

Embedded Smart Farming System for Soil and Hydroponic Planting Media Based on IoT

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Abstract: Smart agricultural technology by applying the internet of things (IoT) purposes to make farmers' work more efficient due to the automation system and assist farmers in monitoring the condition of their agricultural land. The focus of discussion in this research is the application of smart agriculture system technology that uses the concept of embedded systems for soil and hydroponic planting media. This system applies an automation system for water irrigation and fertilizer irrigation using four tanks, namely a water source, a water irrigation tank, a fertilizer tank, and a water circulation system in hydroponics. The system is also equipped with weather monitoring based on temperature, rainfall, and light intensity. Other parameters contained in this system are soil pH, water pH, TDS, fertilizer availability, and irrigation pump status. The monitoring system based on the Android application displays all parameters and the status of the devices used. The use of smart farming technology is highly recommended for utilizing limited land by employing soil and hydroponic planting media in one area, especially for vegetable crops. By utilizing an agricultural land monitoring system, farmers will be able to know the condition of their agricultural land at any time as long as they are connected to the internet.

Keywords: Embedded system,; smart farming; internet of things (IoT); soil planting media: hydroponic planting media

INTRODUCTION

The increasing population will lead to a rise in demand for residential land, which will reduce agricultural land and impact food shortages (Vagisha, Rajesh, Basheer, & Baskar, 2023), meanwhile, the challenge faced by agricultural developers is managing the transition from conventional farming to modern practices by implementing smart farming (Farooq et al., 2022). Smart farming is a modern agricultural concept that utilizes digital and information technology to enhance efficiency, productivity, and sustainability in crop and livestock production (Sciforce, 2023). The application of the Internet of Things (IoT) in smart systems is currently growing rapidly, including in smart farming.

The planting media in agriculture includes not only soil, but also hydroponic systems. There are many reasons that encourage the use of hydroponic systems, including the rapidly increasing global food demand projected until 2050 (Lakshmanan, Djama, Selvaperumal, & Abdulla, 2020). Plants that are widely grown through hydroponics are vegetables, which have become a primary necessity in this world. By utilizing a hydroponic planting system, it will assist the community in growing vegetables despite the limited available land. Hydroponics uses less water and other resources compared to land or soil media, where hydroponic planting systems can yield high harvests with minimal consumption (Atmaja & Surantha, 2022). The troublesome aspect of hydroponics is the daily maintenance, such as maintaining temperature, pH, and nutrient stability. The solution is to use IoT for automation in the hydroponic system (Naveena, Saheb, Mamidi, & Murthy, 2024).

Several important aspects related to the technology needed in smart farming include a plant monitoring system to keep crops free from pests and diseases. One method employed is an irrigation system that operates correctly without human intervention (Mathi, Akshaya, & Sreejith, 2022) (Morichid et al., 2024). In addition, farmers also need weather information to determine the right time for planting to avoid crop failure. Smart farming technology that can help farmers be productive and efficient because they can plan the time to plant, fertilize, water, harvest, review land conditions (pH, soil moisture, and temperature) and other environmental parameters is by implementing IoT in the smart farming system where farmers get access to monitor the condition of their

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agricultural land through a monitoring system application (Bhatt, 2020). This IoT technology thus allows all agricultural devices and equipment to be linked together to make informed decisions on irrigation and fertilizer supply (Said Mohamed et al., 2021). Maintaining the right balance of NPK is very important for plant nutrition. Environmental factors that influence NPK composition such as temperature, rainfall, moisture and soil pH (Purohit, Kumar Singh, & Chatterjee, 2024)(Toselli, Baldi, Ferro, Rossi, & Cillis, 2023).

Based on the explanation above, this research develops a smart farming system using soil and hydroponic planting media by employing the concept of embedded systems for both types of planting media. This system is designed to be embedded for both the soil and hydroponic media to make use of available land, allowing farmers to take advantage of limited space while simultaneously planting with hydroponic media on the same land. This research discussion focuses on the technology used rather than the type of plants. System testing is conducted in the form of a prototype, but the technology developed in this research can already be directly applied in real-world environments and allows for real-time monitoring data reading.

