Automated Phalaenopsis Orchidaceae Watering System with Rainwater Harvesting and Soil Moisture Monitoring: An IoT Approach to Sustainable Horticulture

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DOI: https://doi.org/10.47772/IJRISS.2026.101000088

Received: 11 October 2026; Accepted: 16 October 2026; Published: 28 October 2026

ABSTRACT

Orchid farming, particularly for the Moth Orchid (Phalaenopsis), is a vital source of income for rural smallholder nurseries in Malaysia. However, traditional manual watering is often inconsistent, leading to water waste, underwatering, or overwatering of these delicate plants. This study presents an automated watering and monitoring system designed for Phalaenopsis orchids that integrates rainwater harvesting with real-time Internet of Things (IoT) monitoring. The system uses an Arduino UNO to gather sensor data and an ESP32 to transmit the information over Wi-Fi. Connected components include a capacitive soil moisture sensor, a DHT11 temperature and humidity sensor, a BH1750 light sensor, a rain sensor, and an ultrasonic sensor to monitor the water level in the storage tank. A servo motor automatically operates the storage tank lid based on rain detection to collect rainwater. When soil moisture drops below a preset 30% threshold, a water pump and solenoid valve activate for 3 to 12 seconds. Live data is displayed on a local OLED screen, sent to the Blynk application, and logged via Firebase to Google Sheets. The system was evaluated over a six-week trial using two mature orchids and two saplings. The automated system managed water efficiently, showing a gradual decline in the rainwater storage tank from 84.80% in Week 1 down to 76.70% by Week 6, maintaining a six-week average water level of 80.72%. Furthermore, the monitored orchid achieved a new leaf length of 7.3 cm by Week 6 compared to 5.3 cm for the unmonitored control plant, representing a 37.74% boost in new leaf growth. The system successfully prevents growth delays and supports healthy orchid development while utilizing a sustainable water source.

Keywords: Automated Watering, Internet of Things (IoT), Rainwater Harvesting, Soil Moisture Monitoring, Phalaenopsis Orchids.

INTRODUCTION

Orchid farming, especially growing the Moth Orchid (Phalaenopsis), is highly important in Malaysia because these flowers have a very high market value and are deeply loved for their beauty. In Malaysia's floriculture industry, orchid farming serves as a vital source of income for rural smallholder farmers and family-owned nursery businesses, helping to boost rural economies and support local livelihoods [1][2]. However, the Moth Orchid is an epiphytic plant, meaning it naturally grows on trees rather than in soil, so it has very delicate

roots that need a strictly controlled environment. To grow well and produce high-quality blooms, it requires just the right balance of temperature, air humidity, light, and very steady watering [3][4].

Currently, most local nursery owners still rely on traditional manual watering methods, which are often inconsistent and inefficient. Manual watering makes it hard to keep the moisture levels steady in the pots, leading to either underwatering or overwatering, and it causes huge water waste. This problem is even worse in tropical climates like Malaysia's, where weather conditions can change rapidly from intense heat to sudden humidity shifts within a single day [7]. For small businesses, this inconsistency directly threatens their income, as poor flower quality or plant death can cause severe financial losses [1][8].

Recently, smart farming technologies using the Internet of Things (IoT) have made it possible to build automated systems that manage resources better and take better care of plants. By using affordable microcontrollers and wireless networks, these systems can help farmers track their crops remotely, which lowers the need for constant physical labor, a major benefit given the current shortage of agricultural workers [5][9][10]. Because general field crop systems do not match the unique biological needs of orchids, researchers have had to develop highly specialized methods, such as utilizing computer vision and 3D positioning, just to achieve precise irrigation at the plant level [11]. On top of that, there is very little research on how to easily connect rainwater harvesting tools with automated watering systems in small nurseries.

To bridge this gap, this project focuses on developing a simple, affordable IoT-based automated watering system designed specifically for Phalaenopsis orchids that links rainwater harvesting with real-time environmental monitoring. The system uses low-cost sensors to keep track of soil moisture, temperature, humidity, light levels, and the water level in the storage tank to make sure the plants get the exact amount of water they need [13][14]. All the live data is sent to a user-friendly cloud application interface, allowing nursery owners to monitor their crops from anywhere using their phones. Ultimately, this system seeks to support smallholder orchid growers by promoting improved plant growth and encouraging the adoption of sustainable cultivation practices [10][16].

