

Development of an IoT-Based Smart Watering System for Monitoring and Increasing Soil Moisture Content in “Tabtim Siam” Pomelo Garden in Pak Phanang District, Nakhon Si Thammarat Province, Southern Thailand

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Abstract

In Thailand, “Tabtim Siam” pomelo production is essential for domestic consumption and export. Among several environmental factors, soil moisture is the most important factor for citrus plants’ growth and their fruit quality. During the main developmental stages of these plants, the required soil moisture should be above 70% (no water deficit). Therefore, keeping soil moisture at $\geq 70\%$ in pomelo orchards is crucial. This study developed an IoT-based smart watering system that efficiently monitors soil moisture and assists in maintaining soil moisture at the required level even at a high temperature inside a pomelo orchard in Pak Phanang District, Nakhon Si Thammarat Province, Southern Thailand.

Keywords

Pak Phanang District, smart watering system, soil moisture content, Tabtim Siam ruby pomelo

1. Introduction

Globally, citrus fruits are the leading fruit crops. The three major citrus fruit crops are orange, mandarin, and pomelo in terms of their production and consumption [1]. In 2020–2021, the total production of citrus fruit was 98 Mt worldwide [2]. Citrus fruits have several active compounds such as vitamin C, carotenoids, essential oils, minerals, acridone alkaloids, flavonoids, limonoids, coumarins, and triterpenoids that are beneficial to health [3–6]. They also have antioxidant, antimicrobial, anti-inflammatory, anti-tyrosinase, antihyperlipidemic, and anticancer properties [7–18]. Regularly consuming these fruits can treat various diseases such as inflammation, muscle pain, coughs, ringworm infection, and stomach upsets [8]. Several environmental factors affect the growth and quality of citrus fruits. Among these, soil moisture content is the most critical factor that

determines the plants’ growth, vigor, and productivity potential [19, 20]. The nutrient uptake of the plants depends on water availability in the soil. Lack of water at any stage affects the productivity and the quality of the fruits [20]. Large-scale loss of citrus plants was observed in India due to frequent drought and scarcity of water [21, 22]. Inadequate soil moisture limits the water supply to the roots and reduces the root conductivity directly [23, 24]. For citrus plants, no water deficit is considered when the soil moisture level is above 70% during their main developmental stages. A mild or moderate water deficit is considered when the soil moisture content is 50%–70%. Severe water deficit happens when soil moisture is $< 50\%$ [25]. Fruit quality traits and production absolutely depend on soil water availability [26]. Maintaining a suitable range of soil moisture content in citrus orchards is crucial.

In Thailand, pomelo is one of the top 10 economic fruit crops [1]. In 2020, Thailand exported 25,283.07 tons of fresh pomelo, valued at 1,203.18 million baht [27]. Pomelos are cultured in 60 out of the 76 Thai provinces. The central producing provinces are Phichit, Samut Songkhram, Nakhon Pathom, Prachinburi, and Nakhon Si Thammarat. The total planting area is approximately 94,458 rai, and the average yield is 2,394 kg/rai [28]. Among various types of pomelos, the demand for Tabtim Siam or ruby pomelo is increasing day by day in domestic and international markets, especially in China, Taiwan, Malaysia, Singapore, and Brunei because of their pulp's ruby red color, as well as sweet, juicy, soft, and flavorful aroma. Nowadays, the price of one Tabtim Siam pomelo fruit is 150–250 baht (4–7 USD) from the hands of the farmers [29]. Tabtim Siam Pomelo is mainly grown in Pak Phanang District in Nakhon Si Thammarat Province, Thailand, and it is known as the geographical indication (GI) product of Pak Phanang [29]. The total planting area is approximately 3,933 rai, and the average yield is 2,885 kg/rai [30]. Although the demand for pomelo is increasing nowadays, the quality of pomelo is not enough to fulfill the market demands. The value of ruby pomelo depends on the fruit's quality. High-quality fruits are defined as suitable fruit sizes (>1 kg weight/fruit) with no scars on the fruit surface. The color of the peel must be bright green, and the fruit flesh must be dark ruby red [31]. These qualities depend on many environmental factors, among which soil moisture content is the most important factor. They require soil moisture $\geq 70\%$ in their root zone, but not >30 cm deep during their vegetative growth period. Tabtim Siam pomelo needs a consistent water supply for its photosynthesis process. However, if there is excessive water, it will have a severe impact on the root system. In case of high soil water content or lack of water, the quality of the fruit will be poor. As a result, the fruit will be small and may have a bitter taste [32]. Therefore, appropriate water management is necessary in pomelo orchards to maintain a soil moisture content of $\geq 70\%$. In recent years, technology has brought new changes to agricultural production. It not only increases agricultural output but also effectively improves the quality of agricultural products [33]. Nowadays, smart watering systems are used to monitor and control various environmental factors to increase the growth of trees and the quality of products. For example, a smart watering system was used to control the irrigation process in strawberry greenhouses in Greece [34]. Another study in China used a smart watering management system to control the soil moisture

content in tomato farms [35]. In India, a smart water management system was used to control the soil's moisture content, temperature, humidity, and water flow to improve the irrigation process on agricultural farms [36]. In Thailand, a smart watering system was used to increase humidity and decrease thrips inside mangosteen canopy [37, 38].

This study aims to develop an IoT-based smart watering system to monitor and maintain a soil moisture level of $\geq 70\%$, even when the air temperature is very high. Usually, there is a negative relationship between air temperature and soil moisture, and a low level of soil moisture content during high air temperature affects the growth of plants. Therefore, keeping the soil moisture content at least 70% during the high temperatures is essential. Developing a smart watering system for maintaining the required soil moisture level in Tabtim Siam ruby pomelo orchards will help the farmers to increase their pomelo production and earn more money.

This work's novelties include developing a novel Internet of Things (IoT) sensor-based watering system for monitoring temperature and soil moisture data. The system uploads sensor data to the IoT cloud using an Android or iPhone Operating System (iOS) phone and stores them for further analysis.

II. Materials and Methods

a. Study site

This research was conducted inside a "Tabtim Siam" pomelo garden in Pak Phanang District (latitude: $8^{\circ}22'N$ and longitude: $100^{\circ}05'E$), Nakhon Si Thammarat Province, Thailand. The total area of this garden is $35,200\text{ m}^2$ and it is 10 years old. There are 550 trees, and the trees are approximately 6–8 m high. The trees are approximately 6 m apart. The study area is shown in Figure 1.

b. Developing and using a smart watering system to monitor and increase the soil moisture content in the pomelo garden

An IoT-based smart watering system was developed to monitor and increase the soil moisture content in the pomelo garden. It consists of a watering system, control cabinet, and sensor installation. The watering system consists of water pumps, solenoid valves, a micro-controller board, a power supply, smartphones, Wi-Fi, and the application Blynk, as shown in Figures 2 and 3.

