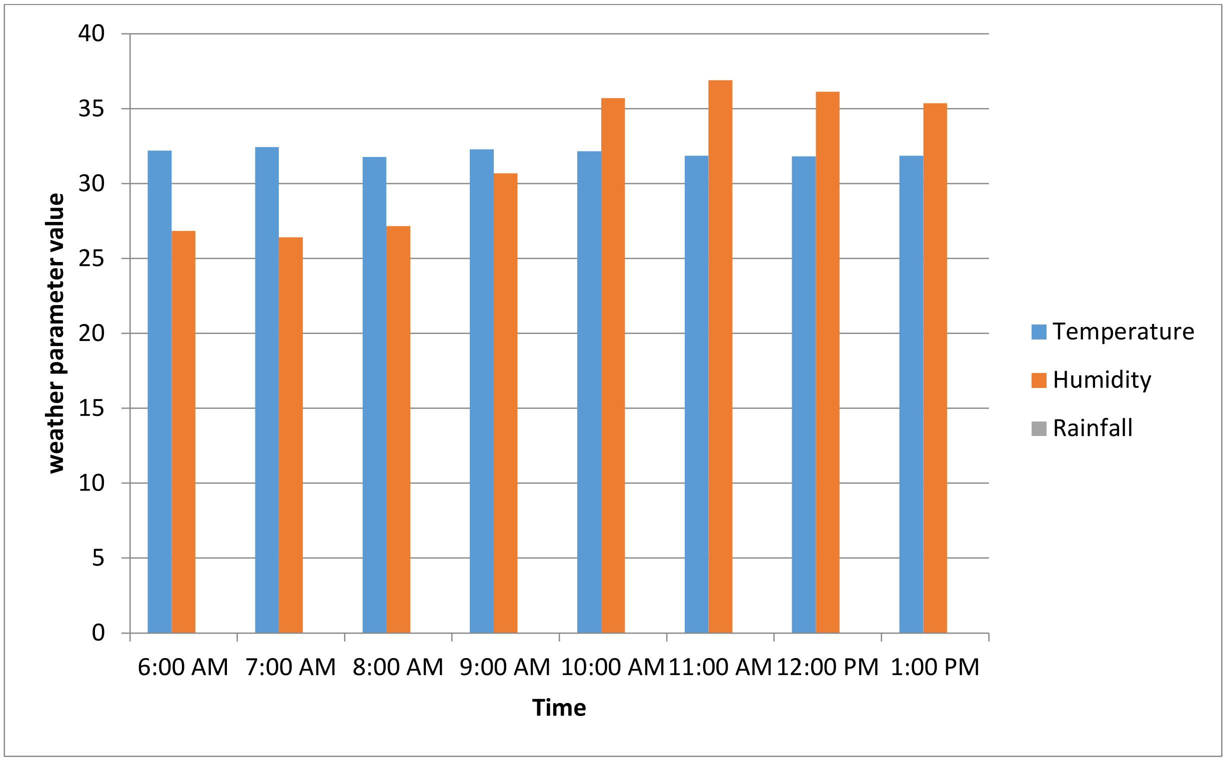

Figure 4.16: Bar chart of Temperature, Humidity and Rainfall on 25/11/2023

The weather monitoring data log for Sunday November 26th, 2023 is depicted in Table 4.5. Consequently the readings were taken at different time intervals.

Table 4.5: Weather monitoring reading for Sunday November 26th, 2023

Time	Temperature	Humidity	Rainfall
6:00 AM	29.88	35.59	0
7:00 AM	30.45	33.02	0
8:00 AM	31.00	31,54	0
9:00 AM	32.23	31.96	0
10:00 AM	31.14	33	0
11:00 AM	31	33.86	0
12:00 PM	31.37	34.38	0
1:00 PM	31.44	34.46	0

The results for Sunday November 26th, 2023 were also analyzed in Figure 4.17.

