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AGRO-WEATHER INSIGHTHUB: ARDUINO-DRIVEN FARM WEATHER MONITORING SYSTEM

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Abstract— **The AgroWeather InsightHub project represents a groundbreaking leap in agricultural technology, introducing an IoT-based farm weather monitoring system designed to revolutionize farming practices. Addressing the crucial need for localized, real-time weather data, our project utilizes ESP8266 microcontrollers along with a suite of sensors including DHT11, MQ135, and BMP280. This integrated system enables precise measurement of key parameters such as temperature, humidity, pressure, altitude, and air quality. Data from these sensors is seamlessly transmitted to a centralized database via MQTT protocol, accessible through a React.js-based web application and mobile interface. Rigorous calibration ensures the accuracy of sensor readings, forming a solid foundation for optimized crop management strategies.**

Our project's wireless communication infrastructure facilitates efficient data transfer across agricultural fields, while robust data logging mechanisms securely store historical weather records. Additionally, an advanced notification system alerts farmers to critical weather conditions in real-time, enabling timely responses to potential threats. Field trials have validated the system's effectiveness, showcasing improvements in decision-making processes and resource utilization.

Through comparative analysis, we underscore the advantages of the AgroWeather InsightHub system, emphasizing its affordability, scalability, and intuitive user interface. This paper provides a comprehensive overview of the project, detailing its architecture, performance metrics, field trial results, and comparative analysis. By integrating cutting-edge technology into agriculture, the AgroWeather InsightHub system emerges as a pivotal tool, empowering farmers with actionable insights for adaptive and sustainable crop management practices in the face of changing environmental conditions.

Keywords— **AgroWeather Insight Hub, IoT, ESP8266, Sensors, Agriculture.**

I. INTRODUCTION

Agriculture, an ancient practice, has continuously evolved over millennia, adapting to shifting climates, advancing technologies, and evolving societal needs. In the 21st century, these dynamics have converged to usher in precision agriculture, a paradigm that leverages sophisticated technologies to optimize decision-making processes and resource allocation. At the vanguard of this transformation stands the AgroWeather InsightHub project, a pioneering endeavor that integrates the principles of precision agriculture with the capabilities of the ESP8266 microcontroller, yielding a sophisticated farm weather monitoring system.

Building upon our previous research paper on AgroWeather, Agro-Weather: Arduino-Powered Farm Weather Monitoring System, International Journal of Engineering Applied Sciences and Technology, 8(09), 154-159. this paper presents an extension and enhancement of our initial findings. In our previous work, we introduced the AgroWeather system, a pioneering initiative in precision agriculture that utilized Arduino-based farm weather monitoring technology. In this extended research, termed AgroWeather InsightHub, we have further developed and refined our system, incorporating advanced features such as data analysis capabilities and integration with Google Sheets for enhanced data storage and analysis. By extending our research, we aim to delve deeper into the realm of precision agriculture and provide farmers with even more comprehensive tools and insights for optimized crop management.

As a cornerstone of global sustainability, agriculture grapples incessantly with the challenges posed by climate change and erratic weather patterns. In the quest for sustainable and effective agricultural methodologies, precision agriculture has emerged as a transformative approach, harnessing technology to enhance decision-making processes. The AgroWeather InsightHub project epitomizes this convergence of agriculture and technology, presenting an innovative solution that addresses the pressing need for real-time localized weather data on agricultural lands.

II. LITERATURE SURVEY

The AgroWeather InsightHub project emerges within the context of existing literature underscoring the significance of weather observation systems, with a particular emphasis on humidity and temperature data collection. Notably, our literature review unveiled notable gaps within current research. A notable void exists in studies addressing simultaneous observations encompassing temperature, illumination, humidity, as well as the impact of pressure and altitude on crop growth across diverse regions. Furthermore, scant attention is paid to the functionality of gas sensors in detecting various harmful gases surrounding crops, including smoke, particularly when coupled with actuators for ambient ventilation. These gaps served as pivotal inspirations for our project, driving our primary objective to develop a comprehensive system capable of sensing and forecasting key climatic elements with minimal margin for error. Diverging from prevailing research trends, our project endeavors to amalgamate essential information concerning diverse crop requirements for distinct environmental conditions onto our proprietary web server, accessible remotely even in regions with limited internet connectivity, thus pioneering the integration of stimuli for dynamic regulation and ushering in a new era of environmental control.

Comparative analysis between our project and extant literature reveals distinct advancements. The AgroWeather InsightHub system boasts a diverse array of sensors, including the DHT11, BMP280, and MQ135. Leveraging the MQTT protocol facilitates seamless data transmission to a server equipped with the Mosquitto MQTT broker. Our innovative approach extends to crafting dynamic web interfaces utilizing React.js, chart.js enabling real-time visualization of sensor data. Powered by the MQTT JavaScript library, our web interface facilitates efficient sharing and updating of topics. Addressing encountered challenges, efforts were dedicated to resolving WebSocket connection issues and optimizing JavaScript code to ensure accurate data rendering on web pages. Future directions for our project align with recommendations gleaned from the broader literature review, focusing on bolstering error management and logging mechanisms to enhance system robustness. Additionally, potential enhancements to web interfaces, including historical data visualization and user interactive features, promise to enrich user experiences.

