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AutoPot: An Innovative Urban Gardening with IoT-Enabled Watering System

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Abstract

Urban living environments such as condominiums, apartments, flats, and other high-rise buildings often lack personal garden spaces, compelling residents to grow plants in pots. Residents who cultivate plants in pots encounter difficulties in regulating watering routines, necessitating irrigation during dry weather while refraining from watering during humid weather. This can be particularly difficult for those with busy work schedules. Therefore, there is a need for an automated watering system to assist them in maintaining optimal soil moisture levels without the constant need for manual intervention. The AutoPot is proposed to address this gap by developing a prototype that leverages IoT technology to optimize watering practices. The AutoPot integrates sensors to monitor soil moisture, humidity, and temperature levels in real-time, automatically activating a water pump when the soil moisture drops below a preset threshold. This study evaluates the AutoPot system based on its efficiency in watering plants by monitoring soil moisture levels. The system's performance is assessed by its ability to maintain optimal soil moisture, ensuring plants receive adequate water without over- or under-watering. Data collected at regular intervals demonstrate that the AutoPot successfully maintains soil moisture, humidity, and temperature within desired ranges. Future work will explore adaptive algorithms that adjust watering schedules based on soil type, plant species, and growth stages to further optimize water usage and plant health.

1. Introduction

In the face of rapid urbanisation, high-rise buildings have become a defining feature of modern cityscapes. While these towering structures efficiently accommodate growing populations, they often need more green spaces for residents' well-being. Engaging in gardening activities, such as planting flowers, has reduced stress, enhanced mood, and provided a sense of accomplishment. However, the constraints of high-rise living, including limited space and busy lifestyles, necessitate innovative solutions to make gardening feasible and enjoyable. For residents of high-rise buildings, finding ways to incorporate gardening into their lives can be challenging and rewarding.

The Internet of Things (IoT) has a transformative impact on our daily lives, offering a range of benefits that enhance convenience, efficiency, and overall quality of life [1]. IoT makes remote monitoring and control of various devices and systems possible, offering significant benefits in managing home appliances, irrigation systems, and even medical devices, ensuring timely interventions and maintenance. Moreover, IoT-enabled devices improve communication between users and devices through notifications, alerts, and real-time updates, helping users stay informed and make better decisions [2]. Overall, IoT technology integrates seamlessly into our daily lives, collectively enhancing our quality of life and making everyday tasks more accessible and more efficient.

1.1 Problem Statement

Urban gardening in high-rise buildings faces several challenges that make it difficult for residents to maintain healthy plants. One major issue is the limited access to water sources, as residents often need to carry water from indoor faucets to their balconies or rooftops. Busy schedules and frequent travel lead to inconsistent watering, harming plant health [3]. Space constraints in high-rise apartments limit how many plants residents can have and the size of watering systems they can use effectively. Carrying heavy watering cans or hoses can be physically demanding, particularly for elderly or physically impaired residents. Plants on high-rise balconies or rooftops are exposed to harsher environmental conditions like strong winds, direct sunlight, and temperature fluctuations, which require more careful and frequent watering [4]. Maintaining and monitoring plant health requires regular attention and expertise that many residents may lack. Additionally, in areas with water restrictions, residents must find ways to conserve water while keeping their plants healthy.

1.2 Objective

The project aims to develop an IoT-enabled AutoPot watering system tailored for urban gardening in high-rise buildings. The main objective is to automate the watering process, ensuring plants receive consistent and optimal hydration with minimal user intervention. By leveraging IoT technology, the project seeks to provide high-rise residents with a convenient, efficient, and sustainable solution for maintaining healthy plants, even in limited spaces and under varying environmental conditions. Additionally, the design of the AutoPot strives to enhance the gardening experience by offering remote monitoring and control, reducing physical effort, and promoting water conservation.

2. Literature Review

The rapid urbanisation and proliferation of high-rise buildings in modern cities have necessitated innovative solutions to incorporate green spaces into urban environments. Urban gardening, particularly within high-rise settings, has emerged as a popular method to introduce greenery, improve air quality, and enhance residents' well-being. However, the unique challenges high-rise residents face in maintaining healthy gardens have driven the need for technological advancements in gardening practices. Innovative plant watering systems involve precisely delivering water to compensate for rainfall deficits or supplement existing water sources, aiming to optimise plant growth and maintain ideal soil moisture levels. These systems are designed for efficient water distribution, ensuring plants receive adequate hydration without waste or runoff. A control system is crucial in regulating intelligent watering systems, offering manual or automated controls for starting or stopping the system, adjusting flow rates, and scheduling irrigation cycles [5].