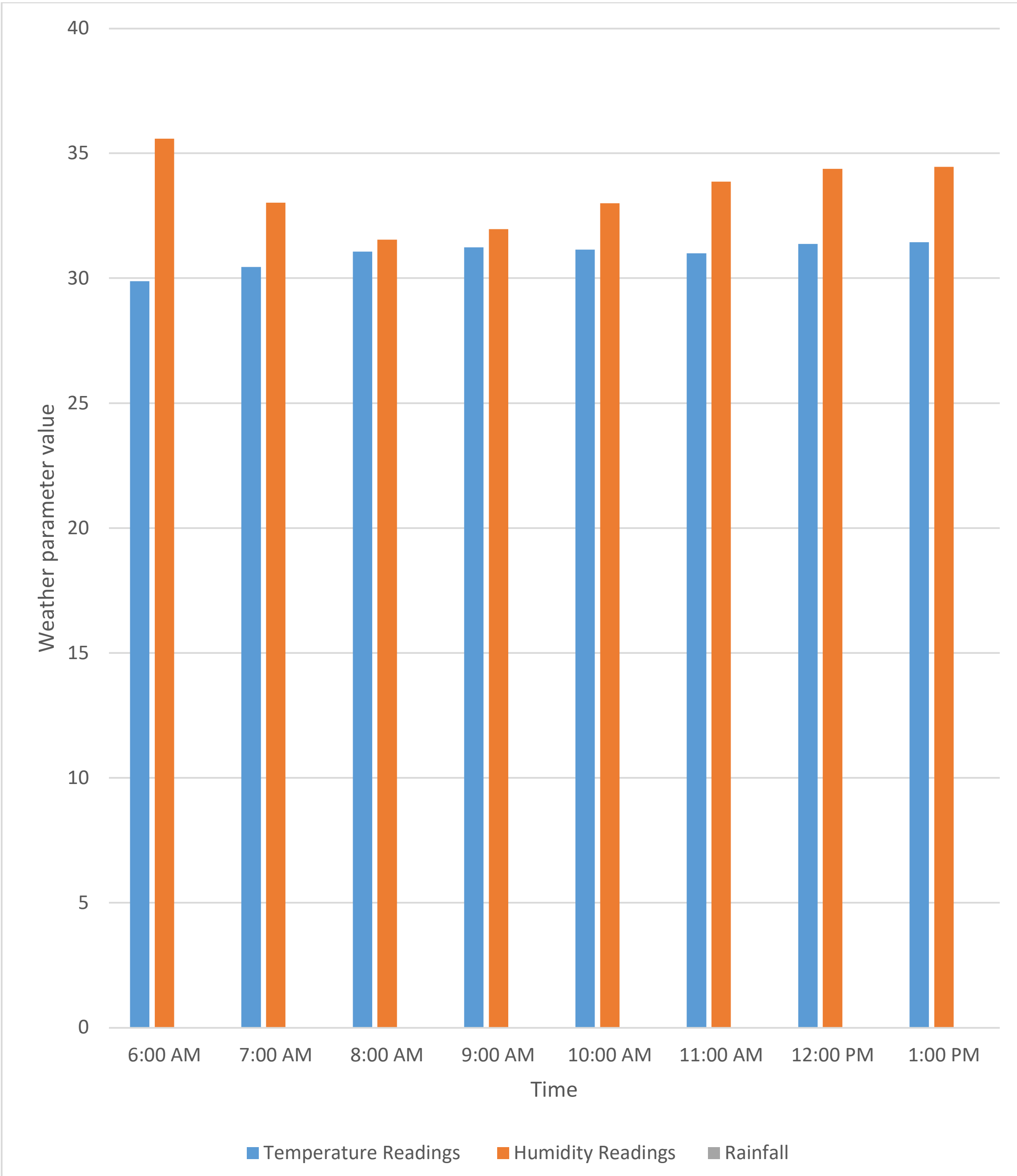

Figure 4.17: Bar chart of Temperature, Humidity and Rainfall on 26/11/2023

Table 4.6: Conventional method (Suleiman, 2022) versus proposed system

Thermometer(Conventional)	DHT11 Sensor (Proposed System)	Difference
28.7	30.66	1.96
29.2	32.95	3.75
29.9	32.4	2.5
29.9	31.87	1.97
30.1	31.75	1.4
29.4	31.51	2.11
29.8	31.55	1.75
30.5	31.71	1.21

Table 4.6 shows the conventional method readings for temperature, the DHT11 sensor was proposed for the study. The difference indicates that the DHT11 sensor measured a higher temperature compared to the Conventional Thermometer.

The results were also analyzed in Figure 4.18

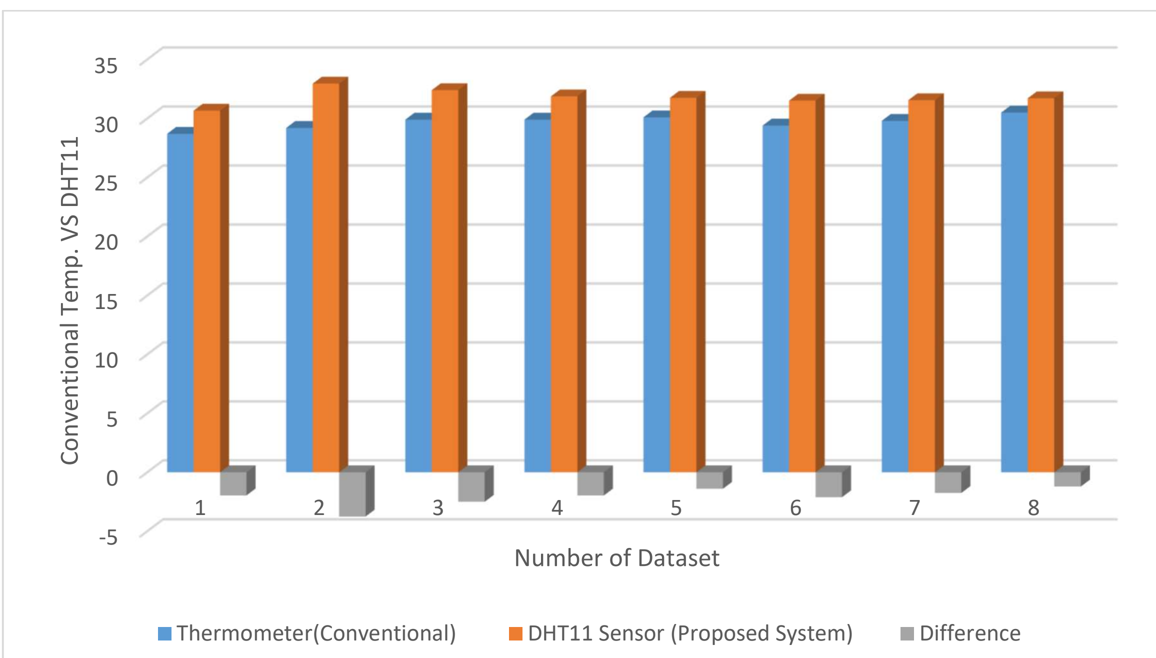

Figure 4.18: Comparison of conventional temperature reading with DHTII sensor

Table 4.7 Temperature Evaluation of Existing Study (Suleiman et. al, 2022) with the Proposed System.

