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Artificial Intelligence-Powered IoT-Based Irrigation System for Precision Farming

Hen-Rin Leao[1,2], Chu-Liang Lee[1], Gregory Soon How Thien[1], It-Ee Lee[3], Gwo-Chin Chung[3], Wai-Leong Pang[4], Zi-Neng Ng[5], Kar-Ban Tan[6], Kah-Yoong Chan[1*]

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Abstract: Agriculture irrigation is an essential agricultural practice that ensures crops' healthy growth. Nonetheless, irrigation is labor-intensive and difficult to manage, particularly in large-scale farming operations. Smart irrigation systems are promising solution to the agricultural sector's challenges. These systems use sensors and other Internet of Things (IoT) technologies to monitor and control irrigation without much human intervention. Hence, several benefits are achievable, including lower labor costs, improved water efficiency, and increased crop yields. This study proposed a smart irrigation system using sensors to detect soil moisture levels and irrigate crops based on the detected moisture level. The proposed system also utilized a cloud-based platform to collect and store sensor data, which monitored the irrigation process and identified potential farming concerns. Besides, the system optimized the irrigation schedule to retain the soil moisture level from 80 to 90%. Therefore, the proposed smart irrigation system is a cost-effective and scalable solution that can improve irrigation efficiency in the agricultural sector.

Keywords: *Smart irrigation system, Internet of Things, smart farming, sensor technology*

1. Introduction

Agriculture is the world's biggest industry, employing over a billion people and producing more than $1.3 trillion of food yearly [1]. This industry has deployed 50% of the Earth's habitable land and provides habitat and food for many species. Irrigation is part of the agricultural process as it replenishes soil water storage in the root zone of plants by means other than natural precipitation [2]. Irrigation has been around for a long time since humans started to grow crops. Egypt and Mesopotamia were home to the first known irrigation systems dating back to 6000 BC. These systems created basin irrigation by using the flooding of the Nile River to water crops involving the gravity flow of water [3]. Farmers use this method today using gravitational force to pump water from surface sources like ponds, rivers, or underground water through earthen channels or pipes.

Traditional irrigation methods are widely recognized for their significant reliance on manual labor within agricultural operations. The usual methodology involves the regular extraction of water from proximate water sources, such as rivers or storage tanks, which are distributed methodically throughout the entire agricultural land [4,5]. This endeavor necessitates a significant amount of personnel, as the task demands several individuals' involvement to ensure effective execution.

The employees involved in this endeavor must acquire specialized training to guarantee consistent and efficient water distribution throughout the agricultural area [6,7]. The labor-intensive characteristics of these irrigation techniques sometimes necessitate farmers to assist many individuals in overseeing their agricultural activities efficiently. This process encompasses a substantial expenditure on labor, underscoring the significance of proficient personnel in ensuring the continuous hydration of crops. Hence, this process highlights the possibility of developments in irrigation technology to mitigate these difficulties.

Amid the unprecedented challenges posed by the COVID-19 pandemic, stringent government-imposed travel restrictions compelled most workers to remain within their respective countries [8,9]. This outcome profoundly impacted various industries in Malaysia, particularly those heavily reliant on migrant labor, notably in the agricultural sector. Agricultural activities, encompassing tasks such as seed planting and farm irrigation, were severely hindered as

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[1] *Centre for Advanced Devices and Systems, Faculty of Engineering, Multimedia University, Persiaran Multimedia, 63100 Cyberjaya, Selangor, Malaysia*
ORCID ID: 0000-0003-1076-5034 (K-Y. C.), 0000-0001-5226-6837 (C-L. L.), 0000-0002-5525-6631 (G. S. H. T.)
[2] *College of Engineering, Chang Gung University, Wenhua 1st Rd, Guishan District, 333, Taoyuan City, Taiwan*
[3] *Centre for Wireless Technology, Faculty of Engineering, Multimedia University, 63100 Cyberjaya, Selangor, Malaysia*
[4] *School of Engineering, Taylor's University, 47500 Subang Jaya, Selangor, Malaysia*
ORCID ID: 0000-0001-8407-5648 (W-L. P.),
[5] *School of Electrical Engineering and Artificial Intelligence, Xiamen University Malaysia, Bandar Sunsuria, 43900, Sepang, Selangor, Malaysia*
ORCID ID: 0000-0003-2677-3055(Z-N. N.)
[6] *Department of Chemistry, Faculty of Science, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia*
** Corresponding Author Email: kycon@mmu.edu.my*

the influx of migrant workers, typically engaged in these crucial operations, was curtailed due to their inability to traverse national borders.