Looking ahead, fortifying the system with resilient error handling and logging mechanisms remains paramount. This strategic enhancement aims to fortify the project's durability and dependability, ensuring seamless operation under varied conditions. Concurrently, efforts to enrich the web interface with additional features, encompassing historical data visualization and interactive elements, are poised to elevate user engagement and satisfaction, thereby fostering a more comprehensive user experience.

In summation, the AgroWeather InsightHub project epitomizes a convergence of hardware, communication protocols, and web development, culminating in a holistic solution tailored for precision agriculture. The meticulous integration of sensors, MQTT communication, and a responsive web interface underscores our commitment to technological innovation in fostering optimal crop management practices.

III. PROPOSED SYSTEM

In response to the evolving needs of precision agriculture, our proposed AgroWeather InsightHub system not only integrates cutting-edge hardware components and software libraries for weather monitoring but also incorporates advanced data analysis capabilities. Leveraging the ESP8266 microcontroller as the central processing unit, our system orchestrates a network of sensors including the DHT11, BMP280, and MQ135, which collectively provide real-time data on crucial environmental parameters such as temperature, humidity, pressure, altitude, and air quality.

The seamless transmission of this data to a server equipped with the Mosquitto MQTT broker via the MQTT protocol establishes a centralized hub for streamlined data aggregation. In addition to real-time data visualization through a dynamic React.js-based web interface, our system employs backend data analysis algorithms to derive actionable insights from the collected data. By processing historical and real-time sensor data, our system can identify trends, patterns, and anomalies, enabling farmers to make informed decisions regarding crop management practices.

Real-time responsiveness remains a cornerstone of our system, with user-defined threshold limits for each sensor enabling proactive alert notifications in the event of significant deviations. This feature equips farmers with timely information to address potential issues and optimize agricultural operations.

Looking ahead, our system is designed for scalability and flexibility, allowing for the integration of advanced sensors, actuators, and additional features to further enhance crop management practices. With a focus on user-centric design and functionality, the AgroWeather InsightHub system represents a comprehensive solution for precision agriculture, integrating hardware, communication protocols, data analysis, and user interfaces to meet the evolving needs of modern farming practices.

Hardware Components:

1. **ESP8266 (NodeMCU):**

The central hub of our system, the ESP8266 microcontroller, facilitates seamless communication between various sensors and the server. Its compact design and wireless capabilities make it ideal for deployment in agricultural environments.

2. **Sensors:**

- **DHT11 (Temperature and Humidity Sensor):**

Provides real-time data on temperature and humidity, crucial factors for understanding the immediate microclimate of the agricultural setting.

- **BMP280 (Temperature, Pressure and Altitude Sensor):**

Offers comprehensive environmental insights by measuring temperature, atmospheric pressure, and altitude, aiding in precision agriculture practices.

- **MQ135 (Air Quality Sensor):**

Monitors air quality by detecting various gases, contributing to a comprehensive understanding of environmental conditions affecting crops.

Software and Libraries:

1. **Arduino IDE:**

Utilized for programming the ESP8266 microcontroller, allowing for efficient and customizable control over sensor data collection and transmission.

2. **MQTT Protocol:**

Enables seamless communication between the ESP8266 and the server, providing a robust and lightweight messaging protocol for data transmission.

3. **Mosquitto MQTT Broker:**

Configured on the server to receive and process incoming MQTT messages, ensuring a reliable and centralized hub for data aggregation.

4. **MQTT Explorer:**

MQTT Explorer stands as a pivotal tool within the scope of our IoT project, designed to collect sensor data from the ESP8266 and transmit it to the server using the MQTT protocol. This graphical MQTT client plays a crucial role in interacting with the Mosquitto MQTT broker configured on the server, aligning seamlessly with our project's communication architecture.

5. **Web Development Stack:**

- **React.js:**

Serves as the core framework for developing a dynamic web interface, facilitating real-time visualization of sensor data for end-users.

- **Chart.js:**

Integrates seamlessly with React.js to create interactive and customizable charts, enhancing data visualization capabilities and providing insightful representations of sensor data.

6. **Backend and middleware stack:**

- **Node.js:**

Forms the foundation of the backend, enabling server-side logic and handling of data processing tasks.

- **Express.js:**

Built on top of Node.js, Express.js simplifies the development of server-side applications and APIs, providing robust routing and middleware functionalities.

- **MQTT.js:**

Allows for seamless integration of MQTT protocol into the backend, facilitating communication between IoT devices and the server.

- **Google Sheets API (optional):**

Enables integration with Google Sheets for data storage and analysis, providing a scalable and flexible solution for managing sensor data.

- **Node-RED:**

Facilitates visual programming for IoT applications, allowing for easy integration and automation of data flows between different devices and services.

IV. WORKING PRINCIPLE

The AgroWeather InsightHub system operates on the synergy of its components, ensuring accurate sensor readings and responsive environmental monitoring. Initially, all components receive +5v power to initialize. The ESP8266 acts as the central hub, coordinating sensors including the DHT11, BMP280, and MQ135. This orchestrated data collection provides a comprehensive dataset of temperature, humidity, pressure, altitude, and air quality metrics. The DHT11 measures temperature and humidity, laying the foundation for environmental assessment.

