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Enhanced IoT Solution System for Smart Agriculture in Indonesia

Hugeng Hugeng[1,*], Dedi Trisnawarman[2], Axel Irving Yoshua Huntarso[1]

[1]Department of Electrical Engineering, Universitas Tarumanagara, Jakarta, Indonesia
[2]Department of Information System, Universitas Tarumanagara, Jakarta, Indonesia

*Correspondence: hugeng@ft.untar.ac.id

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ABSTRACT: This innovative solution encompasses an IoT-based smart agricultural system. The system includes a solar panel power supply, a weather station (monitoring temperature, humidity, air pressure, wind speed and direction, raindrop), an air quality monitoring module (measuring NH_4, CO_2, and PM2.5 levels), a soil quality measurement module, a microcontroller, a GSM cellular module for internet connectivity, and an automated relay actuator for a water pump. The water pump's operation is contingent upon the soil moisture levels, ensuring efficient irrigation. The utilization of an IoT-driven smart agricultural system enables real-time monitoring of weather conditions, air quality, and agricultural soil conditions. Additionally, it facilitates the remote control of automated water pumps via smartphones—an aspect that remains unattainable within the confines of traditional Indonesian agriculture. Leveraging an Android application on smartphones, this system delivers detailed insights. To present the collected sensor data in accordance with prevailing environmental and soil states, a dedicated Android application has been developed. Moreover, this application facilitates the control of the water pump to irrigate arid soil as required. The data is transmitted via the internet to a cloud server, serving as the intermediary that receives data from the IoT system's sensors positioned at the farm.

KEYWORDS: Internet of things, smart agriculture, android application, Arduino mega

1. Introduction

As stated by the Food and Agriculture Organization of the United Nations (FAO), the overall prosperity and well-being of populations around the world largely depended on how well countries managed their agricultural sectors. In Indonesia, 31.36 percent of the land area or around 57 million hectares were currently used for agricultural purposes. This sector contributed to 14.43 percent of the national GDP, providing employment for around 41 percent of the total workforce or approximately 70 million people [1]. As weather and soil conditions were critical to the performance of the agricultural sector, it was necessary to monitor and record their conditions so that the data could be utilized for follow-up decision-making [2]. Recently, the Indonesian government officially launched a roadmap called "Making Indonesia 4.0". This is a new term that refers to the fourth industrial revolution in the world. The government encouraged and facilitated key innovation and research in digital technology, leading to a more efficient economy. This is in line with the concept of Agriculture 4.0, which can be considered as a data-driven agricultural system or a smart agricultural system whose components include telematics, data management, and precision agriculture [3-5]. Note that according to the National Research Council (1997), precision agriculture makes use of multisource data to make decisions and operations for crop production. In general, Agriculture 4.0 uses the Internet of Things (IoT) to collect data from the fields.

Farmers traditionally went to the fields to check on the state of their crops and make decisions based on their expertise. The traditional approach had concerns with efficiency, sustainability, and availability. On the other hand, an IoT-based agricultural system would solve these issues, thereby improving the welfare of the farmers. In addition, farm management processes were standardized, manageable, and could be improved, thereby reducing overall operating costs and improving the quality of agricultural products. In recent years, IoT and wireless sensor network (WSN) technologies have been applied in many agricultural applications, as surveyed in [6][7]. The applications of IoT technology in agriculture are intended to increase yields or quality and to reduce costs. Furthermore, the applications of WSN in precision agriculture help farmers statistically, assisting them in making better and well-informed decisions [8][9]. Fang et al. [8] introduced a novel integrated information system (IIS) based on IoT for monitoring and managing the regional environment, to increase the efficiency of complex tasks. They suggested a combined IIS that consists of geoinformatics, IoT, cloud computing (RS, GIS, and GPS), and e-Science for managing and monitoring the environment, with case studies on the ecological response of regional climate change and climate change itself, which is still one of the trend issues recently. The great advantages of such an IIS resulted not only in data collection enabled by IoT but also in web services and applications based on e-Science platforms and cloud computing. The effectiveness of decision-making and monitoring has been greatly developed.

Additionally, IoT was applied in the production chain of agro-industry [10-13]. Medela et al. [11] suggested an innovation in architecture based on the concept of IoT, combining dedicated distributed and wireless sensor devices with simulated climate conditions to track the evolution of grapes for vineyards. Li et al. [12] found a system of formation with a distributed architecture for agriculture based on IoT. In the study, tracking and tracing of the entire agricultural production process were carried out with a distributed IoT server. In addition, information discovery systems were designed to implement, capture, standardize, manage, discover, and query business data from agricultural production. Pang et al. [14] proposed a value-centric business-technology co-design framework to provide end-users/consumers with information about product origins and properties. Capello et al. [10] implemented IoT for real-time monitoring services to enable product tracking from the end consumer back to the field. The researchers in [13], Ruan and Shi, proposed an IoT framework for assessing fruit freshness in e-commerce carriage, which was a modern retail service that encounters particular challenges in transportation due to expensive logistics and product durability.

