Universal Journal of Agricultural Research 10(6): 785-793, 2022 http://www.hrpub.org
DOI: 10.13189/ujar.2022.100616

High-efficiency Low-cost Smart IoT Agriculture Irrigation, Soil's Fertility and Moisture Controlling System

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Received August 25, 2022; Revised November 9, 2022; Accepted December 22, 2022

Cite This Paper in the Following Citation Styles

(a): *[1] Mohamed Haziq, Wai Leong Pang, Kah Yoong Chan, It Ee Lee, Gwo Chin Chung, Sew Kin Wong , "High-efficiency Low-cost Smart IoT Agriculture Irrigation, Soil's Fertility and Moisture Controlling System," Universal Journal of Agricultural Research, Vol. 10, No. 6, pp. 785 - 793, 2022. DOI: 10.13189/ujar.2022.100616.*

(b): *Mohamed Haziq, Wai Leong Pang, Kah Yoong Chan, It Ee Lee, Gwo Chin Chung, Sew Kin Wong (2022). High-efficiency Low-cost Smart IoT Agriculture Irrigation, Soil's Fertility and Moisture Controlling System. Universal Journal of Agricultural Research, 10(6), 785 - 793. DOI: 10.13189/ujar.2022.100616.*

Abstract The world's population increased exponentially and more food is required to support the growing population. However, the existing agriculture solutions are too costly for small-scale farmers. This has motivated us to design a Smart IoT Agriculture System (SIAS) to monitor and control the soil's moisture and fertility levels. SIAS is a low-cost Internet of Things (IoT) solution that used an online app to monitor and control water consumption and the soil's fertility level. ESP8266 microcontroller is used in SIAS to automatically control the irrigation system that consists of a soil moisture sensor, thermal probe, and water pump. The pH sensor is used to monitor the soil's fertility level. The data collected from the IoT sensors are uploaded to the ThingSpeak cloud database through WiFi. Blynk app is used to control the SIAS on the smartphone. The prototype development, implementation details and the optimal operation condition of SIAS are reported in this paper. SIAS with a total cost of USD46 is proven to have lower water consumption (85% lower), real-time monitoring of the soil's fertility and a better crop growth rate compared to the existing conventional watering timer system.

Keywords Smart Agriculture, Internet of Things, Fertility, Irrigation, Low-cost

1. Introduction

Malaysia has about 32.7 million population in 2020 [1]. Increasing the food supply's productivity to support the population is quite challenging. A low-cost smart agriculture system is needed to enable the small farmers to deploy it on the farm. The existing time-based irrigation system used in the farms was the main contributor to high-water usage. Reducing water consumption can significantly reduce the operation cost of a farm. A better irrigation system is needed to reduce water consumption and maintain a high output yield.

The farmers need to maintain the soil's fertility level in order to maintain the output yield. The cost of maintaining the soil's fertility level is high due to the high price of the fertilizer. There is no specific measuring tool to measure the soil's nutrients. However, fertility can be measured by measuring one of the factors that affect the soil's nutrient level which is the soil's pH value. The research carried out by Montana State University stated that the soil pH had an impact on the soil's functions and plant nutrients. The acidic (pH = 0 - 6) and alkaline (pH = 8 - 16) solutions are based on the pH value caused by the concentration of hydrogen ions (H+) [2]. H+ takes up the space in the soil and displaces the metal ions in the soil which will make the plant absorb the soil's nutrients easily. As compared to the metal ions that are heavy to move, the plant cannot absorb the nutrients from the soil.

Conventional agriculture limits production to support the high demand for the food supply [3-4]. The existing solution used a simple irrigation system and pipes to water the plantation. It was a good solution rather than flooding the plants with a water bucket and watering them in sequence. However, the conventional irrigation system was proposed and the user was required to turn on the irrigation system manually.

The plantation data is critical for the farmers to know the farm’s condition as it leads to produce high-quality crops. A comprehensive plantation data management is the key to the success of a plantation. IoT can transform the world's industries for a better future, including the agriculture sector [6]. To fulfil the demand for food, smart farming is introduced with the help of IoT. Smart farming will help growers and farmers to minimize waste and increase productivity. The optimal amount of fertilizer to be used was studied in order to minimize the operation cost. Studies showed that with soil moisture sensors, water consumption can be reduced by up to 62% if compared with traditional irrigation methods [5]. The crops' data collected by the IoTs are uploaded to the cloud. The farmers can carry out future planning after analyzing the data collected.