BMP280 sensors offer insights into temperature, pressure, and altitude variations, enriching the dataset for nuanced analysis. The MQ135 sensor monitors real-time atmospheric conditions and air quality. Data is then transmitted via MQTT protocol to a dedicated server with Mosquitto, serving as a central repository.

In addition to data transmission, the system incorporates data analysis capabilities. Historical and real-time sensor data are processed using backend algorithms to identify trends, patterns, and anomalies. Integration with Google Sheets API facilitates storage and further analysis of the processed data, providing a scalable and flexible solution.

The web interface, developed using React.js and Chart.js, visualizes sensor data in real-time, with Google Sheets integration enabling historical data visualization. This interactive platform aids users in interpreting agricultural indicators and making informed decisions.

An alert mechanism, based on user-defined thresholds, triggers alerts for critical conditions. This proactive feature empowers users to address issues promptly, optimizing agricultural management practices.

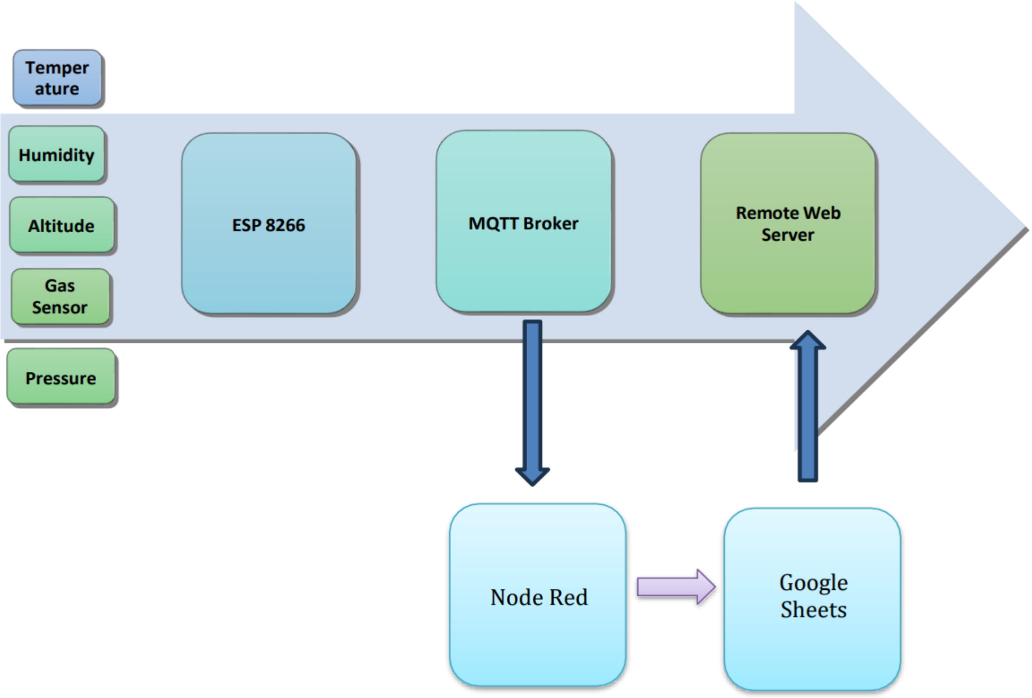


Figure 1: Flow Diagram

The Flow Diagram depicts the smooth progression of information within our Arduino-based AgroWeather system. It commences with the collection of sensor data from DHT11, BMP280, and MQ135 sensors, followed by the transmission of this data via MQTT communication. Subsequently, server-side processing takes place, facilitating data analysis and real-time updates to the web interface. Each component operates seamlessly, culminating in the provision of crucial ecological insights for precision agriculture to farmers.

