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AGRI-DRONE: monitoring and classification of soil fertility based on internet of things using autonomous drone

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ABSTRACT

Indonesia, an agricultural country, faces significant challenges in maintaining soil fertility, exacerbated by weather fluctuations and climate change. To address this, an Internet of Things (IoT) system called Agri-Drone was developed. It uses fuzzy logic for soil fertility classification and machine learning for weather prediction, assisting farmers in crop management. Agri-Drone integrates components such as Soil Test, Weather Station, and LoRa Gateway carried by autonomous drones, along with a website for monitoring. This improves resource use efficiency, reduces crop failure risk, and supports national food security. The system has succeeded, with Soil Test and Weather Station components demonstrating end-to-end delays and response times of less than 30 seconds. Measurement accuracy for soil elements includes nitrogen (91.93%), phosphorus (91.31%), potassium (88.7%), pH (95.03%), and moisture (93.54%), with high precision. The LoRa Gateway maintained a stable connection over a wide range, and the Weather Station showed high precision. Machine learning for weather classification achieved 98% accuracy, and weather prediction with mae value each parameter different. The website is user-friendly with an average score of 4.584 out of 5 from 51 respondents, reaching 100% performance according to GTMetrix, enabling effective monitoring of measurement results.

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1. INTRODUCTION

The big challenge of Indonesia as an agricultural country is to protect its natural resources, starting from maintaining soil conditions to supporting the productivity of the agricultural and plantation sectors. Extreme climate change occurring in Indonesia includes an increase in the earth's temperature, changes in precipitation, increases in sea surface temperature and height, and an increase in extreme climate and weather events[1]. One of the impacts of this climate change is fluctuations in soil conditions that affect the balance of nutrients in the soil and plant growth.

Food and Agriculture Organization (FAO) estimates that the human population in 2050 will reach 9.6 billion, causing agricultural production to increase by 70% to meet global food demand[2]. A food crisis will occur when agricultural production is not met. Therefore, increasing the productivity of agriculture and plantations is important. Soil fertility management using appropriate technological assistance is one solution to overcome the above problems.

Improving national food security requires effective soil fertility management, this not only affects meeting domestic food needs but helps improve the welfare of farmers and can strengthen their economy. The implementation of technologies designed to overcome soil fertility problems is a good step in overcoming agricultural problems and supporting sustainable development in Indonesia.

2. THEORITICAL REVIEW

2.1. Agriculture

Agriculture is one of the sectors that can fulfill food needs. Agriculture has a major role in the economic sector because it can provide decent employment and can be managed properly. In addition, involving the use of technology in agriculture can create an increase in the quality of agricultural products, and if the quality of agricultural products gets better, many jobs will be created[3].

Soil is a natural material found on the earth's surface, consisting of minerals from rock weathering and organic matter from animal and plant remains. Soil is also a good medium for plants and has specific properties because it is formed from several combinations of natural factors such as climate, living organisms, basic materials, topography, and the period of formation[4].

In agriculture, especially the soil part, there are nutrients that are divided into 2 types, namely macro elements, and micro elements. Plants really need macro nutrients because they consist of nitrogen, phosphorus, potassium[5]. Each of the nutrients has an important role in plant growth.

a. Nitrogen has a role in the formation of plant cells, tissues, and organs so it is required in large quantities[6].
b. Phosphorus is an important component of various enzymes and proteins that have a role in energy transfer. In addition, phosphorus also plays a role in seed growth, as well as root, flower, and fruit development[6].
c. Potassium is a macro-type of element that has a role in regulating various plant physiological processes such as photosynthesis, accumulation, translocation, carbohydrate transportation, and water distribution in cells and tissues[7].
d. Soil moisture is the water content kept between the soil pores. The amount of water in the soil is very dynamic because it can be influenced by the air temperature on the surface of the soil. Each type of plant has a different ideal soil moisture level[3].
e. Soil pH Potential of hydrogen stands for pH, which is a standard measurement to determine the acidity or basicity of a soil. The chemical properties of the soil can be seen from the pH value with the optimal pH value being at 7[3].