The introduction of soil moisture sensors onto their agriculture system in 2011 has led to the success of reducing water usage. Different plants require a different environment for them to thrive. Some plants need plenty of water and require daily checkups, and some plants do not necessarily need constant daily moisture [5]. The soil moisture sensor was used to ensure crops will not be under or overwatered. The best irrigation system is to use a suitable amount of water to grow crops. For instance, the irrigation system was turned off on a rainy day to save water consumption.

Various IoT sensors were installed in the existing agriculture systems. The sensors detected the conditions of the soil. The data collected will later help the farmer decide what to do to help their crops thrive and produce a high-quality yield. The irrigation system was controlled by the data collected. IoT–based smart farming solutions are a new route to elevate the existing ecosystem of the agricultural industry [6].

The wireless IoT sensors were embedded in the agriculture system in the year 2019. Aspects such as crop status, irrigation, soil preparation, and pest detection system were also considered. With all the data collected from the farm, the agriculture system itself will automatically control whether to add more water or scatter fertilizers or spray pesticides or more [3].

A smart agriculture system that uses the soil’s moisture as an indicator to reduce water usage in watering plants and monitor the soil’s fertility level in real time is needed. SIAS is proposed to monitor and control the soil’s moisture level, water consumption, and fertility level automatically. SIAS is a low-cost solution that is enhanced with the latest IoT technology. An app is developed to monitor and control the SIAS system. The data collected are stored in the cloud and the data can be accessed through the app.

This paper is organized as follows. The design of the SIAS system is illustrated in section 2. The results and discussion are reported in section 3. Finally, a conclusion is drawn in the last section.

2. Design of Smart IoT Agriculture System (SIAS)

SIAS is an IoT system consisting of a microcontroller, sensors and an irrigation system. The sensors were used to monitor the condition of the crops. The three main parameters monitored by SIAS are the soil moisture level, the temperature and the soil’s fertility. The soil moisture level and the temperature can easily be detected by using a soil moisture sensor and temperature sensors. There is no alternative method that can specifically detect the fertility of the soil. However, we can still monitor the soil’s pH value. Whenever fertilizers are added to soil, the pH value of the soil changes. Depending on the fertilizer, the pH may drop or increase in value. Hence, a pH probe sensor was used as an indicator of the soil’s fertility.

The sensors will detect the conditions of the soil and transfer all the data to a smartphone with an app. The user could check their plantation everywhere as long as their phone is connected to the internet. The app will have a button that could turn on the irrigation system to water the plants. By default, the irrigation system will automatically water the crops as soon as the moisture level drops below the preset threshold value. Therefore, SIAS is saving tons of water as well as keeping the plants growing healthily. The block diagram of SIAS is shown in figure 1 which consists of hardware and software.