Existing System (DHT11) (in degree Celsius)	Proposed system (DHT11) (in degree Celsius)	Difference (in degree Celsius)
28.5	30.66	2.16
29.6	32.95	3.35
29.6	32.4	2.8
29.5	31.87	2.37
29.1	31.75	2.62
29.3	31.51	2.05
28.9	31.55	2.65
29.6	31.71	1.81

As shown in Table 4.8, the value 28. 5, 29.6, 29.6, 29.5, 29.1, 29.3, 28.9, 29.6 degree Celsius represents the temperature measured by the DHT11 sensor in the existing system under specific conditions and the value 30.66, 32.95,32.4,31.87, 31.75,31.55,31.71 degree Celsius represents the temperature measured by the DHT11 sensor in the proposed system under different conditions.

4.1.6 Hardware Design Prototype

As shown in Figure 4.19, the hardware design prototype for the improved IoT-based weather monitoring system was successfully developed. It included components such as the DHT11, BMP280, rain, and LDR sensors integrated with the NodeMCU ESP8266 microcontroller by a 9v battery. All the available sensors are connected to the Node MCU micro controller via the jumper wires. The system reliably captured real-time weather data and transmitted it to the Bylnk IoT platform via a Wi-Fi module. The compact design, low power consumption and solar power integration ensured efficiency and sustainability. Initial tests confirmed the proper functionality of all the components.

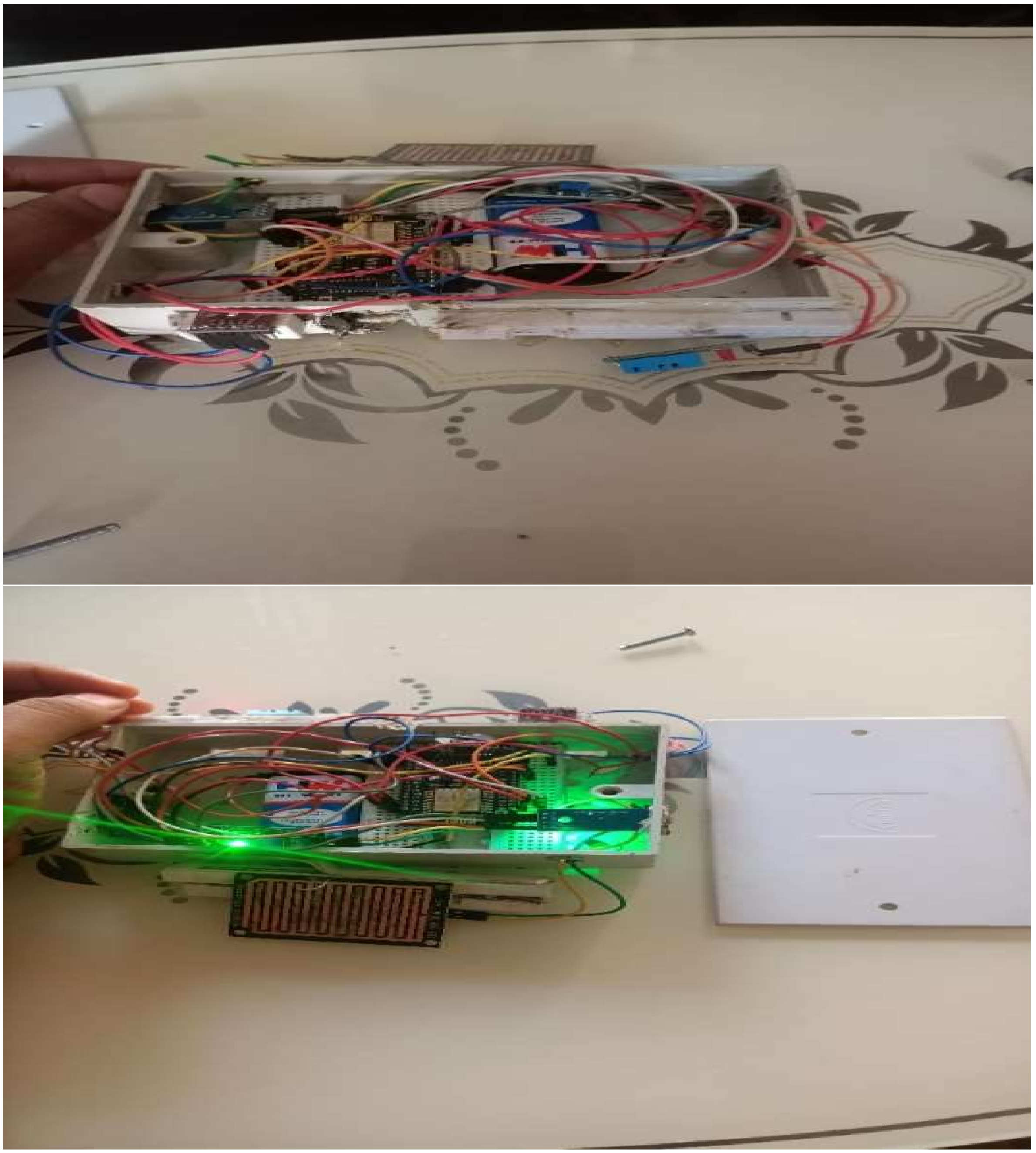

Figure 4.19: Hardware Design Prototype

4.2 Discussion

4.2.1 Hardware Layout of the System

The hardware design prototype of the IoT-based weather system successfully met the design objectives demonstrating reliable data collection and transmission. The system's hardware layout demonstrates how the cables, sensors, and microcontroller are connected. The complete incorporation of the hardware components is depicted in Figure 4.18. The integration of the DHT11, BMP280, rain and LDR sensors with the NodeMCU ESP8266 microcontroller, powered by a 9 battery proved to be effective in monitoring real-time weather conditions. Blynk platform is the IoT Platform considered in this work for displaying sensor data ensuring real-time monitoring.