2.1 Strengths and Weaknesses of the Existing System

Numerous studies have explored smart watering and irrigation systems, encompassing various approaches such as intelligent irrigation systems, IoT multi-sensor smart agriculture, smart water dripping systems, and automated plant recognition. Table 1 outlines the strengths and weaknesses of these existing systems.

Table 1 *Strengths and weaknesses of the existing system*

System	Strength	Weakness
Intelligent irrigation system [6]	• Provides real-time information on field irrigation. • Cost reduction. • Resource optimisation. • Improves the environment quality. • Increases irrigation. • Reduces water logging.	• Does not make the efficient use of water. • Leads to water scarcity. • The quantity of water is not defined for each water supply in the irrigation system.

Table 1 *(cont.)*

System	Strength	Weakness
Smart agriculture using IoT multi-sensors [7]	• Reduces costs. • Increases agricultural productivity. • Saves energy, increases efficiency, and enables excellent communication between the farm and the gateway. • Improves yields as well as quality.	• Requires challenging storage of large amounts of data.
Smart water dripping system [8]	• Conserve water. • Avoidance of constant vigilance. • Remote automation.	• Requires challenge on wireless internet for farmers.
Automated plant recognition [9]	• No excess water is wasted. • The irrigation system is flexible.	• Requires challenge in a bigger variety of classes.

2.2 Features Comparison Between the Existing System

Table 2 compares the previously mentioned systems based on their data-gathering methods, water distribution uniformity, labour requirements, cost-effectiveness, and potential for automation and remote monitoring. By evaluating these criteria, it becomes possible to identify the strengths and weaknesses of each system, guiding the development of the AutoPot to incorporate the most compelling features.

Table 2 *Features comparison between the existing systems*

System	Way of gathering data	Uniformity of Water Distribution	Labour Requirement	Cost Effectiveness	Potential for Automation and Remote Monitoring
Intelligent irrigation system	Offers more sensors, i.e. temperature sensor, humidity sensor, and soil moisture sensor	High	Low	Low	High
Smart agriculture using IoT multi-sensors	Uses wireless sensor networks	High	Low	Low	High
Smart water dripping system	Uses various software components, i.e. web-scraper, android studio, MySQL database server, data mining techniques, and C/C++.	High	Low	Medium	High
Automated Plant Recognition	Uses an automated mobile application tool	High	Low	Medium	High

The Intelligent Irrigation System gathers data using temperature, humidity, and soil moisture sensors. This system ensures precise water distribution based on real-time environmental conditions. However, its reliance on specific sensor types may limit adaptability to varying agricultural contexts. The Smart Agriculture System leverages IoT multi-sensors and wireless sensor networks, offering a more integrated approach to monitoring and managing agricultural environments. Using multiple sensors and wireless connectivity enhances data accuracy and system responsiveness, although it may increase complexity and maintenance requirements. The Automated Plant Recognition System utilises an automated mobile application tool, providing a user-friendly plant identification and management interface. While this system simplifies plant recognition tasks, its effectiveness may be contingent on the accuracy and comprehensiveness of the mobile application's database. The Smart Water Dripping System incorporates various software components, including a web-scraper, Android Studio, MySQL database server, data mining techniques, and C/C++. This system's multifaceted software approach enables detailed data analysis and precise water delivery, but the technical expertise required for its setup and maintenance could be a potential drawback.

All these systems demonstrate good uniformity in water distribution, ensuring efficient irrigation. Moreover, they all require minimal labour, making them suitable for large-scale deployment. Regarding cost-effectiveness, the Intelligent Irrigation System and Smart Agriculture System using IoT multi-sensors are relatively low-cost, making them accessible for small to medium-scale farmers. On the other hand, the Smart Water Dripping System and Automated Plant Recognition System are relatively cost-effective, reflecting their more sophisticated features and capabilities.

3. Materials and Methods

This section outlines the materials and methods implemented in developing the AutoPot. The approach includes detailed descriptions of the hardware components, software tools, and experimental procedures to ensure the system's functionality and efficiency.