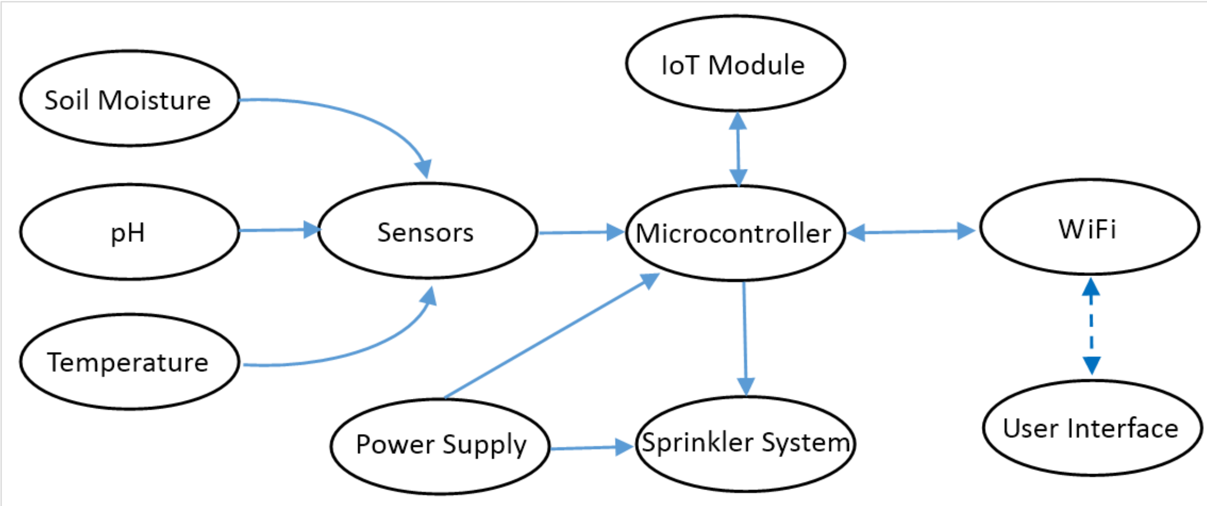

Figure 1. The Block Diagram of the proposed SIAS System

SIAS used the NodeMCU-LoLin-V3-CH340 microcontroller (USD4.15) to control the system. NodeMCU is cost-effective with an ESP8266 firmware and a WiFi module that supports the IEEE802.11b/g/n WiFi standard embedded in this device. The WiFi detection range is 45m.

The soil moisture sensor (USD0.69) was used to measure the soil's moisture. It consists of two exposed fork-shaped probes that serve as a variable resistor whose resistance varies according to the water content of the soil. The resistance is inversely proportional to the soil moisture. DS18B20 thermal probe (USD1.86) was used in SIAS. DS18B20 is specialized to be immersed in a liquid or a medium. It can detect the temperature ranges from -55°C to +125°C with the accuracy of ±0.5°C. It is programmable which enables it easy to be deployed.

The pH sensor (USD20.36) was used to measure the acidity and the alkalinity of a sample. This sensor measures the pH value, and the scale is represented by a value that ranges from 0-14 with an accuracy of ±0.1pH. The electrodes of this sensor are used to measure the H+ inside a sample. The voltage produced between the electrodes is proportional to the pH of the solution. This sensor is programmable to compute the pH value.

A DC 12V-24V powered water pump (USD7.11) was used to transfer water in SIAS via a water pipeline. The selected pump is strong enough to transfer the water up to 5m and is suitable for small plantations. The power consumption is 22W, and the max flow rate is 800l/m. A single-channel relay module is used to control the water pump. The relay module controls the current flow of the power supply to the water pump. The system can connect through a relay to a bigger water pump which can transport more water to the plantation.

The circuit diagram of the SIAS is shown in figure 2. There are two power supplies in this system. The first power supply is using a micro USB to power the NodeMCU. The second power supply is two 9V batteries connected in series to power up the water pump. A single-channel relay module is used to control the flow of the water pump. The pin D4 on the NodeMCU is connected to the relay switch. The VCC is connected to 3.3V (on NodeMCU) and the Ground pin, GND is connected to the GND on NodeMCU.