Problem Statement

Rainwater is an excellent, free, and highly sustainable water source for orchids because it is naturally pure, rich in oxygen, and free from harsh city water chemicals like chlorine, which can harm delicate orchid roots. Even so, because many small nurseries lack proper storage tanks and automated pumps, they miss out on using rainwater effectively, leading to major water loss during heavy downpours [12], which directly leaves delicate orchid root architectures vulnerable to inconsistent moisture stress [17]. In Malaysia, growing populations and industrial expansion have pushed up the demand for water, making the integration of targeted water demand models and localized storage infrastructure a national priority for the agricultural sector [18][19]. Using rainwater harvesting (RWH) is a practical solution to collect, store, and reuse water for nurseries [19][20]. However, most existing setups do not connect rainwater tanks to automated irrigation systems, leading to uneven water supplies. Since Phalaenopsis orchids need incredibly precise moisture conditions to survive, an integrated automated system is urgently needed to allow smallholder growers to dynamically harness stored rainwater, thereby bypassing expensive municipal city water tariffs while securing crop health [4][16].

The growth and financial yield of Phalaenopsis orchids depend entirely on stable climate conditions, especially substrate moisture, air temperature, humidity, and light. When manual watering is inconsistent and tropical weather changes unexpectedly, orchids experience severe physiological stress [6][7]. Too much water quickly causes root rot from fungal diseases, which can wipe out an entire nursery batch, while too little water stunts plant growth, stops flowers from blooming, and causes young buds to drop early [4][6]. Without continuous data tracking, it is almost impossible for a busy farmer to maintain the perfect growing conditions manually. Therefore, a reliable IoT monitoring system is necessary to give farmers live updates on their greenhouse climate and water storage levels [14][15].

The main issue is that the lack of real-time data in traditional orchid farming makes it very difficult for growers to manage their water use efficiently and prevent plant disease before it spreads. Without continuous sensor

insights, smallholder nursery owners struggle to keep their crops healthy, leaving them highly vulnerable to sudden economic shocks and volatile production drops [4][8]. To solve this socioeconomic and technical problem, this study proposes an affordable IoT-based automated watering and monitoring system integrated with rainwater harvesting. This setup allows growers to track soil moisture, temperature, humidity, and tank levels instantly. Testing the performance of this system is highly necessary to prove its real-world value in helping Malaysian orchid farmers save water, reduce labor costs, and achieve steady, healthy crop growth [16][22]. Guided by these challenges, this study aims to develop an automated rainwater harvesting and watering system with real-time remote monitoring to facilitate water management; collect and analyse orchid growing-condition data through an IoT application interface to examine the relationship between environmental changes and pot moisture levels; and evaluate the performance of the integrated system in maintaining suitable growing conditions for orchids and supporting sustainable cultivation practices. [21][22].

METHODOLOGY

Figure 1 illustrates the block diagram of the automated orchid watering system with rainwater harvesting. The system integrates soil moisture monitoring, environmental sensing, automatic irrigation, and Internet of Things (IoT) technology to support orchid care.