The results of this research will provide recommendations on the technologies used in agriculture to achieve the goals of smart farming systems as mentioned above.

LITERATURE REVIEW

In this research utilizing embedded systems, IoT is applied in smart farming. The system is made embedded with the aim of how to utilize a narrow area for farming with soil and hydroponic media planting systems. Hydroponic planting media is a planting media used in agriculture that is suitable for small land (Kushawaha, Shah, Vora, Zade, & Iyer, 2024). Population growth is rapid and agricultural land is decreasing, while the demand for food is increasing, so the solution is to utilise hydroponic planting media (Malkawi, Hagare, & Maheshwari, 2024).

This research offers how to make IoT-based smart farming system technology where IoT is an effective solution in managing agricultural problems applied in smart farming (Mathi et al., 2022) (Said Mohamed et al., 2021). The embedded system aims to monitor and control several systems in smart farming such as irrigation systems, fertiliser systems and weather monitoring systems on agricultural land.

In previous research, an embedded system was used in smart farming where all sensors (temperature sensor, soil moisture sensor, and rain detector sensor) were embedded in the AVR microcontroller (Ashokkumar, Krishnagandhi, Kannan, & David Solomon Raju, 2020). It is used in smart farming for an Internet of Things-based smart irrigation management system to enhance agricultural water security by using many sensors as inputs (temperature, humidity, soil moisture, and water level) incorporated in a system they called the embedded controller (Morchid et al., 2024). Another study proposes a smart hydroponic system that combines hardware and software, allowing users to set up productive and efficient farms in small-scale and constrained urban situations such as homes (Kushawaha et al., 2024).

In this research, an embedded system is utilized for embedded smart farming (soil and hydroponic planting media) by integrating weather monitoring systems (air temperature, air humidity, and light intensity), soil conditions (pH and soil moisture), hydroponic water conditions (pH and TDS), smart irrigation, and smart fertilization. The system in this research not only creates an embedded hardware and software system based on IoT but also develops agricultural land with embedded soil and hydroponic planting media that can be utilized for limited (narrow) areas, especially for vegetable crops.

METHOD

Research Stages

The stages in this research, as shown in Fig. 1, start from literature review, identification of needs, designing and building a system, testing the system and analyzing the system.

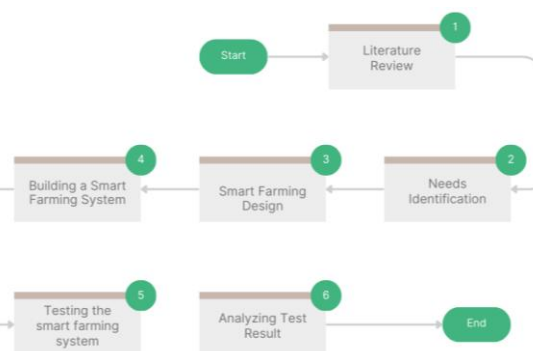


Fig. 1 Research Stages

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Automatic System Design (Hardware)

The smart farming system developed in this research consists of several main components, namely the smart farming system with soil planting media (master and slave), the smart farming system with hydroponic planting media, and the gateway system. The block diagram of the entire system looks like Figure 2. The description of each part of the smart farming system is presented in Table 1.