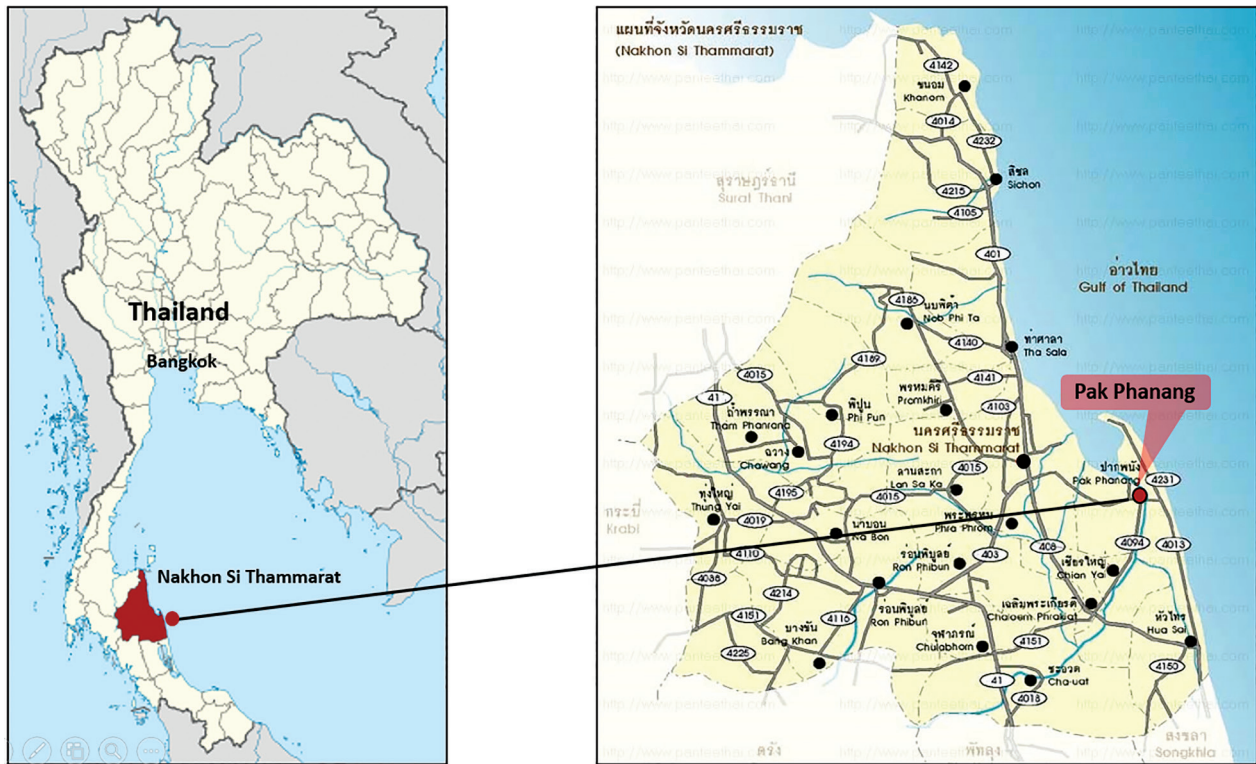


Figure 1: The red circle inside Thailand map indicates Nakhon Si Thammarat Province (left-hand side), and another red circle inside the Nakhon Si Thammarat Province map indicates Pak Phanang District (right-hand side).

Blynk is an IoT platform (<https://blynk.io/>) from Miami, USA. The water pump and solenoid valves were automatically turned on and off using the application Blynk, which was installed on a smartphone (Figure 4). The application Blynk can be used in Android and iOS operating systems. The control cabinet contained diverse components: a microcontroller board, Wi-Fi, power supply, relays, magnetic contactor, circuit breaker, AC/DC converters, and DC to DC converters step-down (Figures 5 and 6). All the electronics used to develop the smart watering system are shown in Table 1. The smart watering system was designed and developed from February 2023 to February 2024.

c. Experimental design

This study included two treatments: (1) a conventional watering system and (2) an IoT-based smart watering system. In both treatments, three pomelo trees were randomly selected. In the conventional watering system, the farmers provided water at the bottom of each tree for half an hour in the morning (from 8.00 a.m. to 8.30 a.m.) and for half an hour in the afternoon (from 13.00 p.m. to 13.30 p.m.) (totally 60 min of watering

time). A soil moisture sensing system was installed at the bottom of each tree to collect data on soil moisture content (%). Soil moisture sensors (Modbus RTU RS485) were installed 30 cm above the ground level (Figure 7). Soil moisture data were collected every half an hour in a day.

On the contrary, in the smart watering system treatment, the watering system was controlled to provide water at 6.30 a.m., 9.30 a.m., 12.30 p.m., and 3.30 p.m. Each time, water was provided for 15 min at the bottom of each tree using a water sprinkler (60 min of watering time) (Figure 8). Similarly, a soil moisture sensing system with a sensor was installed at the bottom of each tree to collect data on soil moisture (%). The experiment lasted for 10 days (April 1–10, 2024). The components used in the two treatments are presented in Table 2.

d. Data collection through sensors

This experiment collected soil moisture (%) and air temperature (°C) data through soil moisture and temperature sensors, respectively. In this study, commercial sensors were used to collect data. The sensors

were manufactured by ETT Company Limited (<https://www.ett.co.th/>) in Bangkok, Thailand. For collecting soil moisture data, soil sensors (Modbus RTU RS485) were used. The real-time data were collected and stored every half an hour daily. The sensors send the data to the Blynk cloud via a Wi-Fi internet connection. The data were then collected from the cloud and sent to the computer. The users can use their

smartphones to control the system by using the application Blynk and the web server Blynk Cloud. The whole system is shown in Figure 9.

