Application of fuzzy logic to develop Internet of Things control system for durian planting

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Abstract: The concept of "Smart Farming" integrates fuzzy logic, a form of artificial intelligence, to manage control systems in an adaptive manner, similar to human decision-making under uncertain conditions. The cooperative operation of sensors measuring humidity, temperature, and irrigation systems ensures the most favorable conditions for plant growth. The researchers designed the experiment as follows: Group A: Newly planted durian trees grown using IoT technology inside a greenhouse. They are irrigated using Fuzzy Logic-controlled sprinklers, and the temperature is regulated through mist spray. Group B: Newly planted durian trees grown using IoT technology outside a greenhouse. They are irrigated using Fuzzy Logic-controlled sprinklers, but temperature control is not implemented. Group C: Newly planted durian trees with automatic irrigation.The statistics used in this study for evaluating growth efficiency include one-way ANOVA that reveals significant differences in tree height, branch count, and leaf count among the three groups. Group A demonstrated the highest values, followed by Group B and Group C, with statistical significance. DC power consumption efficiency was also recorded and calculated and showed that group A consumed significantly more power than Groups B and C. Groups B and C, however, did not significantly differ in power consumption. Despite higher power consumption, Group A benefited from reduced water usage due to the precision offered by the IoT technology. Group B, utilizing IoT technology in an open-field setting, consumed less power and conserved more water than conventional cultivation. Group C.

Keywords: fuzzy logic, Internet of Things, IoT, durian planting

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1 Introduction

The Internet of Things (IoT) technology is a system that utilizes interconnected devices for various measurements. It consists of electronic circuits, software, sensors, and network connections, enabling real-time data recording and exchange. Smart farming relies on collaborative systems of sensors measuring humidity, light levels, temperature, plant databases, and irrigation systems. These interconnected systems work harmoniously to create an ideal environment for maximum crop growth. Additionally, they assist farmers in effectively estimating harvest times and crop yields (Meesad, n.d., 2023) . Fuzzy logic, a branch of artificial intelligence, has found applications in various fields and is gaining prominence in computer research.

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It plays a significant role in adapting computer systems to dynamic environments and making informed and nuanced decisions based on uncertain data. This technology has the potential to reduce costs, enhance agricultural processes, and address challenges such as unpredictable weather conditions, ensuring safe and environmentally friendly agricultural practices (Department of Agriculture, online). To achieve precision agriculture, fuzzy logic, a form of artificial intelligence, is integrated into control systems, mimicking human decision-making in uncertain data conditions. This integration has the potential to significantly reduce costs, improve the efficiency of agricultural processes, and effectively manage variable factors such as weather and pest control. Many farmers have not employed automated irrigation systems, relying instead on manual labor for watering. They often need to employ a substantial workforce, especially when they have multiple fields. This manual approach may result in overwatering or under watering, leading to increased costs. Monitoring soil moisture manually can also be imprecise at times. Therefore, employing automated tracking and control systems through devices and technology aids in risk mitigation, cost reduction, and improved crop quality.

In response to these challenges, researchers by Hadkhuntod et al. (2023) have embarked on the development of technology solutions. One noteworthy initiative is the utilization of fuzzy logic to create an IoT control system tailored for durian cultivation. This innovative system aligns with market demands, particularly for high-value produce. The IoT control system incorporates an array of sensors responsible for data collection and precise process analysis, including:

(1) Water Management System: This system efficiently oversees irrigation, ensuring that durian trees receive the optimal amount of water for their growth.

(2) pH Monitoring System: Soil pH monitoring is crucial in durian cultivation, maintaining the soil's acidity or alkalinity at ideal levels.

(3) Soil Nutrient (NPK) Assessment System: This system evaluates soil nutrient content, specifically nitrogen (N), phosphorus (P), and potassium (K), ensuring soil fertility and overall tree health.

(4) Light Measurement System: The system gauges light exposure, a vital factor for photosynthesis and overall plant development.

(5) Soil Moisture Detection System: This system constantly tracks soil moisture levels, enabling precise irrigation management and preventing over- or under-watering.

(6) Soil Temperature Monitoring System: Soil temperature profoundly affects root health and nutrient absorption. This system guarantees that soil temperature remains within the optimal range**.** Furthermore, the system records data related to watering and fertilization schedules, enabling enhanced precision in the production process. It generates graphical representations of various data points, facilitating informed decision-making for farmers regarding resource management.

The integration of technology serves as a pivotal tool in driving the shift from traditional farming practices to modern, smart farming approaches. This transformation empowers farmers to increase their income and take on entrepreneurial roles, reducing reliance on government assistance and fostering self-sufficiency. Additionally, this research contributes to diversifying durian varieties, particularly those of high value, thereby enhancing the economic potential of agricultural regions and promoting sustainable agri-tourism. Ultimately, the integration of technology and innovation into agriculture not only improves efficiency and precision but also lays the foundation for a more prosperous and sustainable future for both farmers and their communities to develop IoT control system for durian planting using of fuzzy logic.