4.2.2 Evaluation of Results of the Existing system and Proposed System

In evaluating the results of the existing and proposed system, the main focus was on temperature measurements obtained using a conventional thermometer and the DHT11 sensor.

Firstly for the thermometer, the proposed system consistently recorded higher and more accurate temperature reading compared to the conventional method as shown in Table 4.6. The difference indicates that the DHT11 sensor measured a higher temperature compared to the Conventional Thermometer. This difference between the conventional and the proposed system are due to the fact that the thermometer have a limited measurement range and accuracy as well as sustainable to reading errors due to parallax or human interpretation. It also has a slow response time and require time for the temperature to stabilize before obtaining an accurate reading whereas DHT11 sensors provides a wider measurement range which reduces reading errors and improves accuracy. It also has a faster response time and can provide readings more quickly. Both the conventional thermometer and the DHT11 sensor can be influenced by environmental factors, such as ambient temperature, humidity and exposure to sunlight or heat sources but DHT11 offer better insulation and shielding against environmental interference

However, for the DHT11 sensor as shown in Table 4.7, the proposed system demonstrated superior accuracy which can be attributed to the utilization of a 9v batter and the ESP8226 microcontroller. Even though the DHT11 sensor is designed to operate within a certain voltage range, variations in voltage supply can impact its accuracy.

As a result of these variations we ensured that our power supply voltage was stable and within the recommended range for the DHT11 sensor and our ESP 8266 performs more optimally than the ATMEGA32 to improve accuracy of our results. These enhancements ensured improved power efficiency and better performance of the sensor thereby contributing to the overall accuracy of the system.

4.2.3 Improvements made in the Proposed IoT-Based Weather Monitoring system

The improvements made in the improved IoT-based weather monitoring system compared to the existing system can be summarized as follows:

The existing system utilized a 5v battery leading to shorter operating times as a result depletes quickly. Some components may need a higher voltage input for optimal performance, leading to compatibility issues or the need for additional voltage regulators. Future enhancements or additional features requiring higher power consumption may be limited due to the constraints of the lower voltage battery whereas the proposed system utilized a 9v battery offering a higher capacity, allowing for longer operating times and reduced frequency of recharging or replacement. The higher voltage provides a more stable power supply, minimizing voltage drops and ensuring consistent operation of the system. The higher voltage capacity of 9v allows for easier integration of additional features enhancing the system's overall flexibility.

However, the existing system that measured pressure utilized BMP 180 sensor. The BMP180 sensor have lower accuracy compared to BMP280, leading to less precise pressure measurements. The BMP180 sensor also have a limited measurement range, which can be a constraint in certain weather monitoring scenarios where a wider range is required. The improved IoT-based weather monitoring system is designed to utilize BMP280 sensor. The BMP280 sensor offers higher accuracy in pressure measurements, providing more reliable and precise data for weather monitoring applications. BMP280 provides a wider measurement range, allowing it to capture a broader range of pressure variations, making it suitable for diverse weather conditions.

Additionally, the existing system depended on LCDs for display. LCDs are limited by the size of the screen and most times requiring scrolling or limited display information at once. LCD-based systems typically have limited user interaction options, such as buttons or menus. It is static and require physical access to view data, limiting remote monitoring capabilities and real-time data access. LCD-based system have limited integration capabilities with other devices, making it challenging to expand functionalities or integrate with cloud services. LCD-based system also require additional hardware components, wiring, and maintenance, adding to the overall cost and complexity whereas the proposed system offers a larger and more flexible display area via the Blynk IoT platform allowing for comprehensive and easy-to-read visualizations of weather data. Blynk IoT platform provides a customizable interface via smartphones, enabling interactive features like touch controls, real-time updates, and customizable widgets. Blynk IoT platform allows remote monitoring of weather data from anywhere with internet connectivity providing instant access to sensor readings. It offers seamless integration with a wide range of IoT devices, sensors, and cloud services allowing easy expansion, customization and integration of new features. Blynk IoT platform via smartphones reduces hardware costs, simplifies installation and maintenance and leverages existing devices such as smartphone, making it a more cost-effective and user-friendly solution in the long-run.

Finally, power consumption was optimized. The existing system requires an uninterrupted power supply on the other hand the proposed system offers flexibility by providing a USB port for connecting to solar power or electrical power. This allows for more reliable power supply management, backup options, reducing the risk of system interruptions and allowing continuous operations. The improvements made in this research demonstrated the cost-effectiveness goal of the research. Also the proposed system not only showed more precise weather data but displayed it with greater power efficiency and reliability which is essential for enhancing agricultural productivity.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this work, Improved IoT-based Weather Monitoring System was developed for effective farming. Ignite IoT Technology was adopted in the development of the improved IoT-based weather monitoring system. This ensured appropriate selection of hardware, software, sensors, design and development of cloud integration for the system. DHT11, BMP 280, Rain and LDR sensors were integrated to collect accurate and real-time weather data. NodeMCU Microcontroller and Wi-Fi Modulus, Blynk Cloud API and a mobile based application were also used to show the various readings from weather data logs monitored. The system is designed to capture, store and retrieve a wide range of weather data including temperature, humidity, pressure, rainfall and light intensity providing a comprehensive view of environmental conditions crucial for farming and robust solution for effective farming.