Moreover, air temperature ($^{\circ}\text{C}$) data were collected using a temperature sensor (DHT22 module) every half an hour for 10 days. The temperature sensor was installed inside the control cabinet (Figures 5 and 9). The sensor's signal was

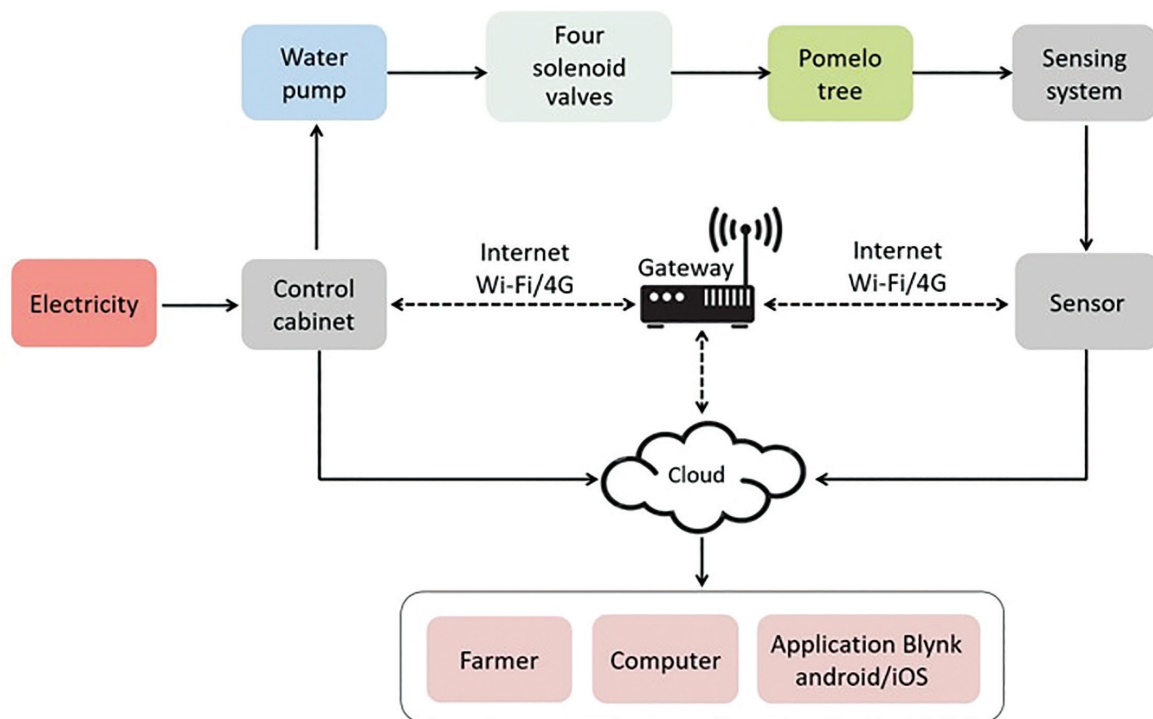


Figure 2: The development stage of the IoT-based smart watering system.



Figure 3: The demonstration of the installation pump system and solenoid valves.

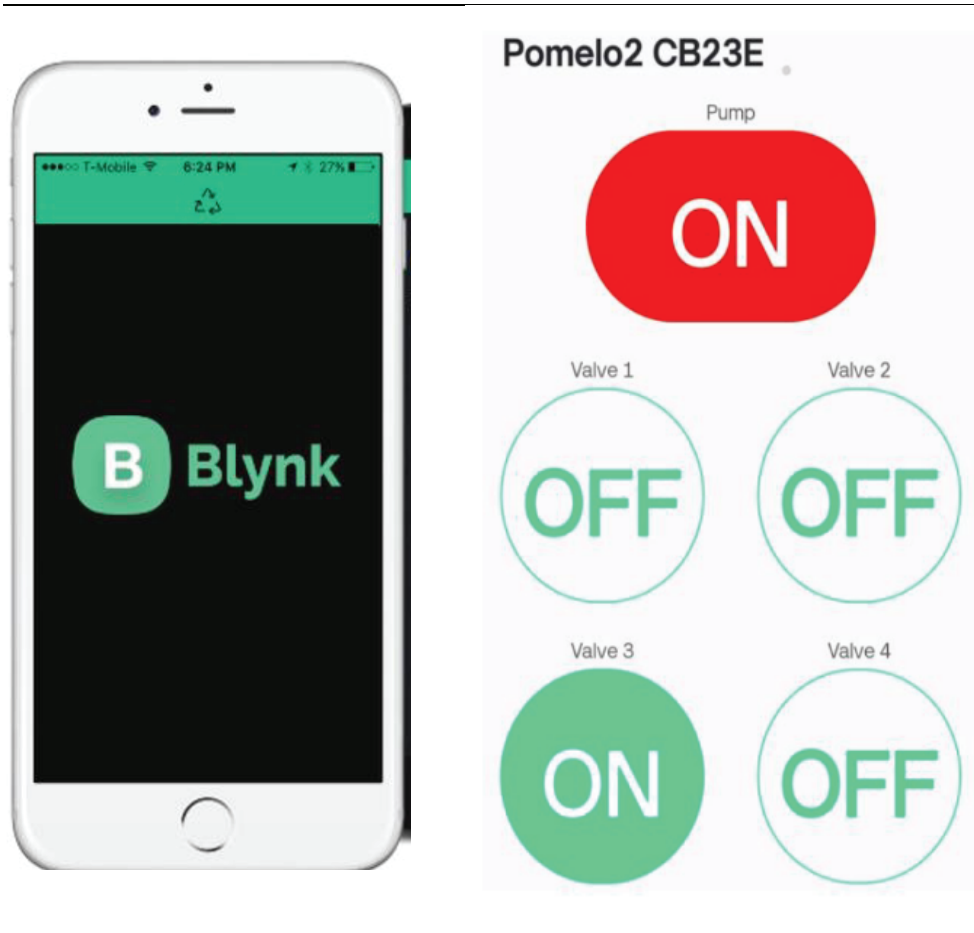


Figure 4: The process of automatically “on and off” system of water pump and solenoid valves by using the application Blynk.

transmitted with Wi-Fi (frequency band of 2.4 GHz). Data were sent to the gateway, stored on the server, and retrieved on Google Sheets. Data were collected at the same time while soil moisture data were collected.

e. Data analysis

Daily soil moisture (%) trend lines were made for conventional and smart watering systems. An independent sample *t*-test was conducted to test the differences in soil moisture (%) between conventional and smart watering systems. In both treatments, linear regressions were made between air temperature (°C) and soil moisture (%). The relationships between air temperature (°C) and soil moisture (%) for both treatments were compared using an analysis of covariance (ANCOVA), in which “soil moisture” was used as the response variable, “treatments (i.e., conventional and smart watering systems)” as the factor, and “air

temperature” as the covariate. Before statistical analysis, the normality of the data was tested using the Shapiro–Wilk test, and it was observed that the data were normally distributed. All data were reported as mean $\pm$ standard deviation (SD), and the test was considered statistically significant at $p < 0.05$.