2.2. Weather

Weather is the state of the air at a certain time in a relatively narrow area and in a short time[8]. The elements that affect weather and climate are:

a. Air temperature changes from one place to another depending on the altitude of the place and its astronomical location (latitude).
b. Air humidity is the content of water vapor in the air. Water vapor in the air comes from the evaporation of water on the earth's surface, groundwater, or water from the evaporation of plants.
c. Air pressure is the weight of the air mass in a given area. Air pressure indicates the force that works to move the air mass in each specific unit area.
d. Rainfall is the quantity of rainwater that falls during a certain time.
e. Wind direction indicates where the wind is blowing from. The wind direction is shown in degrees.
f. A wind gust refers to a wind speed that suddenly increases quickly and briefly decreases again.
g. Rain Intensity is the speed at which rain falls each time.
h. Wind Speed, a measure of how fast the wind is moving each time.

2.3. Internet of Things (IoT)

Internet of things (IoT) is a concept with the purpose of expanding internet connectivity and allowing us to connect with machines, equipment, and other physical objects with network sensors and actuators. This aims to obtain data that can later be managed and can be seen the results and performance of each of these objects[4].

2.4. Machine Learning

Machine Learning is an application or mathematical algorithm that performs learning from data to produce future predictions. The learning process in question is a way to gain intelligence through two stages including training and testing[9].

3. METHOD

3.1. System Realization

Overall System Design Agri-Drone consists of several components that are interconnected to create a monitoring system as can be seen in figure 1. Agri-Drone is a system that has several devices, such as a soil Test, Weather Station, and drone as a place for LoRa Gateway, and website. Soil Test serves to measure soil fertility. Sensors used in the Soil Test include soil moisture sensors, pH to determine the acidity or basicity of the soil, and NPK sensors to detect the content of Nitrogen (N), Phosphorus (P), and Potassium (K). Weather Station is a device that can measure weather parameters of air temperature, wind speed, air pressure, air humidity, wind direction, wind gust, and rainfall.

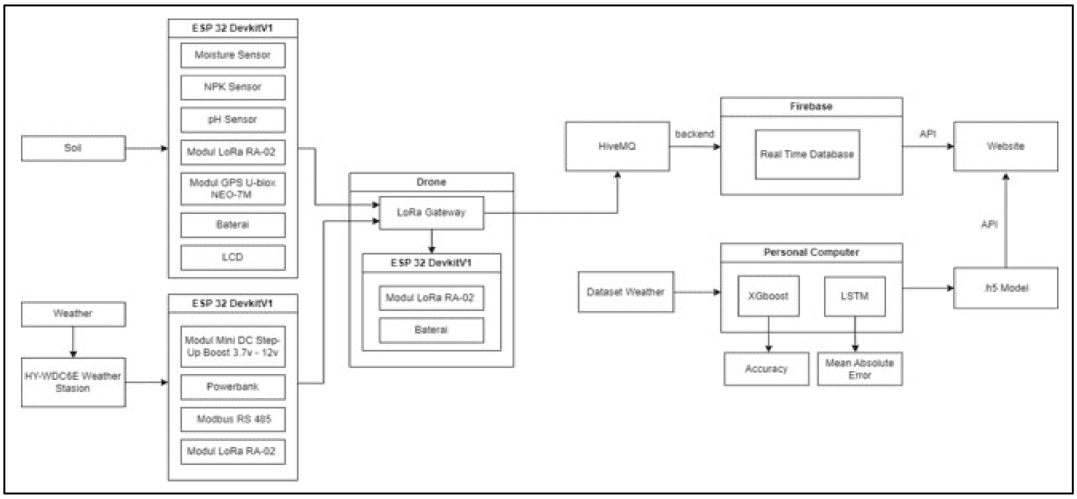

Figure 1. Overall System Design Agri-Drone

Data from the Weather Station and Soil Test is sent using the LoRa module to the LoRa Gateway on the drone. The drone will fly according to the location of the Soil Test and Weather Station coordinates autonomously. The data collected from the LoRa gateway is sent to HiveMQ then the data is retrieved by the backend which is then forwarded to Firebase which will be displayed on the website. Website development is done using HTML, CSS, JavaScript. soil fertility data will be processed using the Fuzzy Logic algorithm to determine the classification of soil fertility levels, and Weather Station measurement data will be processed using XGboost for classification of weather conditions and LSTM to predict weather forecasts for seven days.

