Real-time soil monitoring and irrigation system for taro yam cultivation

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ABSTRACT

The yam cultivation industry faces hurdles in satisfying the world's rising demand. Meanwhile, agricultural activities encounter issues such as monitoring systems for soil composition that are not directly integrated with the irrigation system. Hence, this research aims to develop an irrigation and soil monitoring system using NodeMcu ESP8266 for taro yam cultivation. A soil composition and irrigation device were developed using NodeMcu ESP8266 to control the irrigation system autonomously. Then, the real-time monitoring systems using Blynk 2.0 was designed. The final method is used to test the irrigation and soil monitoring system in a taro yam growing area. The results show that the irrigation and soil monitoring system reduced water usage by about 32.5%, as the 3.6 liters of water used daily before applying the irrigation and soil monitoring device was reduced to 2.43 liters per day. In conclusion, the developed device can conveniently display the ambient air's humidity, temperature, and soil moisture conditions on smartphones and desktops. In addition, this system can maintain soil moisture according to a set value, which can prevent excessive water use for taro yam cultivation.

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1. INTRODUCTION

Agriculture is critical for increasing the food supply and ensuring food security [1]–[4]. In 2018, the global population surpassed 7.6 billion and is expected to reach 9.7 billion by 2050, with a projected increased food demand of 59-102% [5], [6]. If such projections are accurate, agricultural productivity must be expanded by approximately 60-70% to feed the world's population in 2050 [7], [8]. Hence, a sophisticated and efficient system is needed to increase crop yields to meet the global food demand. Integrating numerous variables in agricultural production systems is necessary to maximize crop yields while minimizing these systems' environmental impact.

Assessing the soil's present and reserved-nutrient status, understanding its nutrient-release and nutrient-holding capacity, and knowing plant-based and environmental factors that impact nutrient availability are necessary to guide fertilization rates, sources, and methods of applying additional nutrients [9], [10]. Information about current conditions, such as the surrounding temperature, humidity, and nutrition supplied, is intended to provide fundamental principles to aid farmers' management decisions related to factors affecting crop growth. Furthermore, soil condition is vital to maintaining a diverse community of soil organisms that help control plant diseases and insect and weed pests. A proper soil condition benefits symbiotic relationships with plant roots, recycles essential plant nutrients, improves soil structure, benefits soil water and nutrient-holding capacity, and ultimately improves crop production [11]–[13].

The agricultural industry contributes significantly to water waste, as watering and harvesting crops consume substantial amounts of water [14], [15]. This level of water consumption can be classified as a waste that needs to be addressed, as clean water resources are essential for people's daily lives, not just for agriculture. Hence, efficient and cost-effective irrigation systems should be applied to agriculture to address the problem of high-water consumption. For example, researchers [16]–[18] have developed a smart agriculture management system consisting of two modules (data monitoring and crop prediction) to address high water consumption in agriculture. Although farmers can monitor soil conditions and the data acquired by the sensors, the system cannot record the amount of water that farmers have used throughout their agricultural activities. Various technologies have been implemented in agricultural systems, but problems still arise in existing systems. Environmental considerations such as the usage of clean water resources must be considered while using technology in agriculture today. The agriculture industry should utilize clean water to its full potential without being squandered. Irrigation systems should give an amount of water that corresponds to the needs of plants, such as taro yam (Colocasia esculenta), for which water should be kept at a depth of 2.5 to 5.0 cm when new roots are developing and the first leaves appear [19]–[21]. Hence, crops require a specific amount of water, and the existing system cannot supply the correct amount of water.

One significant problem is that the existing soil composition monitoring system is only focused on monitoring the readings from the sensors for analysis without being connected to the irrigation system [22], [23]. For example, the system does not channel water to the plants when the soil moisture sensor detects low humidity. Instead, the irrigation system should channel water to the plants at a set time. Another problem is that irrigation systems cannot determine the amount of water used in agriculture [24]. The level of water consumption must be known to avoid waste when using clean water sources. Pipe leaks in an irrigation system can be detected when a massive monthly increase in water consumption readings is recorded. In addition, recording the amount of water allows farmers to identify water leakage in irrigation systems. Water wastage also increases crop production costs. Hence, this research aims to develop an irrigation and soil monitoring system using NodeMcu Esp8266 for taro yam cultivation. The first objective is to develop a soil composition and irrigation device using NodeMcu Esp8266. Then, a real-time monitoring and detection system for agricultural soil and irrigation is developed using Blynk apps. Finally, the water flow rate and soil moisture are analyzed to estimate an ideal water supply for taro yam.