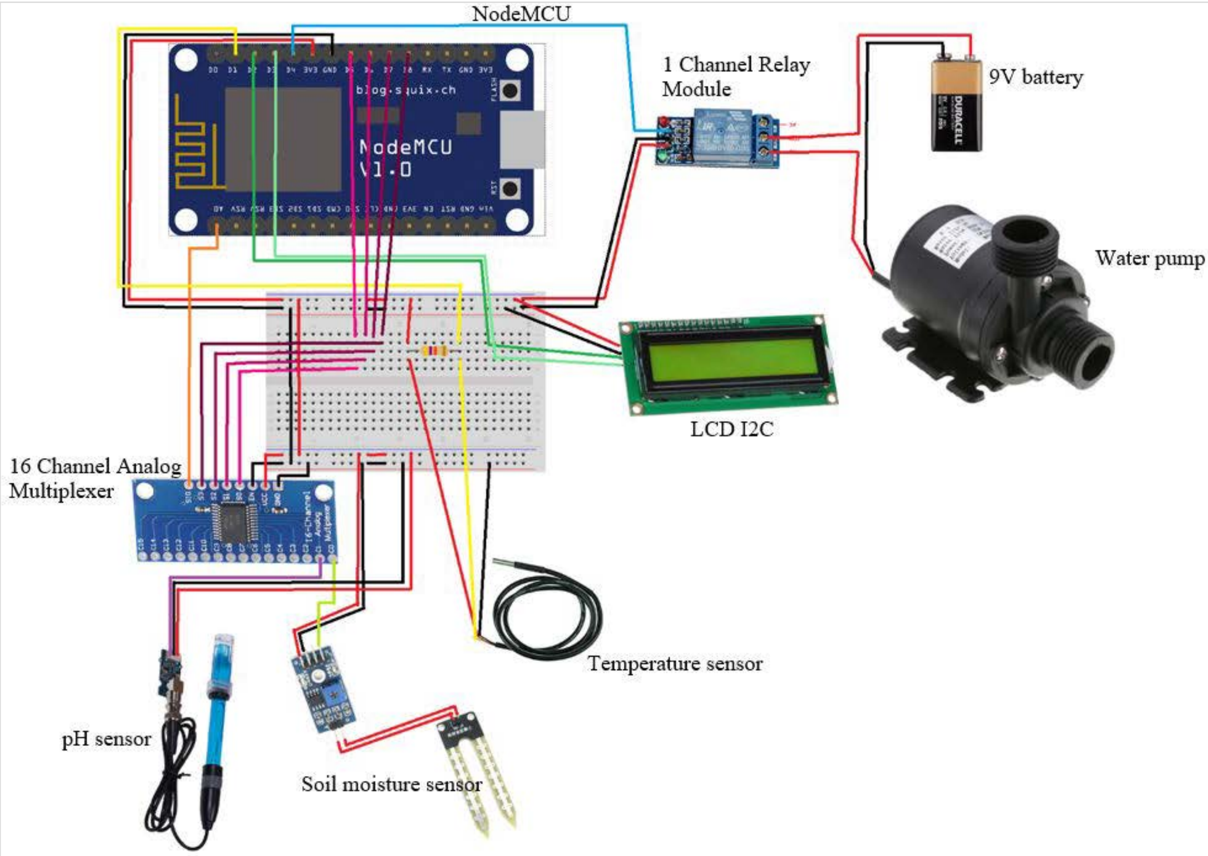

Figure 2. The Circuit Diagram of the proposed SIAS System

An LCD I2C is used to display the data on the circuit system. The VCC from LCD is connected to VUSB, VU (+5V) on NodeMCU and the GND is connected to GND. The Data Signal pin (SDA) and Clock Signal pin, SCL pins are connected to pins D2 and D3 respectively. The single-channel relay module has three pins that are required to be connected to a power supply and that power supply is directly connected to the water pump. This relay module controls the current of the power supply to the water pump.

The soil moisture sensor and the pH sensor require the same pin on the NodeMCU which is the analog pin, A0. To allow data transfer according to each sensor with the same analog pin, a multiplexer is needed. On the multiplexer, the VCC is connected to 3.3V and the GND, EN pins are connected to the GND. S0, S1, S2 and S3 pins are connected to pins D5, D6, D7 and D8 on the NodeMCU. The wire that carries the data of each sensor is connected to the multiplexer pins C1 (for pH sensor) and C3 (for soil moisture sensor).

The third sensor does not require an analog pin for data transfer. Therefore, the data pin is connected to D1 in the NodeMCU. However, this sensor requires a resistor since it does not have any modules unlike the soil moisture and the pH sensors. The connection for this resistor is in parallel with the data pin and the VCC pin. The prototype of the SIAS is shown in figure 3.

ThingSpeak was used in SIAS. ThingSpeak enables users to build multiple channels and different data can be stored in each channel. ThingSpeak allows free users to create up to four channels per account and paid users can create up to 250 channels. Three keys (i.e. a channel ID, a read and a write key) were assigned to each channel through the Application Programming Interface (API). The channel number and the Write API key obtained from the ThingSpeak channel were used by the ESP8266 to upload the data collected. The Blynk IoT platform allows the user to store and display the data collected. The user was able to control and access the data collected by SIAS through the Blynk app installed on the smartphone remotely.