3.2. Realization of Embedded Systems

3.2.1. Soil Test

Soil Test functions to determine soil fertility parameters, namely NPK, pH, and soil moisture. Table 1 shows the range of nutrients to determine the soil fertility category[10].

Table 1. Soil Fertility Parameter Range

Parameter	Poor	Moderate	Maximum Value
N	< 150	150 - 200	> 250
P	< 6	6 - 12	> 12
K	< 65	65 - 155	> 155
pH	< 6	6 - 7,5	> 7,5
Moisture	< 20%	20% - 60%	> 60%

Figure 2. Soil Test

In the process of collecting soil parameter data, it starts by plugging the soil test device into the soil. Each sensor connected to the microcontroller will measure the parameters of soil nutrients such as pH, moisture, and NPK. Components used in the soil test as shown in figure 2 include:

- ESP32-DevKitC: Microcontroller
- Moisture Sensor: Measuring soil moisture.
- NPK Sensor: Measure Nitrogen (N), Phosphorous (P), and Potassium (K) content in the soil.
- pH Sensor: Measuring soil acidity and alkalinity.
- LoRa RA-02 433 MHz Module: Sends measurement data to the LoRa gateway.

3.2.2. Weather Station

Weather Station as shown in figure 3 is an advanced internet of things based tool designed to obtain comprehensive weather parameters.

Figure 3. Weather station

The system operates efficiently by collecting data from a variety of environmental metrics such as humidity, light intensity, air pressure, rainfall, temperature, wind direction, wind gusts, and wind speed. The components that constitute the Weather Station include:

- ESP32-DevKitC: A microcontroller that serves as the brain of the Weather Station, managing data collection and communication.
- Modul LoRa RA-02 433 Hz: This module is responsible for sending the collected measurement data to the LoRa gateway, ensuring long-range communication.
- Power Bank: Acts as a portable power source, providing the necessary energy to keep the Weather Station operational.
- HY-WDC6E Compact Ultrasonic Weather: A sophisticated weather parameter sensor that measures various environmental conditions with high accuracy.
- Modbus RS485: A robust communication protocol that facilitates reliable data exchange between the Weather Station and connected devices.
- Modul Mini DC Step-Up Boost 3.7v - 12v: A power converter that efficiently boosts the voltage from 3.7V to 12V, ensuring that all components receive the appropriate power supply.

Together, these components work in harmony to provide precise and real-time weather data, making the Weather Station a crucial tool for weather monitoring and analysis.

3.2.3. Lora Gateway

Figure 4. LoRa gateway is used to receive data from the Soil Test and Weather Station which is then sent to the server. The LoRa gateway is placed on the drone with the aim of wide coverage, mobility that can be moved according to field needs, and affecting LOS (Line of Sight).

Figure 4. LoRa Gateway

The LoRa gateway is connected to a MiFi device that functions as a source of internet connectivity. This MiFi helps the LoRa gateway to connect to the internet via the Wi-Fi network it provides. With this connectivity, it is very helpful for the LoRa gateway to send all the data that has been obtained from various sensors and can easily forward it to the MQTT broker, HiveMQ, then the data will be forwarded to Firebase. The LoRa Gateway component consists of ESP32-DevKitC V1, LoRa RA-02 SX1278 Wireless 433 MHz Module, 18650 RILL 6800 mAh Battery, and 18650 Holder 2P 3.7V Li-Ion Lithium Battery Box.


Figure 5. LoRa Gateway Installation on Autonomous Drones

3.2.4. Machine Learning

The dataset used for modeling is sourced from https://openweathermap.org/ and includes weather data for the city of Bandung from 2019 until 2024. For weather classification, XGBoost, an implementation of a gradient boosting machine (GBM) known for its high performance in supervised learning[11], was utilized. The classification model predicts weather conditions into four classes: Haze (0), Clouds (1), Rain (2), and Clear (3). For the seven-day weather forecast, a Long Short-Term Memory Neural Network (LSTM), a type of Recurrent Neural Network (RNN), was employed. LSTM networks are capable of storing information about patterns in data and can learn which data to retain and which to discard, as each LSTM neuron has several gates managing its memory[11].