The remainder of this paper is organized as follows: Section 2 discusses the method used in this project, including the development of soil moisture and irrigation devices, real-time monitoring systems using Blynk 2.0, and the soil composition and monitoring system operation, as well as the experimental work. Section 3 presents the results and discussion of the project. Finally, section 4 provides the conclusions.

2. DEVELOPMENT OF THE IRRIGATION AND SOIL MONITORING SYSTEM

Figure 1 is a block schematic depicting the soil composition and irrigation monitoring system, with the NodeMcu ESP8266 microcontroller serving as the system's principal controlling component. The soil moisture sensor was utilized to collect soil moisture data for processing by the microcontroller. When the value of the moisture sensor exceeds 75%, the soil is deemed dry and should be re-watered. The threshold value is set to 75% since previous research [25] states that the growth of the Colocasia esculenta species is good when soil moisture is between 50 and 100%. NodeMcu communicates with the solid-state drive to operate the water pump to provide water to the soil. A water flow rate sensor is mounted on the irrigation pipe to record and assess the readings from the water channel. The DHT11 sensor measures the ambient temperature and humidity, and the soil moisture sensor obtains soil moisture measurements for the Blynk application. The system wirelessly transmits all captured data to the Blynk server. NodeMcu provides a Wi-Fi connection, enabling communication between the device and the Blynk server [26].

Figure 2 shows the soil composition and irrigation device. Figure 2(a) is a schematic diagram of a soil composition and irrigation device. Meanwhile, Figure 2(b) depicts a complete NodeMcu microcontroller with all attached components. The connection for the DHT 11 sensor is displayed in label 1. The DHT 11 sensor has three terminals; the positive terminal was connected to the power source, the data terminal was connected to digital port 2 on the NodeMcu, and the ground terminal was connected to the sensor's ground. Label 2 denotes a solid state relay, and its positive terminal was attached to NodeMcu port D8. NodeMcu port A0 was coupled to a capacitive soil moisture sensor identified by label 3. The cable labeled with the number 4 was connected by the water flow rate sensor to the NodeMcu D7 port. Label 5 depicts the NodeMcu V3 base, which serves as the connection's point of origin, and label 6 is a NodeMcu microcontroller used to regulate the entire system. Label 7 indicates a connection for a 12-volt power source.

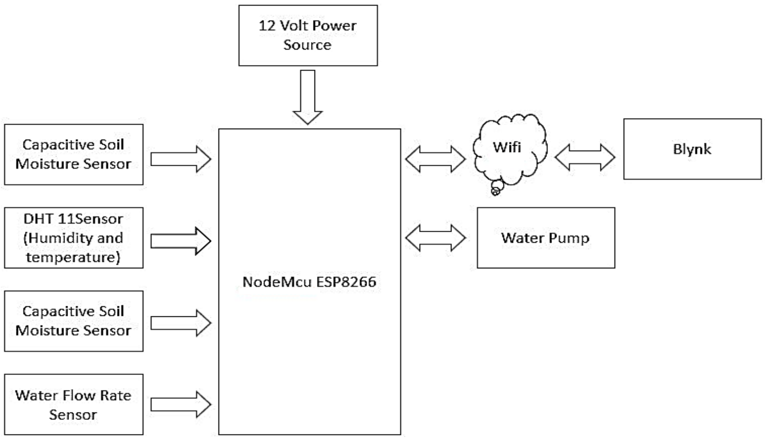
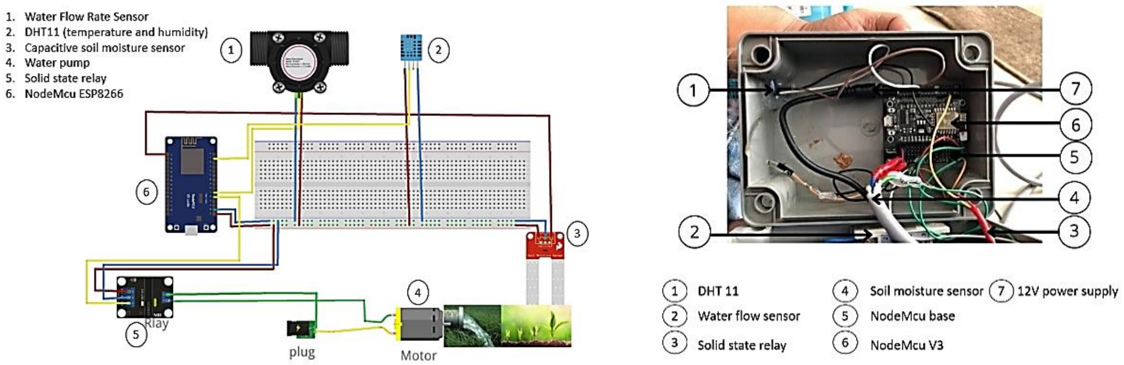