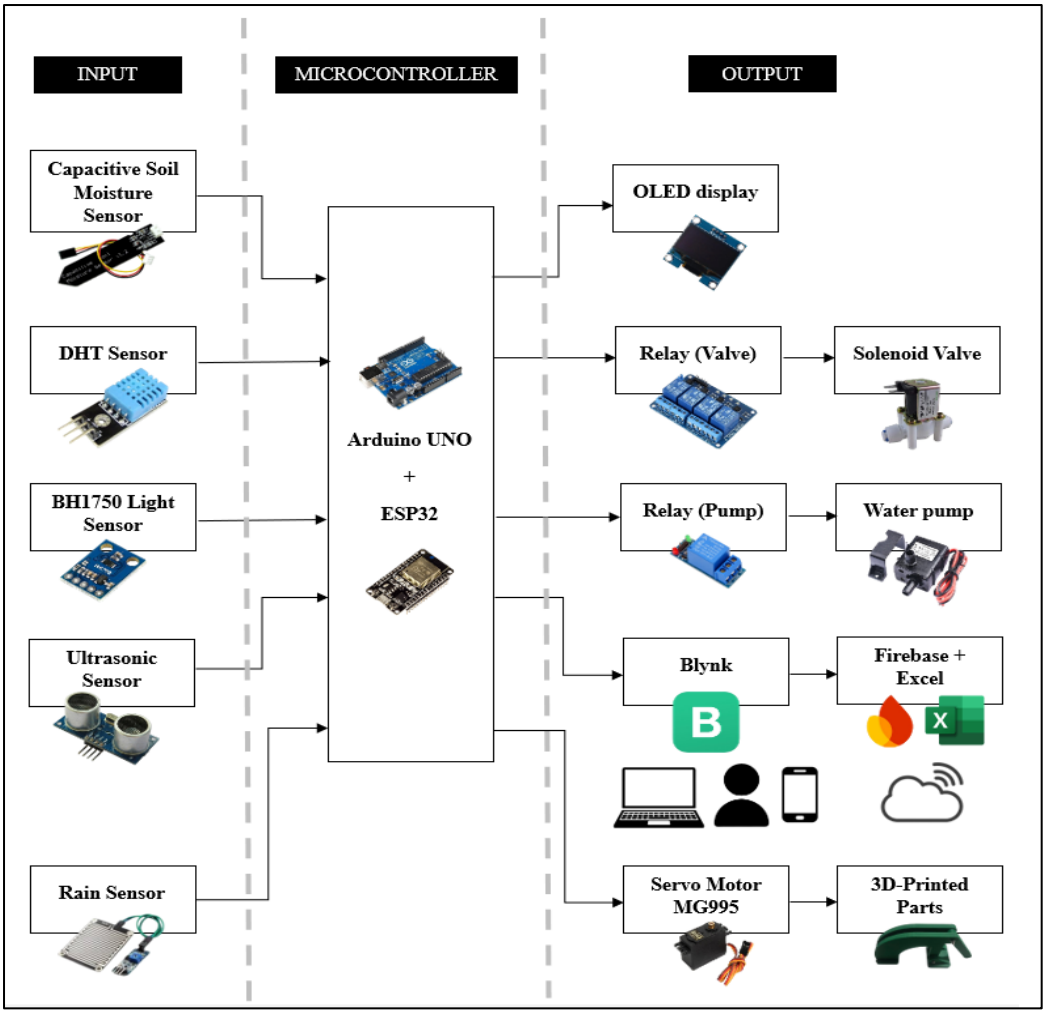


Figure 1: Block diagram of the automated orchid watering system

The system uses an Arduino UNO to collect data from the connected sensors, while an ESP32 transmits the data to the IoT platform through a Wi-Fi connection. A capacitive soil moisture sensor monitors the moisture level near the orchid roots. A DHT11 sensor measures temperature and relative humidity, while a BH1750 sensor measures light intensity. An ultrasonic sensor monitors the water level in the rainwater storage tank, and a rain sensor detects rainfall.

When the soil moisture level falls below the preset threshold of 30%, the system activates a water pump and the corresponding solenoid valve to irrigate the affected orchid. The watering duration ranges from 3 to 12 seconds, depending on the number of orchids requiring irrigation. The rain detection mechanism also controls a servo motor that opens or closes the storage tank lid through a custom-designed mechanism, supporting rainwater collection.

The monitored parameters are displayed on an OLED screen and transmitted to the Blynk application for remote monitoring. Sensor data are stored in Firebase Realtime Database and subsequently transferred to Google Sheets using Google Apps Script for data recording and analysis. This enables the system to monitor soil moisture, environmental conditions, and rainwater availability while supporting the evaluation of orchid growth and condition. The overall physical layout and system architecture of this setup are illustrated in Figure 2, while the complete hardware prototype are shown in Figures 3.

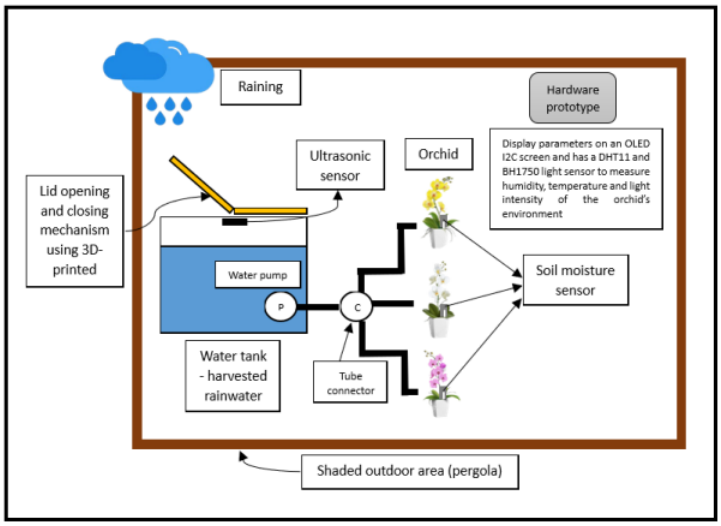


Figure 2: System architecture and physical layout of the automated orchid watering system