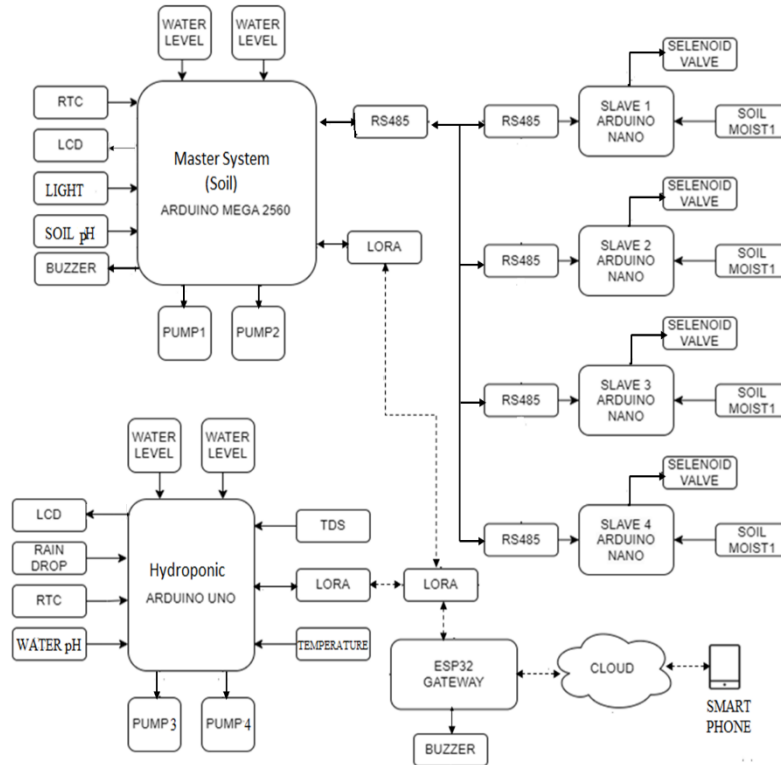


Fig. 2 The Block Diagram of Embedded Smart Farming System

There are five primary components, as shown by the block diagram in Fig. 2 are the irrigation system, gateway, hydroponics, soil planting media master system, and monitoring system. The devices in the smart farming system consist of 1) a real-time clock module (RTC-DS3231 I2C) for reading the time in real-time and determining the timing for automatic fertilization, 2) light sensor (BH1750) is used to read light intensity (Lux) in agricultural areas, 3) The soil pH sensor reads the soil pH value to determine soil moisture levels, 4) the water level sensor determines the water level in the irrigation and fertilization tank, 5) the rain drop sensor is used to detect rain in the agricultural area, 6) the temperature sensor is used to read the air temperature in the agricultural area, 7) the total dissolved solids (TDS) sensor measures the total dissolved solids in the water, 8) the liquid crystal display (LCD 20x4 with I2C) is used to display the sensor readings, 9) the buzzer is used to provide an audio notification as an indicator that the water in the irrigation tank is running out, 10) the water pump is used for irrigation and fertilization, 11) the solenoid valve is used to control the water flow based on the measured soil moisture level, 12) the RS485 module is used to support data transfer speed, 13) the microcontroller modules used are Arduino and ESP32, 14) the monitoring system uses an application created through MIT App Inventor. The working system of each component is explained in Table 1.

Table 1. Smart Farming System Specifications

Specification	How It Works	Planting Media	Hydroponic
Water Irrigation	Automatic by utilizing a water level sensor to determine the remaining water level in the water tank and will be filled automatically through the water source provided.	√	√
Fertilizer Irrigation	Notify when the fertilizer is running low and the liquid fertilizer is manually refilled..	√	√

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Specification	How It Works	Planting Media	Hydroponic
pH	Automatically reads via pH sensor to determine soil/water pH.	√	√
Light	Automatically reads via light sensor for weather conditions.	√	√
Temperature	Automatically reads via temperature sensor for weather conditions.	√	√
Rainfall	Automatically reads via raindrop sensor to determine rainfall and weather.	√	√
Soil moisture	Automatically read through the soil moisture sensor.	√	-
Water Tank (Pump 1)	Activating water irrigation.	√	√
Fertilizer Tank (Pump 2)	Activating fertilizer irrigation.	√	√
Water source tank (Pump 3)	Activating water source for soil watering and hydroponic water circulation.	√	√
Water Circulation Pump (Pompa 4)	Activating water circulation in hydroponics.	-	√
Valve	Carrying out the watering process.	√	-
Buzzer	Indicators of water level, fertilizer, water circulation, water source, and network connection.	√	√