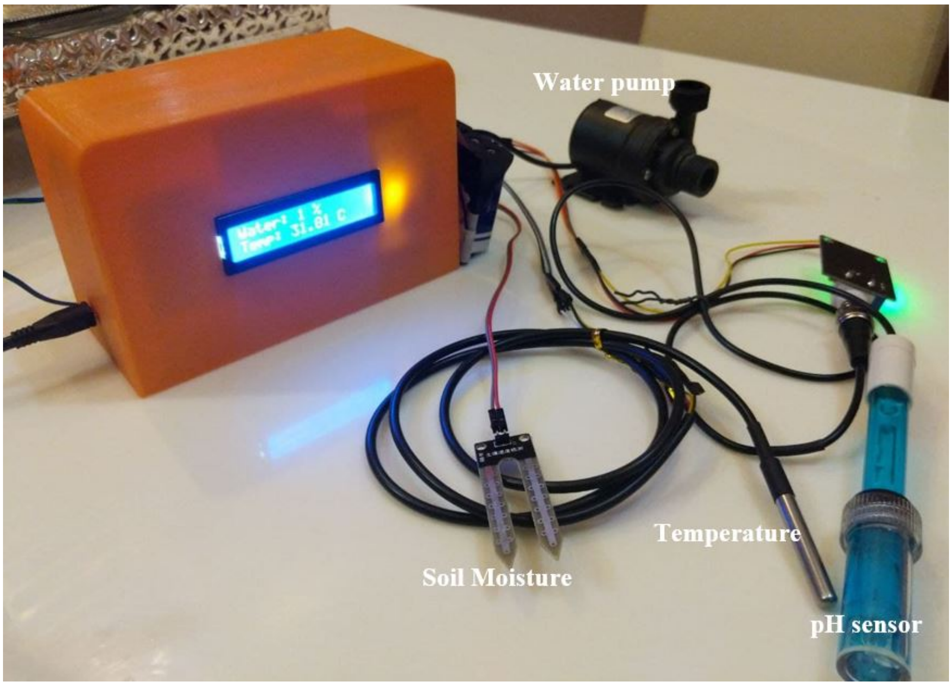

Figure 3. The prototype of the SIAS

Figure 4. The testbed for the SIAS

3. Results and Discussion

3.1. Experimental Test

The testbed shown in figure 4 was used to evaluate the performance of the SIAS proposed. An extensive experimental test was carried out to evaluate the optimal position of the soil moisture sensor to detect the soil's water storage capacity in response to distance. 1 liter of water has been poured into the soil, and the soil moisture over a distance has been recorded.

The experiment is carried out with the placement of the sensors and water sprinkler as shown in figure 5. The soil's water content is almost 100% from the first 20cm away from the center of the location of the water poured (figure 6). The optimal position for the soil moisture sensors is not more than 20cm away from the plant to ensure that the soil is fully watered and the water is evenly distributed. The soil moisture sensor of SIAS was placed at a distance of 20cm away from the plant. The SIAS monitored the soil's condition for one week and the data collected were analyzed to further improve the SIAS system.

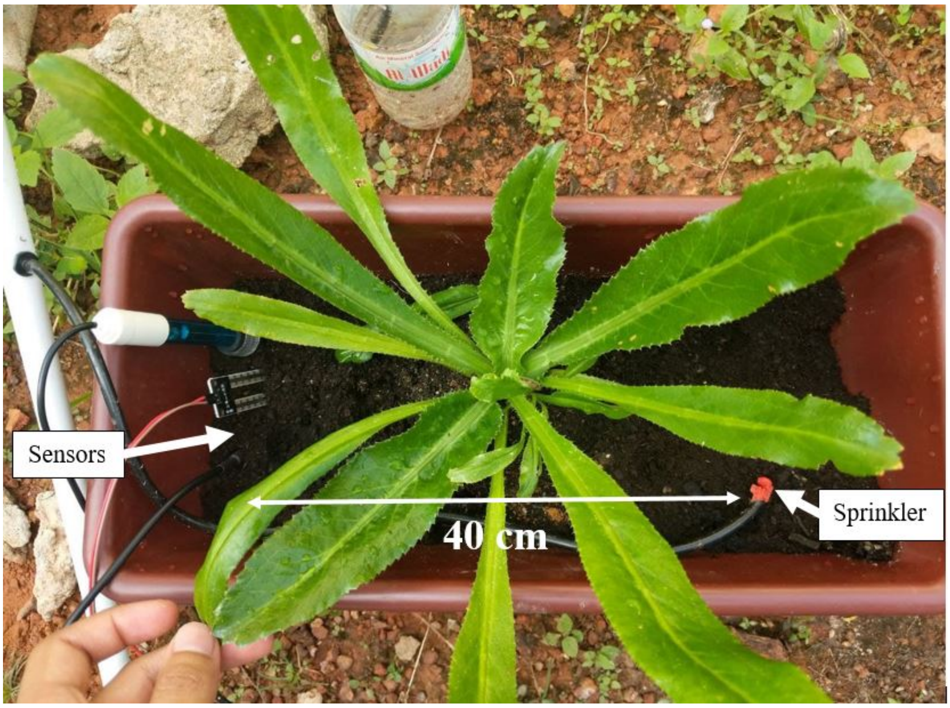

Figure 5. The example of the placement of the sensors and sprinkler with a distance of 40cm