Figure 3: Complete hardware prototype of the automated orchid watering system

The system was evaluated over a six-week testing period using four Phalaenopsis orchids, consisting of two mature plants and two young saplings. To evaluate how the system handles different growth stages and watering conditions, the test plants were divided into four distinct groups:

- Orchid 1 (Monitored Mature): A mature plant cultivated under the automated, soil-moisture-monitored watering system.
- Orchid 2 (Unmonitored Control Mature): A mature plant grown under standard, unmonitored conditions to serve as an experimental control.

- Orchid 3 (Monitored Sapling): A young sapling monitored by the system that successfully adapted to the growing environment.
- Orchid 4 (Unmonitored Sapling): A young sapling grown under standard conditions that proved highly sensitive to environmental stress.

Throughout the monitoring period, experimental observations and sensor data logs were closely analyzed to track soil moisture patterns, ambient environmental conditions, rainwater availability, leaf elongation, and the overall physical condition of the orchids. The resulting experimental findings are detailed throughout the subsections below.

RESULT AND DISCUSSION

Data were collected over six weeks from four Phalaenopsis orchids: two mature plants (Orchids 1 and 2) and two saplings (Orchids 3 and 4). Sensor measurements were recorded daily between 8:00 a.m. and 10:00 p.m., although measurement times varied slightly. The results below describe the recorded soil moisture, environmental conditions, rainwater tank level, and observed plant growth. Because the trial involved a small number of plants and a short monitoring period, the findings should be interpreted as observations from this trial rather than evidence of general effects.

Soil Moisture Analysis

Figure 4 presents the comparison of soil moisture percentages among the four experimental orchids over the 41-day monitoring period. Orchid 4 (sapling) generally showed the highest readings, frequently exceeding 60% and reaching approximately 80–90% after watering. In contrast, the readings for Orchid 2 (mature) often decreased to around 30–35% before recovering. Orchids 1 and 3 showed intermediate patterns.

The differences between plants indicate that the recorded moisture levels varied across the four orchids. The increases following watering are consistent with the system supplying water when the configured soil-moisture threshold was reached. However, the readings alone do not establish that moisture was maintained at an optimal level for every orchid. Differences in plant size, growing medium, root development, sensor placement, and watering response may also have contributed to the variation. The 30% trigger should therefore be described as the system's configured threshold, not as a universally optimal moisture level for Phalaenopsis orchids.

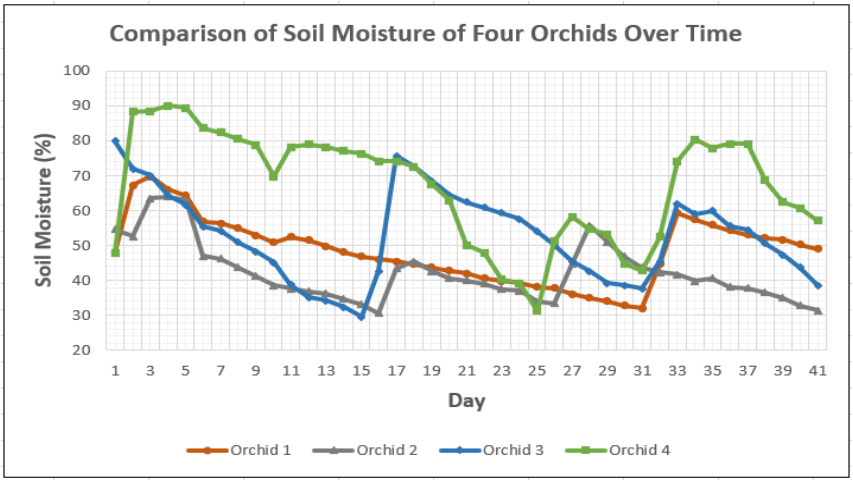


Figure 4: Comparison of soil moisture percentages

Environmental Conditions and Soil Moisture

To truly understand how soil moisture shifts inside the pots, the surrounding outdoor weather elements must be looked at together. Over the six-week trial, the outdoor shaded area experienced wide variations in temperature, air humidity, and sunlight. These day-to-day atmospheric changes directly controlled how fast

water evaporated from the soil and how quickly the plants used it up. By tracking these weather factors side-by-side with real-time soil logs, a clear pattern emerges showing how Orchid 1 (the mature plant) and Orchid 3 (the young sapling) responded to their environment. The individual impacts of temperature, humidity, and light intensity are broken down in the following sections.