Monitoring System Design (App)

This smart farming system is accompanied by a monitoring system for the environmental conditions of soil and hydroponic planting media. All data readings through the sensors and actuators used will be sent to the application to display the readings so that farmers can see the condition of their agricultural land. This system design is shown in Fig. 3. Some of the things monitored in this system are soil moisture for 4 locations, air humidity, air temperature, pH, rain status, fertilizer status, water status in watering tanks and water sources, valve status (spray water), water pump status and fertilizer pump status.

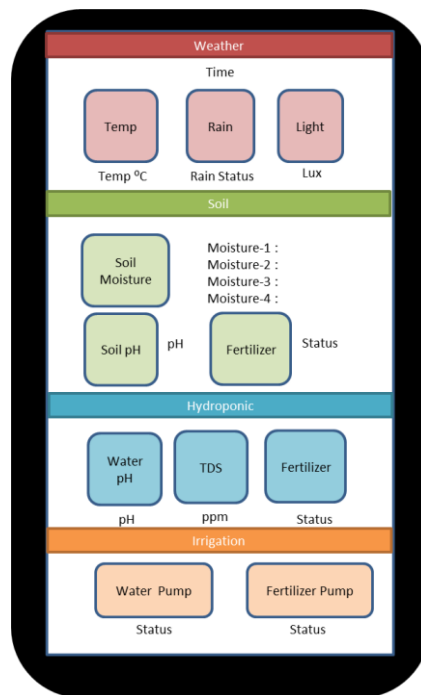


Fig 3. Smart Farming Monitoring System Design

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RESULT

The test results of the soil media irrigation system are shown in Table 2. The ideal soil moisture value for various plants ranges from 30% to 70% [13]. In this research, for system testing, the program is set with the condition that if the humidity read is below 50%, it is considered that the soil has started to dry, so the system will activate the pump1 in tank1 (watering water for plants) will be on. If the soil moisture reading is 70%, pump 1 will automatically turn off.

Tabel 2. Soil Media Irrigation System Testing

Sub System	Output Data	System Response
Based on soil moisture (Ideal: 50%-70%)	Read: humidity <50%	Watering process: Pump 1 On, Valve On,
	Read: Humidit ≥70	Pump 1 Off, Valve Off
Based on Tank 1 Water Level (Watering)	Read: Water level ≤5 cm	Tank 1 Water Filling (empty water): Buzzer 1 On (5 seconds), Pump 2 On
	Read: Water level ≥25 cm	Water tank 1 full: Pump 2 Off
Based on Tank water level (water source)	Read: Water level ≤5 cm	Tank 1 (Water source): Tank 2 is empty, Buzzer 2 On
	Read: Water level ≥25 cm	Tank 2 full

As for filling tank1 (watering) and tank2 (water source) is done based on the water level using a water level sensor. In the program, if the water level read from the bottom of the tank is less than 5 cm, tank1 will fill the water automatically by channeling water from tank2 to tank1 as an indicator, buzzer1 will sound (on). In addition, if the water level is read equal to 25 cm, the tank1 water filling process is complete and stops automatically. The same applies to the water source, but it is filled manually.

Table 3 shows the test results of the hydroponic irrigation system. Similar to the irrigation system on soil media, water filling in the hydroponic system is based on the water level, but the difference is that water circulation must run continuously.