Figure 1. Soil composition and irrigation system block diagram



(a) (b)

Figure 2. Soil composition and irrigation device: (a) a schematic diagram and (b) a device connection diagram

All configurations and graphical user interfaces have been created for desktops and smartphones on the Blynk 2.0 website. All configurations were done on the desktop interface first, then followed by the configuration for the smartphone interface. Figure 3 depicts the desktop interface that shows the three-gauge indicators were set up to display data for ambient temperature, surrounding humidity, and soil moisture value.

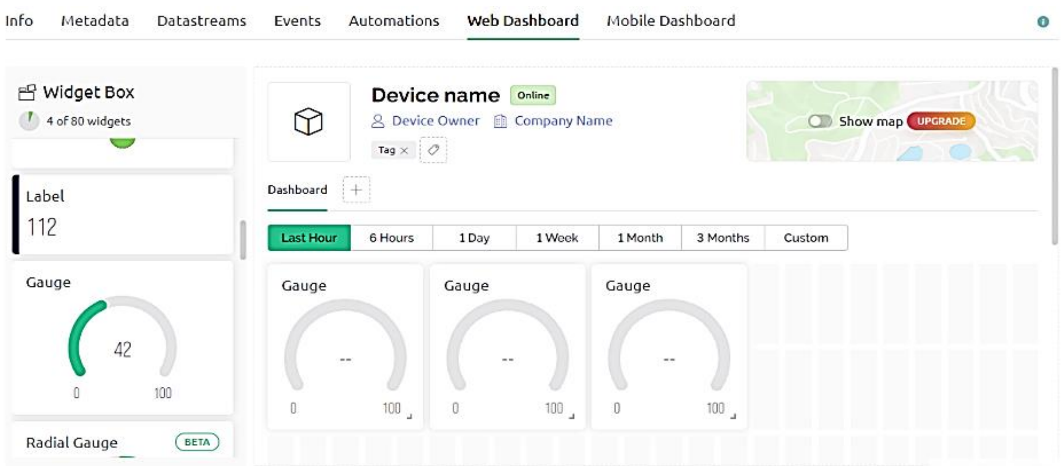
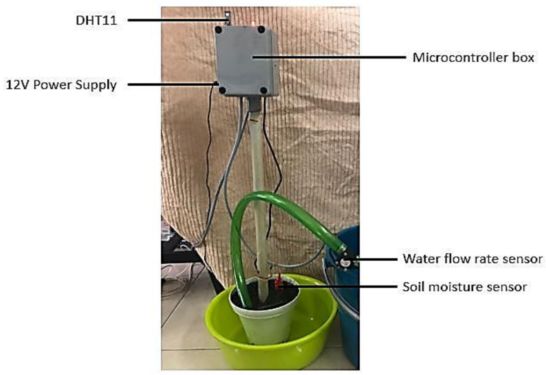


Figure 3. Blynk user interface development for the desktop interface

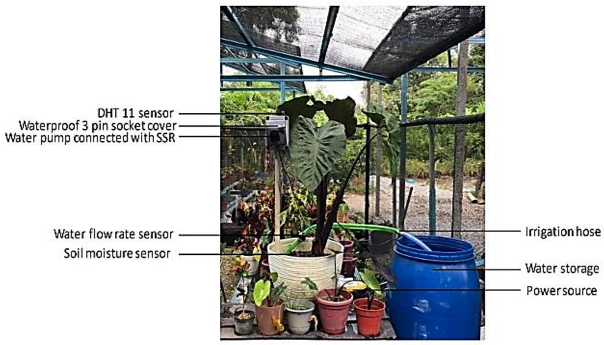
Figure 4 shows the prototype of the soil composition and irrigation device. As shown in Figure 4(a), the completed prototype comprised three physical components: the microcontroller box, the probing rod, and the water pump. A red LED indicator on top of the box indicates the device's Wi-Fi connection to the Blynk App 2.0 server. When the gadget was initially attached to a power source, the LED flashed rapidly to signal that NodeMcu was prepared to connect to Wi-Fi. The LED blinked dimly and slowly when the Wi-Fi connection was successfully established. The DHT 11 sensor was placed at the very top to obtain more accurate readings of ambient temperature and air humidity because, at the top, the DHT 11 sensor was more exposed without being covered by other components.