Consequently, the system was powered by a 9 voltage power capacity and a USB interface for alternative power source like solar power which allowed for longer operation time and more stable supply, promoting energy efficiency and sustainability. The weather data is securely stored and easily retrievable and higher accuracy in weather data measured were recorded. Larger and more flexible display area via Blynk IoT platform which allowed for comprehensive and easy to read visualization area were also achieved. This enhances usability and adoption of the weather monitoring system in agricultural settings.

In contrast to conventional methods, the IoT-based weather monitoring system eliminated manual data collection and made use of cost-effective IoT devices which in turn reduced the overall cost of implementation. The smartphone interface provided by the Blynk IoT platform offers a user-friendly experience for farmers to access weather data and interact with the system, this enhances usability and adoption of the weather monitoring system in agricultural settings. By leveraging this IoT-based weather monitoring system, farmers can optimize resource usage, increase crop yields and mitigate the impact of adverse weather events.

5.2 Recommendation

In view of these findings, the researcher recommends the following:

i. Sensor Placement and Calibration: Ensure proper placement and calibration of sensors such as DHTII sensor for temperature, BMP 280sensor for pressure, rain sensor for rainfall, and light sensor for light intensity. Optimal sensor placement and calibration ensure accurate and reliable data.
ii. Data validation and Quality Control: Implement data validation techniques to detect and debug errors or anomalies in weather data. Quality control measures such as sensor calibration checks and data validation algorithms help maintain data accuracy and integrity.
iii. Integration with Agricultural Systems: Integrate the weather monitoring system with other agricultural systems such as irrigation systems, pest management systems, and crop monitoring platforms. This integration enables data sharing, interoperability and automation of farm management, tasks based on weather data.
iv. Real-time Alerts and Notifications: Configure the system to generate real-time alerts and notifications based on predefined thresholds for weather parameters. Alerts can notify farmers of critical weather conditions such as heavy rainfall, extreme temperature or high humidity levels.

5.3 Contribution to Knowledge

This work has made significant contribution to the body of knowledge. The following are the contributions made in this work:

i. Creation of a user- friendly IoT-based weather monitoring system for effective farming.
ii. Evaluation of the system effectiveness in providing accurate weather information.
iii. Development of a cloud integration for data capture, storage and retrieval.
iv. Integration of advance sensors technology that enhanced real-time updates, accuracy and specificity in weather measurement.
v. Optimization of power efficiency and data transmission protocols in IoT-based weather monitoring system.

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Appendix A

Program Source Code

```
#define BLYNK_PRINT Serial
/* Fill in information from Blynk Device Info here */
#define BLYNK_TEMPLATE_ID         "TMPL2oC_r8_ym"
#define BLYNK_TEMPLATE_NAME       "Weather Monitoring System"
#define BLYNK_AUTH_TOKEN          "WKzb5taN4nhzLpaIeIM8NMBLhQIIbT55"
 #include <Wire.h>
 #include <SPI.h>
 #include <Adafruit_Sensor.h>
 #include <Adafruit_BMP280.h>
 #include <Adafruit_GFX.h>
 #include <Adafruit_SSD1306.h>
 #include <Blynk.h>
 #include <ESP8266WiFi.h>
 #include <BlynkSimpleEsp8266.h>
 #include <DHT.h>
 char auth[] = "WKzb5taN4nhzLpaIeIM8NMBLhQIIbT55";      // You should get Auth Token
in the Blynk App.
 char ssid[] = "TECNO SPARK Go 2020";                   // Your WiFi credentials.
 char pass[] = "Ogbonna";

 # define SEALEVELPRESSURE_HPA (1013.25)
 Adafruit_BMP280 bmp; // For I2C interface
 //Adafruit_BMP280 bmp(BMP_CS); // hardware SPI
 //Adafruit_BMP280 bmp(BMP_CS, BMP_MOSI, BMP_MISO,  BMP_SCK);

 DHT dht(D3, DHT11);//(sensor pin,sensor type)
```

```
BlynkTimer timer;
//Create three variables for pressure
double T, P;
char status;
float h, t, value;
#define light D0
#define rain A0
void setup()
{
  Serial.begin(9600);
  Blynk.begin(auth, ssid, pass);
  dht.begin();
  delay(1000);  // wait a second
// set I2C pins [SDA = GPIO4 (D2), SCL = GPIO5 (D1)], default clock is 100kHz
  //Wire.begin(4, 5);
  Wire.begin();
  pinMode(light,INPUT);
  // initialize the BME280 sensor
  Serial.println(F("BMP280 test"));
if (!bmp.begin()) {
    // connection error or device address wrong!
    Serial.println(F("Could not find a valid BMP280 sensor, check wiring!"));
  }
  //Call the functions
  timer.setInterval(100L, DHT11sensor);
  timer.setInterval(100L, rainSensor);
  timer.setInterval(100L, LDRsensor);
```