III. Results

a. Soil moisture (%) trend lines at different times (o'clock) in a day in the conventional and smart watering systems inside pomelo garden

Soil moisture (%) trend lines show that the conventional watering system always had less moisture (%) than the smart watering system. Moreover, the moisture level in the conventional watering system was always $<70\%$, which is considered a mild or moderate

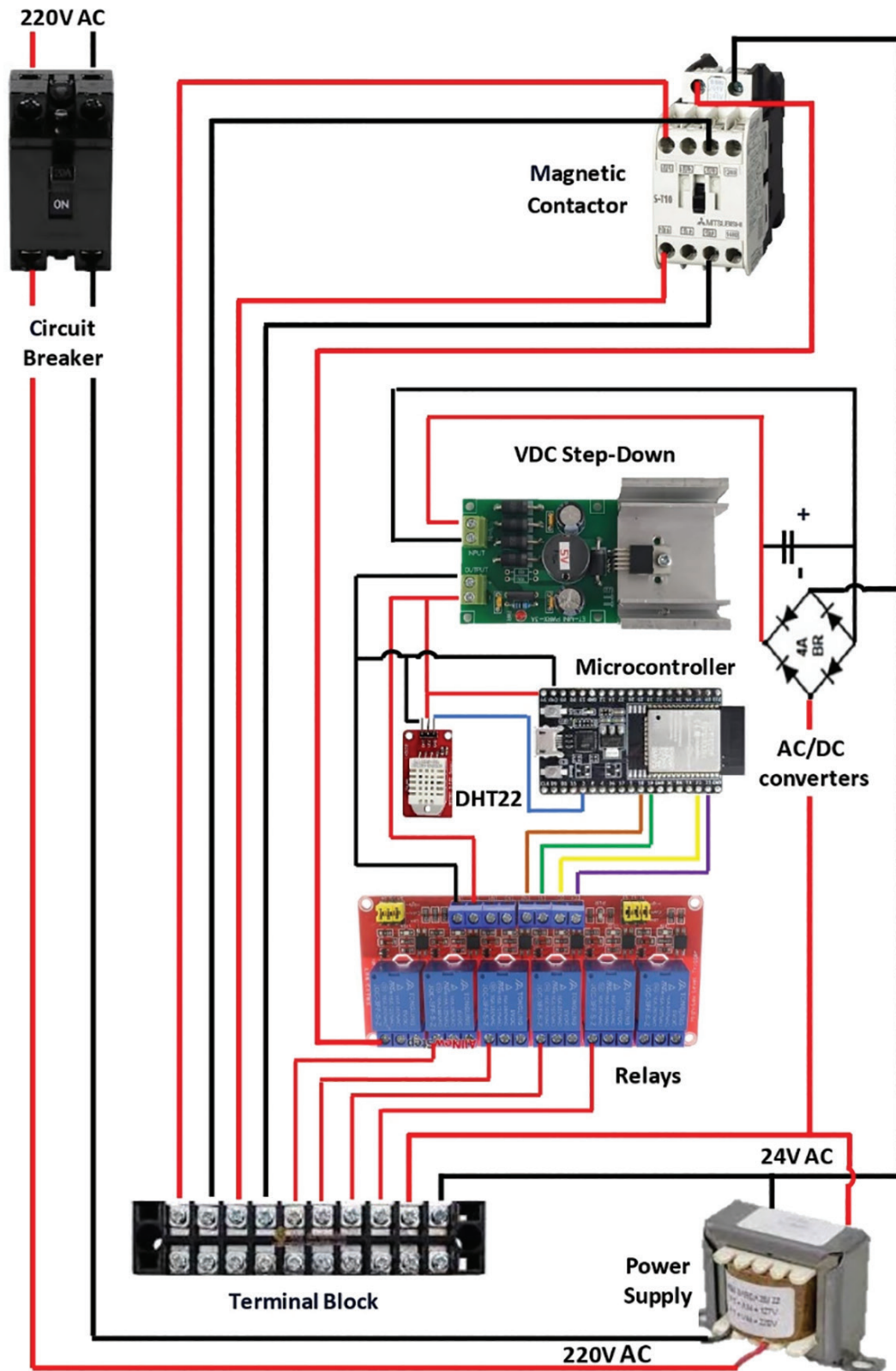


Figure 5: The schematic diagram of the electronic circuit in the control cabinet. VDC refers to Voltage Direct Current.