Many studies have tried to develop IoT functionality [15] [16]. Diedrichs et al. [17] proposed the development of an IEEE-802.15.4-based WSN for use in characterizing ice in precision agriculture by temperature measurement. As presented by Fourati et al. [18], a web-based decision support system (DSS) communicated with the WSN to plan irrigation in olive groves. To do this, the researchers used sensors to measure solar radiation, humidity, temperature, and rain. As explained in [15], Hasim et al. verified the temperature and humidity control of the floor with an electronic device (Arduino) and used an Android-based application on smartphones for functionality and flexibility. They found advantages in low cost and flexibility for agricultural operational control over expensive components such as high-end personal computers. Luan et al. [16] designed and implemented a synthetic system that integrated drought monitoring and forecasting as well as forecasting of irrigation quantity into a single platform based on IoT, parallel computing, and hybrid programming. Kanun et al. [19] and Kaewmard and Saiyod [20] focused on irrigation systems that used WSN to collect environmental data and control irrigation systems using smartphones. Chen et al. [21] presented a system for monitoring multilayer soil temperature and moisture in agricultural land with WSN to improve water use and collect basic research data on groundwater infiltration variations and for intelligent precision irrigation. Kaewmard and Saiyod [20] provided a long-term sustainable solution for agricultural automation to obtain data for environmental measurements or from horticultural crops. They implemented portable measurement technologies, including air temperature and humidity sensors and soil moisture sensors.

Li et al. [22] presented an environmental monitoring system for an agricultural greenhouse based on IoT, with real-time monitoring of environmental information remotely in greenhouses, combining international, wireless networks, and cellular networks. Furthermore, Luke et al. [23] proposed a long-range monitoring system of water level for troughs via WSN based on LoRa transceivers, even when the barn is 1 or 3 km away, enabling farmers to monitor water availability for livestock. Sarangi et al. [24] proposed an agricultural support system based on Wisekar to provide automated value-added services that integrate interoperability of IoT web repositories with farm advisory call centers. Wong and Kerkez [25] implemented a real-time data architecture and web service that includes an adaptive controller that updates the parameters of each sensing node in the WSN based on predefined policies. Xian [26] proposed a new convenient online monitoring system for IoT based on cloud computing. After collecting sufficient data from the agricultural IoT system, relevant functional requirement modeling is presented to promote the implementation of big data analysis in the field of agriculture. However, only a few studies have applied data mining to extract useful information and knowledge, thus the current work will collect data from IoT and then the collected data will be mined in the next future research.

In this paper, we designed and reported the implementation of an integrated IoT system for a smart agricultural system, which consists of a weather station that monitors temperature, relative humidity, air pressure, soil moisture and temperature, soil pH levels, and monitoring other environmental parameters, such as levels of CO_2, NH_4, and PM2.5 particles in the air. This system will also be integrated with a water level monitor and pump relay actuator to activate the water pump when the water level sensor indicates a low water level condition. This IoT system was designed as an integrated system, which uses several agricultural and environmental sensors. It is then connected to a 3G/4G wireless cellular network as a gateway system, which is useful for collecting data from all sensors to cloud storage. Data from cloud storage can be further processed by a specially made Android-based application. The urgency of this integrated IoT system is to increase the quality and quantity of agricultural production. Currently, most farmers cannot monitor and control the real condition of their agricultural land either remotely or in real-time. For example, based on soil moisture information obtained from the system created, farmers can anticipate the dry season and take appropriate preparatory actions. Because of this, the IoT agricultural system can help farmers minimize the possibility of crop failure and inefficient agricultural processes caused by bad weather conditions, as well as knowing the condition of the soil parameters after the fertilization process.

2. Research Method

The Arduino Mega 2560 R3 microcontroller module was used as a control center and data processor in the design of the IoT-based smart agricultural system. It has features such as 4 kB EEPROM, 8 kB SRAM, 256 kB flash memory, 54 digital I/O pins, 16 digital I/O with PWM pins and 16 analog pins. Our system is made up of the following components: a microcontroller module, a weather station module, an air quality module, a soil moisture sensor and a soil pH sensor, as detailed in the subsections below. Block diagram of our build system can be seen in Figure 1.

