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Smart Irrigation System Using ESP32 with Real-Time Soil Moisture and Temperature Monitoring via the ThingSpeak IoT Platform

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Abstract— **Water scarcity and ineffective water management are persistent issues facing the agriculture sector that have a big impact on crop hauls and operating expenses. Conventional irrigation techniques, which frequently include physical intervention, are labor-intensive and prone to inefficiencies including underwatering and overwatering. These practices lead to the waste of valuable water and energy resources, worsening the sustainability issue in agriculture. This paper presents the development and implementation of an IoT (Internet of Things) based automatic irrigation system designed to address these challenges, in line with Malaysia's climatic conditions. The suggested system makes use of microcontrollers (ESP32) and temperature and soil moisture sensors (DHT11) to automate watering and monitor soil conditions in real time. The system's integration of cloud computing guarantees accurate water distribution that is customized to the unique requirements of crops, maximizing water consumption and augmenting crop yield. As a result, when the temperature (°C) is high and the humidity (%) is low, the water pump is automatically activated. The recorded soil moisture data is then stored and visualized in ThingSpeak, enabling easier analysis and supporting informed decision-making for future irrigation planning.**

Index Terms—**Internet of Things (IoT), smart irrigation system, soil moisture sensor, temperature sensor, Thingspeak**

I. INTRODUCTION

Efficient water management has become a critical priority in modern agriculture due to growing concerns over water scarcity, climatic variability, and the rising demand for sustainable food production. Due to global warming and water pollution, clean, usable water is becoming increasingly limited. Thus, managing water use in irrigation techniques is vital for sustainable agriculture and gardening [1], [2], [3]. One of the biggest challenges in agriculture is the effective use of water resources. Conventional watering techniques might result in under or overwatering, which would waste water and result in poor plant development. Although it was effective in the past, traditional irrigation techniques mostly cause significant water waste and uneven crop watering. Therefore, integrating technology into irrigation systems has become an essential strategy for optimizing water usage while maintaining crop performance [4], [5], [6].

The impact of the COVID-19 pandemic on agricultural food yield has made food security a major global concern [7], [8]. Malaysia was also affected by COVID-19 in terms of the nation's agriculture and raw food supply [9]. The purpose of this work [10] is to explore opportunities for enhancing existing practices in the agricultural sector. The proposed technological integration includes mechanization, automation, irrigation system and the application of advanced technologies. This research is consistent with the initiatives of the Malaysian Agricultural Research and Development Institute (MARDI) in advancing Agriculture 4.0, wherein Industry 4.0 (IR4.0) technologies are adopted to minimize labor dependency, reduce production time, and improve overall productivity and food quality [10].

Precision irrigation through Internet of Things (IoT) frameworks has emerged as a cornerstone of modern smart agriculture, enabling dynamic resource management driven by real-time microclimate data [11]. By shifting from manual schedule-based watering to sensor informed decision-making, automated systems optimize water use efficiency and mitigate crop stress caused by environmental fluctuations. Central to this paradigm shift is the seamless synthesis of field sensors, processing microcontrollers, and cloud telemetry, which collectively minimize manual labor while optimizing water application rates. For rapid prototyping and empirical data analysis, platforms like ThingSpeak provide a robust cloud architecture, facilitating real-time telemetry visualization and historical trends evaluation alongside microcontroller based hardware [12], [13].

IoT can greatly impact the efficiency of a system in agriculture. By using a soil moisture sensor, added with IoT, it can record data on trends surrounding the soil. To provide farmers with timely information on irrigation, planting, and harvesting schedules, [10] designed an automated agricultural system with weather monitoring capabilities. The data from local weather forecast is used to monitor wind speed, temperature, and humidity of the atmosphere. The works in [14], [15] monitor weather using IoT for their smart farming

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project. It use temperature sensors, pressure sensor, rain sensor and moisture sensor to predict the suitable condition for crop growth and better crop yield [16]. Automated and smart irrigation systems will help ensure that the crops get the correct amount of water at the correct time and therefore help to reduce water use. Along with saving water, this encourages better plant development and greater yields [17].

This paper presents the development of a real-time soil moisture monitoring and automated irrigation system using a microcontroller and the ThingSpeak IoT platform, designed for Malaysia's climatic conditions. The system continuously measures soil moisture levels, transmits the data to the cloud, and automatically activates a water pump when moisture drops below a defined threshold. The proposed system demonstrates how IoT-enabled automation can contribute to sustainable water management and support smart agriculture initiatives.