Temperature

As shown in Figure 5, temperatures ranged from 30 °C to 42 °C. Naturally, as the days got hotter, the soil dried out for both plants. However, they reacted quite differently to extreme heat. When temperatures climbed past 38 °C (especially around days 10 to 14), the sapling's soil moisture dropped rapidly. The mature orchid, on the other hand, held onto its moisture much better, showing only a slow, steady decline. When it was cooler, the soil moisture for both plants stayed relatively stable. This tells us that young sapling orchids are much more sensitive to heatwaves and lose water much faster than older, well-established orchids.

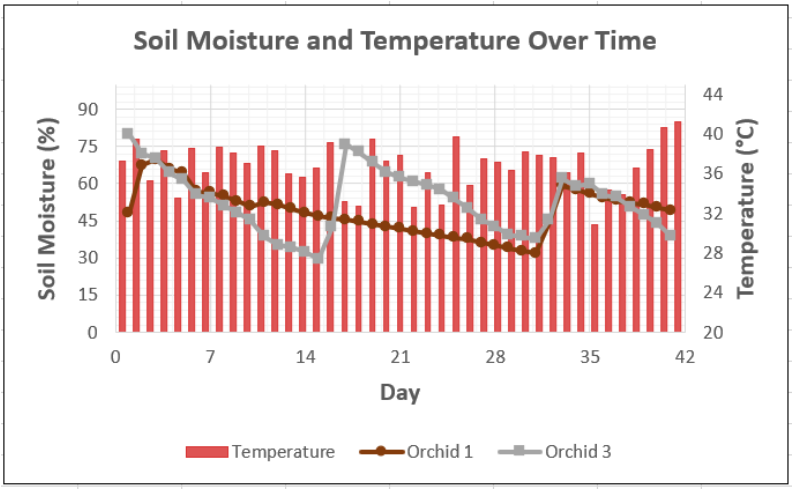


Figure 5: Soil Moisture and Ambient Temperature Trends

Humidity

Figure 6 shows that humidity levels fluctuated between 35% and 75%. High humidity acted like a protective blanket, helping both orchids keep their soil moist. But when the air dried out and humidity dropped below 45%, both plants started losing water. Just like in the temperature test, the sapling orchid lost moisture much faster than the mature one. This shows that younger orchids struggle to handle dry air. While high humidity definitely helps save water, it acts more like a protective buffer, making its impact a bit less direct than the heat of the sun.

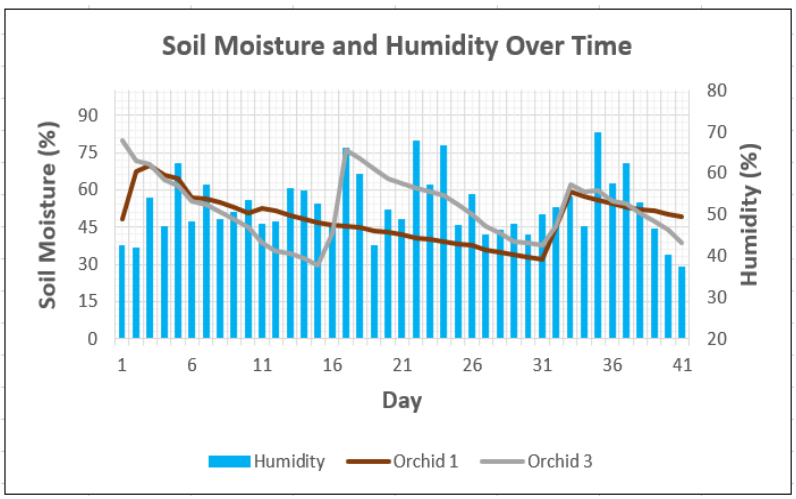


Figure 6: Soil Moisture and Relative Humidity Trends

Light Intensity and Drying Soil

According to Figure 7, light levels ranged from 3,000 lux to 16,000 lux. As the light grew brighter, the soil dried out faster for both orchids. When the light got intense—passing 12,000 lux later in the study—the sapling orchid experienced a sharp, sudden loss of soil moisture. Meanwhile, the mature orchid managed a much safer, gradual decline. This proves that young orchids are highly sensitive to strong light. Bright light essentially speeds up how fast the soil dries out, acting much like high temperatures and increasing the need for frequent watering.