2.1. Microcontroller Arduino Mega 2560 R3.

As previously stated, the IoT solution system for smart agriculture makes use of an Arduino Mega 2560 R3 microcontroller, enhanced by the incorporation of an ESP8266 chip featuring Wi-Fi connectivity and programmability. This amalgamation yields a dual programmable chip configuration within a singular microcontroller module, endowed with 54 pins. The Arduino Integrated Development Environment (IDE) serves as the designated programming tool for this microcontroller. The selection of the Arduino Mega 2560 R3 stems from its inherent attributes. Notably, it boasts an integrated Wi-Fi module on its board, rendering it particularly well-suited for IoT applications. Moreover, this microcontroller fulfills the pin prerequisites of the entire system while maintaining an affordable price point.

2.2. Anemometer sensor.

Featured within the weather station module, as shown in Figure 1, was the anemometer sensor. This sensor played a pivotal role in gauging the wind speed within our system. Operating at a voltage of 5 V, the sensor delivered analog data as its output voltage. Notably, the wheel's dimensions spanned 16 cm across from one end to the other, with an overall height of 22 cm.

2.3. Air temperature and humidity sensor.

Incorporated within the weather station module depicted in Figure 1, the DHT11 sensor served the purpose of overseeing air temperature and humidity levels. This sensor operated effectively within a voltage range of 3.3V to 5V. Boasting four pins, this sensor exclusively generated digital data. Impressively, it exhibited an air humidity measurement span from 20% to 95%, accompanied by a precision error of around 5%. Concomitantly, the air temperature measurement envelope extended from 0°C to 50°C, with a marginal measurement inaccuracy of approximately 2°C. An intriguing feature of the DHT11 was its ability to furnish updated data every two seconds.

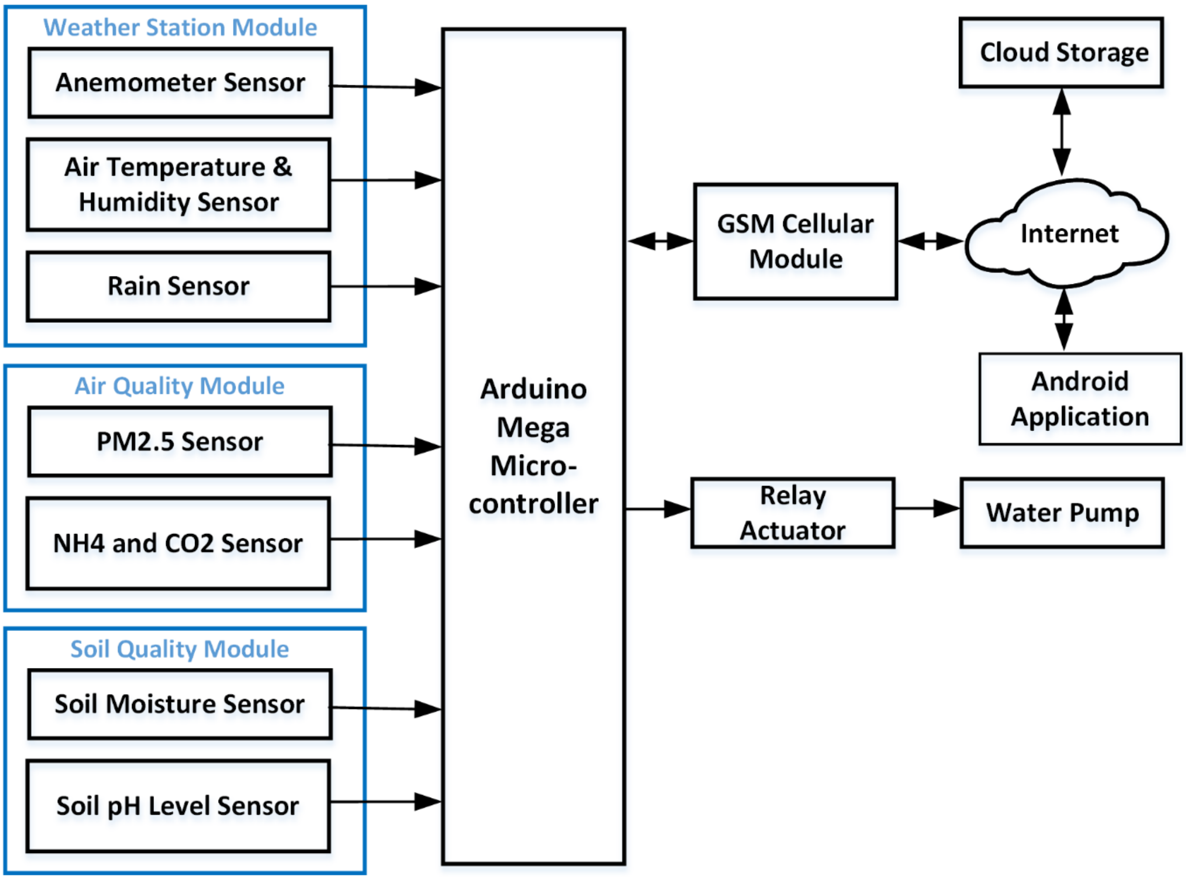


Figure 1. Block diagram of the IoT-based smart agricultural system.