II. METHODOLOGY

This paper focuses on the integration of modern technologies, specifically utilizing the ESP32 microcontroller. The work aims to address the challenge of optimizing water usage in agricultural settings through automated monitoring and control mechanisms. The automatic watering system developed incorporates several key components, including the DHT11 sensor and moisture sensor for environmental data collection, the ESP-32 microcontroller for processing and control, an OLED display for real-time feedback, a regulator for power management, and water pump. These components were selected based on its compatibility and availability in the simulation software. ThingSpeak, an IoT software with the main function of graphing and tabling data is used to record data in an accessible and readable way for its users.

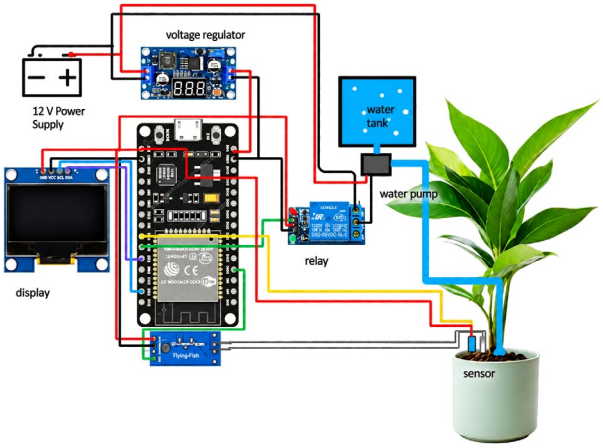


Fig. 1. System diagram Smart Irrigation System.

The ESP-32 connects the whole system together as in Fig. 1. The sensors used in the system is placed on the soil of the plant to have an accurate reading of the soil's parameter. The water pump has a water pipe to connect the water source to the plant's soil. The water pipe is placed near the soil moisture sensor to control the water poured into the soil.

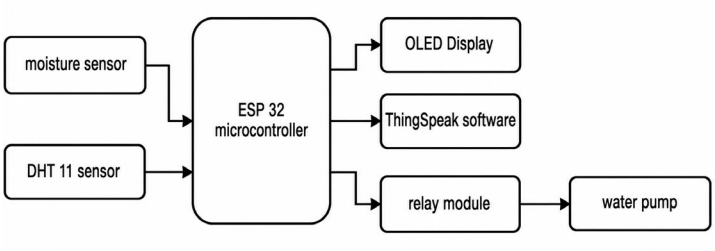


Fig. 2. Block diagram of the system.

Fig. 2 shows the block diagram of this project. It consists of a DHT11 sensor, a moisture sensor, an ESP-32 microcontroller, OLED display, a relay module, and a water pump. the ESP-32 microcontroller receives data from the DHT11 and soil sensor which is the soil moisture and temperature level. The data recorded will be displayed on the OLED display. After reading the data, the ESP32 microcontroller will compare the data to the threshold written down in the microcontroller. If the humidity is lower, and the temperature is higher than the threshold, the microcontroller will switch on the water pump.

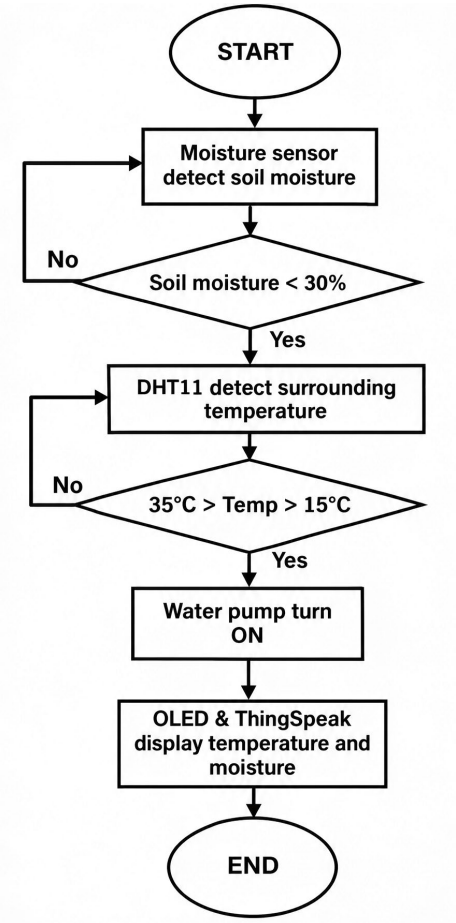


Fig. 3. Flowchart of the Smart Irrigation System.