A comprehensive survey conducted by the Malaysian Agricultural Research and Development Institute (MARDI) yielded significant insights into the ramifications of the pandemic on the agri-food sector. The findings indicated that an overwhelming majority of agri-food entrepreneurs, specifically 91.1%, experienced adverse effects directly attributable to the pandemic [10]. This process underscored the substantial disruption and challenges faced by Malaysia's agricultural landscape, underscoring the critical need for adaptive strategies and resilience-building measures in the face of such global crises.

The Malaysian government implemented the 12th Malaysia Plan in 2021, which served as a strategic endeavour to facilitate the use of intelligent technology in the agricultural industry. The study aimed to increase productivity while decreasing the industry's reliance on physical labor [11,12]. The forward-thinking strategy attracted considerable attention from local businesses, as they acknowledged smart technology as a practical remedy for addressing the labor constraints commonly observed in the agricultural sector of Malaysia. Thus, these firms initiated the advancement of intricate technologies designed exclusively to enhance irrigation systems.

Although implementing cutting-edge technology offers significant prospects for mitigating the issues faced by farmers and minimising labor demands, it presents a fresh array of obstacles. Farmers may encounter challenges acquiring knowledge, effectively overseeing, and resolving issues related to these advanced systems, potentially resulting in psychological barrier [13]. Rather than functioning as a seamless tool, sophisticated technology can unintentionally generate worry among farmers.

A viable solution emerges by combining the Internet of Things (IoT) with sensor integration to tackle this technological challenge [14,15]. The farmers can easily implant sensors into the soil, which then interact with the irrigation system to autonomously adjust water distribution according to real-time soil moisture levels [16]. Furthermore, integrating solar energy as the primary power source in this solution serves as a fundamental basis for its sustainability aspect. Solar energy is widely recognized as an environmentally friendly energy choice due to its utilization of a renewable resource and its minimal environmental impact [17]. In addition, recent developments have increased solar technology's efficiency and cost-effectiveness, positioning it as a highly suitable option for powering intelligent irrigation systems in agricultural fields or horticultural settings [18].

This study demonstrated a mobile IoT application to optimize usability, facilitating users in monitoring soil moisture levels and granting them the ability to exert control over the irrigation system. The data acquired by sensors was transferred to a controller smoothly and uninterruptedly. Once received by the controller, the data was analyzed before being forwarded to the cloud for storage and retrieval. This integrated strategy enhances the efficiency of agricultural operations and empowers farmers with data-driven insights, revolutionizing their management of irrigation processes

2. Method

2.1 Irrigation System for Smart Farming

Figure 1 presents the block diagram of the proposed system, which represents a smart solar-powered irrigation system designed for residential gardens and agricultural applications. This innovative system operated in real-time to monitor soil moisture levels and facilitated efficient irrigation control. The plan was composed of two distinct solar circuits, each tailored to meet the specific power requirements of different system components. A 10 W 18 V solar panel served as the energy source to power the microcontroller (NodeMCU), charging a lithium battery. A DC-to-DC mobile charger was interposed between the solar panel and the lithium battery to regulate voltage and current flow from the solar panel to the battery, ensuring optimal charging efficiency.

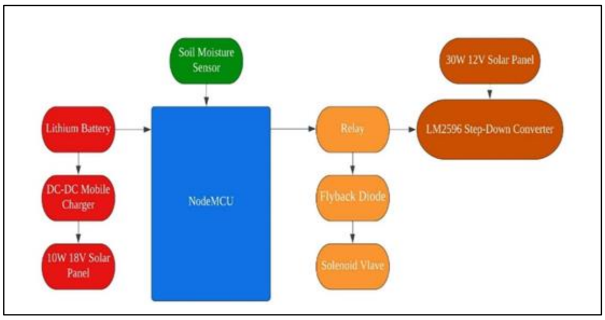


Fig 1. Diagram representing the block diagram in this study.