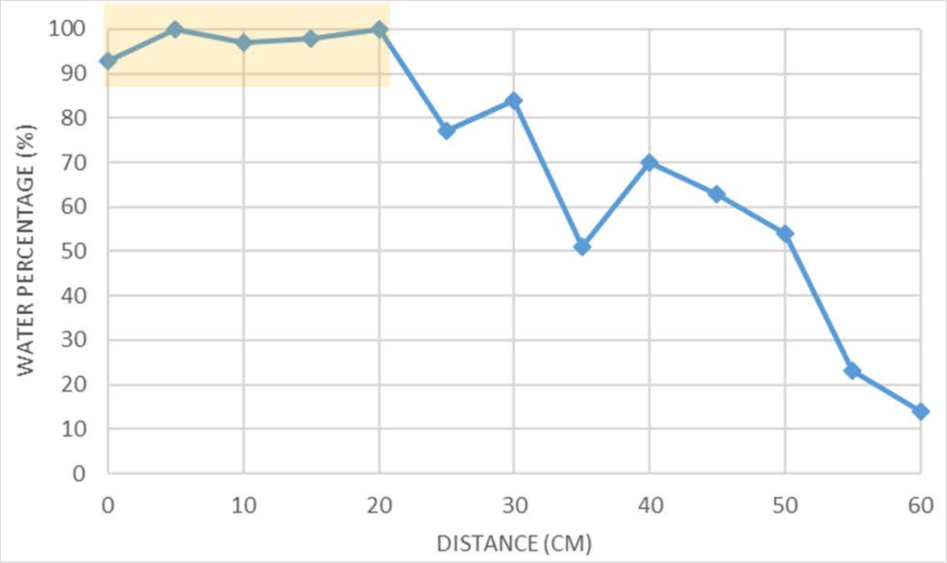

Figure 6. Water percentage over the distance from the water source

The irrigation system is turned on if the soil moisture is less than 90%. The soil moisture is maintained at a level of more than 100% in the next hour after the SIAS detected the soil moisture level is dropped (figure 7). This shows that SIAS successfully maintains soil moisture through the smart automatic irrigation system.

Figure 8 shows the pH values obtained over a week from the soil. The average value of soil pH value is about 6.844, which is normal. The ideal soil's pH should be around 6 to 7, which is neutral [7]. The soil has already been fertilized to achieve such a value. The pH values were reduced from 7.05 to 6.4 over a week. There were a few spikes observed from the pH values collected and that was mainly contributed by the random distribution of the fertilizer through the water flow from the irrigation system over a week. This shows that there is a direct relationship between the pH value and soil fertility.

As shown in figure 9, the soil's heat reached its highest temperature (44.5°C) on the first day. Watering the plants during hot weather could affect the plants' growth. The plants should be watered in the morning when the soil temperature is below 30°C. SIAS is programmed to activate the irrigation system when the soil temperature is less than 30°C to avoid watering the plants during high temperatures.