Figure 4(a) shows the experimental setup for the first experimentation phase in the house area. This test utilized a multi-purpose organic soil with six combinations of ingredients, including micro, coco peat, red burn soil, fine sand, ancient humus, and charcoal. After all devices and irrigation systems-including water pumps, pots containing organic soil, and power supply connections-were made, the device was connected to the home's Wi-Fi network so it could communicate with the Blynk server. Accurate soil moisture readings were obtained by inserting two-thirds of a capacitive soil moisture sensor into the soil. A bucket was filled with tap water and a water pump to pump the water to the soil in the pot. The findings indicate difficulties that need to be resolved, such as the difficulty in establishing a Wi-Fi connection, the water pump's failure to follow the readings of the soil moisture threshold value, and the inability to manually operate the water pump control switch. These issues were resolved before the experiment was conducted.

The experimental procedures were conducted at the street Keluli community garden Section 7, a taro yam growing area in Shah Alam, Selangor, which is displayed in Figure 4(b). The experiment was conducted to obtain data input for three days for analysis. The taro yam cultivation garden is an outdoor garden exposed to sunlight and rain. Since the second experiment of the device was exposed to unpredictable weather conditions, the device was upgraded to include a waterproof switch plug to prevent the device from short-circuiting if exposed to rainwater. A waterproof box containing the microcontroller and the wire connection was used to prevent water from entering. The taro yam orchard was equipped with an irrigation and soil monitoring device, as shown in Figure 4(b). Colocasia esculenta 'Hilo Bay' was the designated taro plant. The size of this 'Hilo Bay' species plant has a height of 80 cm and a diameter of 10 cm and was planted in a flowerpot with a diameter of 50 cm and a height of 30 cm. This 'Hilo Bay' species uses a soil mixture of sand, compost, topsoil, and cocopeat.



(a)



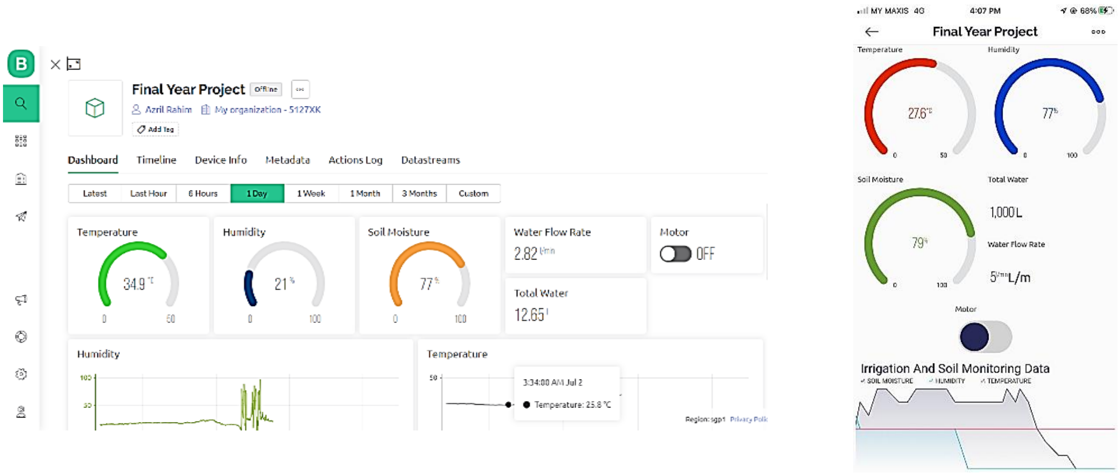
(b)

Figure 4. Prototype of the soil composition and irrigation device for: (a) the experimental setup carried out in the home area and (b) the experimental setup carried out in Keluli community garden Section 7

3. RESULTS AND DISCUSSION

Figure 5 shows the real-time monitoring system. Figure 5(a) depicts the desktop user interface. Before configuring the smartphone interface, the configuration and datastream needed to be created on the desktop Blynk 2.0 application. Datastream was a crucial platform component that enabled the configuration of how data was transmitted between the device and Blynk cloud. At the pre-configured interface, three gauges displayed the output temperature (V1), humidity (V0), and soil moisture value (V2). Two labels were used to indicate the water flow rate readings and the amount of water consumed; the data streams used were virtual pins V3 and V4. Utilizing a virtual V5 pin, a switch was used to manually control the water pump motor. Five graphs were generated to display the five data outputs described earlier as graphs. All the indicators on the desktop displayed the output readings, and switches on the smartphone's interface were replicated. Smartphone graphs only provided charts of all tasks, not graphs of each reading result.