2 Materials and methods

2.1 Description of the study area

Ban Yaeng Subdistrict, Nakhon Thai District, Phitsanulok Province, Thailand is the area of study, and the region lies within latitudes 16 ^{o}N and Longitudes 100 ^{o}E. This timeline spans from January to August 2023.

2.2 Materials

Table 1 Materials

Hardware	Software
-NodeMCU ESP8266 microcontroller	- Arduino IDE
- PH Sensor	- Appserv
- Temperature Sensor	-PHP Language
- Relay	-C/C++ Language
- Pump	- MariaDB
- Wifi Module (Internet 4G)	

2.3 Methods

This research is a research and development (R&D) project. The research team conducted the study by following a process adapted from the analysis and system design framework proposed by Dennis et al.)2021(, which divides the process into four distinct steps:

2.3.1 Step 1 of the research process

It involves three sub-processes:

(1) Needs analysis

In this sub-process, a comprehensive study of documents and field visits to Nakhon Thai District, Phitsanulok Province, was conducted. It was observed that local farmers cultivate various durian varieties. The major challenge faced in durian cultivation is during the initial growth phase. Without prior experience and proper care, young durian plants are vulnerable, and inexperienced farmers may inadvertently cause them to die. Therefore, farmers often seek the assistance of experts to guide them in the initial stages of durian cultivation. This is particularly crucial for the Mon Thong durian variety, which requires specialized environmental care. Adequate watering is of paramount importance, and experienced farmers must ensure that the water supplied to young durian plants is neither excessive nor insufficient. Inadequate watering can stunt the growth of durian trees, while excessive watering can lead to root diseases and decay. Additionally, since a large number of young durian plants are involved, a substantial amount of time and a team of experts are required to thoroughly assess and monitor their suitability over an extended period.

(2) Feasibility study

From the information gathered in the needs analysis phase, the research team conducted a feasibility study on the environmental requirements for newly planted durian trees. These requirements include soil pH levels between 5.5 and 6.5, soil fertility falling within the IDEAL range ($50<N<200$, $4<P<14$, $50<K<200$), light intensity at approximately 30%-40%, soil moisture content around 50%-69%, soil temperature ranging from 25 ℃-30 ℃, and relative humidity of between 75% and 85% (Department of Agriculture, 2020). With this information, there was a conceptualization of developing an IoT technology as an effective means to control and maintain the environmental conditions suitable for optimal plant growth. During the experimental phase of cultivating newly planted durian trees, which spanned approximately 6 months, known as the initial growth phase, the application of this IoT technology resulted in significantly higher survival rates for the newly planted durian trees.

The researchers designed the experiment as follows: Group A: Newly planted durian trees grown using IoT technology inside a greenhouse. They are irrigated using Fuzzy Logic-controlled sprinklers, and the temperature is regulated through mist spray. Group B: Newly planted durian trees grown using IoT technology outside a greenhouse. They are irrigated using Fuzzy Logic-controlled sprinklers, but temperature control is not implemented. Group C: Newly planted durian trees with automatic irrigation. Subsequently, a comparative analysis of the growth performance of newly planted durian trees under all three systems will be conducted to determine their suitability for future durian cultivation.

Step 1 planning: The research team has allocated a timeline for studying requirements, selecting equipment, system development, experimentation, and system refinement. This timeline spans from January to August 2023.

Step 2 analysis: In this step, the research team employed a use case diagram to analyze the system's functionality as follows:

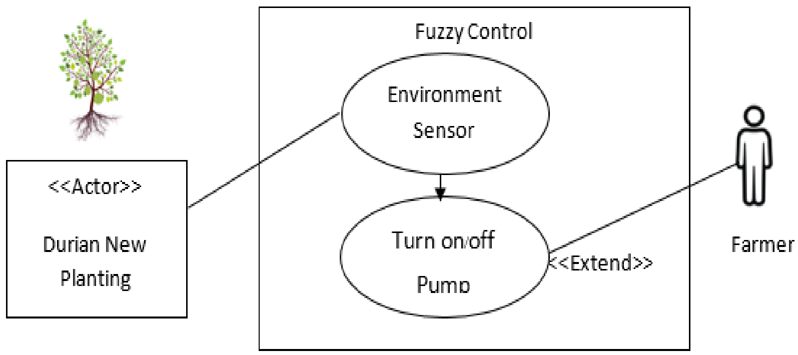

Figure 1 Use case diagram of IoT for durian new planting systems

Step 3 **Design**: In this step, the research team utilized data from the analysis phase to design and develop a physical model. They began by designing both hardware and software components, including the input, processing, output, and storage parts. They designed data models, reports, and user interface screens in the form of a web application. This allowed them to illustrate the overall system architecture and the related tools as follows:

(1) Circuit diagram design: The research team designed two circuit diagrams, closely aligning with the requirements of newly planted durian trees:

Group A's IoT system in the durian greenhouse consists of the following components: ESP8266 as the main circuit diagram, Capacitive Soil Moisture Sensor for soil moisture detection, PH Sensor Arduino Soil Sensor for pH level monitoring, RS485 Soil NPK Sensor for NPK level monitoring, DS18B20 Temperature Sensor for soil temperature monitoring, Analog gray sensor line finder sensor tracking module for light intensity detection, DHT22 Temperature and Humidity Sensor for air temperature/humidity monitoring.