2.4. Rain sensor.

Employed for rain monitoring, the MD0127 sensor took center stage. Renowned for its rain-condition tracking capabilities, this sensor seamlessly translated observations into both digital and analog output signals. Notably, the sensor's composition was rooted in the durable RF-04 material, ensuring prolonged functionality. Integral to its operation was the LM933 comparator, enhancing its performance as a rain-monitoring tool.

2.5. PM2.5 sensor.

The PM2.5 sensor, denoting Particulate Matter 2.5, was harnessed for the purpose of detecting air pollution in the atmosphere. Within this module, the configuration involved placing a phototransistor and an infrared light-emitting diode diagonally, enabling the sensor to perceive light reflected by airborne particles. Notably, this sensor exhibited minimal power consumption, drawing just 20 mA, and was capable of being powered by a voltage of up to 5V. Functionally, the PM2.5 sensor yielded an analog voltage output that corresponded proportionally to the concentration of particulate matter in the air. This output voltage was measured with a sensitivity of 0.5V per 0.1 mg/m^3, providing a precise indication of the dust concentration present.

2.6. Gas sensor.

Utilized as the air quality sensor, the MQ135 gas sensor played a crucial role in determining the concentration of NH_4 and CO_2 gases within the range of 10 to 1000 ppm. This sensor was deliberately selected to oversee the levels of carbon dioxide gas within this intelligent agricultural framework. Distinguished by its remarkable sensitivity and rapid response time, the MQ135 sensor stood out. Generating an analog signal as its output, this sensor exhibited a voltage requirement of 5 V_{DC}. The resistance of the sensor underwent changes upon detection of specific gases. To facilitate the sensor's integration into the system, the analog pin on the Arduino Mega microcontroller was connected to the sensor's output, setting the stage for further processing of the acquired data.

2.7. Sensor for soil pH level.

This module served the purpose of detecting the pH level within water, generating an analog voltage output. Operating within a voltage range of 3.3V to 5V, this sensor module proved itself apt for measuring soil pH levels in agricultural contexts. Furthermore, its utility extended to diverse applications including hydroponics, environmental water testing and aquaponics. The pH level it measured spans from 0 to 14, signifying the spectrum of solution alkalinity or acidity. This metric encapsulated the degree of alkalinity or acidity presented within the solution, rendering it invaluable for assessing the quality of water and soil in various scenarios.

2.8. GSM cellular communication module.

The GSM cellular communication module played a pivotal role in transmitting data from the serial monitor to the internet via General Packet Radio Service (GPRS). The module facilitated serial communication through two lines, specifically Serial TTL (U_RXD and U_TXD), which could be directly linked to an Arduino Mega or a USB Serial TTL converter. This selection was influenced by both the module's cost-effectiveness and its compact size. The chosen communication protocol was a familiar one—AT Command—a standard modem communication approach. This selection aligned well with the objectives of the project. The module's significance stemmed from its ability to provide extensive coverage for wireless communication, a crucial attribute in fulfilling the requirements of the smart agricultural system.

2.9. Solar panel power source.

The solar cell module, recognized as a photovoltaic (PV) panel, held a central role in producing electric current that could be stored in a battery or accumulator. With measurements of 485 x 360 x 25 mm, the solar panel encompassed a collective count of 36 cells. Employing polycrystalline technology, this solar panel adeptly converted the strength of sunlight into usable electrical energy. This energy source demonstrated a peak power output of 20 watts per hour.

2.10. Realization of the whole system.

Figure 2 illustrates the schematic diagram depicting the integrated circuitry of the developed system. The weather station component was designed to monitor air temperature and humidity through the application of the DHT11 sensor. Additionally, wind speed data were captured via the anemometer, while rain conditions were detected. The DHT11 sensor featured three pins—digital output, Vcc, and ground. Notably, the digital output pin of the

DHT11 was connected to pin 26 of the Arduino Mega 2560 R3. The analog output of the anemometer, providing voltage-based data, was linked to pin A2 of the microcontroller. Detection of rain conditions hinged upon the MD0127 sensor, with its digital output pin connected to pin 28 of the microcontroller.