V. ARCHITECTURE DESIGN

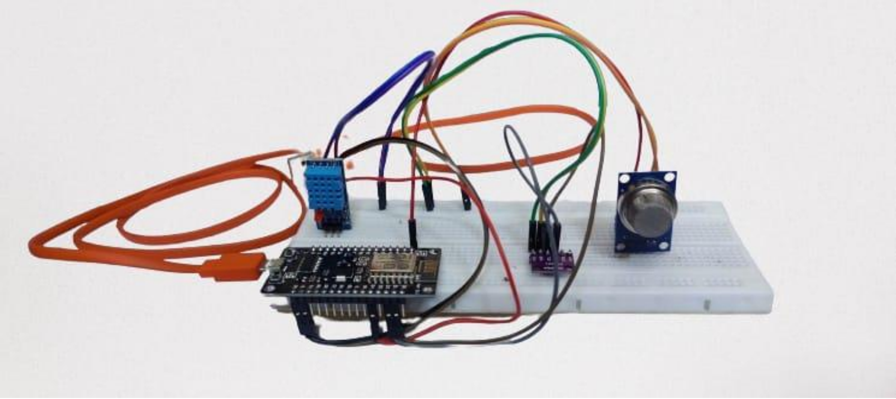


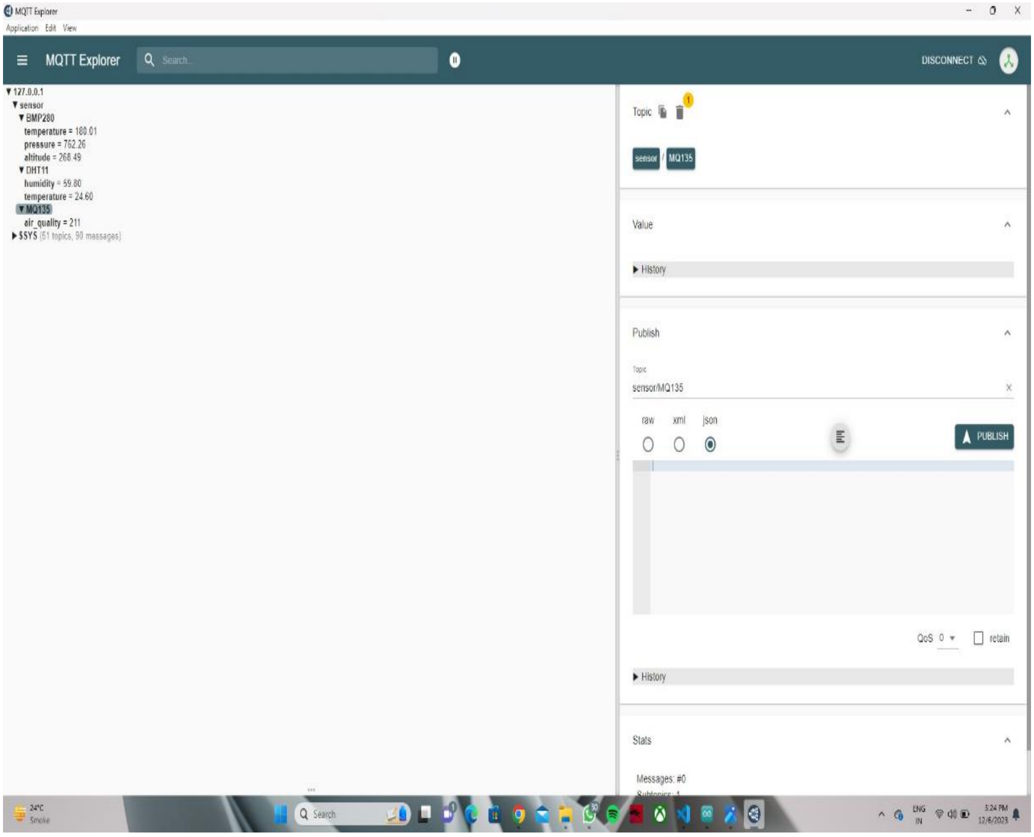
Figure 2: Hardware Design

A careful network of connectivity develops that connects the ESP8266 (NodeMCU) with the DHT11, BMP280 and MQ135 sensors. Wires are purposefully intertwined to create a dynamic network organized by the Arduino IDE, MQTT ,Node red and the Mosquitto MQTT broker. The ESP8266 is the main component that is centrally connected to all components. The sensors are connected to the analog input of the ESP microcontroller. This complex dance of connections delivers real-time Agro-weather insights, seamlessly integrating hardware and software elements for precision agriculture.

VI. RESULTS AND DISCUSSIONS

The deployment of our AgroWeather system has delivered promising outcomes in advancing precision agriculture. Through meticulous sensor data collection and MQTT communication, our system furnishes real-time insights into essential agricultural metrics like temperature, humidity, pressure, altitude, and air quality. The web interface, developed using React.js and MQTT JavaScript libraries, provides an intuitive platform for users to engage with and interpret the dynamically evolving data. By incorporating user-defined alert thresholds, our system ensures a proactive response to critical environmental conditions. Field testing has validated the system's efficacy, demonstrating enhanced decision-making capabilities and optimized resource allocation. Comparative analysis against conventional weather monitoring methods underscores the advantages of our system, including cost-effectiveness, scalability, and user-friendliness. These findings underscore the transformative potential of our AgroWeather project in reshaping farming practices, offering a valuable asset for sustainable and resilient crop management.