Fig. 3 illustrates the overall process of the project. The ESP32 microcontroller evaluates the readings from the DHT11 and soil moisture sensor based on predefined thresholds, where soil moisture must be below 30% and temperature must fall between 15°C and 35°C [16], [19]. If these conditions are not satisfied, no action is initiated. The water pump operated continuously for 2–3 minutes or until the soil moisture level

reached 30%, whichever occurred first. The ESP32 subsequently transmits the sensor data for display on the OLED screen, and all readings are simultaneously uploaded and recorded on the ThingSpeak platform.

A. Circuit Diagram

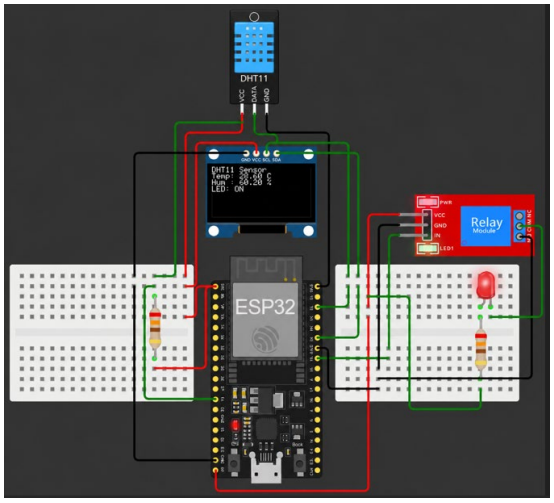


Fig. 4. Circuit diagram of the Smart Irrigation System.

The circuit diagram using Wokwi software in Fig. 4 shows how each component is connected and implemented in the hardware's wiring. The DHT11 sensor is connected to GPIO pin 14. The relay connecting the LED to the ESP32 is connected to GPIO pin 19. The i2c OLED display is connected to GPIO pin 21 and 22 as it is the default pin for the display pin. The red wires are all the power source pins.

B. Parameter Setup

Table I presents the classification of ambient temperature conditions based on the temperature in Malaysia. The temperature ranges are grouped into categories that reflect the environmental suitability for plant growth. This classification helps determine how environmental temperature influences irrigation needs and plant health during system testing.

TABLE I. TEMPERATURE RANGE

Temperature Range	Condition
0°C -14°C	Too cold
15°C -19°C	Cold
20°C - 24°C	Normal
25°C - 29°C	Optimal
30°C – 34°C	Hot
> 35°C	Too hot

Table II describes the soil moisture classification used to interpret the readings from the soil moisture sensor. The percentage ranges correspond to different soil hydration conditions. This categorization is essential for defining the irrigation threshold values used in the automated watering system. The ESP32 triggers the water pump based on these moisture categories to maintain optimal soil conditions for plant growth.

TABLE II . SOIL MOISTURE RANGE

Soil Moisture (%) Range	Condition
0 – 9%	Too dry
10% - 19%	Quite Dry
20 – 29%	Dry
30% - 39%	Moist
>40%	Wet

Table III presents the decision logic used by the smart irrigation system to control the water pump based on two key environmental parameters: soil moisture percentage and temperature. The system uses data from a soil moisture sensor and a DHT11 temperature sensor, and the ESP32 microcontroller determines whether the water pump should be activated according to the defined threshold conditions. The water pump will automatically turn OFF at high temperatures to protect the plant from heat damage. Although the soil moisture level indicates dry conditions, the water pump remains OFF when the ambient temperature exceeds the predefined threshold. This control strategy is implemented to prevent thermal stress and potential damage to the plants. The water pump is activated only when dry soil conditions are detected and the ambient temperature remains within the specified operating range. Under Malaysian climatic conditions, the ambient temperature typically decreases to below 35°C during the evening. Consequently, when the soil remains dry and the temperature falls below the predefined threshold, the water pump is automatically activated to irrigate the plants.