3.2.5. Website

The Agri-Drone website is created with HTML, CSS, and JavaScript programming languages for the frontend, while the backend uses the Node.js language. The website is integrated with the LoRa Gateway on the drone. The communication protocol used between ESP32 in the LoRa Gateway is MQTT on the HIVEMQ platform then the data is retrieved by the backend which will be sent to Google Firebase. Sending data from ESP32 to Firebase is done in real-time using a feature from Firebase, namely Realtime Database, then connected to the API to be integrated with the website.

Figure 6. Soil Dashboard

This website is designed to facilitate users in knowing real-time weather conditions and monitoring soil conditions and can see the condition of the soil classified as fertile soil or not. This. Weather station data will be processed using Machine Learning to see predictions of weather forecasts for the next 7 days and classify the type of weather and soil data will be processed using Fuzzy Logic to classify the soil as fertile or not. Figure 6 Display of the soil dashboard with information that can be seen is a map that displays the coordinates of the soil test that has been installed, with information on the longitude and latitude of the soil test and soil fertility categories can be seen with a color index.

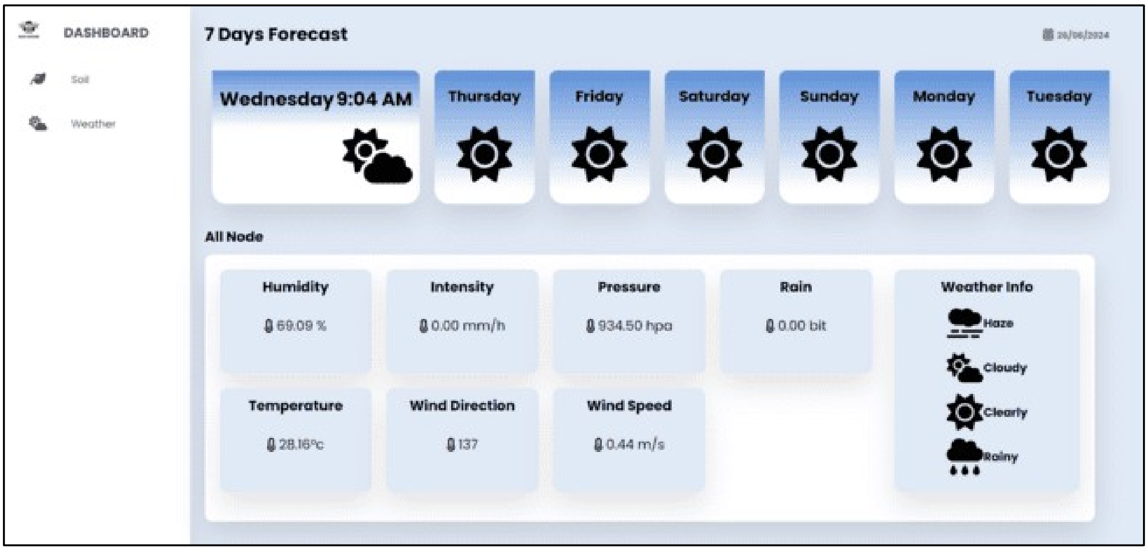

Figure 7. Weather Dashboard

Figure 7 is a display of the weather station dashboard with information that can be seen, namely weather conditions today and 6 days in the future, then in the current condition there is information about wind speed, air temperature, air pressure, air humidity, wind direction, rainfall, and wind gusts. The information displayed is the result of the last data recorded in Firebase history and then displayed on the website dashboard. The website can be accessed on the following page https://agri-drone-dashboard.vercel.app/.

4. RESULTS AND DISCUSSION

4.1. Result

To ensure the success of this system, a test scenario is needed that covers all the desired aspects. Testing will be done by testing system integration, end-to-end delay, and testing on the website.

4.1.1. System integration

The overall system testing stage can be seen in Figure 8. Testing is carried out in paddy fields with a distance between the soil test and the weather station of 30m. On the autonomous drone that has been installed, the LoRa gateway will be set in the mission planner to create an autonomous mission.