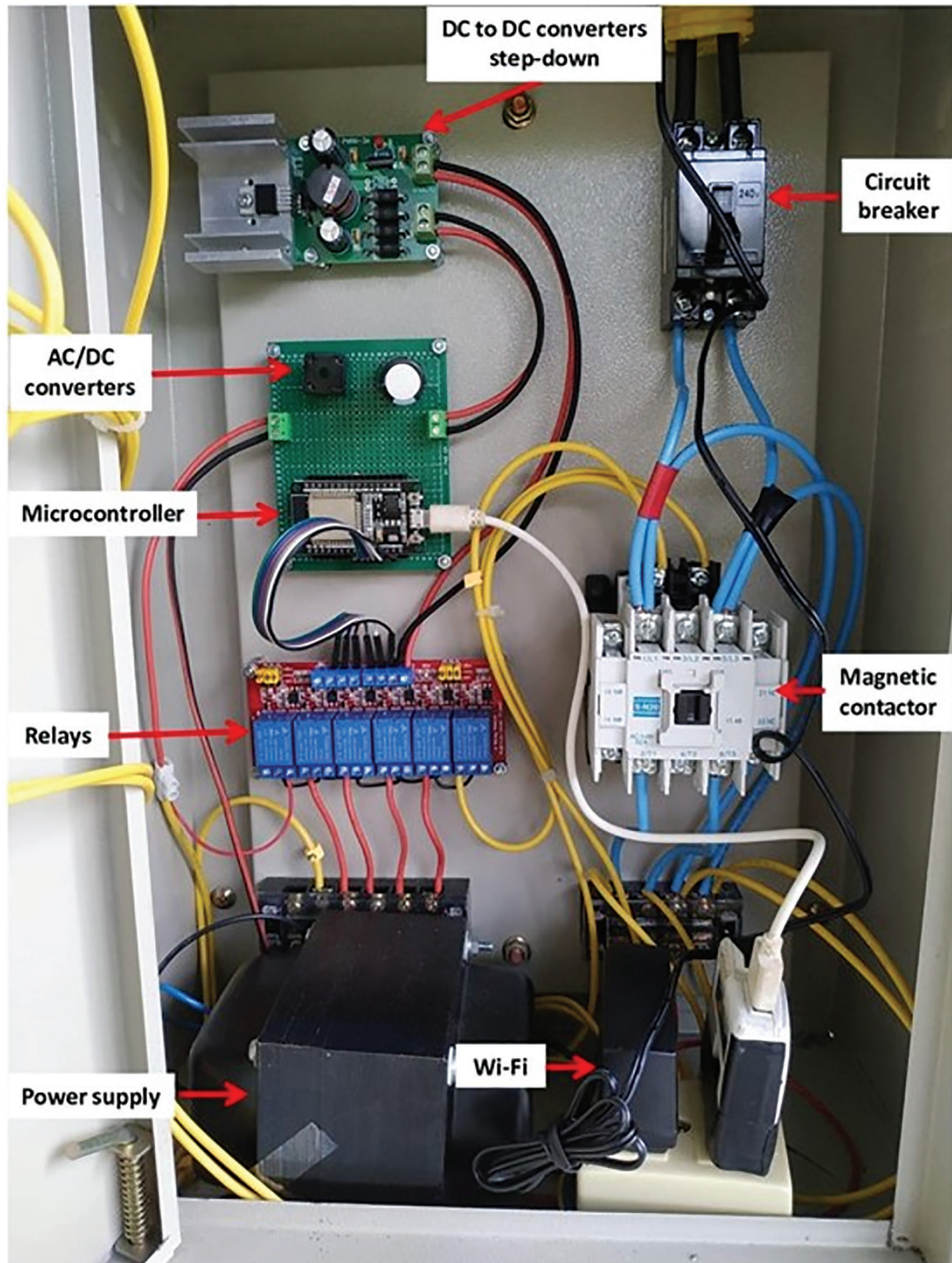


Figure 6: The equipment installed inside the control cabinet.

Table 1: Electronics used to develop the smart watering system

Electronics used	Description
Microcontroller	NodeMCU ESP32
Soil moisture sensor	Modbus RTU RS485
Temperature sensor	DHT22 Module
Power supply	Transformer
Smartphone and operating system	Xiaomi and Android
Relay	Relay Module
Magnetic contactor	S-N20 Coil AC24V
Circuit breaker	Safety breaker AC240V 30A
AC/DC converters	Bridge rectifier diode and capacitor
DC to DC converters step-down	ET-MINI PWR12-3A

water deficit. On the contrary, in the smart watering system, $\geq 70\%$ moisture was observed from 9.30 a.m. to 11.30 p.m. (Figure 10). The highest moisture level (i.e., $>72\%$) was observed at 5.00 p.m. However, the moisture level (%) was low from midnight to morning. Since no water was provided in the evening or night, the soil moisture (%) level became low.

b. Differences in soil moisture (%) between “conventional watering system” and “smart watering system” inside pomelo garden

In the conventional watering system, the mean soil moisture (%) was 68.04 ± 1.24 , whereas in the smart watering system, the mean soil moisture (%) was 70.14 ± 1.53 . The statistical analysis shows that soil moisture (%) in the smart watering system was significantly higher than in the conventional watering

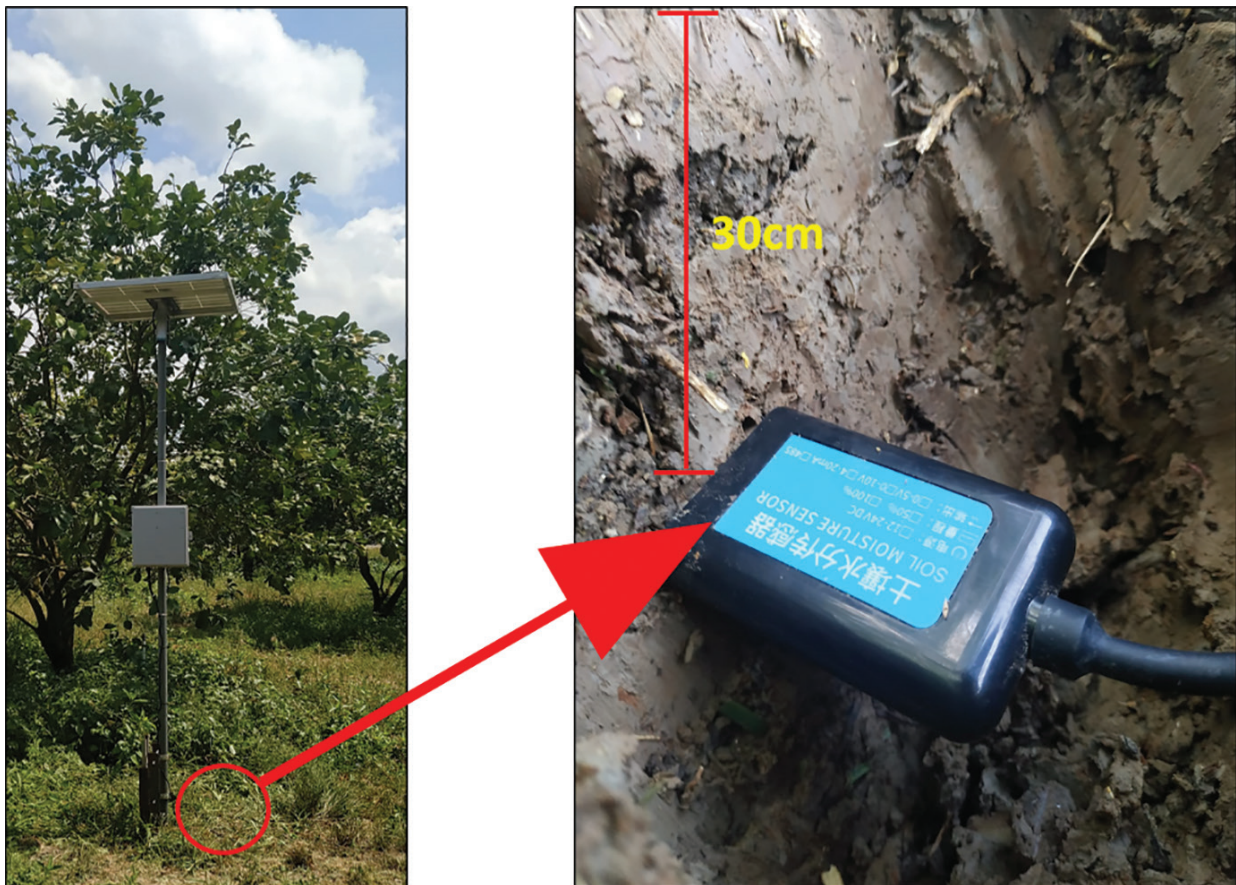


Figure 7: The installation of soil moisture sensors under pomelo trees.



Figure 8: Water sprinkler at the bottom of a pomelo tree.