A 30 W 18 V solar panel was employed to power the solenoid valve. This circuit used a step-down converter to reduce the voltage output from the solar panel to 12 V, matching the operating voltage of the solenoid valve. Subsequently, a dedicated mobile IoT application was developed to enhance user interaction and data management. This application enabled users to monitor soil moisture levels in real time and exercise control over the irrigation system.

Sensor data collected from the field was transmitted to the system controller, which performed data analysis before relaying the processed information to the cloud for storage and further utilisation. Subsequently, the mobile application retrieved the stored data from the cloud and presented it to the user, facilitating informed decision-making and efficient irrigation management. The components used in the smart irrigation system in the hardware configuration were the NodeMCU esp8266, NodeMCU baseboard, soil moisture sensor, a water sprinkler, a piping system, and a solar panel.

2.2 System Operation

The smart irrigation system consisted of two operating modes: automatic and manual. The button on the Blynk application will control these two systems. The automatic operation was designed to irrigate the farm or garden based on soil moisture value. Firstly, the maximum wet and dry soil boundaries (x) are determined as follows:

1. Dry : $x > 1002$
2. Ideal : $1002 < x < 960$
3. Wet : $x < 960$

The code's threshold values for dry and wet soil were 1002 and 960, respectively. When the microcontroller received a command from the Blynk apps that requested to switch to automatic operation, the microcontroller read the sensor's value to check whether it was lower or higher than the threshold value. Supposing the sensor's value is more than 1002, it will turn on the solenoid valve and allow the water sprinkler to irrigate the farm until the soil moisture value is lower than 960. Figure 2 illustrates the entire process flow.

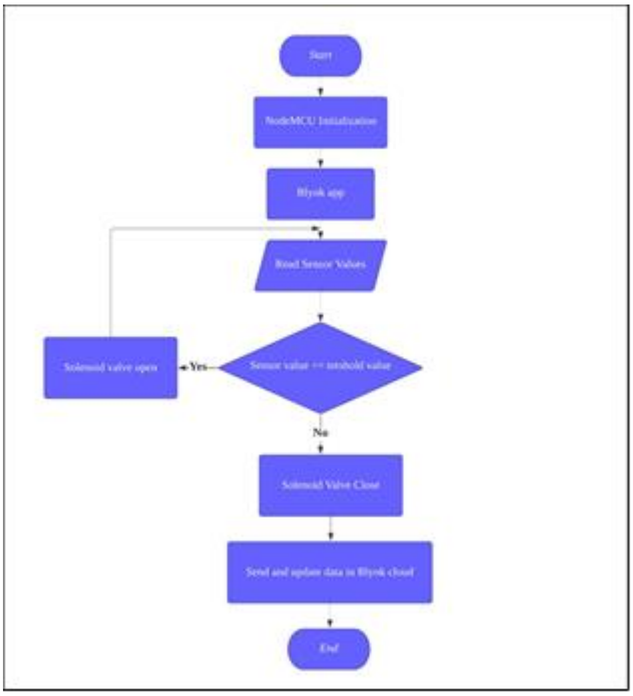


Fig 2. Schematic flowchart for the automatic operation.

The smart irrigation system provided manual control for the farmer or user through the Blynk application, utilising a valve switch. Figure 3 elucidates the operation of this mode. In the manual mode, if the valve switch was set to 'ON', the solenoid valve was activated, disregarding the sensor's moisture value. This manual operation was designed to take precedence over the automatic irrigation mode. When the microcontroller received a command from the Blynk application to transition into the manual process, it assessed the signal sent from the manual button. Based on this signal, the microcontroller determined whether to activate or deactivate the solenoid valve. This functionality gave the user direct control over the irrigation process, effectively overriding the automatic system and enabling on-demand irrigation management.