Figure 5(b) shows the interface displayed on a smartphone. The data displayed on this smartphone interface was the same as that displayed on the desktop. The chart combines all the data output in a graph. Users must first download the Blynk 2.0 application on a smartphone to use the interface in Figure 5(b). Data for temperature, air humidity, and soil moisture were displayed as gauges on the desktop and smartphone interfaces. Additionally, manual water pump control switches are available on both user interfaces.



(a) (b)

Figure 5. Real-time monitoring system for: (a) the desktop interface and (b) the smartphone interface

The chart in Figure 6 depicts the data collected for the experiment conducted outdoors in the taro yam planting area of Seksyen 7 Shah Alam, Malaysia's community garden. All data collected during the preliminary test show that the capacitive humidity sensor and thermistor on the DHT 11 can function correctly. As depicted in Figure 6, the highest humidity reading for this experiment (91.4%) occurred on the third day at 8:00 a.m. The sensor obtained the lowest humidity value of 30% on the first day at 2:00 p.m. When the experiment was conducted, the state of the equipment directly exposed to the environment, such as sunlight, rain, and wind, caused the data reading to vary significantly according to the ambient circumstances. Figure 6 shows that air humidity depends on the ambient temperature; when the temperature is high, the humidity reading is low and vice versa.

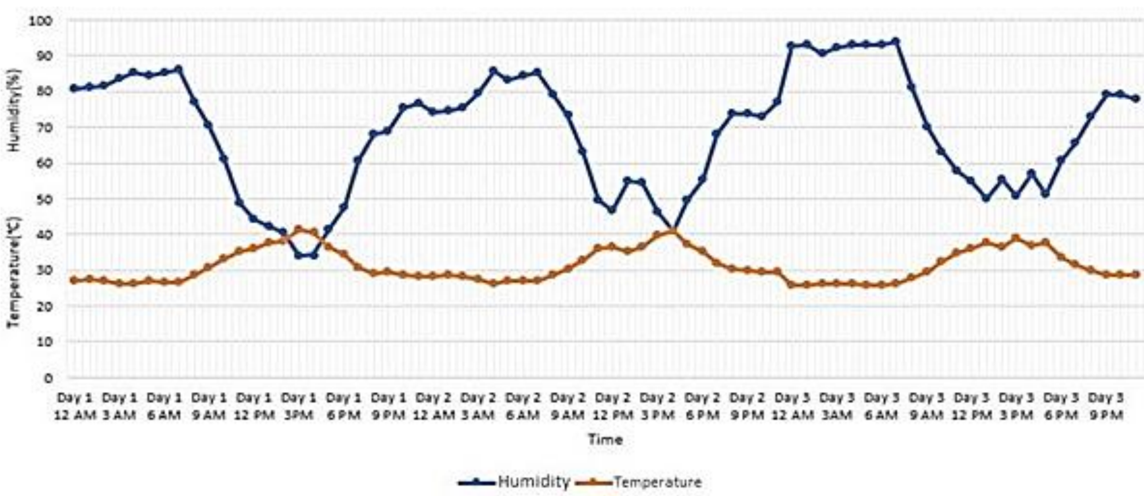


Figure 6. Temperatures and humidity data

The water pump supplied five liters of water at the beginning of the experiment on day 1 at 12 a.m because when the device was set up and turned on, the soil moisture reading was below the threshold value. 7,288 liters of water were channeled to cover the entire soil until the soil moisture reading was 79.8, as shown in Figure 7. Figure 7 is a graph showing the soil moisture data. The soil moisture readings decreased as the ambient air humidity readings decreased. On Day 1, between 6:00 a.m. and noon, the soil moisture reading was low (below 79). The humidity reading was also low in the field from 7:00 a.m. to 2:00 p.m. While the air humidity reading was high (above 90) on Day 3 from 1:00 a.m. to 8:00 a.m., the soil moisture reading increased by 12 at 6 a.m. The observations indicate that the temperature and humidity of the environment affect the soil moisture readings even if no water is channeled into the soil.