Table 2: Components used in the conventional and smart watering systems

Components used	Conventional watering system	Smart watering system
IoT-based smart watering system	No	Yes
Soil moisture sensing system	Yes	Yes
Watering method	Water sprinkler at the bottom of each tree. Farmers turn on the pump and water valve manually.	Water sprinkler at the bottom of each tree. Farmers can set time and control water pumps and valves automatically by using their smart phones.
Watering time/day	8.00 a.m. to 8.30 a.m. and 13.00 p.m. to 13.30 p.m.	6.30 a.m. to 6.45 a.m., 9.30 a.m. to 9.45 a.m., 12.30 p.m. to 12.45 p.m., and 3.30 p.m. to 3.45 p.m.
Watering duration/tree/day	60 min	60 min
Water amount/tree/day	200 L	200 L

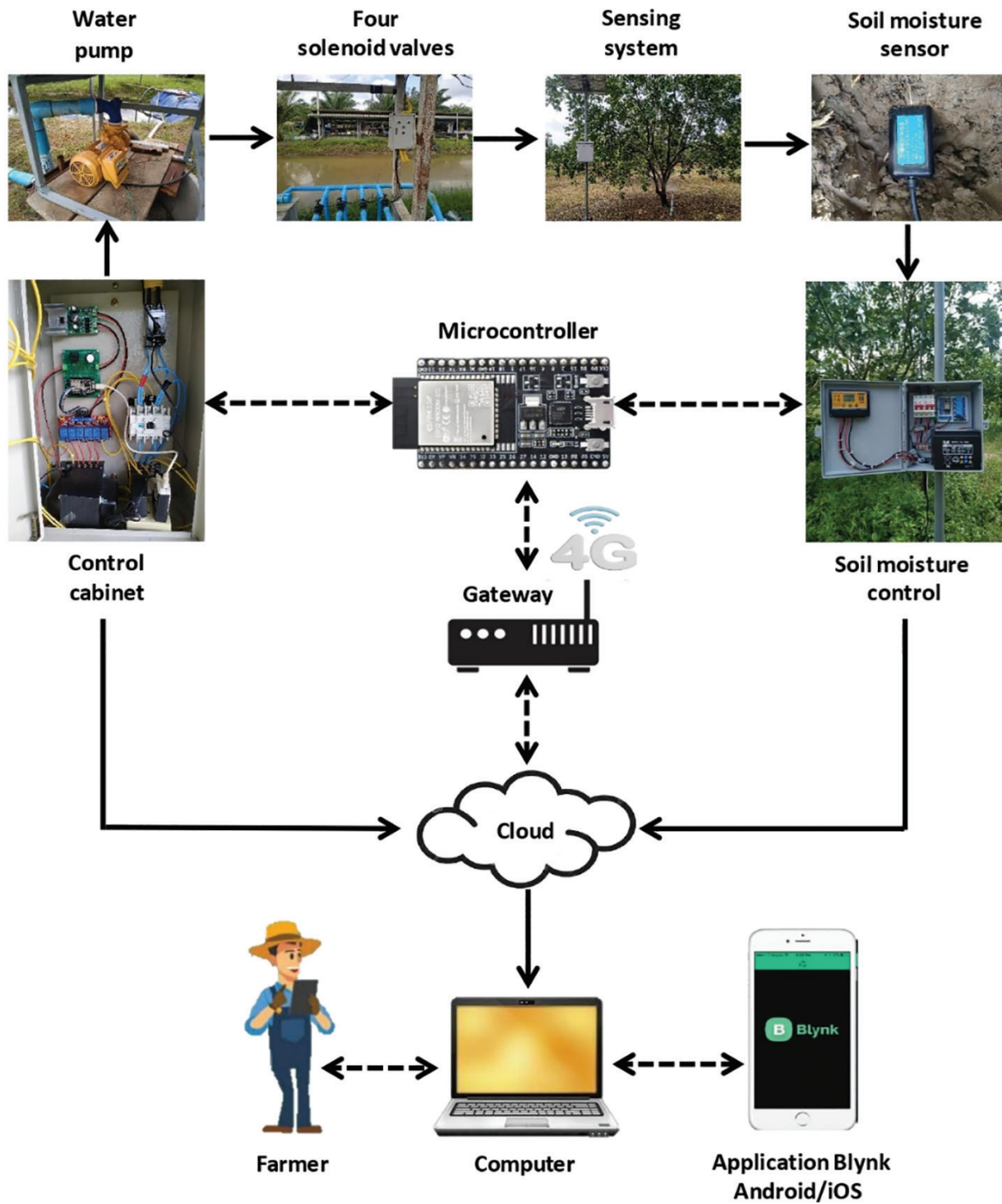


Figure 9: The complete process of smart watering system for monitoring and increasing soil moisture content in pomelo garden.

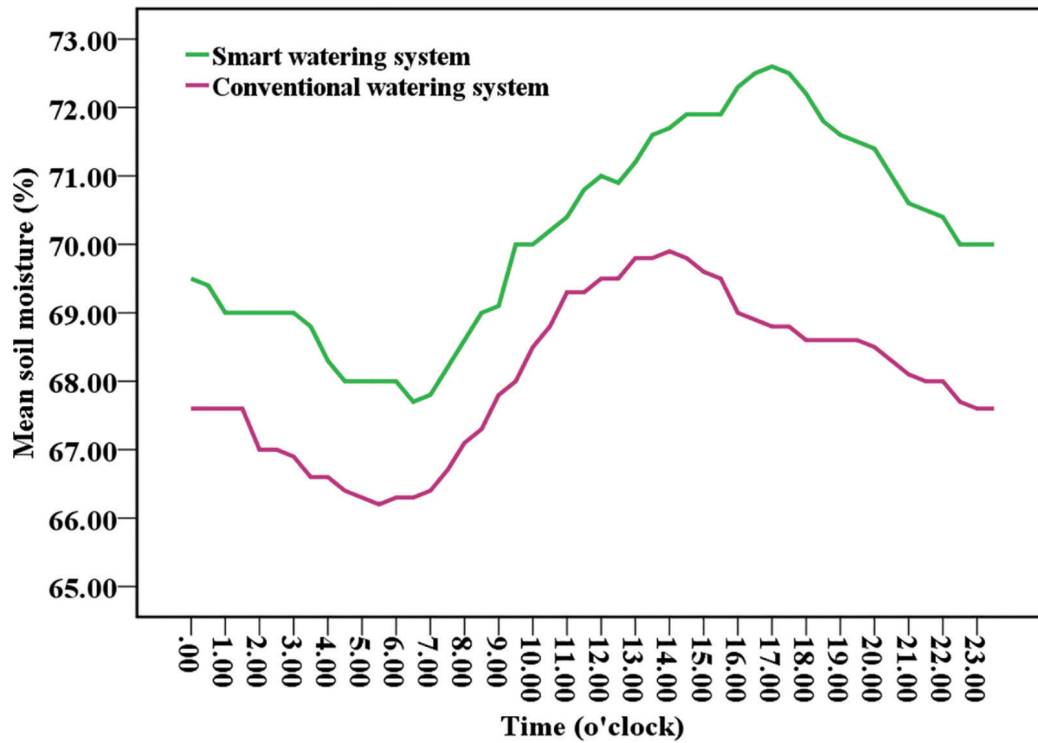


Figure 10: Soil moisture (%) trend lines in the conventional and smart watering systems.