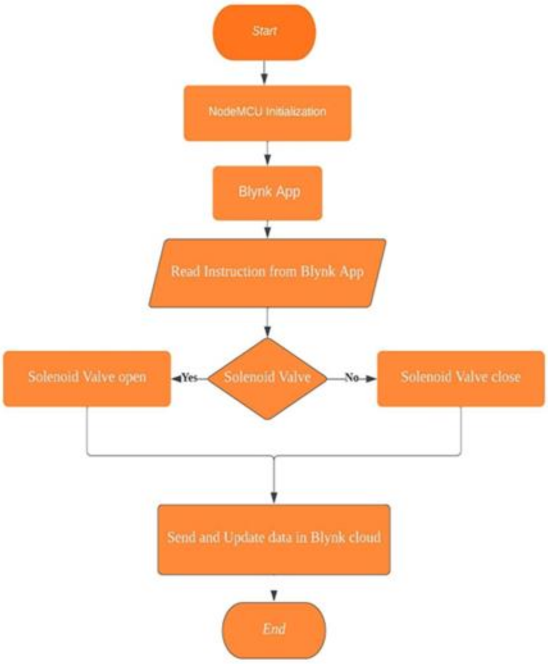


Fig 3. Schematic flowchart for the manual operation.

3. Results and Discussion

3.1 Hardware Development

The smart irrigation sensing module comprised a soil moisture sensor that the NodeMCU controlled. Most circuits were housed within a junction box measuring 195 × 152 × 80 mm (see Figure 4).

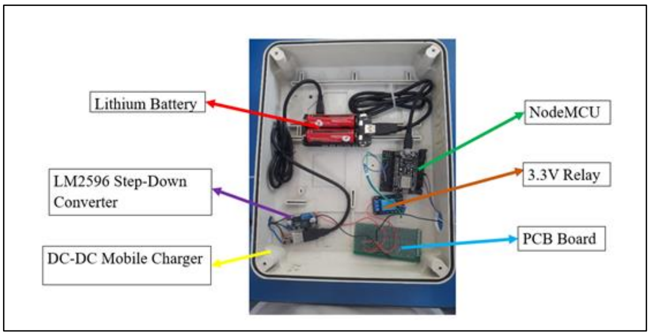


Fig 4. The smart irrigation module in this study.

A purpose-designed solar stand was created to securely accommodate two solar panels: one with a power rating of 30 W at 18 V and the other at 10 W with the same voltage specification (see Figure 5a). The 30 W solar panel was exclusively allocated to power the solenoid valve, while the 10 W solar panel was primarily responsible for charging the 18650 lithium battery [19]. A PVC flexible conduit was thoughtfully employed to protect the cables against potential water exposure [20]. The sealing and stabilization of both ends of two PVC hoses were meticulously achieved using hose clips, fortifying the system's durability and resilience (see Figure 5b).

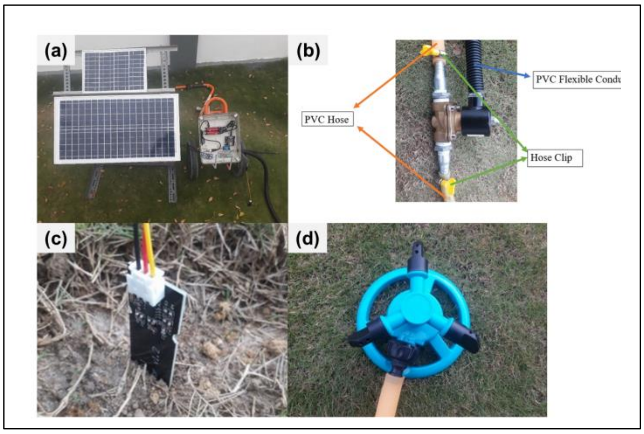


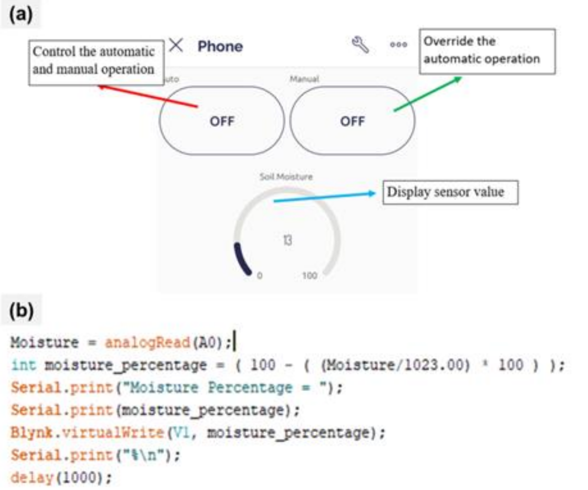
Fig 5. (a) Smart irrigation system, (b) solenoid valve, (c) soil moisture sensor, and (d) water sprinkler components in this study

When positioning the soil moisture sensor in the soil, it is crucial not to bury it too deeply, as the IC chip on the probe may be vulnerable to damage (see Figure 5c) [21,22]. Farmers are encouraged to plant it until it reaches the designated warning line. Finally, Figure 5d showcases the strategic placement of a water sprinkler within the garden. The sprinkler was designed to rotate 360 degrees and effectively cover an approximate diameter of 8 meters. This component is pivotal in ensuring comprehensive and efficient irrigation coverage for the garden area [23].