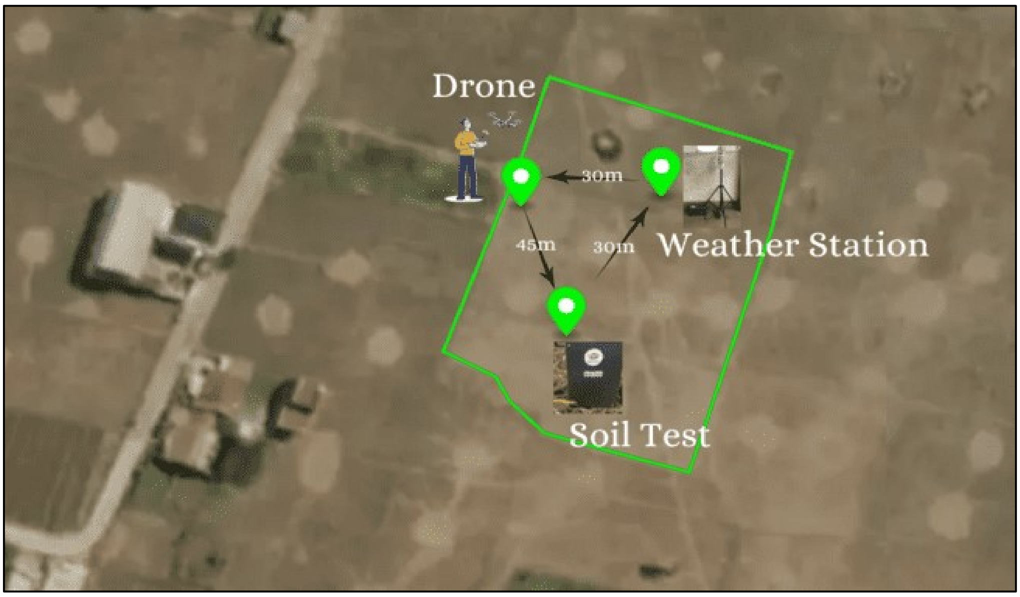

Figure 8. System Testing Illustration

Then the drone will move towards the soil test, which is 45m from the home point, then the drone will stand above the soil test for 40 seconds to collect data from the soil test with data that can be seen in Table 2.

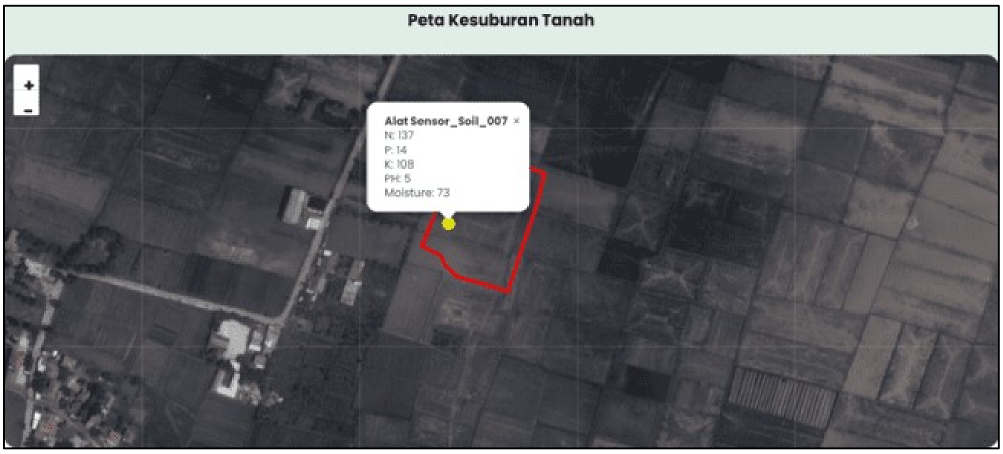

Figure 9. Result Fertility Soil

Figure 9 is the result of soil fertility classification in Tegal Sumedang Village, on Wednesday, June 26, 2024, at 08.00 - 10.00 WIB showing the value of N 137ppm, P 14ppm, K 108ppm, pH 5, Moisture 73%. This shows the classification results belong to the moderate category or yellow color.