TABLE III . WATER PUMP CONDITION

Soil Moisture (%)	Temperature (°C)	Water pump
<30% (Dry)	35°C > Temp > 15°C	ON
<30% (Dry)	<15°C (Cold)	OFF
<30% (Dry)	>35°C (Too Hot)	OFF
>30% (Moist)	35°C > Temp > 15°C	OFF

C. Connection Setup

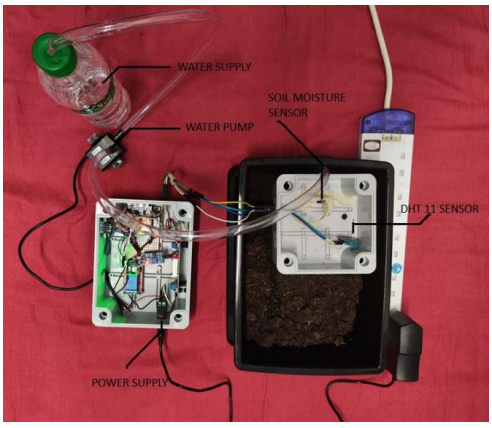


Fig. 5. Connection Setup for Smart Irrigation System.

The connection setup in Fig. 5 integrates sensing, control, and irrigation components to enable automated watering based on real-time soil conditions. The ESP32 microcontroller serves as the central processing unit and is housed within an electronics enclosure alongside the required circuitry and power connections. A soil moisture sensor is placed directly in the

planting tray to measure the volumetric water content of the soil, whereas a DHT11 sensor is positioned beside the tray to capture ambient temperature and humidity. Both sensors are wired to the ESP32 input pins for data acquisition.

A DC water pump connected to a water reservoir delivers irrigation through a transparent tube to the soil bed. The pump is powered and controlled via the ESP32, which activates it when the soil moisture level falls below a predefined threshold. The entire system is powered through an external supply and operated continuously. All sensor readings and system responses are transmitted to the ThingSpeak IoT platform, enabling real-time monitoring and data visualization

D. ThingSpeak

The data from the sensor are also sent to the ThingSpeak software where it is displayed and recorded in a graph. The soil moisture and temperature reading will be recorded and presented in a graph. The water pump status also displayed in ThingSpeak using an LED as an indicator. Whenever the water pump is turned on in the simulation, it will also show in ThingSpeak.

III. RESULTS

TABLE IV . SIMULATION AND HARDWARE RESULT

	Soil Moisture (%)	Temperature (°C)	Condition	Water pump
Simulation Result	4%	30	Too dry & Hot	ON
	43%	30	Wet & Hot	OFF
	20%	10	Dry & Too cold	OFF
	20%	38	Dry & Too hot	OFF
Hardware Result	4%	30	Too dry & Hot	ON
	43%	31.3	Wet & Hot	OFF
	25%	28	Dry & Optimal	ON
	68%	28	Wet & Optimal	OFF

Table IV presents the simulation results obtained from Wokwi and the corresponding results from the prototype hardware. By adjusting the temperature variable in Wokwi, the corresponding outcomes can be observed. When the temperature exceeds the predefined thresholds of below 15 °C or above 35 °C, and the soil moisture level is less than 30%, the water pump will activate. Otherwise, the relay module remains idle, and the sensors continue to read and transmit data to the OLED display via the ESP32. For the hardware results, the prototype was tested with different soil moisture and temperature levels. The water pump was activated based on the same threshold values programmed into the ESP32. The Wokwi simulation closely matched the expected behavior of the system. The simulated environment effectively demonstrated the system's response to changes in temperature and humidity.

For hardware result, the DHT11 sensor and soil moisture sensor provided consistent temperature readings throughout the testing period. With the temperature threshold set between 15°C and 35°C and humidity at 30%, the relay module successfully activated the water pump whenever the soil moisture dropped below the predefined threshold. On average, the water pump was activated 5 times per day for durations of 2-3 minute. The OLED display accurately showed real-time temperature, humidity, and system status. ThingSpeak was able to record the data from the readings of the sensor.