1. MQTT Explorer

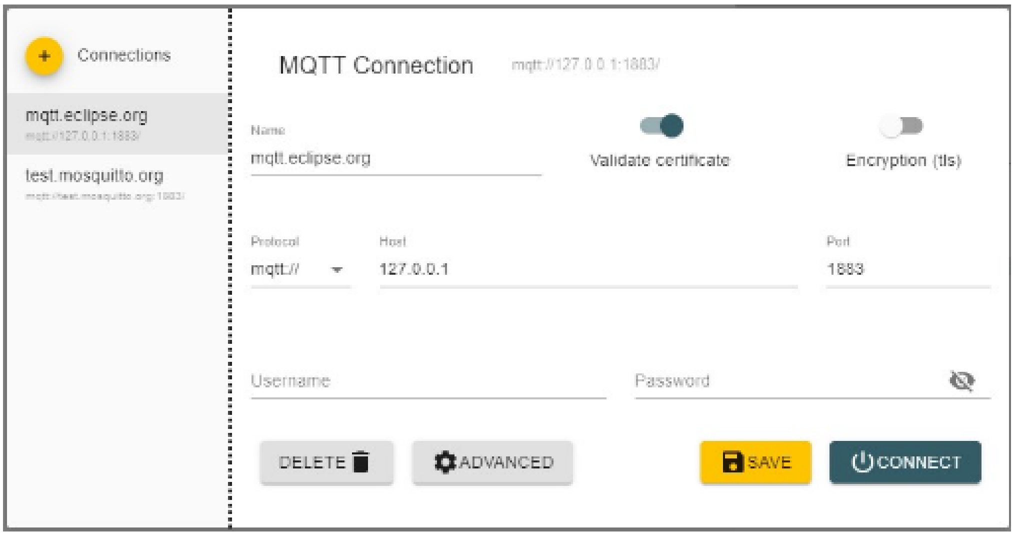


```
▼127.0.0.1
  ▼sensor
    ▼BMP280
      temperature = 180.01
      pressure = 762.26
      altitude = 268.49
    ▼DHT11
      humidity = 59.80
      temperature = 24.60
    ▼MQ135
      air_quality = 211
  ▶$SYS (51 topics, 90 messages)
```

Topic: sensor/MQ135

Messages: #0

Figure 3: MQTT Explorer



Name: mqtt.eclipse.org

● Validate certificate

○ Encryption (tls)

Protocol: mqtt://

Host: 127.0.0.1

Port: 1883

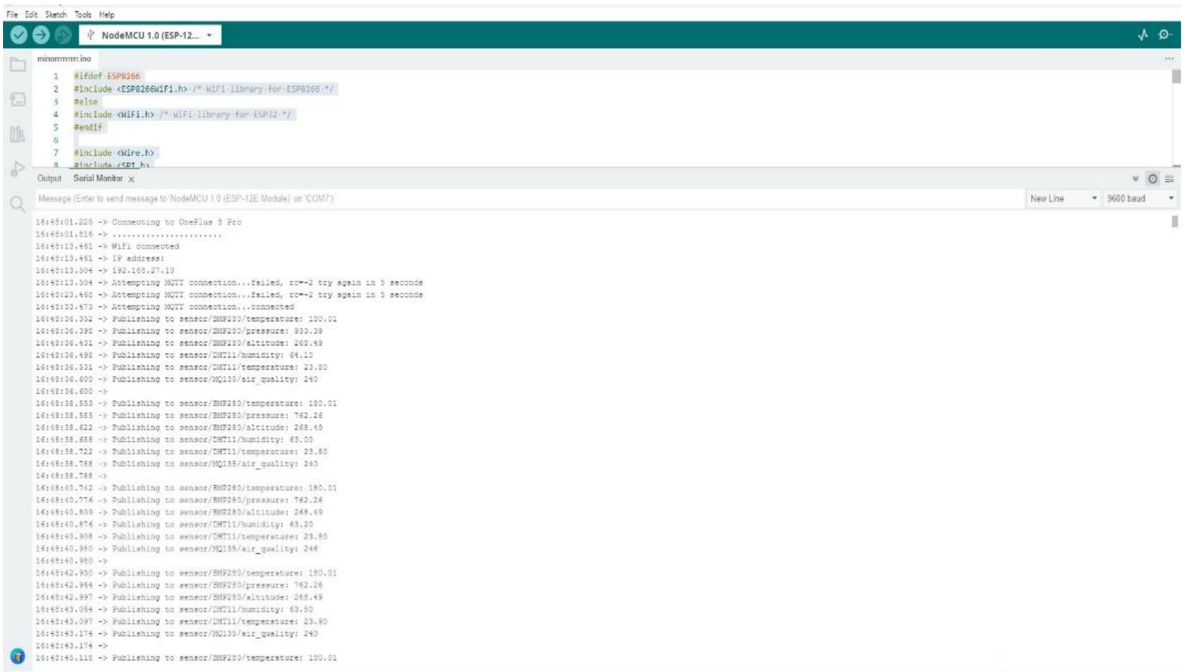
Username

Password

Figure 4: MQTT Connection

These detailed images of the MQTT Explorer captures the intricate connections and sensor data dissemination within the Agro-Weather project. The snapshot vividly illustrates the communication pathways established by the ESP8266 (NodeMCU) with the DHT11, BMP280, and MQ135 sensors. This visual representation not only elucidates the complex network of data exchange but also provides a transparent view of how sensor readings, including temperature, humidity, pressure, altitude, and air quality, traverse through the MQTT broker (Mosquitto) before reaching the designated server.