Table 2. Soil Test Results

Distance	N	P	K	Ph	Moist	RSSI	Long	Lat	Classification	Information
10	156	16	120	6	72%	-90	107,7256277	-6,9760917	Moderate	System works
10	156	16	119	6	71%	-92	107,7256277	-6,9760917	Moderate	System works
10	156	15	119	6	71%	-92	107,7256277	-6,9760917	Moderate	System works
20	171	17	129	6	70%	-106	107,7256277	-6,9760917	Moderate	System works
20	174	16	129	6	68%	-110	107,7256277	-6,9760917	Moderate	System works
20	167	15	128	6	65%	-110	107,7256277	-6,9760917	Moderate	System works
30	168	15	125	6	63%	-117	107,7256277	-6,9760917	Moderate	System works
30	171	16	129	6	62%	-119	107,7256277	-6,9760917	Moderate	System works
30	167	15	102	6	64%	-119	107,7256277	-6,9760917	Moderate	System works

After the soil test, the drone will move towards the weather station with a standby time above the weather station for 40 seconds to collect data with test results data in Table 3.

Table 3. Weather Station Testing Results

Distance	Humidity	Intensity	Pressure	Rain	Temp	Wind Direction	Wind Gust	Wind Speed	RSSI	Information
10	85.95	0	938.18	0	24.15	143	0	0.00	-91	System works
10	86.00	0	938.17	0	24.18	143	0	0.00	-99	System works
10	85.85	0	938.25	0	24.28	143	0	0.00	-99	System works
20	73.57	0	938.24	0	27.42	142	0	0.00	-110	System works
20	74.49	0	938.31	0	27.51	196	0	0.79	-103	System works
20	75.45	0	938.12	0	27.52	87	0	0.00	-107	System works
30	68.23	0	938.56	0	27.87	45	0	0.00	-120	System works
30	67.98	0	938.52	0	27.93	55	0	0.45	-119	System works
30	67.55	0	938.51	0	27.80	98	0	0.00	-123	System works

4.1.2. End to End Delay

Figure 10 is the end-to-end delay test flow. Testing is done by measuring how long the data has been taken through the sensor until the data can be seen on the website.

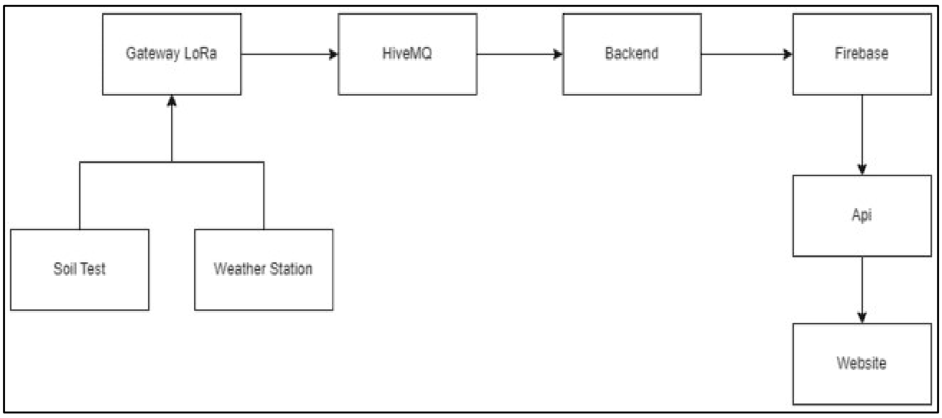

Figure 10. End-to-end Delay Flow

The test is by looking at the serial monitor, when the sensor takes data there will be a time when the soil test or weather station sends data, later that time will be disputed with the time when the data has been displayed on the website.