Air quality was effectively assessed by utilizing the PM2.5 sensor, tasked with identifying airborne particles less than 2.5 microns in width, and the MQ135 gas sensor, geared toward measuring CO_2 and NH_4 levels. The soil moisture sensor's analog output pin was linked to the microcontroller's A0 pin, where the data informed the relay controlling the water pump's ON/OFF operation. Moreover, the pH level of the soil was captured by the microcontroller from the pH soil sensor's analog output (pin A3). All data from the sensors were transmitted by the microcontroller through the GSM module, subsequently sent to a 3G/4G cellular network connected to cloud storage for data storage. Command data received from the cloud storage facilitated control over the automatic water pump module. The realized implementation of this system entailed the integration of all applied modules into the microcontroller, compactly housed within a 21 cm x 14 cm x 5 cm enclosure. The system's power was sourced from a solar panel, specifically a 20 Wp polycrystalline variant. This solar panel, measuring 485x360x25 mm and featuring 36 cells (9x4 arrangements), offered a maximum power output of 20 watts per hour. The power supply module encompassed a solar panel, a solar controller, and a 12V, 7 Ah battery. The IoT-based smart agricultural system's composition is presented in Figure 3.

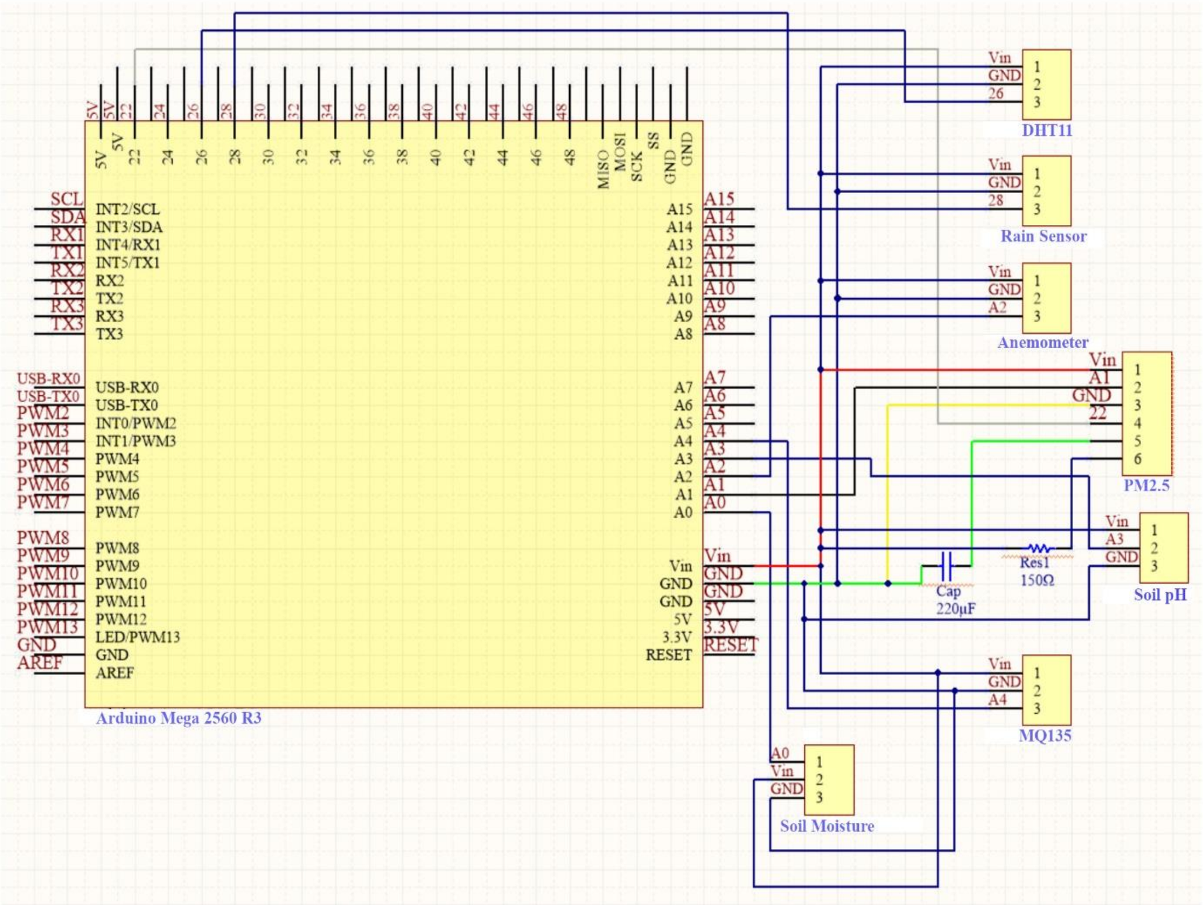


Figure 2. Schematic circuit diagram of the developed system.

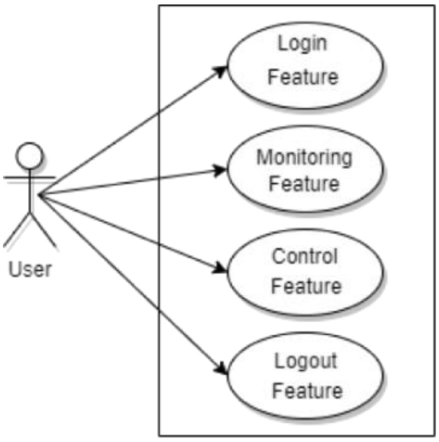
Figure 3. Photograph of the IoT solution system for smart agriculture.