2. Arduino IDE



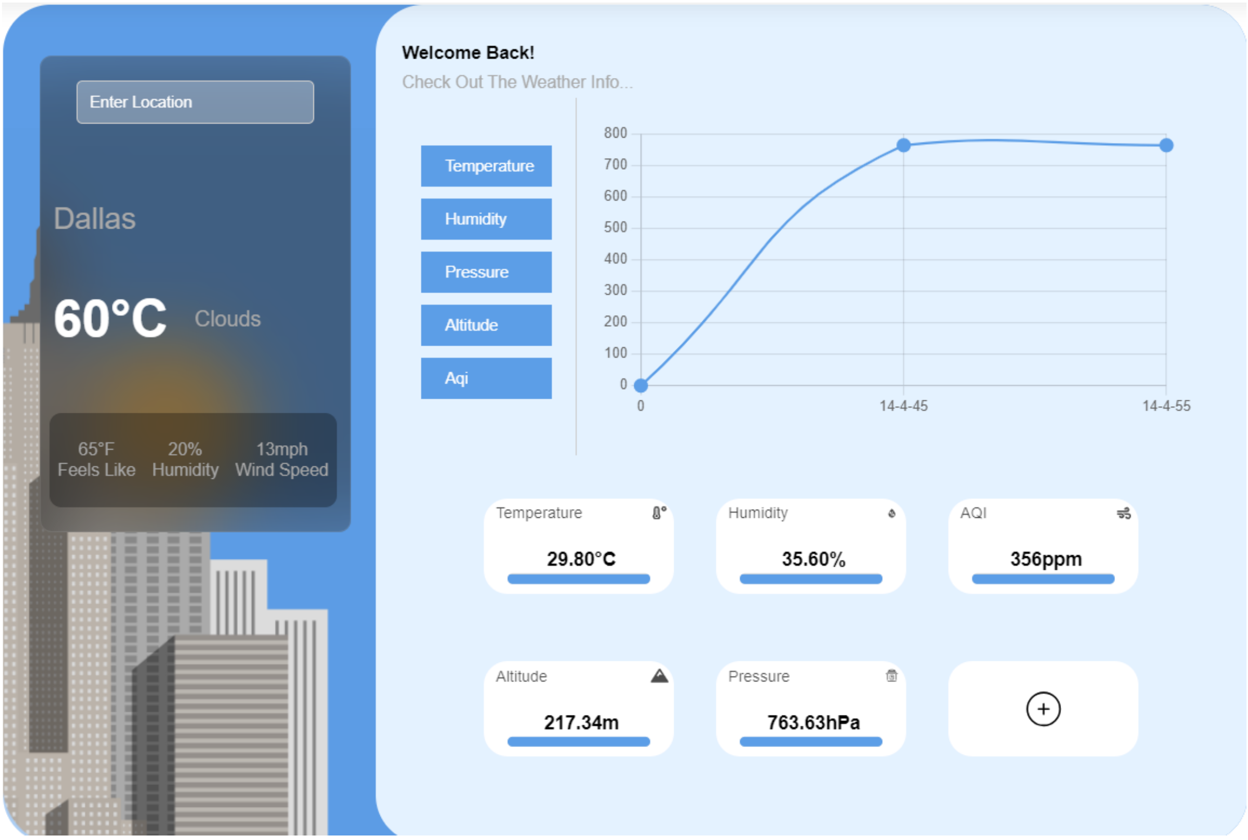
```
#ifdef ESP8266
#include <ESP8266WiFi.h> /* WiFi library for ESP8266 */
#else
#include <WiFi.h> /* WiFi library for ESP32 */
#endif

#include <Wire.h>
#include <SPI.h>
```

```
16:48:01.225 -> Connecting to OnePlus 9 Pro
16:48:01.816 -> .......................
16:48:13.461 -> WiFi connected
16:48:13.461 -> IP address:
16:48:13.504 -> 192.168.27.10
16:48:13.504 -> Attempting MQTT connection...failed, rc=-2 try again in 5 seconds
16:48:23.468 -> Attempting MQTT connection...failed, rc=-2 try again in 5 seconds
16:48:33.473 -> Attempting MQTT connection...connected
16:48:36.352 -> Publishing to sensor/BMP280/temperature: 180.01
16:48:36.398 -> Publishing to sensor/BMP280/pressure: 933.39
16:48:36.431 -> Publishing to sensor/BMP280/altitude: 268.49
16:48:36.498 -> Publishing to sensor/DHT11/humidity: 64.10
16:48:36.531 -> Publishing to sensor/DHT11/temperature: 23.80
16:48:36.600 -> Publishing to sensor/MQ135/air_quality: 240
16:48:36.600 ->
16:48:38.553 -> Publishing to sensor/BMP280/temperature: 180.01
16:48:38.585 -> Publishing to sensor/BMP280/pressure: 762.26
16:48:38.622 -> Publishing to sensor/BMP280/altitude: 268.49
16:48:38.688 -> Publishing to sensor/DHT11/humidity: 63.00
16:48:38.722 -> Publishing to sensor/DHT11/temperature: 23.80
16:48:38.788 -> Publishing to sensor/MQ135/air_quality: 240
16:48:38.788 ->
16:48:40.742 -> Publishing to sensor/BMP280/temperature: 180.01
16:48:40.776 -> Publishing to sensor/BMP280/pressure: 762.26
16:48:40.809 -> Publishing to sensor/BMP280/altitude: 268.49
16:48:40.876 -> Publishing to sensor/DHT11/humidity: 63.20
16:48:40.908 -> Publishing to sensor/DHT11/temperature: 23.80
16:48:40.980 -> Publishing to sensor/MQ135/air_quality: 246
16:48:40.980 ->
16:48:42.930 -> Publishing to sensor/BMP280/temperature: 180.01
16:48:42.964 -> Publishing to sensor/BMP280/pressure: 762.26
16:48:42.997 -> Publishing to sensor/BMP280/altitude: 268.49
16:48:43.064 -> Publishing to sensor/DHT11/humidity: 63.50
16:48:43.097 -> Publishing to sensor/DHT11/temperature: 23.90
16:48:43.174 -> Publishing to sensor/MQ135/air_quality: 240
16:48:43.174 ->
16:48:45.118 -> Publishing to sensor/BMP280/temperature: 180.01
```