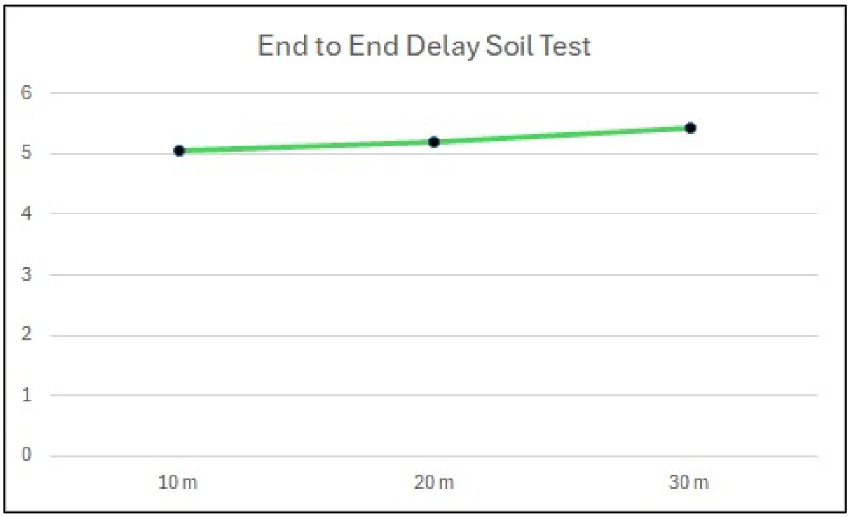

Figure 11. End to End Delay Chart Soil Test

Figure 11 dan Figure 12 records the measurements of Quality of Service: End-to-End Delay at the Weather Station and Soil Test at every 10m, 20m, and 30m distance with six measurements at each distance. Standard QoS measurement value limit: end-to-end delay <30s in ITU-T G.1010 application in low priority transactions. From the data on the bar chart, the Weather Station end-to-end delay value at a distance of 10m is 5.0442s, a distance of 20m is 5.2070s, and a distance of 30m is 5.414s. The average value of QoS: end-to-end delay at a distance of 10m is 5.0442s, at 20m is 5.2078s, and at 30m is 5.414s. Therefore, the end-to-end delay values for the Weather Station and Soil Test comply with the set standards.

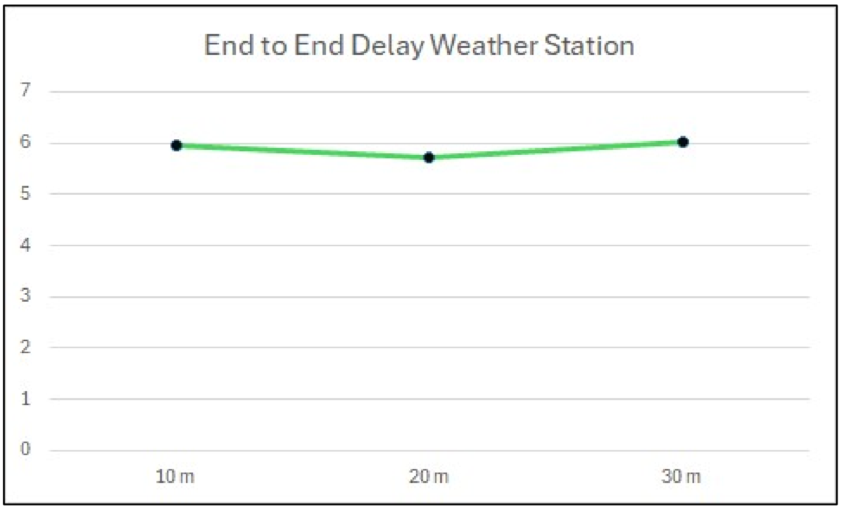

Figure 12. End to End Delay Chart Weather Station

4.1.3. Machine Learning

The XGboost model can classify weather into Haze, Cloudy, Rain, and Clear with an average accuracy of 98%. While predicting cauca for seven days using the Long Short-Term Memory (LSTM) model, has a different MAE (Mean Absolute Error) value in each parameter with a low MAE value indicating accurate prediction. The following table shows the MAE results of weather prediction parameters.

Table 4. Value MAE Parameter Weather Forecast

No	Parameter	Value
1	Temperature	0.80
2	Temperature minimum	1.04
3	Temperature maksimal	1.10
4	Air preassure	2.19
5	Humidity	7.59
6	Wind Speed	0.37
7	Wind Direction	91.53
8	Clouds	10.95

4.1.4. Performance

Website testing is categorized into two main parts, namely testing website performance and website loading time. Performance testing is carried out using the GTmetrix platform with the aim of seeing how well the performance of the website has been created. The result of website performance testing obtained from GTmetrix with a performance value of up to 100% and getting grade A from GTmetrix.