2.11. The android application for monitoring and control.

A user had to be connected to the internet network on his/her smartphone to open the application and log in first to access the application created here. The method to log in to the application involved filling in the username and password fields that had been created. Then, a user pressed the sign-in button using the login feature. If a user was not registered, they had to first 'sign up'. On the main page, the observed sensor data was categorized into air quality, weather conditions, soil conditions, and water pump conditions. This data was displayed to users on their smartphones when they pressed the sensor data monitoring logo button on the main page. An illustration of the program using a 'use case diagram' can be seen in Figure 4. The sensor data displayed in this application was received in the form of analog voltage obtained from the sensors, which was transmitted through the cloud server by the IoT hardware system. The monitored sensors included sensors of rain, temperature, air humidity, soil moisture, wind speed, level of NH_4, CO_2, and PM2.5. The user of this application could also control the water pump using a switch, which was then sent to the cloud server. As seen in Figure 4, the application had login, logout, monitoring, and control features.

2.12. Designing the features of the application.

The feature testing is conducted through several methods as explained below. Initially, the login feature involves accessing the device by entering user account credentials and password to gain access rights to the device [27]. Here, users will access the login page to input their username and password by pressing the login button. If the user successfully logs in, the application will display the main page. In the case of a failed login attempt, the application will remain on the login page. Secondly, monitoring and control data stored by the cloud server will be displayed through view pages in the application. Thirdly, the logout feature will log the user out of the application. The system application block diagram can be seen in Figure 5.



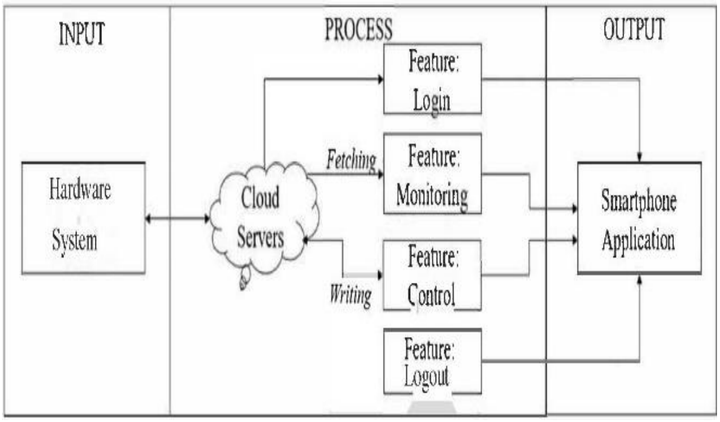


Figure 4. Illustration of the use case diagram for the developed application.

Figure 5. Block diagram of the developed application.

The fetching and writing function are designed to capture and transmit sensor data to the cloud server. The Fetching process in the application is designed for monitoring air quality, weather conditions and soil conditions, while the writing process is designed for controlling the water pump when the switch is pressed. Sensor data is stored in the cloud server, after which the sensor data will be displayed on the Android application view and read from the cloud server by issuing a "GET" request to the "URL" endpoint and sending data with REST API [28]. Firebase Cloud can serve as a real-time database, allowing the application to synchronize with the database [29], created through the console at https://Firebase.google.com. Users will obtain authentication keys and URL addresses to be used in the application connected to Firebase. ThingSpeak is a service that offers an Application Programming Interface (API), which is open source for storing and retrieving data from various devices using Hypertext Transfer Protocol (HTTP) over the internet [8]. ThingSpeak employs HTTP to connect the Android application with addresses to access resources present in each ThingSpeak cloud channel. These channels can be accessed using the following address:

a. https://api.thingspeak.com/channels/1160643/feeds/last.json?api_key=0C52E70NY1PIJ391&status=true
b. https://api.thingspeak.com/channels/1257596/feeds/last.json?api_key=U234GCAI8100EMST&status=true

This URL address is used to gather data on ThingSpeak. Last.json serves as the data exchange format that will be retrieved, while the API key code is a unique code present in each channel. This created Android application implements one of the web services, allowing connection with the application by entering the URL address in the MIT Inventor App2 program. The cloud server diagram used by the application can be seen in Figure 6.