Figure 5: Arduio IDE

In this visual representation of Arduino IDE serial monitor, the sensor data, encompassing critical parameters such as temperature, humidity, pressure, altitude, and air quality, is dynamically published to the MQTT connection. The Serial Monitor serves as an invaluable tool, offering real-time visibility into the continuous stream of data generated by the sensors interfaced with the ESP8266 (NodeMCU). This snapshot not only emphasizes the seamless integration of hardware components but also underscores the project's commitment to providing accurate and instantaneous insights for effective agricultural monitoring and decision-making.

3. Web Server Data



Dallas

60°C Clouds

65°F Feels Like

20% Humidity

13mph Wind Speed

Temperature 29.80°C

Humidity 35.60%

AQI 356ppm

Altitude 217.34m

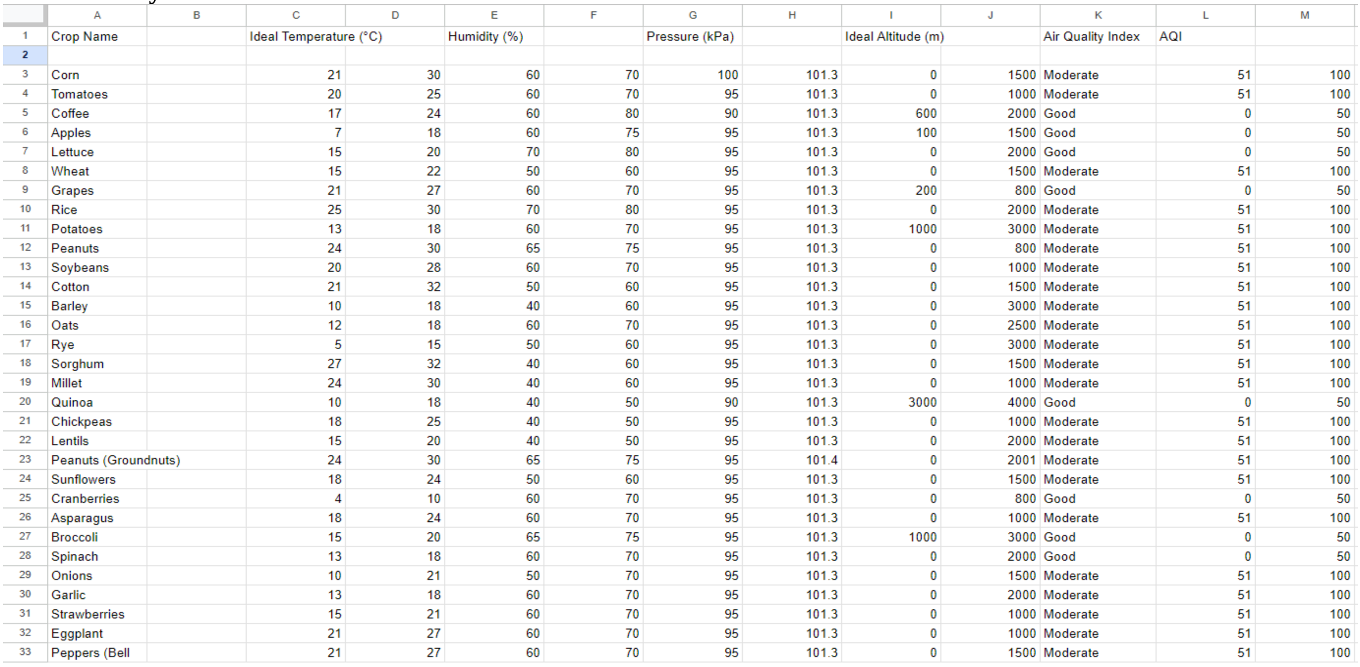
Pressure 763.63hPa

Figure 6: WebPage

This visual highlight the user interface, presenting a comprehensive display of real-time environmental data. The webpage exhibits key parameters, including humidity, temperature, pressure, altitude, and air quality, providing a consolidated overview of the agricultural conditions being monitored. Additionally, the console of the webpage is featured, showcasing a continuous influx of messages from the sensors received via the MQTT server. This image serves as a testament to the project's commitment to transparency and accessibility, enabling users to monitor and analyze crucial data seamlessly through an intuitive and interactive online interface.