3.2 Software Development

3.2.1 Blynk App Setup

Figure 6a depicts the Blynk application interface, which serves as the control hub for the smart irrigation system. Notably, the interface features two buttons, one on the left and the other on the right. The button on the left side corresponded to manual operation control, while the one on the right pertained to automatic operation control. A display gauge positioned at the bottom of the interface also provided real-time visualisation of the soil moisture level in percentage. Figure 6b outlines the specific equation used for calculating this percentage.



```
Moisture = analogRead(A0);
int moisture_percentage = ( 100 - ( (Moisture/1023.00) * 100 ) );
Serial.print("Moisture Percentage = ");
Serial.print(moisture_percentage);
Blynk.virtualWrite(V1, moisture_percentage);
Serial.print("%\n");
delay(1000);
```

Fig 6. (a) Smart irrigation system set up in the Blynk app. (b) Equation for converting soil moisture value to a percentage

3.2.2 Blynk App Automatic Operation

Users were instructed to choose the "AUTO" button in the Blynk program to activate the automated operating mode (see Figure 7a). Converting the threshold values 1002 and 960 into percentages resulted in corresponding values of 2% and 6%, respectively. Within the system's functioning framework, the solenoid valve was set to initiate its opening mechanism if the soil moisture percentage went below the threshold of 2%. In contrast, if the soil moisture percentage surpassed 6%, the solenoid valve would be shut, effectively controlling the irrigation operation. Users were instructed to activate the "MANUAL" function by selecting the corresponding button of the Blynk application (see Figure 7b). It is important to emphasise that users can override the automatic process by choosing the "MANUAL" button. Nevertheless, a crucial requirement for initiating manual operation involved deactivating the "auto" button. Failure to adhere to this requirement lead to system instability or crashes, requiring a restart of the microcontroller and the Blynk programme to ensure optimal performance.

Fig 7. The (a) "AUTO" and (b) "MANUAL" functions in the Blynk app

3.3 Soil Moisture Level Results

The soil moisture sensor was positioned in various weather conditions to assess how moisture levels fluctuated under differing weather conditions. Regular checks of the sensor were conducted hourly, both on rainy and sunny days (see Figure 8). In analyzing the soil moisture data for sunny days (see Figure 8a), the moisture content remained relatively stable at 83% from 7 am to 12 pm. As temperatures soared during the afternoon, the moisture level experienced a slight decline, reaching 80% [24,25]. Subsequently, the moisture content increased to 83% again as temperatures cooled in the late evening, only to drop back to 80% between 4 pm and 6 pm. During the night hours, the moisture level increased, maintaining a consistent reading of 84% [26]. Conversely, as the sun rose again, the moisture level decreased to 83% in conjunction with rising temperatures and declining humidity levels.

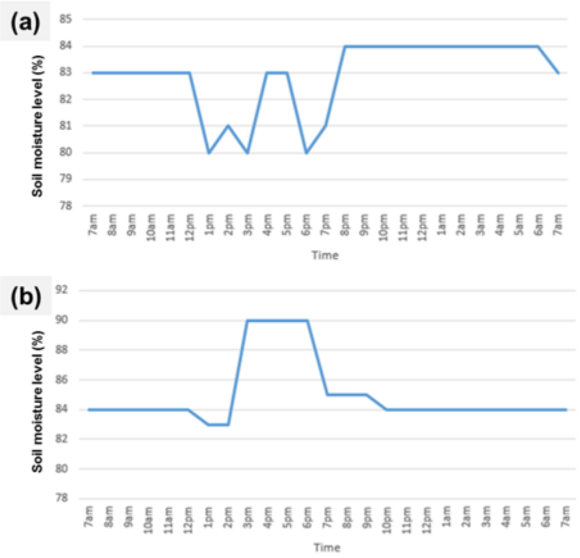


Fig 8. Soil moisture percentages in a 24-hour interval on (a) Sunny and a (a) rainy day