3.1 Materials

The AutoPot system utilises several electrical components to automate plant watering, including the ESP8266 NodeMCU, DHT11 sensor, soil moisture sensor, relay module, 18650 battery, water pump, LCD, and Blynk software. The system's core is the ESP8266 NodeMCU, which enables devices to connect to the internet. The ESP8266 can connect to a Wi-Fi network and communicate with the internet, allowing for remote monitoring and control of devices [10]. The soil moisture sensor measures the water content in the soil. It typically has two probes that detect the soil's resistance, which is inversely proportional to moisture content. The DHT11 is an essential digital temperature and humidity sensor. It measures temperature using a thermistor and humidity with a capacitive sensor. The sensor communicates data using a single-wire protocol, sending temperature and humidity information as a sequence of bits, which the microcontroller reads and processes [11].

The relay module acts as an electrically operated switch, isolating control circuits to ensure that low-power devices like microcontrollers can safely control higher voltages and motors. The AutoPot system is powered by a 18650 lithium-ion battery, known for its high density, long lifespan, and low self-discharge rate, providing a reliable power source. The water pump transfers water from a lower to a higher level and removes excess water. Controlled by the relay module, the pump is activated to water plants when the soil moisture sensor detects low moisture levels. The LCDs have real-time data such as temperature, soil moisture, and humidity.

The leading software in the AutoPot system is Blynk, a user-friendly web application platform and mobile SDK for building IoT applications. It simplifies integrating hardware with the internet and developing mobile apps to manage and control the devices [12].

3.2 Methods

The research adopts a quantitative approach and emphasises secondary data collection. The development of the AutoPot system entails two main components: the system block diagram and the electrical component connections.

3.2.1 AutoPot Block Diagram

Crafting a concise block diagram (refer to Fig. 1) delineated the system's components as part of the requirements analysis. The soil moisture sensor and DHT11 detect soil moisture, temperature, and humidity. Subsequently, the ESP8266 processes the gathered data to determine the activation of the relay and the status of the DC water pump. Additionally, the DHT11 sensor provides temperature and humidity readings for more accurate plant or garden monitoring. This streamlined data flow allows users to access real-time information on soil moisture, humidity, and temperature near their plants via the Blynk Application.

The operation of AutoPot starts with the soil moisture sensor sending data to the ESP8266. The ESP8266 then sends this data to the Blynk server, which updates the Blynk app in real-time. If the soil is dry, the Blynk app can send a command to the ESP8266 to activate the relay module and turn on the water pump, watering the plants. Users can also manually control the pump using the button widget in the Blynk app.

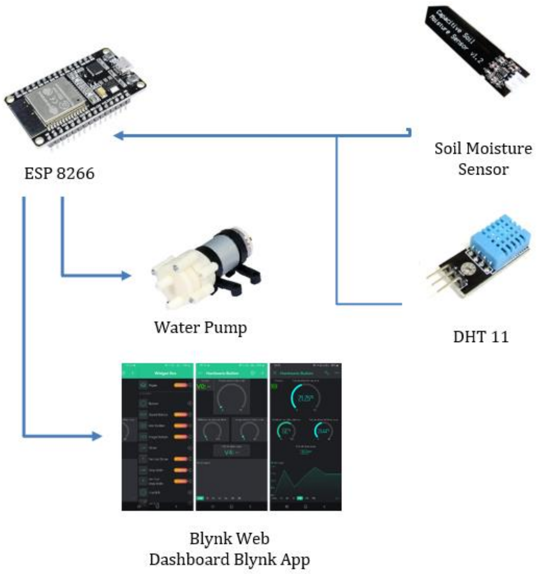

Fig. 1 *AutoPot block diagram*

3.2.2 Circuit Diagram

Ensuring the proper and secure connection of electrical components is crucial, as it plays a significant role in the system's safe and efficient operation. Fig. 2 provides an overview of the interconnections among various components, such as the ESP8266 DEVKIT, DHT11, 5V Relay, 16x2 I2C LCD, capacitive soil moisture sensor, water pump, ON/OFF button, 18650 battery, and wires and connectors.