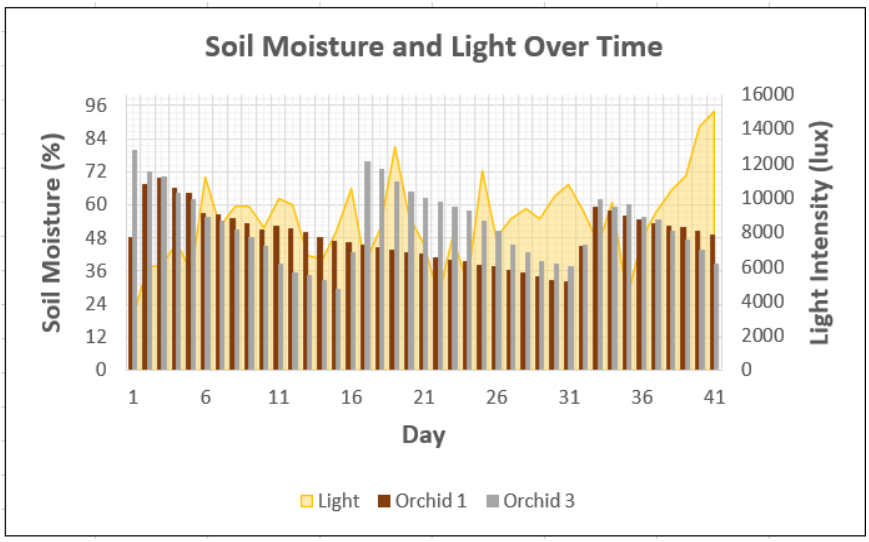


Figure 7: Soil Moisture and Relative Humidity Trends

Rainwater Tank-Level Monitoring

As shown in Table 1, the water level in the storage tank steadily decreased from roughly 85% in Week 1 downto about 76% by Week 6, resulting in a total relative decrease of 9.55% (an absolute reduction of 8.10 percentage points) and maintaining a 6-week average water level of 80.72%. This smooth, gradual decline proves that the automated watering system managed water efficiently. Instead of wasting water on a rigid schedule, the system only triggered watering events when the soil moisture dropped below the required threshold, ensuring controlled and sustainable water consumption.

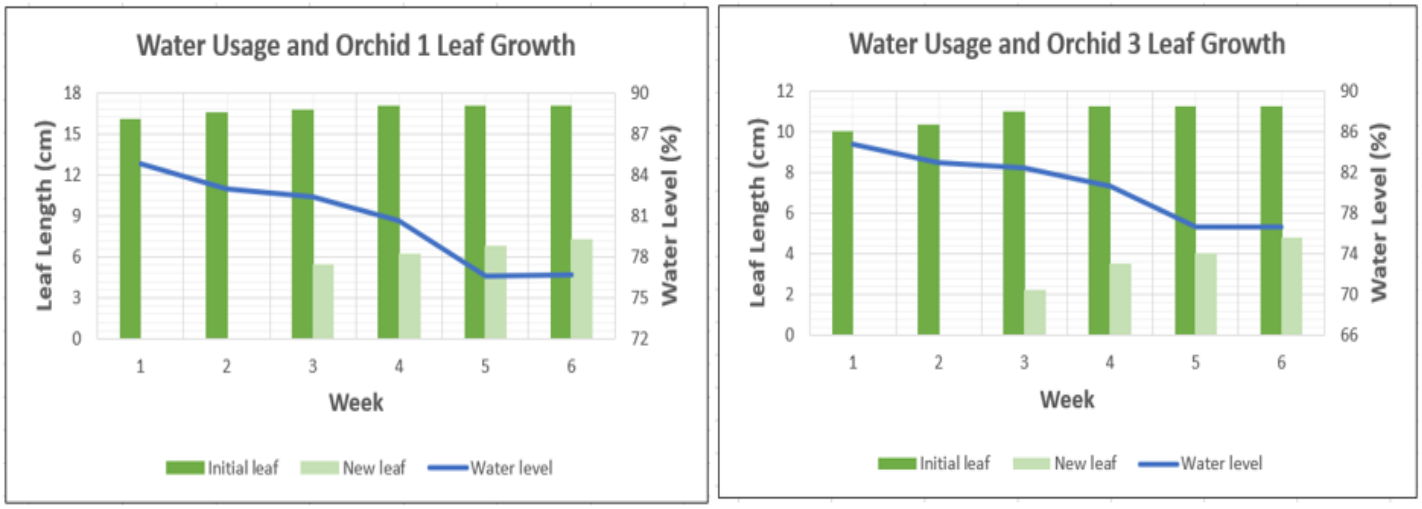
Table 1: Storage Tank Water Levels Over a Six-Week Period