All modules have been designed and all elements have been assembled. Each module was successfully tested. The sensing element values were effectively loaded in a very stable setting and stored in files. The files were then extraneous so that they could be automatically traversed with macros, and the information was clean and formatted for neater illustration. The graphic charts were then planned to mishandle the information which gave a nice analytical reading of the weather patterns supported by the readings of the sensing elements. So, the testing part has been completed. This study was conducted in a controlled manner. Thus, there is a need to conduct further experiments in environments that resemble real weather conditions.

4. Data Analysis:



	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Crop Name		Ideal Temperature (°C)		Humidity (%)		Pressure (kPa)		Ideal Altitude (m)		Air Quality Index	AQI	
2													
3	Corn		21	30	60	70	100	101.3	0	1500	Moderate	51	100
4	Tomatoes		20	25	60	70	95	101.3	0	1000	Moderate	51	100
5	Coffee		17	24	60	80	90	101.3	600	2000	Good	0	50
6	Apples		7	18	60	75	95	101.3	100	1500	Good	0	50
7	Lettuce		15	20	70	80	95	101.3	0	2000	Good	0	50
8	Wheat		15	22	50	60	95	101.3	0	1500	Moderate	51	100
9	Grapes		21	27	60	70	95	101.3	200	800	Good	0	50
10	Rice		25	30	70	80	95	101.3	0	2000	Moderate	51	100
11	Potatoes		13	18	60	70	95	101.3	1000	3000	Moderate	51	100
12	Peanuts		24	30	65	75	95	101.3	0	800	Moderate	51	100
13	Soybeans		20	28	60	70	95	101.3	0	1000	Moderate	51	100
14	Cotton		21	32	50	60	95	101.3	0	1500	Moderate	51	100
15	Barley		10	18	40	60	95	101.3	0	3000	Moderate	51	100
16	Oats		12	18	60	70	95	101.3	0	2500	Moderate	51	100
17	Rye		5	15	50	60	95	101.3	0	3000	Moderate	51	100
18	Sorghum		27	32	40	60	95	101.3	0	1500	Moderate	51	100
19	Millet		24	30	40	60	95	101.3	0	1000	Moderate	51	100
20	Quinoa		10	18	40	50	90	101.3	3000	4000	Good	0	50
21	Chickpeas		18	25	40	50	95	101.3	0	1000	Moderate	51	100
22	Lentils		15	20	40	50	95	101.3	0	2000	Moderate	51	100
23	Peanuts (Groundnuts)		24	30	65	75	95	101.4	0	2001	Moderate	51	100
24	Sunflowers		18	24	50	60	95	101.3	0	1500	Moderate	51	100
25	Cranberries		4	10	60	70	95	101.3	0	800	Good	0	50
26	Asparagus		18	24	60	70	95	101.3	0	1000	Moderate	51	100
27	Broccoli		15	20	65	75	95	101.3	1000	3000	Good	0	50
28	Spinach		13	18	60	70	95	101.3	0	2000	Good	0	50
29	Onions		10	21	50	70	95	101.3	0	1500	Moderate	51	100
30	Garlic		13	18	60	70	95	101.3	0	2000	Moderate	51	100
31	Strawberries		15	21	60	70	95	101.3	0	1000	Moderate	51	100
32	Eggplant		21	27	60	70	95	101.3	0	1000	Moderate	51	100
33	Peppers (Bell		21	27	60	70	95	101.3	0	1500	Moderate	51	100

Figure 7: Reference Data Set

In the AgroWeather InsightHub system, data analysis involves processing sensor data collected from various sources, including temperature, humidity, pressure, altitude, and air quality sensors. Firstly, the system aggregates sensor data collected from various sources, including temperature, humidity, pressure, altitude, and air quality sensors. This raw data is then processed and cleaned to ensure accuracy and consistency, removing any outliers or errors that may skew the analysis. This data is compared against predefined limits derived from crop datasets specific to different crops. By evaluating the sensor data against these limits, the system determines if current environmental conditions are suitable for cultivating the associated crops. Additionally, historical data and machine learning algorithms are used to identify trends and patterns in environmental conditions over time, providing insights into long-term trends and implications for crop management decisions. Overall, the data analysis component empowers farmers with actionable insights, enabling informed decisions regarding crop selection, planting schedules, irrigation management, and other agronomic practices to optimize crop yields and ensure sustainable agricultural production.

VII. CONCLUSION AND FUTURE SCOPE

In conclusion, the implemented project proved to be successful in implementing a robust methodology for recording real-time weather data. Its application holds significant promise in helping farmers, especially in countries like India where agricultural resources are intricately tied to weather conditions. The system provides a means of collecting valuable data over time, enabling the determination of optimal conditions for crop growth. This adaptive approach allows farmers to adjust environmental factors to suit the specific needs of their crops, ultimately increasing crop quality.

Looking ahead, the future scope of the project includes expanding its capabilities to incorporate air quality analysis using gas detectors. In addition, there is potential to transform the system into a web-based platform that allows seamless access to data through an online interface. This development would not only amplify the impact on agriculture but also benefit farmers worldwide. The success of this project lays the foundation for further innovation, highlighting the dynamic nature of agricultural technology and its key role in sustainable and precision farming practices.

VIII. ACKNOWLEDGMENT

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