Table 3. Hydroponic Irrigation System Testing

Sub System	Output Data	System Response
Based on tank water level 2	Read: Water level ≤5 cm	Tank 1 (Water source): Tank 2 is empty, Buzzer 2 On, Pump 3 Off
	Read: Water level ≥ 25 cm	Tank 2 full,
Based on tank water level 3	Read: Water level ≤5 cm	Water circulation: Pump 3 Off,
	Read: Water level ≥ 25 cm	Pump 3 is always on

Table 4 presents the results of the nutritional system testing for soil and hydroponic media. In this study, the fertilizer used is liquid fertilizer, with the stipulation that the tank filling (source of liquid fertilizer) is the same as the irrigation system requirements. The fertilization process will be carried out according to the scheduled time. In this study, the time is set to 08:00 AM, and fertilization will be conducted for 2 minutes, after which the fertilization process will stop automatically. Time reading by utilizing an RTC module that reads the time in real time. The time of fertilization and the level of fertilizer delivered can be adjusted according to the needs of the farm.

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Table 4. Ferlization System Testing

Sub System	Output Data	System Response
Based on Fertilizer Level (Tank 4)	Read: Water level ≥ 25 cm	Fertilizer filling: Pump 4 Off, Buzzer 3 on
	Read: Water level ≥ 25 cm	Full fertilizer
Time (RTC) (Time Display on LCD)	Time read: 08.00 A.M.	Fertilization Process: Pump 4 On (time set as needed)
	Time read: 08.02 A.M.	Fertilization completed: Pump 4 Off (time set as needed)

Testing the weather monitoring system as shown in Table 5. Weather monitoring is seen from the readings of temperature, rainfall and light intensity that are read in the environment through sensors. All these readings are displayed on the LCD and sent to the monitoring system (app).

Table 5. Weather Monitoring System Testing

Sub System	Output Data	System Response
Temperature	Reading in $^{\circ}\text{C}$	Send the read temperature data to the app and display it on the LCD
Rainfall	No rain (read data = 0) Rain (read data = 1)	Send the read rain status to the app and display it on the LCD.
Light Intensity	Reading the intensity of light in lux units.	Send the read light intensity data to the app and display it on the LCD

The monitoring system that can be accessed through the Android application as shown in Table 6. Some of the parameters displayed in this monitoring system are temperature, rainfall, light intensity, pH, water irrigation status and nutrients. This monitoring system will help farmers monitor the condition of the farm and take action if needed.

Table 6. Monitoring System on Android Application

Sub System	Input Data	System Response
Temperature	Receive temperature data in $^{\circ}\text{C}$	Display the temperature value
Rainfall	Receive rain status: No rain (data = 0) Rain (data = 1)	Display rain status
Light Intensity	Receives light intensity value in lux	Display the light intensity value
Soil pH	Receive soil pH value	Display the soil pH value
Water pH	Receive water pH value	Display the water pH value.
Fertilizer	Receive fertilizer status data =0 (no fertilizer) data =1 (fertilizer present)	Display fertilizer status data
TDS	Receive TDS value data	Display TDS value
Pumps	Receive pump status data data = 0 (pump off) data =1 (pump on)	Display pumps status

Table 7 is a table of testing the Wifi network used. The internet network in a smart farming system is very important, so this research is also accompanied by a warning when the internet network is disconnected through a buzzer4. If the connection is lost then the buzzer sounds, thus notifying the farmer who is around the land about this condition.

Table 7. Network Testing

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Sub System	Output Data	System Response
Network Connection	Not connected	Wifi network disconnected / not connected : Buzzer 4 On
	Connected	Network connected: Buzzer 4 Off

The prototype of embedded smart farming is as shown in Fig. 4 and Fig.5. This system is designed with a soil media size of 1,600cm x 100cm, for hydroponic media with a media size of 40cm x 30cm x 50cm.



Fig. 4 Embedded Smart Farming Prototype for Soil and Hydroponic Planting Media (side view).



Fig. 5 Embedded Smart Farming Prototype for Soil and Hydroponic Planting Media (front view)

Fig. 6 is the output of the sensor value readings displayed through the Arduino IDE serial monitor and the smart farming monitoring system interface in the form of an application created using MIT App Inventor.