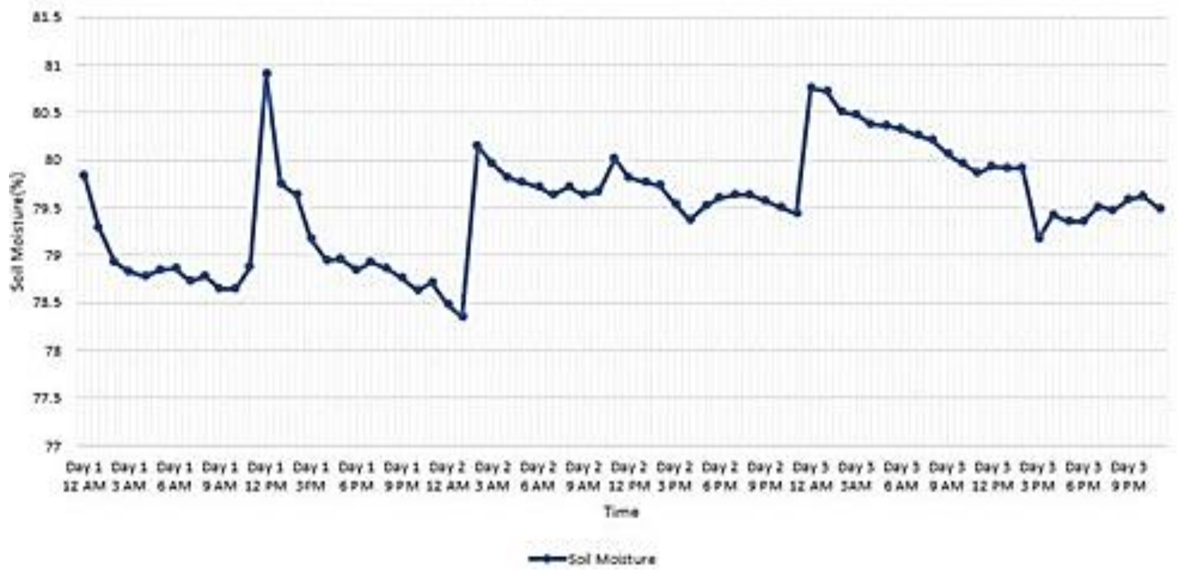


Figure 7. Three days monitoring soil moisture data

Based on the interview with the garden owner, the old method used to water ‘Hilo Bay’ plants involved watering these plants twice a day, once in the morning and once in the evening. The first time was drowning in the morning, and the second time was in the evening. Each watering uses 1.8 liters for a total daily water consumption of 3.6 liters. Meanwhile, during the three-day experiment, the ‘Hilo Bay’ species used 7.288 liters of water to keep the soil moisture reading above the 75% threshold.

Figure 7 demonstrates that the plant did not need to be watered often to sustain the required soil moisture readings. The results show that delivering water to plants based on the soil moisture rate can reduce water consumption compared to the traditional method used by gardeners who consumed 3.6 liters of water daily by watering plants twice a day. The total amount of water used throughout the three-day experiment was 7.288 liters, or 2.43 liters per day. This represents a 32.5% decrease in water usage compared to the previous approach employed by garden owners, which required 3.6 liters of water each day.

4. CONCLUSION

The proposed irrigation and soil monitoring system can automatically distribute water to plants based on soil moisture measurements. The system also responds by automatically channeling water to plants based on the obtained data to control the soil moisture level according to the crop’s suitability while reducing water consumption without overwatering, thereby lowering water use in agricultural irrigation systems. The application’s real-time monitoring enables users to check the present condition of their crops. All monitoring is performed through the Blynk application dashboard on a desktop computer, eliminating the need to physically visit the garden. In addition, the irrigation and soil monitoring system can reduce water consumption by 32.5% compared to conventional plant watering techniques used by gardeners. Moreover, an autonomous irrigation system can reduce daily water consumption to 2.43 liters by using soil moisture as an indicator. The experiments revealed that soil moisture depends not only on the water source that is channeled but also on the environmental humidity and temperature. Because the soil is always moist when the experimental system is used, agricultural activities in regions with high humidity and low temperatures are likely to need only a small amount of water. Improvements that the present work can make include increasing the number of soil moisture sensors on the device so that the system can read the entire soil area in more detail. In addition, researchers could incorporate sensors to detect the amount of water in the water storage tank.

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