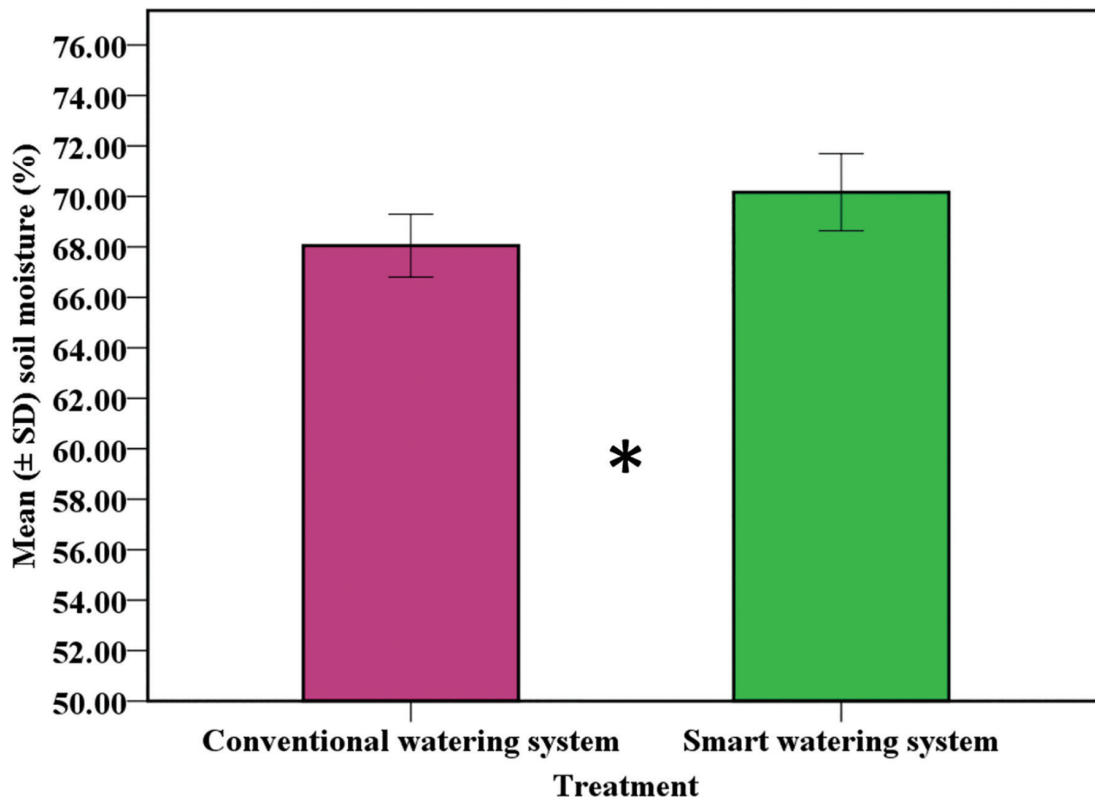


Figure 11: Soil moisture (%) differences in the conventional and smart watering systems.

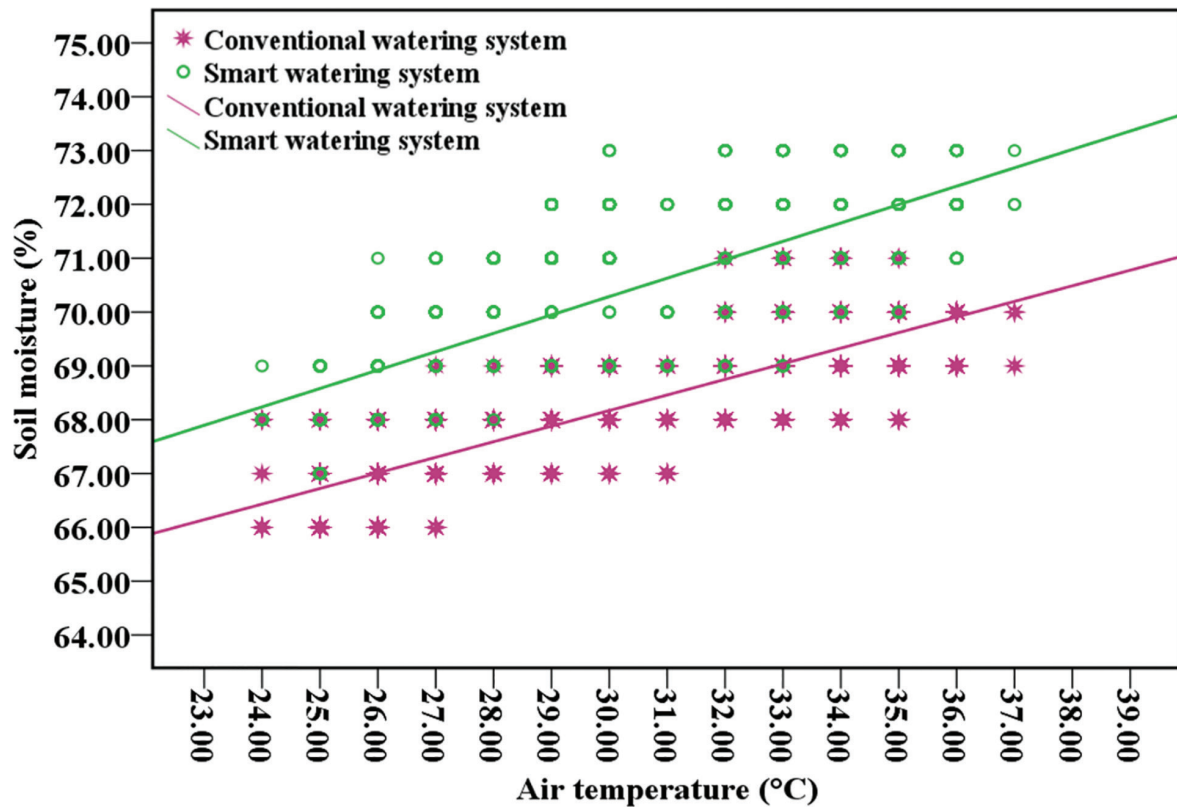


Figure 12: The relationships between air temperature (°C) and soil moisture (%) in the conventional and smart watering systems.