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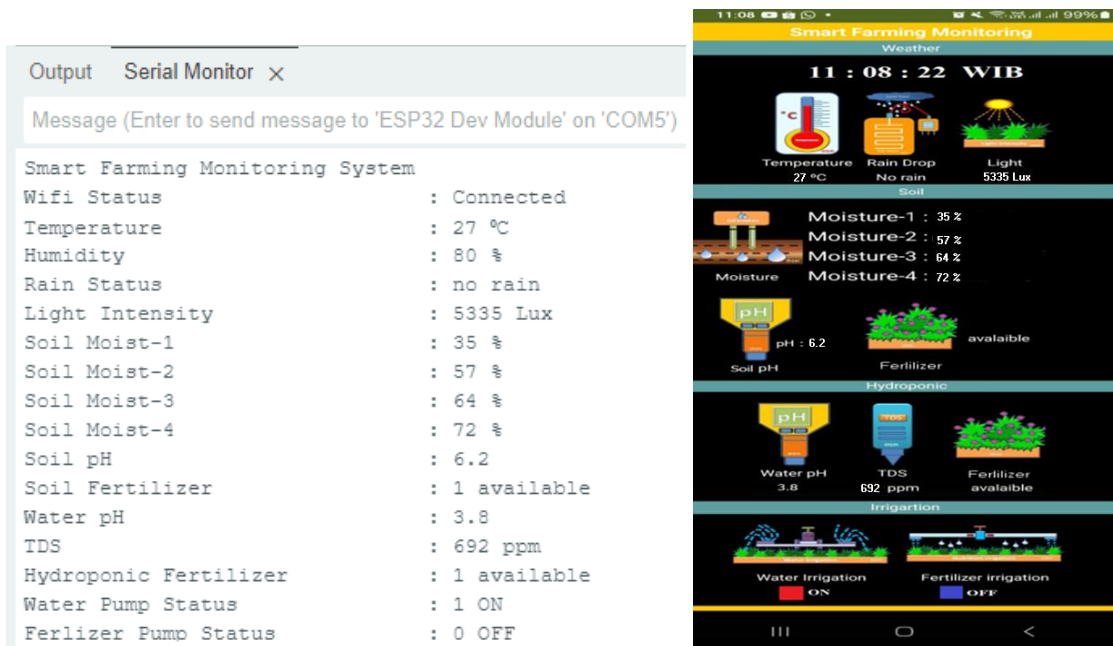


Fig. 6 Arduino IDE Serial Monitor Output and Monitoring System Output

DISCUSSIONS

Based on the results of this research, it produces smart farming technology that is tested in the form of a prototype. This system uses several sensors that serve as inputs categorized into weather monitoring, soil media monitoring, hydroponic media monitoring, and irrigation systems. All data read through the sensors will be sent to the IoT platform, in this case, Firebase, and then forwarded to the monitoring system application. In the monitoring application, all sensor reading data will be displayed so that farmers can know the condition of the land at any time, anywhere, and anytime. As a warning system, this system uses a buzzer as an indicator for internet disconnection, empty water tank, and empty fertilizer. For the water tank, it can be filled automatically and watering can be done automatically. For fertilization, it can be done automatically, but if the liquid fertilizer runs out, it must be handled manually because the liquid fertilizer requires a mixture with a predetermined ratio, which the system does not currently address. In this system, LoRa modules are also utilized so that the devices can be monitored from a distance.

CONCLUSION

This research produces a technology by applying the internet of things to smart farming which consists of a water irrigation system, fertilization system, weather station system, farming land condition information, and monitoring system in the form of an Android-based application. The weather station system with parameters are temperature, humidity, rainfall, and light intensity. The land condition monitoring system with parameters are soil pH, water pH, TDS, nutrients, and soil moisture. All these parameters and the status of the devices on the irrigation system are displayed in the monitoring system application. This system is made in an embedded for agricultural systems with soil and hydroponic planting media which aims to assist farmers in utilizing limited land or utilizing land for these two planting systems. In the future, this research can be developed to be tested in a real environment and develop a web-based application with a database to store all agricultural monitoring data history.

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