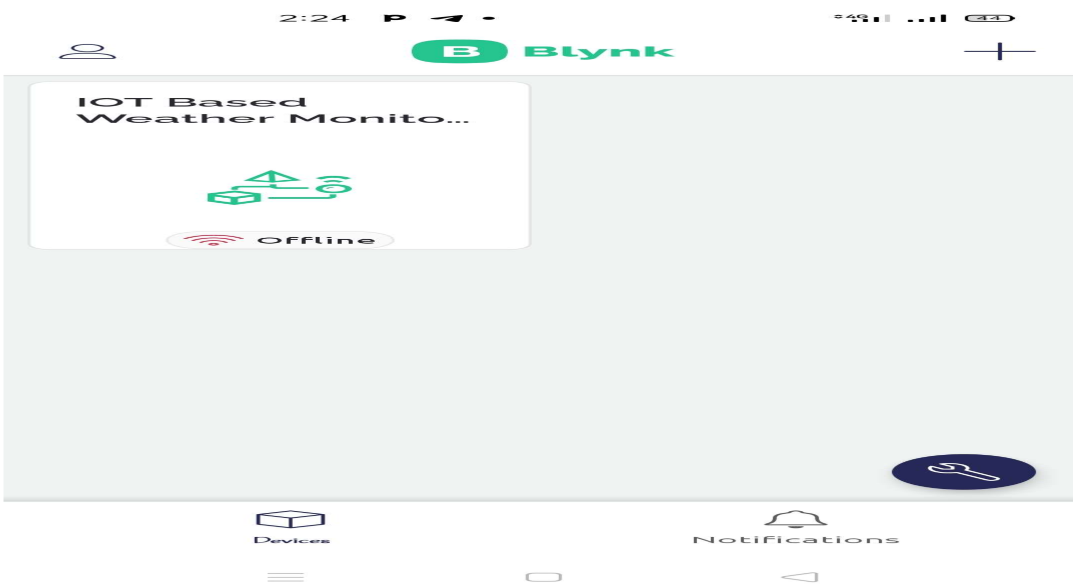
```
  bmp.setSampling(Adafruit_BMP280::MODE_NORMAL,     /* Operating Mode. */
                  Adafruit_BMP280::SAMPLING_X2,     /* Temp. oversampling */
                  Adafruit_BMP280::SAMPLING_X16,    /* Pressure oversampling */
                  Adafruit_BMP280::FILTER_X16,      /* Filtering. */
                  Adafruit_BMP280::STANDBY_MS_500); /* Standby time. */
 }
//Get the DHT11 sensor values
void DHT11sensor() {
  float h = dht.readHumidity();
  float t = dht.readTemperature();
  if (isnan(h) || isnan(t)) {
    Serial.println("Failed to read from DHT sensor!");
    return;
  }
  Blynk.virtualWrite(V0, t);
  Blynk.virtualWrite(V1, h);
}
//Get the LDR sensor values
void LDRsensor() {
  bool value = digitalRead(light);
  if (value == 0) {
    WidgetLED LED(V5);
    LED.on();
  } else {
    WidgetLED LED(V5);
    LED.off();
  }
```

```
}
void rainSensor() {
  int value = analogRead(rain);
  value = map(value, 0, 1024, 0, 100);
  Blynk.virtualWrite(V2, value);
}
 void loop()
 {
   Blynk.run(); // Initiates Blynk
   timer.run();//Run the Blynk timer
 // read temperature, humidity and pressure from the BME280 sensor
   float temp = bmp.readTemperature();    // get temperature in degree Celsius
   float pres = bmp.readPressure()/100;       // get pressure in Pa
   float alti = bmp.readAltitude(SEALEVELPRESSURE_HPA);       // get altitude in meter
   delay(1000);  // wait a second
   // print temperature
   Serial.print("Temperature = ");
   Serial.print(temp);
   Serial.println("*C");
   Serial.print("Rain = ");
   Serial.println(value);
   // print temperature
   Serial.print("Temperature = ");
   Serial.print(t);
   Serial.println("*C");
   // print humidity
   Serial.print("Humidity = ");
   Serial.print(h);
```

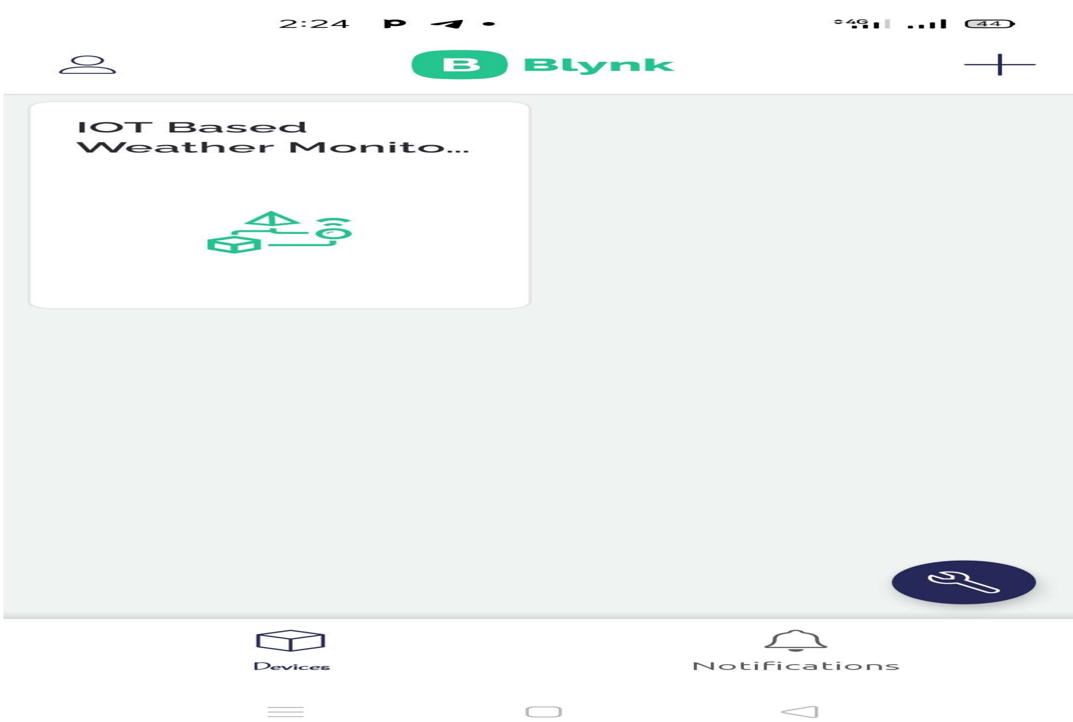
```
  Serial.println("*C");
//print pressure
  Serial.print("Pressure = ");
  Serial.print(pres);
  Serial.println("hPa");
  //print Altitude
  Serial.print("Approx. Altitude = ");
  Serial.print(alti);
  Serial.println("m");
// wait a second
Serial.println();
int Press = t * 100;
  Blynk.virtualWrite(V7, pres); // For Pressure
  Blynk.virtualWrite(V4, alti); //For Approx. Altitude
  delay(1000);
}
```