Table 3: The performance of some existing smart watering systems

Existing watering systems	Performance	References
Sensor-based smart irrigation networks system for efficient irrigation and water savings	A sensor-based smart irrigation networks system was successfully used to monitor and maintain soil moisture and water consumption in strawberry greenhouses in Greece.	[34]
Sensor-based smart irrigation systems to monitor soil moisture and maintain irrigation process	A sensor-based smart irrigation system was used successfully to monitor real-time soil moisture and maintain the irrigation process to save water in tomato greenhouses in China.	[35]
An IoT-based smart watering system to increase moisture (%) content	An IoT-based smart watering system was used successfully to increase the moisture (%) content inside the mangosteen canopy in Thailand.	[37]
An IoT-based smart watering system to reduce thrips numbers	An IoT-based smart watering system was used successfully to reduce the thrips numbers in mangosteen orchards in Thailand.	[38]
Sensor-based irrigation system to control irrigation-related parameters	A sensor-based irrigation system was used successfully to measure and control temperature and humidity in melon orchards in Thailand.	[50]
Sensor-based automatic watering system to monitor and maintain the required level of soil moisture	A sensor-based automatic plant watering system was used successfully to monitor air temperature and soil humidity as well as to maintain required levels of soil moisture in eggplant farm in Indonesia.	[56]

system ($t_{286} = -2.25$, $p = 0.025$) (Figure 11). This indicates that the smart watering system increased soil moisture (%) significantly more than the conventional watering system and maintained the required soil moisture level for pomelo orchards.

c. The relationships between air temperature (°C) and soil moisture (%) in the conventional and smart watering systems

Positive linear regressions were found between air temperature (°C) and soil moisture (%) in conventional and smart watering systems (conventional system: $R^2 = 0.70$, $F_{1, 1438} = 3441.64$, $p = 0.000$, $Y = 59.48 + 0.29X$; smart watering system: $R^2 = 0.64$, $F_{1, 1438} = 2609.82$, $p = 0.000$, $Y = 60.04 + 0.34X$). Moreover, ANCOVA showed that the positive relationship was significantly stronger in the smart watering system than in the conventional watering system (ANCOVA: $F_{1, 2877} = 4802.66$, $p = 0.000$) (Figure 12). This indicates that soil moisture in the smart watering system was higher than that in the conventional system at any temperature in a day.

IV. Discussion

In this study, a smart watering system was developed and used successfully to monitor and increase soil moisture content in the Tabtim Siam pomelo garden. Soil moisture content affects the growth, quality, and production of citrus fruits [39–41]. When the soil moisture content is too low, the fruits will be shriveled, the yield of citrus fruits will decrease, and the weight of each fruit and vitamin C level will decrease [42]. Several studies show that low soil water content negatively affects plant water status, reducing leaf water potential and gas exchange [43–45]. Additionally, water deficit affects the content of amino acids, organic acids, and sugars in the fruit [46]. Fruit splitting and nutritional deficiencies also occur due to a lack of water in the orchards [47]. In the case of pomelo trees, if there is a lack of water, the growth of trees becomes delayed, insects attack pomelo trees easily, the flowers and immature pomelos fall off, and the matured pomelos lack sugar, juice content, and quality [28, 31, 40]. Low soil moisture content affects pomelos and other fruits in Thailand. Therefore, several intelligent watering systems were developed and used in different fruit orchards. For example, an intelligent irrigation system was developed to control soil moisture inside a durian garden in Nakhon Si Thammarat Province [48].

An intelligent irrigation system was developed to monitor and control a cassava garden's soil moisture content in Nakhon Ratchasima Province [49]. Another study developed and used a sensor-based watering system to monitor and control the soil moisture levels in melon orchards in Nakhon Pathom Province [50]. The details of some existing smart watering systems are provided in Table 3.

It was also observed that the smart watering system could hold more soil moisture content (%) compared with the conventional watering system, even at very high air temperatures (e.g., $>30^{\circ}\text{C}$). The conventional watering system also maintained soil moisture level by 67%–68% when the air temperature was very high, but it could not reach up to 70%, which is the required level for Tabtim pomelo. Naturally, moisture content in soil is controlled by several factors but primarily by air temperature [51]. Air temperature negatively affects soil moisture, and soil moisture retention, diffusion, and loss can be impacted by rising air temperatures [52, 53]. In most cases, air temperature negatively correlates with soil moisture [54, 55]. However, artificial watering/soil irrigation can increase the moisture content in the soil if it is done properly and, in that case, it is possible to get a positive relationship between air temperature and soil moisture, which is observed in our study. Another study also showed that providing water inside an eggplant orchard increased soil moisture content and maintained moisture level by nearly 60% even when the temperature was 30°C [56]. Our study also found that the smart watering system maintained moisture levels by 70% even when the temperature was $>30^{\circ}\text{C}$. This happened because water was automatically provided for 15 min at 12.30 p.m. and 3.30 p.m. when the temperature was $>30^{\circ}\text{C}$. This indicates that watering time is also essential to maintain the required moisture content in the soil.

Future research could be conducted to develop an innovative and cost-effective IoT sensor-based watering system that will not only monitor the soil moisture but also provide or stop watering automatically based on the required soil moisture level (%). This system could be used more effectively in fruit/vegetable orchards where maintaining soil moisture (%) is crucial.

V. Conclusion

This study designed and used an IoT-based smart watering system to monitor and increase soil moisture level effectively inside a Tabtim Siam ruby pomelo garden. This study also observed that soil moisture was at the required level even when the air temperature was very high. It presumably happened because

of the watering time management by using the smart watering system. Though farmers provided water twice daily (30 min each time), it did not help them to keep the soil moisture at the required level when the temperature was high. On the contrary, in the smart watering system, providing water four times (15 min per time) daily maintained the required level of soil moisture during high temperatures, and it used the same amount of water that the farmers use in their conventional watering method. Therefore, this study shows that using a smart watering system and providing water systematically helps the farmers to keep the soil moisture level of $\geq 70\%$ in the ruby pomelo orchards. This system might be helpful for other fruit orchards requiring high soil moisture. Now, this smart watering system needs to be familiar to the farmers who cultivate pomelo or other fruits in southern Thailand, so that they will be able to use this system easily, increase the quality and quantity of the fruits, and earn more money.

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