Based on the soil moisture results observed on a rainy day, the soil moisture levels remained within the range of 83 to 84% before the onset of rainfall, from 7 am to 2 pm (see Figure 8b). Subsequently, the weather transitioned to a rainy condition between 2 pm and 3:30 pm. During this period, the moisture level experienced a significant increase, reaching 90%, which it maintained consistently for 4 hours [27,28]. As the evening approached, with the sun setting between 6 pm and 7 pm, temperatures rose while humidity levels fell. Consequently, the moisture level gradually decreased from 90% to 85%. The moisture level continued declining throughout the night, stabilizing at 84% until midnight.

Upon comparing the data from both graphs, it becomes evident that on non-rainy days, the soil moisture level tends to be lower in the morning and afternoon. This process was primarily due to decreased humidity as temperatures increased under bright sunlight [29]. Conversely, in the absence of sunlight, lower temperatures and increased humidity result in a slightly higher soil moisture level during the nighttime.

3.4 Sprinkler Irrigation Coverage

A 30-minute test run of the sprinkler was conducted to assess its coverage area (see Figure 9). The sprinkler irrigation system demonstrated the capability to cover an impressive diameter of up to 8 meters. There were variations in wetting intensity within this coverage area, denoted by different shades of blue. The dark blue area represented the region receiving the most significant amount of water, while the light blue area indicated less wetting.

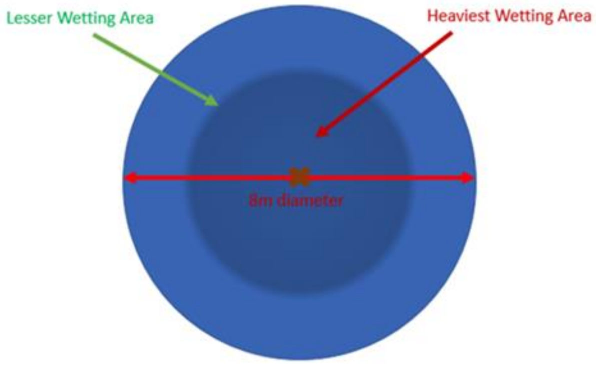


Fig 9. Diagram indicating the sprinkler coverage in this study

The effectiveness of the sprinkler's coverage could be influenced by external factors, such as wind and water pressure [30]. In instances of strong wind, the force displaced the water spray from the sprinkler, potentially leading to non-uniform coverage. Additionally, the water pressure from the water source, such as a tap, plays a crucial role. If the water pressure is low, the sprinkler irrigation may cover only a limited area effectively [31]. To extend the coverage range, users have the option to enhance the system by adding more sprinklers, thereby increasing the overall irrigation capacity, and ensuring uniform moisture distribution.

4. Conclusion

In this study, a smart irrigation system powered by IoT and solar energy was designed and developed to maximize water resources for agricultural productivity. The smart irrigation system, which could be controlled remotely via smart devices, proved highly user-friendly. Because the system was powered by solar cells and a rechargeable battery, it ran efficiently for extended periods without needing a continuous power supply. The smart irrigation system demonstrated its scalability by allowing for the integration of additional water sprinklers, contingent upon available water supply pressure. This scalability optimized moisture levels from 80% to 90%, ensuring efficient and uniform soil hydration. This development and associated technology aligned seamlessly with the national agenda for modernizing our agriculture sector, positioning it as a beacon of modern agriculture in the country.

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Author contributions

Hen-Rin Leao: Conceptualization, methodology, formal analysis, investigation, writing—original draft preparation

Chu-Liang Lee: Validation, visualization

Gregory Soon How Thien: Writing-review and editing, validation, visualization

It-Ee Lee: Validation, visualization

Gwo-Chin Chung: Validation, visualization

Wai-Leong Pang: Validation, visualization

Zi-Neng Ng: Validation, visualization

Kar-Ban Tan: Validation, visualization

Kah-Yoong Chan: Conceptualization, methodology, formal analysis, investigation, writing—review and editing, supervision, project administration, funding acquisition.

Conflicts of interest

The authors declare no conflicts of interest.

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