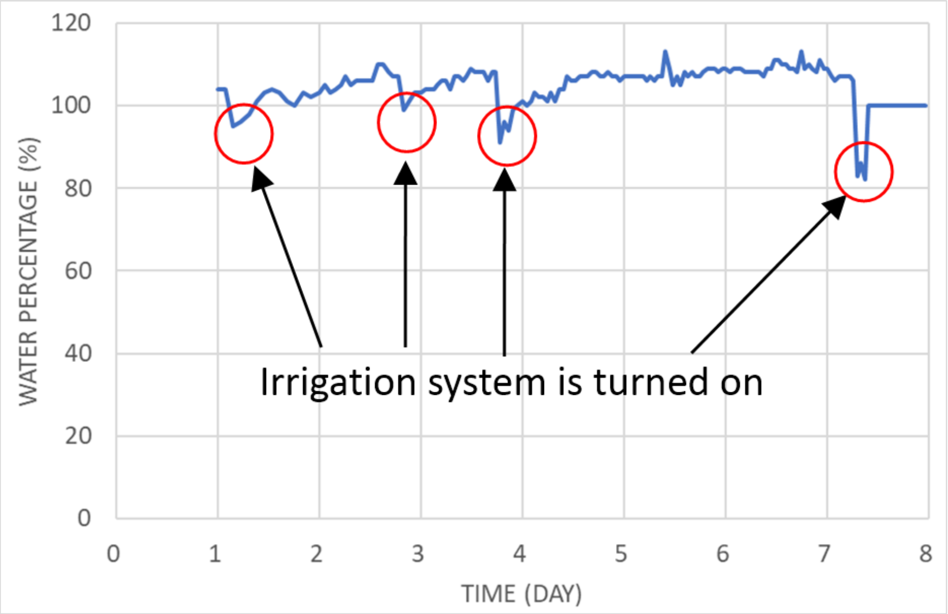

Figure 7. Soil Moisture level measured over a week

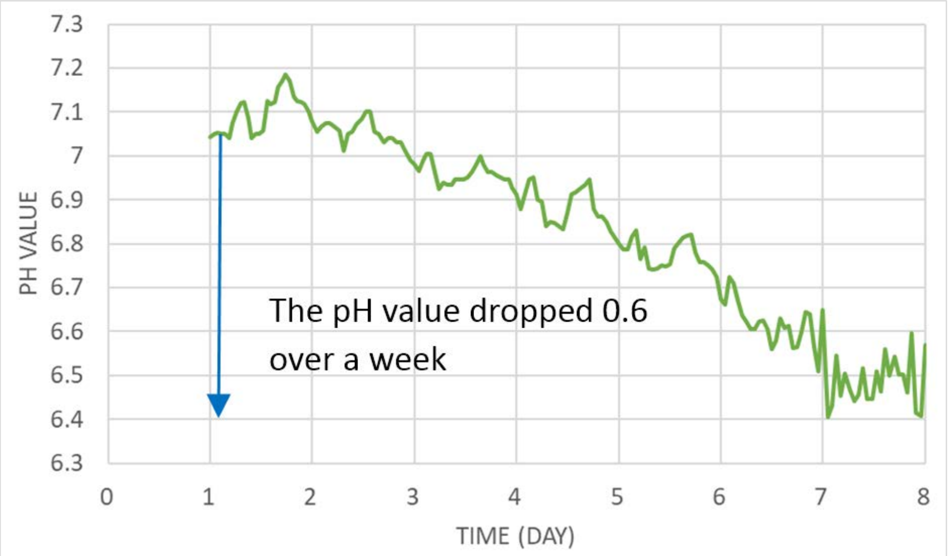

Figure 8. The pH values obtained over a week

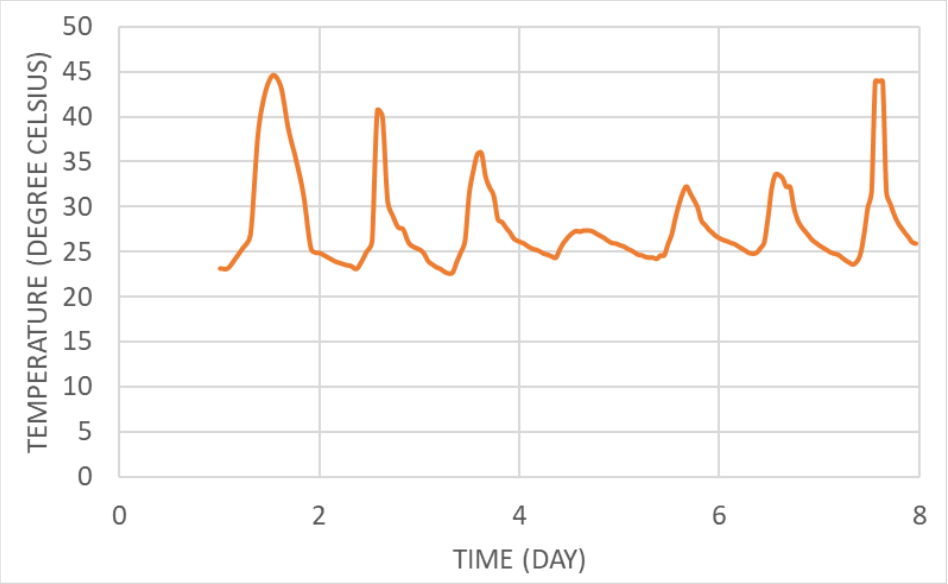

Figure 9. The soil temperature values obtained over a week

3.2. Performance Analyses

Two identical plants in the same size pots were prepared to evaluate the effectiveness of SIAS in water saving. The first plant used the SIAS, and the second plant used the conventional scheduled timer watering system. The timer system is set to water the plants daily at 8 a.m. Both plants have the same type of soil, the same environment, under the same shade, and the same type of pot. The purpose of this experiment is to measure the amount of water consumed by both systems. An extra sprinkler is added to each irrigation pipe, and this sprinkler was channelled directly into a water bottle to calculate the amount of water used by both systems. The testbed shown in figure 10 and figure 11 shows the water bottles that were used to measure the water consumption.