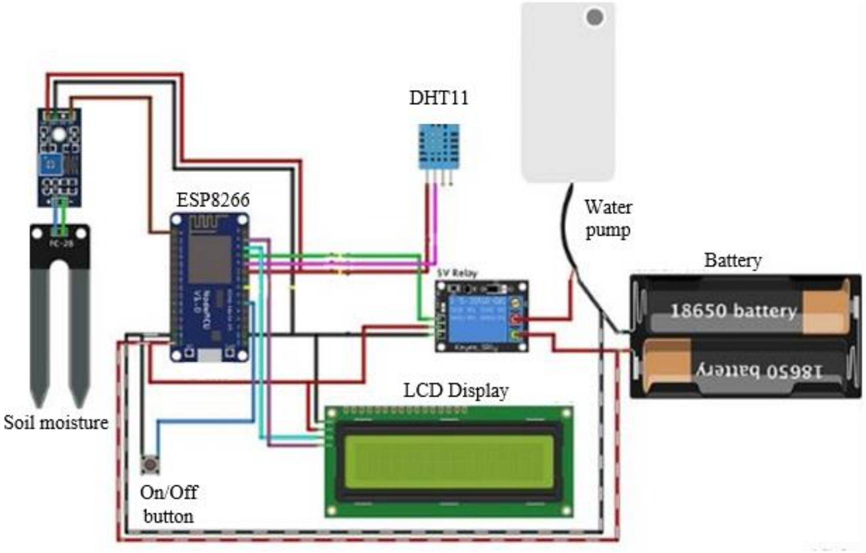

Fig. 2 *Circuit diagram of AutoPot*

The circuit diagram features an ESP8266 microcontroller with Wi-Fi capability to operate the system and send data to a smartphone app. It includes a DHT11 sensor for measuring temperature and humidity and a soil moisture sensor for monitoring soil moisture levels. A 5V relay is a switch to control the water pump, and a 16x2 I2C LCD shows data such as temperature, humidity, and soil moisture content. The ON/OFF button manually controls the water pump.

The ESP8266 microcontroller connects to the DHT11 sensor, 16x2 I2C LCD, and soil moisture sensor. The DHT11 and soil moisture sensors provide real-time data on the plant's temperature, humidity, and soil moisture, displayed on the 16x2 I2C LCD display via I2C communication with the ESP8266. The 5V relay is an electronic switch to manage the water pump, powered by an 18650 battery. The battery also powers the ESP8266 and the relay, enabling the system to operate independently of external power sources.

The soil moisture sensor measures the moisture level in the soil and sends this data to the ESP8266, which acts as the system's brain. When the moisture level drops below a preset threshold of 20%, the ESP8266 signals the relay to activate the water pump, providing water to the plant. The DHT11 sensor provides temperature and humidity, which the ESP8266 also processes. The 16x2 I2C LCD panel shows these data for convenient monitoring. The automatic system can be overridden, if necessary, by manually controlling the water pump using the ON/OFF button. The ESP8266 allows remote monitoring and control by sending data via Wi-Fi to a smartphone app. The 18650 battery powers the entire system, making it portable and self-sufficient in power sources.

4. Results and Discussion

The test conducted over three consecutive sunny days yielded the results. The testing measured soil moisture, humidity, and temperature changes over 18 hours daily. Data was collected from the soil moisture sensor and the DHT11 sensor every four hours, from 6 AM to 10 PM. The soil moisture sensor monitored changes in soil moisture levels, while the DHT11 sensor recorded temperature and air humidity. This data was then visualised as a line graph, as shown in Fig. 3.