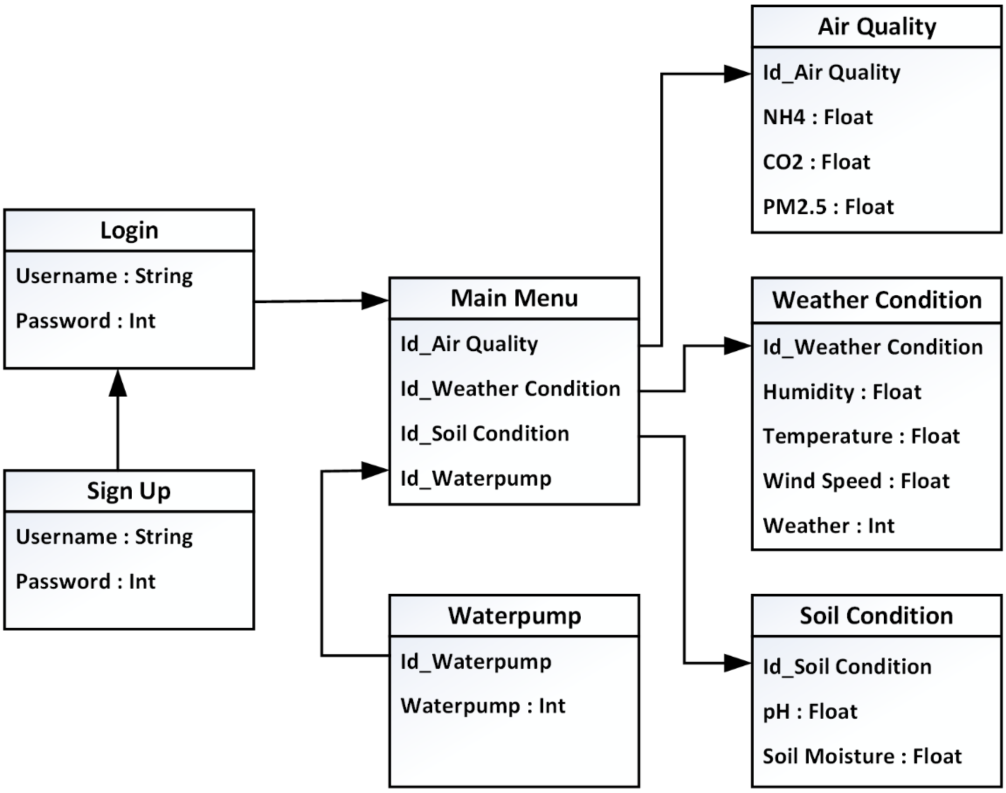


Figure 6. Cloud server diagram used in the application.

3. Results and Discussion

We conducted tests on the implemented system by seamlessly integrating all deployed modules. In order to provide power to the entire array of modules within the system, we harnessed solar panels as an energy source. The integration involved linking the weather station module, air quality module, water pump module, and water pH-level module to the Arduino Mega 2560 R3. The testing phase encompassed several stages. We initiated the process by monitoring the weather station module, which included components like the anemometer sensor, DHT11 sensor, and rain sensor. The air quality module, which incorporated an MQ-135 sensor and a PM2.5 sensor, was also observed. Furthermore, we scrutinized the water pump module, comprising a soil moisture sensor and a water pump. The data yielded by these sensors was presented as monitoring and control results, accessible through the serial monitor of the Arduino IDE. Subsequently, the accumulated data was transmitted via the GSM cellular communication module to an Android application on a smartphone, forming the basis for our upcoming research endeavor involving the application's construction. The transmission of data occurred over the internet. Notably, our system followed a 10-minute interval, sending monitoring and control data to a cloud server via the internet.

3.1. Testing results of environmental condition.

The test results in monitoring environmental conditions of the whole system can be seen in Table 1. The table shows the condition of air temperature, humidity and air quality on a particular day. The time of experiments in the first column of Table 1 was chosen to represent the time windows of morning, afternoon, evening and night.

Table 1. The performance of the IoT-based agricultural system for environmental conditions.

Time	Serial Monitor Output						
	Temp. (ºC)	Humidity (%)	Wind Speed (m/s)	Rain	CO_2 (ppm)	NH_4 (ppm)	PM2.5 (µg/m^3)
09.00	25	90	20	No	0.05	0.10	120
12.00	31	80	20	No	2.00	2.50	150
17.00	30	75	30	No	1.55	2.67	135
21.00	26	85	20	No	1.89	3.04	122

3.2. Testing results of soil condition and watering status.

As can be seen from Table 2, the observed pH level of soil is suitable for each type of used fertilizer, e.g. urea and compost. If the soil moisture sensor detected that the soil was dry, the water pump was activated.

Table 2. The performance of the IoT-based agricultural system for soil condition and watering status

Soil Fertilizer	Soil pH level	Soil Condition	Serial Monitor Output	
			Soil Moisture (%)	Water Pump
Urea	6.45	dry	40	ON
Compost	11.37	dry	45	ON
No fertilizer	7.20	wet	80	OFF

3.3.Testing results of the whole hardware system.