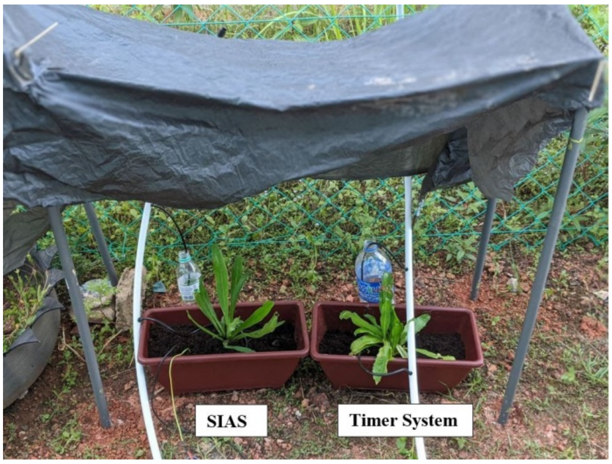

Figure 10. The testbed of the SIAS and timer system

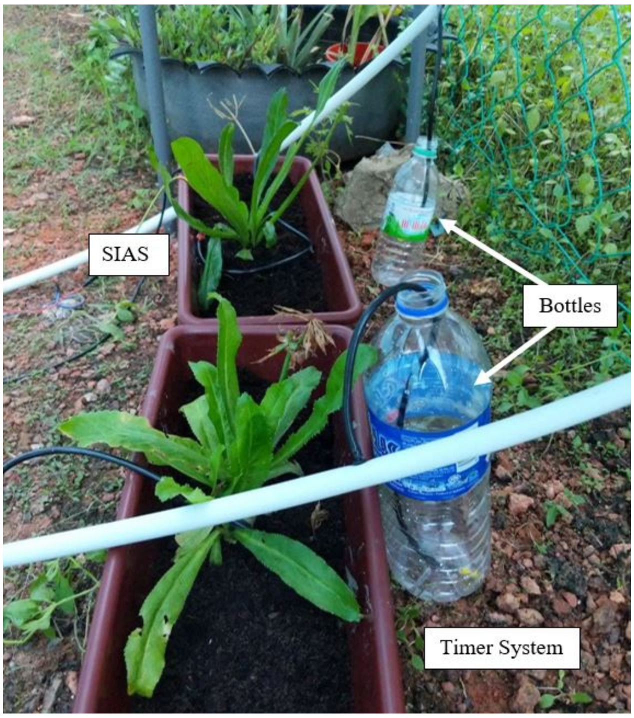

Figure 11. The water bottles used to measure the water consumption for both systems

Table 1 shows the one-week data collected from this experiment. As shown in Table 1, the system does not water the plants from day four until day six due to the weather (Rainy days). The total amount of water usage of the SIAS is 840ml. However, the timer system used 5900ml of water.

Figure 12 shows the plants' condition after one week of using the SIAS and timer system. The Culantro plant that was controlled by SIAS looked green and healthy. The plant controlled by the timer system also looked healthy, but the green colour was slightly yellowish. However, both plants were grown with new leaves. Both systems are suitable to be used in agriculture.

Table 1. Water usage for the SIAS vs Timer System

Day	Water Usage (ml)	
	SIAS	Timer system
1	120	1100
2	100	1500
3	20	1100
4	0	500
5	0	600
6	0	600
7	600	500
Total	840	5900

Figure 12. The plants' conditions after one week

SIAS significantly reduced water consumption by 85% compared to the existing timer system. The low-cost SIAS is proven that it can significantly reduce water consumption, monitor the soil's fertility and have a better crop growth rate compared to the existing system. SIAS brings a positive implication to small-scale farmers, and they can deploy this low-cost SIAS on the farms.

4. Conclusions

More food supply is required to support the growing population. A novel low-cost SIAS is proposed to monitor and maintain the soil's condition (soil moisture, temperature, and pH value) in real time for a better crop growth rate. The uniquenesses of SIAS are as follows. SIAS is a low-cost IoT solution, in which the users can monitor and control the water consumption and the soil's fertility level through the online cloud through a mobile App. A low-cost NodeMCU is used to control the IoT sensors. The data collected are uploaded to the cloud. Users can access the data through their smartphones. The extensive experimental results showed that SIAS significantly reduced water usage (85% less) and had a better crop growth rate. However, the prototype developed is mainly for the small-scale farm. More work is needed to enhance the system for the large-scale farm.

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