Week	1	2	3	4	5	6
Water Level (%)	84.80%	83.00%	82.50%	80.60%	76.70%	76.70%

To see how this watering setup affected plant health, leaf development for both specimens has been measured, as illustrated in Figures 8(a) and 8(b).

- Orchid 1 (Mature): As depicted in Figure 7(a), the orchid's initial leaves maintained a stable length of around 15 cm throughout the six weeks. Meanwhile, its new leaves showed steady, healthy growth, proving that the automated system supplied adequate moisture to sustain mature plant health.
- Orchid 3 (Sapling): As shown in Figure 7(b), the sapling's existing leaves stayed constant at about 10 cm. However, its new leaf growth was highly pronounced, steadily climbing each week and showing an even stronger growth response than the mature orchid under identical watering conditions.

Ultimately, both orchids thrived under the automated watering system. The stable condition of the old leaves and the continuous development of new ones confirm that the system successfully delivered the right amount of water to support healthy growth at both developmental stages.



(a) (b)

Figure 8: Water usage on (a) Orchid 1(mature) (b) Orchid 3 (sapling)

Orchid Condition and Leaf Growth

Initial observations showed that the mature plants (Orchid 1 and Orchid 2) were healthy, with strong, well-developed leaves and roots. In contrast, the saplings (Orchid 3 and Orchid 4) were much smaller, featuring fewer leaves and no flowers. Progress was tracked closely from the beginning to the end of the monitoring period to see exactly how each plant responded. Testing plants across these different growth stages provided a clear picture of how soil moisture and environment affect various phases of plant development.

• Flower and Leaf Condition

The mature plants maintained healthy leaves and even sprouted new ones, showing they received a steady, reliable water supply. While some of the older flowers on Orchid 1 and Orchid 2 wilted over time, this was a normal part of their natural blooming cycle. For the saplings, Orchid 3 stayed resilient and kept growing new leaves despite some minor early damage. Orchid 4, however, struggled significantly, showing yellowing leaves and wilting, which highlighted its high vulnerability to environmental stress under standard conditions.

• Leaf Length Growth

The growth of specific new leaves was measured every week to evaluate how well the watering setups performed. Both mature plants showed steady growth, with new leaves appearing from Week 3 onward. Orchid 1 (monitored) shot up faster in the beginning, while Orchid 2 (unmonitored) maintained a larger overall leaf size. Looking at the younger saplings, Orchid 3 grew steadily and adapted well to its environment, whereas Orchid 4 showed very limited growth and failed to form any distinct new leaves due to stress.

• Comparing Monitored and Unmonitored Orchids

To truly test system performance, the automated, monitored plant (Orchid 1) was compared against the unmonitored control plant (Orchid 2). Orchid 1 utilized automated soil moisture sensors to trigger watering whenever needed. This smart setup kept the plant highly healthy, with steady growth and excellent new leaf development. On the other hand, Orchid 2—kept in the exact same room but watered on an irregular schedule—suffered from more rapid flower wilting and leaf discoloration due to watering inconsistencies.

As shown in Figure 9, both plants started slowly, with no new leaf growth at all during Weeks 1 and 2. However, their paths diverged sharply starting in Week 3:

• Orchid 1 (Monitored): Began growing rapidly in Week 3, jumping straight to 5.4 cm. It continued to climb steadily to 6.2 cm in Week 4, 6.8 cm in Week 5, and reached 7.3 cm by Week 6.