Appendix B

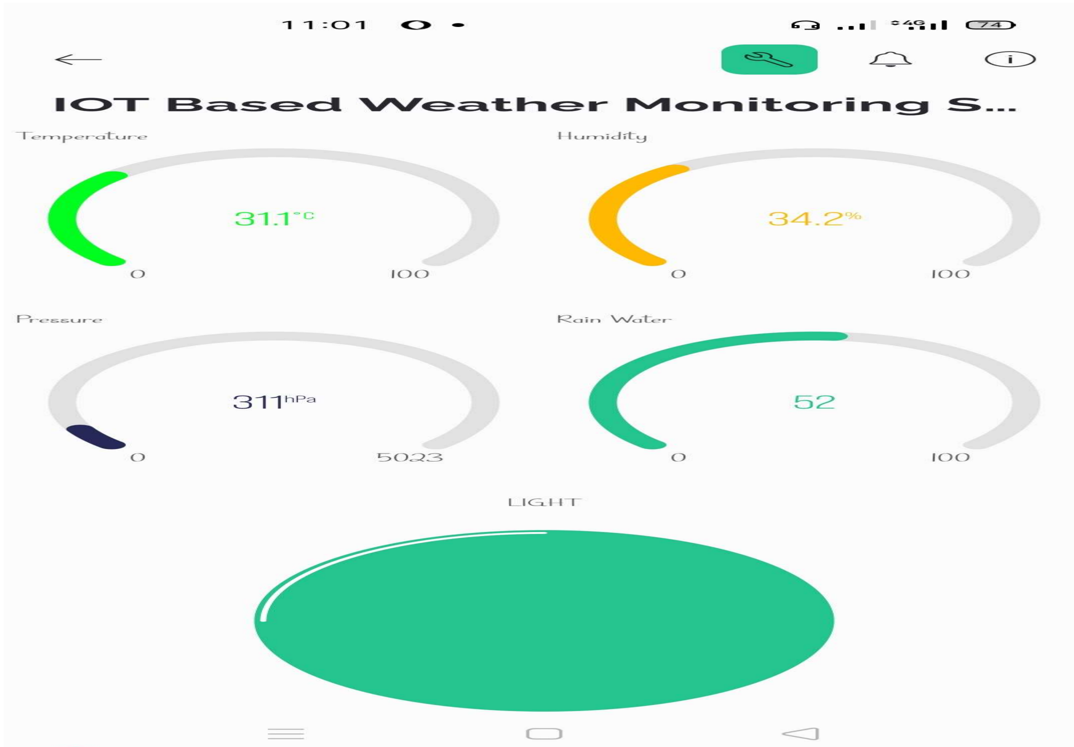
Sample Output



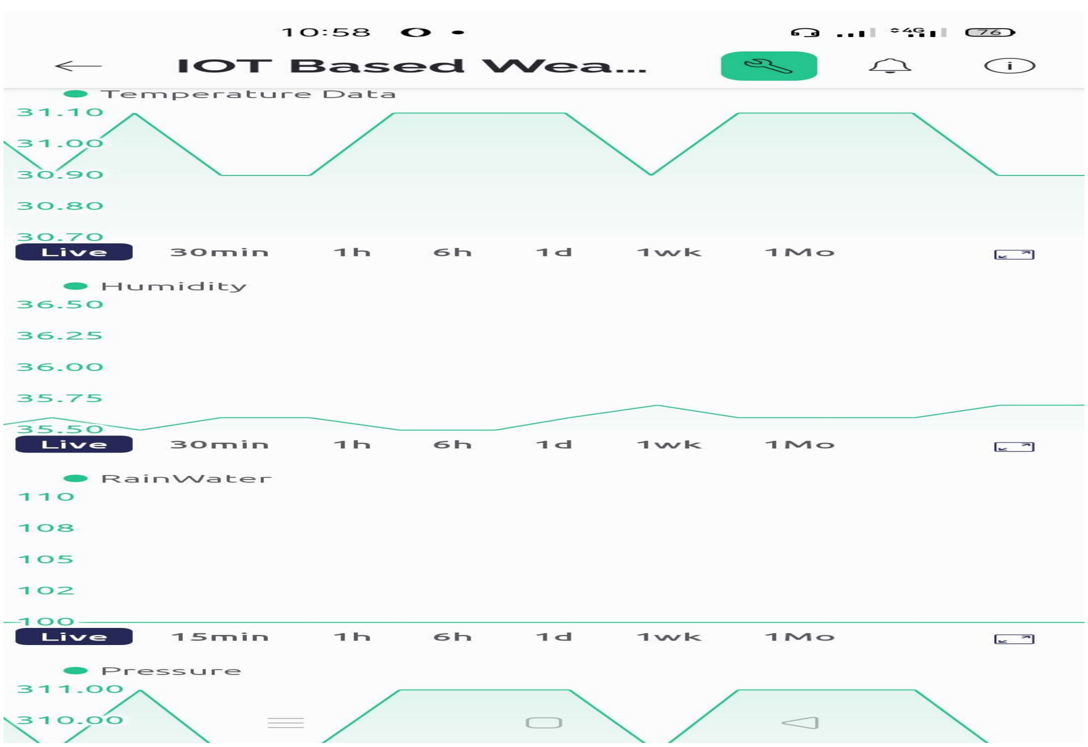
Appendix B1: Offline IoT weather monitoring system



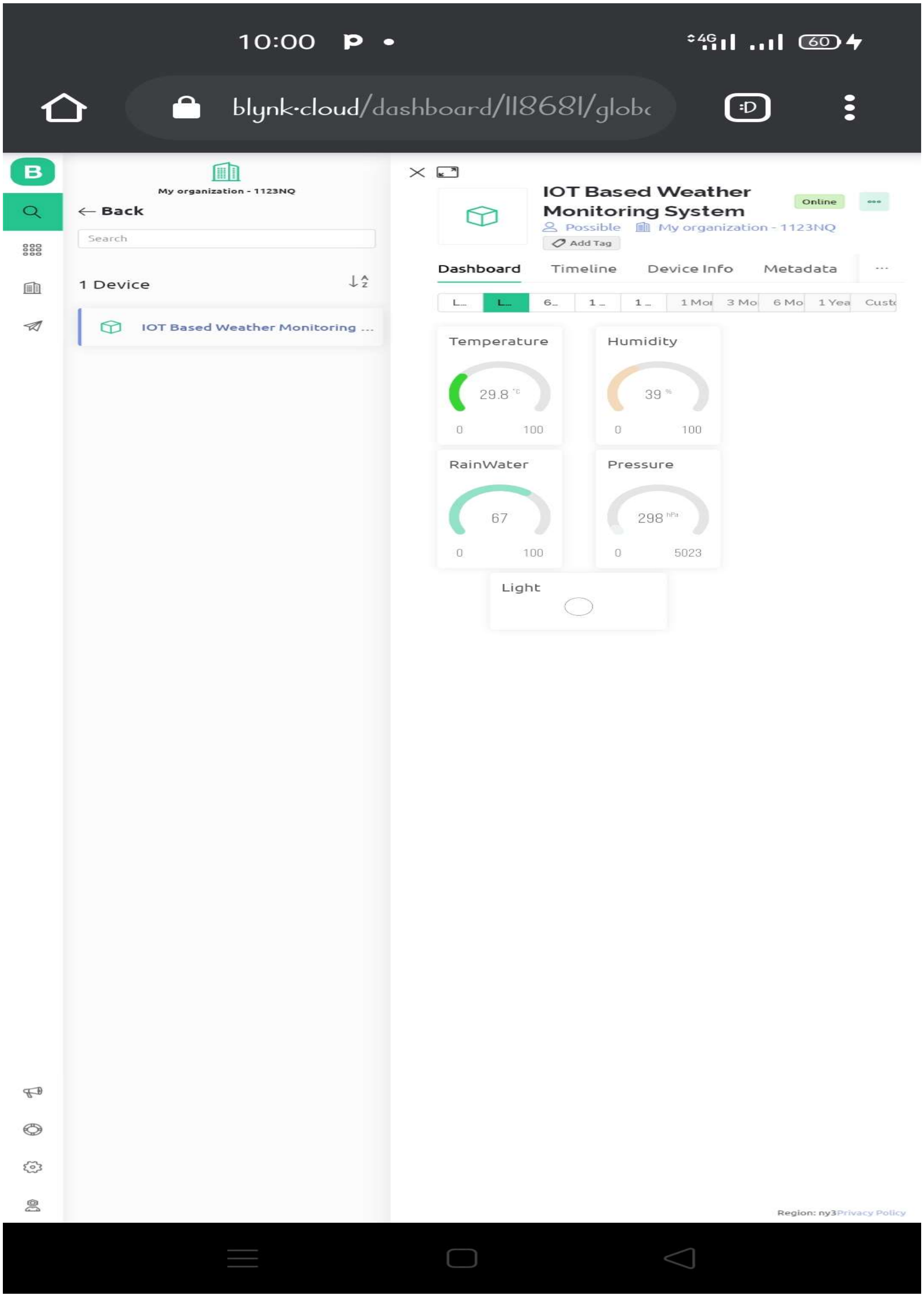
Appendix B2: Online IoT weather monitoring System



Appendix B3: Observations generated by the system



Appendix B4: Real-time weather monitoring



Appendix B5: Display of IoT stored weather parameter readings**.**