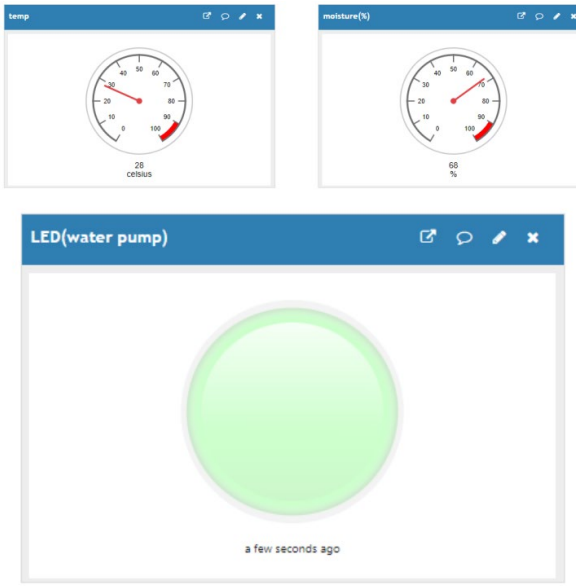


Fig. 6. Display on the ThingSpeak software.

Fig. 6 shows the ThingSpeak display of temperature (°C) and soil moisture (%) readings obtained from the DHT11 sensor and the soil moisture sensor. ThingSpeak was able to record the data from the readings of the sensor. However, as there are no water pumps in Wokwi, water flow level was not able to be recorded and had to be replaced with an LED as an indicator for the water pump. The figure indicates that the LED turned ON briefly before the water pump activated, which increased the soil moisture to 68%. Once the moisture level reached this value, the LED turned OFF.

The soil moisture percentage is continuously recorded and visualized as a graph using the ThingSpeak platform. Fig. 7 presents the moisture readings captured between 10 and 12 January. While the graph in Fig.8 shows temperature readings recorded over time using ThingSpeak. The x-axis represents the date and time, while the y-axis represents the temperature (°C).

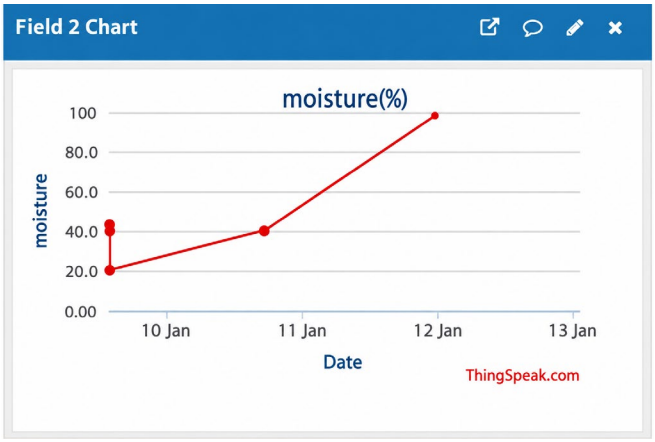


Fig. 7. Moisture reading record and display using ThingSpeak software.

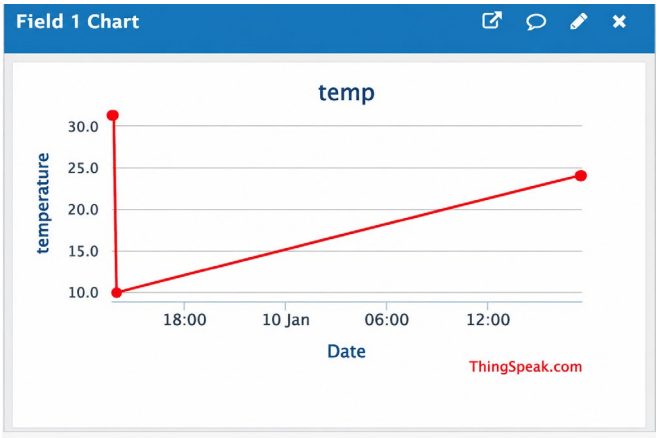


Fig. 8. Temperature reading record and display using ThingSpeak software.

IV. Conclusion

In conclusion, a smart irrigation system utilizing the ThingSpeak IoT platform was successfully developed and evaluated under Malaysia's ambient temperature conditions. Experimental results indicate that the system is capable of continuously sensing soil moisture and temperature parameters and autonomously actuating the water pump based on predefined threshold conditions. Furthermore, real-time sensor data are transmitted to the cloud for storage and graphical visualization, enabling systematic data analysis and supporting informed, data-driven decision-making for optimized irrigation scheduling and management.

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