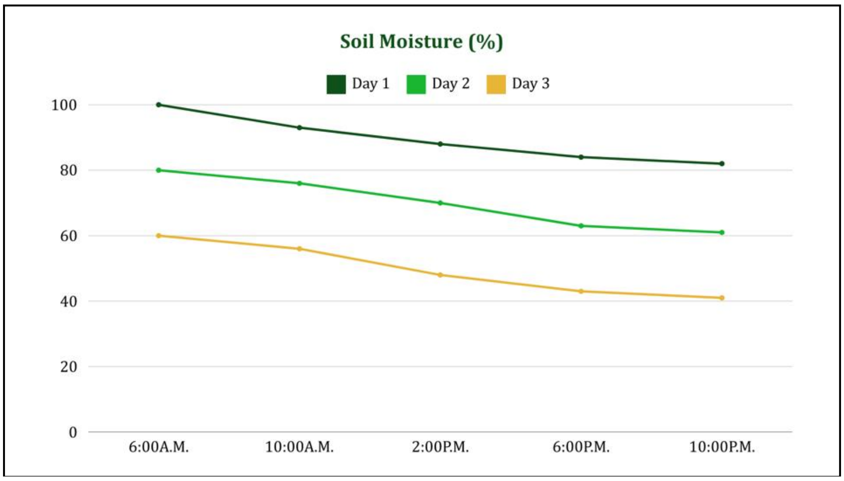

Fig. 3 *Soil moisture (%) from the soil moisture sensor*

The analysis of Fig. 3 depicting soil moisture variation over three consecutive sunny days reveals consistent trends and patterns in moisture levels throughout each day. Day 1, represented by the dark green line, starts with the highest moisture level at 100% at 6:00 AM, gradually decreasing to around 80% by 10:00 PM. This gradual decline suggests ongoing water consumption through evaporation and plant uptake throughout the day. Day 2 (light green line) starts at a lower initial moisture level of 80% and follows a similar decreasing trend, ending around 60% by late evening. Day 3 (yellow line) begins with the lowest initial moisture level of 60%, steadily declining to just above 40% by 10:00 PM. Across all days, there is a noticeable, consistent decrease in soil moisture from morning to night, indicating the influence of factors like sunlight and temperature on moisture loss. Day 1 maintains the highest moisture levels throughout the day, while Day 2 and Day 3 begin and end with progressively lower moisture levels. The rate of moisture decrease remains relatively steady across all three days, suggesting consistent environmental conditions during the test period.

Based on Fig. 4, which illustrates the temperature variation over three consecutive days, several patterns and trends can be observed. Day 1 (dark green line) begins at 6:00 AM with a temperature of 26 degrees Celsius. By 10:00 AM, the temperature increases to 28 degrees Celsius, peaking at 32 degrees Celsius around 2:00 PM. By 6:00 PM, the temperature decreases slightly to about 31 degrees Celsius; by 10:00 PM, it drops further to 28 degrees Celsius. Day 2 (light green line) also starts at 6:00 AM with a temperature of 26 degrees Celsius. By 10:00 AM, it rises to 28 degrees Celsius, reaching its highest point of 33 degrees Celsius at 2:00 PM. The temperature then decreases to 28 degrees Celsius by 6:00 PM and drops to 26 degrees Celsius by 10:00 PM. Day 3 (yellow line) starts with a lower initial temperature of around 24 degrees Celsius at 6:00 AM. By 10:00 AM, it increases to 26 degrees Celsius and reaches its peak of 31 degrees Celsius at 2:00 PM. By 10:00 PM, the temperature drops slightly to 28 degrees Celsius. Overall, all three days show a similar pattern, starting with temperatures in the mid-20s range in the morning and ending with an increase in mid-morning temperatures. Day 1 and Day 2 experienced the highest temperatures in the early afternoon, with Day 1 peaking at 32 degrees Celsius and Day 2 at 33 degrees Celsius. In the evening, temperatures generally begin to decrease from their peak values, except for Day 3, which experiences a slight increase to 31 degrees Celsius by 10:00 PM. Nighttime temperatures drop further, with Day 2 being the coolest at 26 degrees Celsius, followed by Day 1 and Day 3 at 28 degrees Celsius each.