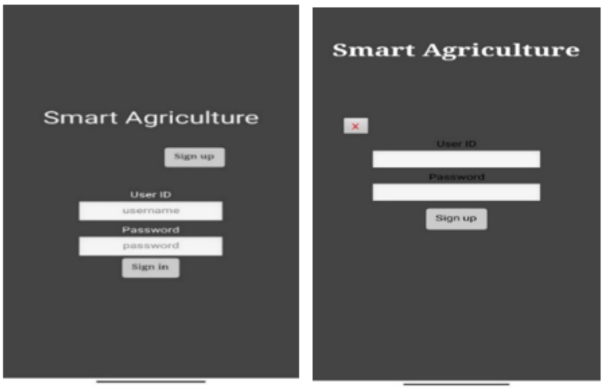
Table 3 shows that all designed modules of the system are functioning properly. Our system is very suitable to be implemented in the agricultural field in Indonesia.

Table 3. The performance of the IoT-based agricultural system

No.	Type of testing	Result
1.	Solar panels can supply the whole set	succeed
2.	The weather station module can monitor the weather	succeed
3.	The air quality module can monitor air quality	succeed
4.	The water sprinkler module can monitor and control the water pump	succeed
5.	The GSM module can connect the rest of system to the network	succeed
6.	The GSM module can send data over the Internet	succeed

3.4. Testing results of the application for monitoring and control.

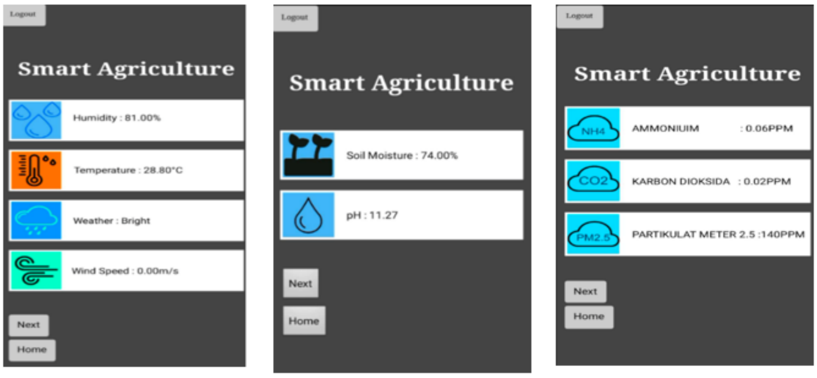
Figure 7a illustrates the login page view for accessing the main page of the created Android application. If a user has not registered an account in the application system, he/she can first register an account by pressing the sign-up button, as depicted in Figure 7b. The subsequent page that appears after a successful login is the main page (Figure 8), featuring four buttons for air quality monitoring, weather conditions monitoring and soil conditions monitoring, all covered by the ThingSpeak Cloud. Users can manually control the water pump by pressing the button on the main page. The created Android application will display graphs of environmental sensor data corresponding to the selected button, as shown in Figure 9. The overall results of application testing can be seen in Table 4.



(a) (b)

Figure 7. Display of the (a) login and (b) sign up page of the application.

Figure 8. Display of the main page of the application.



Humidity : 81.00%
Temperature : 28.80°C
Weather : Bright
Wind Speed : 0.00m/s

Soil Moisture : 74.00%
pH : 11.27

AMMONIUIM : 0.06PPM
KARBON DIOKSIDA : 0.02PPM
PARTIKULAT METER 2.5 :140PPM

(a) Weather condition (b) Soil condition (c) Air quality

Figure 9. Display of the monitoring pages of the application.

Table 4. The performance of the built monitoring and control application.

No.	Type of Android application testing	Result
1.	ThingsSpeak Cloud connects to the application	succeed
2.	Firebase Cloud connects to the application	succeed
3.	Login feature stores list of users	succeed
4.	Sensors' information is displayed on the application in smartphone	succeed
5.	Control feature sends data to ThingSpeak Cloud	succeed

4. Conclusions

Based on the results and discussion above, several remarks can be drawn from our designed system. The weather station module successfully collected data on air temperature, humidity, wind speed, and weather conditions. As expected, the air quality module retrieved data on the levels of CO_2, NH_4, and PM2.5 in the air. The water pump started automatically when the soil was dry and stopped when the soil was wet enough, based on data from the soil moisture sensor. The serial monitor's output was forwarded to a cloud server through the internet, and an Android application successfully acquired the data through the internet. The created application can acquire the user ID and password entered by the user, and the smartphone can effectively validate the user ID and password data. Secondly, the application can display information according to the current environmental and soil conditions and can execute water pump control. All functions of the entire system operate as expected, and the system functions well. Our developed system could be suitable for implementation in agricultural fields in Indonesia.

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Competing Interest

The authors declare that there is no any financial or personal conflict of interest with others.

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