Table 5. Website Performance

Peformance	Structure	Largest Contentful	Total Blocking Time	Cumulative Layout Shift
99%	94%	715ms	0ms	0.04

The second test is testing the loading time on the website using the GTmetrix platform. The goal is to find out how fast the website can be loaded. The results obtained from website testing can be seen in table 5. This result is very important to ensure that users can access website content quickly and without obstacles, thus improving the overall user experience.

4.2. Discussion

From a comprehensive series of tests conducted on the Agri-Drone system in Tegal Sumedang Village, it has been confirmed that the system operates effectively and efficiently according to its intended purpose and functionality. The Agri-Drone system, designed for monitoring soil fertility classification and weather forecasting, leverages the power of the Internet of Things (IoT) along with autonomous drones. The Soil Test and Weather Station components exhibited Quality of Service (QoS) levels with end-to-end delays and response times of less than 30 seconds, highlighting their efficiency in data transmission. The accuracy of the Soil Test was validated using a tool that measured different soil types, with nitrogen (N) at 91.93%, phosphorus (P) at 91.31%, potassium (K) at 88.7%, pH at 95.03%, and moisture at 93.54%. Moreover, the consistency of the data was demonstrated with Relative Standard Deviation (RSD) values for nitrogen (N) at 12%, phosphorus (P) at 0%, potassium (K) at 8%, pH at 0%, and moisture at 4%.

The LoRa Gateway also exhibited robust performance, maintaining a stable connection over a wide range of distances. The data transmission quality was influenced by the distance between the LoRa Gateway and the measuring instrument, with the Received Signal Strength Indicator (RSSI) value decreasing as the distance increased, resulting in some data transmission loss. Conversely, a shorter distance yielded a higher RSSI value and more reliable data transmission. The Weather Station component demonstrated exceptional precision in its measurements, with RSD values for various weather parameters—humidity, rain intensity, air pressure, temperature, wind direction, wind gusts, and wind speed—all at 0%, indicating very high precision. Machine Learning algorithms used for weather state classification achieved a total accuracy of 98%, while weather prediction mae value each parameter different. providing valuable predictive insights. Integration with a user-friendly website further enhances the system's functionality, allowing users to effectively monitor and analyze measurement results. The website scored an average of 4.584 from 51 questionnaire respondents, indicating high user satisfaction, and achieved 100% performance as assessed by GTMetrix. Overall, the Agri-Drone system's performance in Tegal Sumedang Village underscores its effectiveness and reliability for soil fertility monitoring and weather forecasting. The system's components, along with the integration with the website, demonstrated high levels of accuracy, precision, and user satisfaction, highlighting the potential of the Agri-Drone system to significantly enhance agricultural productivity and sustainability through advanced IoT and autonomous drone technologies.

5. CONCLUSION

Agri-Drone has shown significant success as a monitoring tool in soil fertility classification using fuzzy logic and weather forecasting using machine learning based on the Internet of Things (IoT) with the help of autonomous drones to bring LoRa Gateway. The Soil Test and Weather Station components successfully demonstrated Quality of Service (QoS) levels with end-to-end delays and response times of less than 30 seconds The level of accuracy measured using the Soil Test validation tool from the average of each measurement result of paddy soil, potting soil, and flower plant soil is as follows: nitrogen (N) at 91.93%, phosphorus (P) at 91.31%, potassium (K) at 88.7%, pH at 95.03%, and moisture at 93.54%. The consistency shows high precision, with Relative Standard Deviation (RSD) values of N at 12%, P at 0%, K at 8%, pH at 0%, and moisture at 4%.

The LoRa gateway demonstrates the ability to maintain a stable connection over a wide range of distances. The farther the distance of the LoRa Gateway from the measuring instrument. The Weather Station also shows a high level of precision in all paramaters at 0%, indicating very high precision. Machine Learning for weather state classification achieved a total accuracy of 98%, while weather prediction value mae each parameter different. The website is user-friendly, with an average score of 4.584 from 51 questionnaire respondents, and has achieved 100% performance as assessed by GTMetrix, enabling users to effectively monitor measurement results.

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