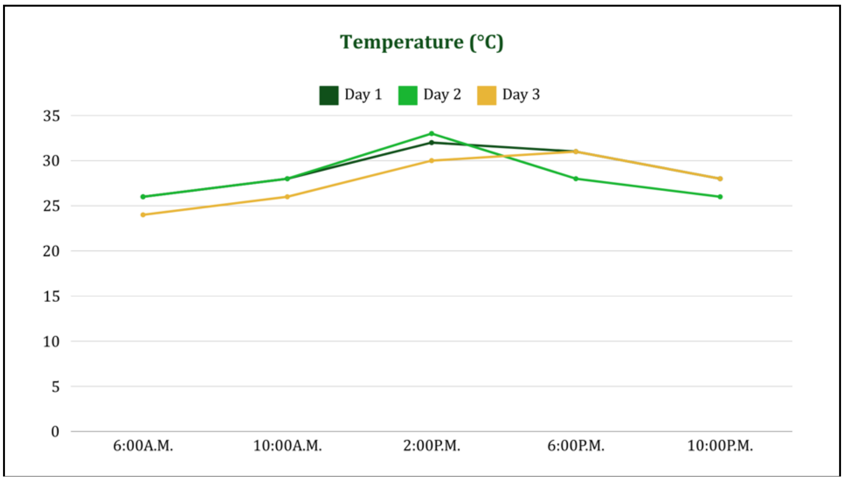

Fig. 4 *Temperature (°C) data from the DHT11*

Fig. 5 depicts humidity variation over three consecutive days, and several trends and patterns emerge. Day 1 (dark green line) begins at 6:00 AM with humidity at 94%, which decreases to 84% by 10:00 AM. The humidity reaches its lowest point for the day at 67% by 2:00 PM, then increases slightly to 70% by 6:00 PM, and returns to 84% by 10:00 PM. Day 2 (light green line) starts at 6:00 AM with humidity at 89%, dropping to 74% by 10:00 AM. At 2:00 PM, the humidity reached its lowest level among the three days at 62%. Humidity rises to 75% by 6:00 PM and climbs back to 83% by 10:00 PM. Day 3 (yellow line) begins with humidity at 93% at 6:00 AM, decreasing slightly to 75% by 10:00 AM. The humidity reaches its lowest point at 67% by 2:00 PM, increases to 71% by 6:00 PM, and rises slightly to 82% by 10:00 PM. Throughout all three days, observers note a consistent pattern of humidity variation: humidity decreases from morning to early afternoon, reaching its lowest point around 2:00 PM, and then increasing towards the evening. Day 1 starts with the highest morning humidity but experiences a slight drop compared to Day 2 by the afternoon. Day 2 shows the most significant afternoon drop but recovers to the highest humidity level by nighttime. Day 3 generally exhibits slightly lower humidity levels than Days 1 and 2 throughout the day.

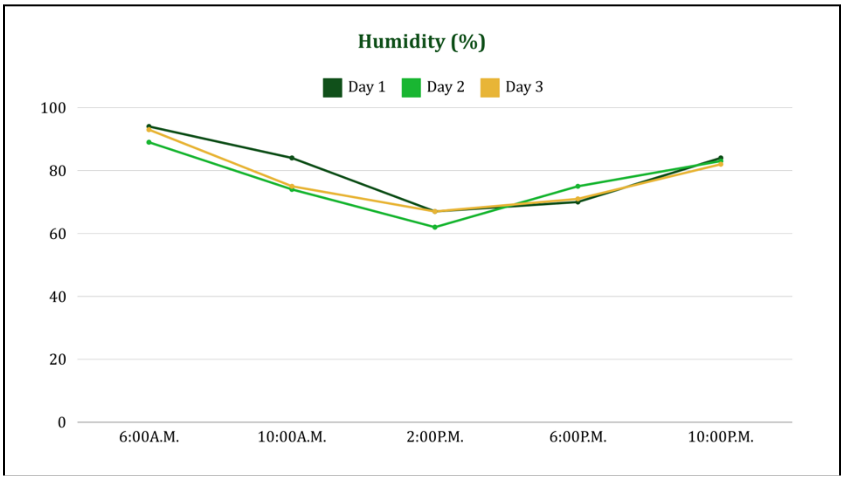

Fig. 5 *Humidity (%) data from the DHT11*

In conclusion, the AutoPot, based on the collected data for soil moisture, temperature, and humidity, is programmed to water the plant when soil moisture falls below 20% and stop when it reaches 80%. Given the observed humidity trends, watering every four days appears suitable to maintain optimal plant conditions, ensuring adequate moisture levels without overwatering during periods of high humidity. This data-driven approach supports effective plant care and conservation of water resources in urban gardening settings.

5. Conclusion

The AutoPot with IoT integration was developed to ensure optimal plant growth and survival conditions amidst variable environmental conditions. By leveraging precision agriculture principles, the system enhances monitoring and adjusts watering schedules based on real-time temperature, humidity, and soil moisture data. This precision allows for accurate decision-making in plant care. Residents in apartment buildings need help accommodating plants, including limited space, varying light conditions, and time constraints. The AutoPot addresses these challenges with its innovative and intelligent approach to indoor plant care. It provides apartment dwellers with a practical solution for maintaining attractive and healthy indoor plants. Automating the watering process and controlling environmental factors enable urban residents to pursue indoor gardening with minimal effort. The AutoPot promotes plant health and contributes to creating a healthier and more enjoyable living environment in modern apartments. This system is ideally suited for apartment living because it can streamline plant care tasks and enhance the overall indoor gardening experience.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The author is responsible for the following contributions: Hanis Nabihah Hamsan and Shaza Batrisyia Amran conceived and designed the study; Muhammad Haiqal Suderman conducted the data collection; Hanis Nabihah Hamsan, Shaza Batrisyia Amran, and Muhammad Haiqal Suderman performed the analysis and interpretation of results; Rafizah Mohd Hanifa was responsible for manuscript editing. All authors reviewed the results and approved the final version of the manuscript.

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