- Orchid 2 (Unmonitored): Experienced a growth delay, staying at 0.0 cm through Week 3. It finally started growing in Week 4 at 1.5 cm, moving up to 3.4 cm in Week 5 and finishing at 5.3 cm in Week

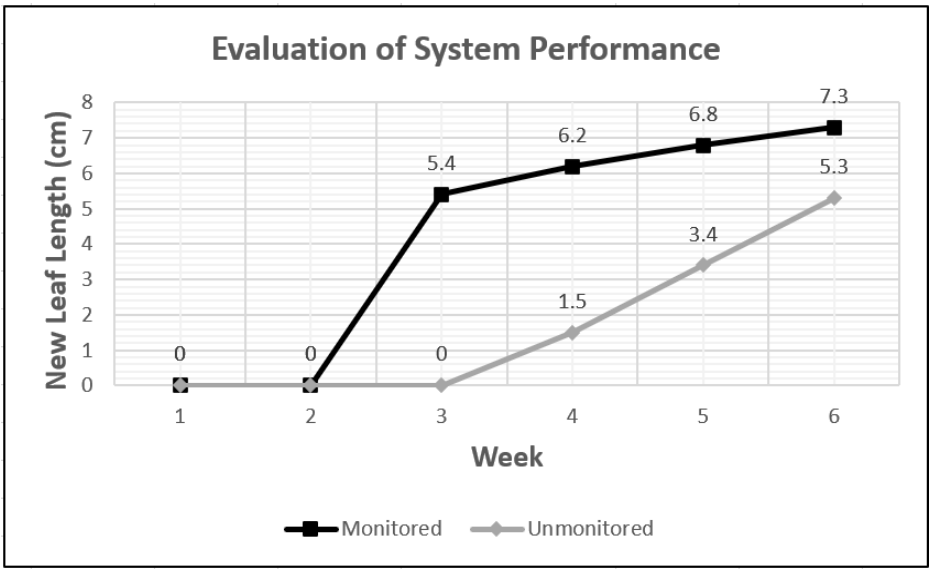


Figure 9: New Leaf Growth Between Monitored and Unmonitored Orchids

By the end of the sixth week, Orchid 1 reached a final leaf length of 7.3 cm, while Orchid 2 stopped at 5.3 cm. This means the automated system delivered a 37.74% boost in new leaf growth. These results clearly show that automating the watering schedule based on actual soil needs prevents growth delays and helps plants thrive.

CONCLUSION

Key Contributions and Conclusions

This project successfully designed and tested an IoT-based automated watering and monitoring system integrated with rainwater harvesting for Phalaenopsis orchids. The system provides an affordable solution for smallholder nursery owners, allowing them to track real-time soil moisture, environmental weather conditions, and rainwater storage levels remotely via a mobile application and automated cloud spreadsheets.

The experimental findings confirm that the system functions effectively under changing environmental conditions, where recorded temperatures ranged from 30 °C to 42 °C, humidity between 35% and 75%, and light intensity from 3,000 to 16,000 lux. The sensor logs showed that the young sapling orchids were highly sensitive to environmental factors, experiencing rapid soil moisture drops when temperatures exceeded 38 °C, when humidity dropped below 45%, or when light intensity passed 12,000 lux. In contrast, the mature orchids held onto their moisture much better, showing a gradual decline.

The automated system demonstrated high efficiency in resource management and plant growth. The system successfully collected and utilized rainwater, showing a controlled, smooth drawdown in the storage tank from 84.80% to 76.70% over six weeks. By automatically triggering watering events only when the soil moisture dropped below the 30% threshold, the system eliminated scheduling irregularities. This directly resulted in a 37.74% boost in new leaf growth for the monitored orchid, which reached a length of 7.3 cm by Week 6

compared to only 5.3 cm for the unmonitored control plant. These results prove that the system successfully mitigates growth delays, keeps plants healthy, and supports sustainable water consumption.

Future Recommendations and Sustainable Design

Because this initial trial involved a small number of plants and a short monitoring period, the findings should be interpreted as observations from this specific test rather than definitive evidence of general effects. Therefore, a primary recommendation for future work is to expand the evaluation by using a much larger number of orchids and extending the monitoring period over several months or full seasonal changes to gather a more comprehensive dataset.

Additionally, future iterations can focus on refining the system's software settings. Since the differences between the test plants showed that moisture levels and drying rates vary significantly based on plant size, root development, and sensor placement, the 30% trigger should not be treated as a universal standard. Future research should explore adjusting and customizing the soil moisture thresholds specifically for different growth stages such as separate preset values tailored uniquely for mature orchids versus younger, more sensitive saplings. Finally, the physical mechanics of the custom 3D-printed lid mechanism can be optimized to ensure maximum rainwater collection efficiency during sudden tropical downpours.

ACKNOWLEDGMENT

The authors sincerely acknowledge the Centre for Research and Innovation Management (CRIM) and Universiti Teknikal Malaysia Melaka (UTeM) for their valuable support, resources, and encouragement in facilitating the successful completion of this research.

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