Group B's IoT system in the durian greenhouse also comprised the same components as Group A: ESP8266 as the main circuit diagram, Capacitive Soil Moisture Sensor for soil moisture detection, PH Sensor Arduino Soil Sensor for pH level monitoring, RS485 Soil NPK Sensor for NPK level monitoring, DS18B20 Temperature Sensor for soil temperature monitoring, Analog gray sensor line finder sensor tracking module for light intensity detection, However, Group B does not include sensors for monitoring air temperature and humidity. This is because the environmental conditions cannot be controlled, and the system relies on a 5V power supply connected to a timer to serve as a backup system to prevent errors. The system is also connected to a 12V water pump relay for watering the durian trees. Group B's setup is enclosed in a control box to protect it from water, and the sensors are placed inside PVC pipes near the base of the durian trees, ensuring that they do not come into contact with the tree roots, as shown in Figure 2.

(2) Preparing the planting area

Twenty-four durian seedlings of the 'Mon thong' variety, Aged 1-2 years, with an average height of 75.33±4.57 cm selected. These were divided into 4 groups: greenhouse cultivation with 4 seedlings, non-greenhouse cultivation using technology with 4 seedlings, normal cultivation with watering by sprinklers for 4 seedlings, covering an area of 1 Rai, with a Spacing of 3×13 meters apart, utilizing soil from the planting area, enriched with 1 bag of raw clay and 1 bag of organic fertilizer per mound, raised to approximately 50 cm. Subsequently, planting holes were dug at the center of each mound, the size of which corresponds to the size of a seedling bag. The seedling bags were removed and the lower part of each bag was taken out by approximately 1 in 5, to allow the durian roots to make contact with the newly mixed soil inside the mound. While removing the soil from the seedling bags, special attention must be given to the taproot, which, if found to be twisted or damaged, should be trimmed. Healthy taproots do not need to be trimmed. The fibrous roots should be spread outward in a circular manner around the seedlings to promote balanced root growth. As the durian trees grow, they develop a balanced root system, facilitating even branch spread around the tree. The durian branches should be positioned in the center of the mound with their trunks held upright. Support posts should be installed and the trees tied to them to prevent being toppled in high winds. The support posts should be placed at a distance from the tree, towards the edge of the mound, to avoid damage to the roots. The ropes should be tied loosely enough to allow for movement but firmly enough to support the tree. Finally, the soil around each durian tree should be backfilled, and straw should be used to mulch the soil surface to retain moisture.

Both group A and group B utilized a sprinkler-type watering system to aid in temperature reduction as part of their water management control system. During the first month, the trees were watered once daily. Subsequently, the watering frequency was adjusted to every other day or every 2-3 days, depending on the moisture level of the soil around the base of the trees. The irrigation system is designed with a Fuzzy Logic controller, operating on the principles of Fuzzy Logic or Set Theory, which can be applied to decision-making under uncertain data conditions, using a reasoning process akin to human thinking. In this experiment, a Fuzzy Logic controller in the Mamdani and Assilian (1975) formats have been employed for decision-making in durian tree irrigation, as elaborated below.

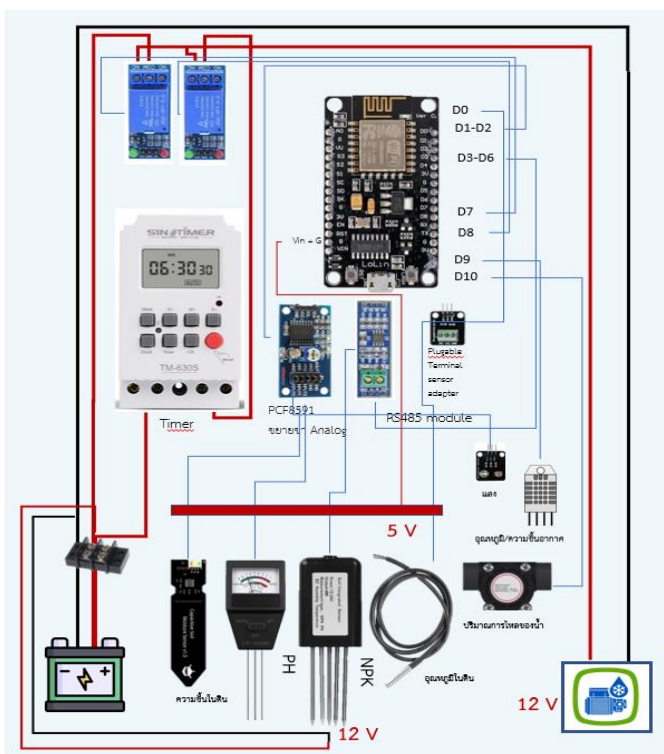

Figure 2 Circuit diagram design

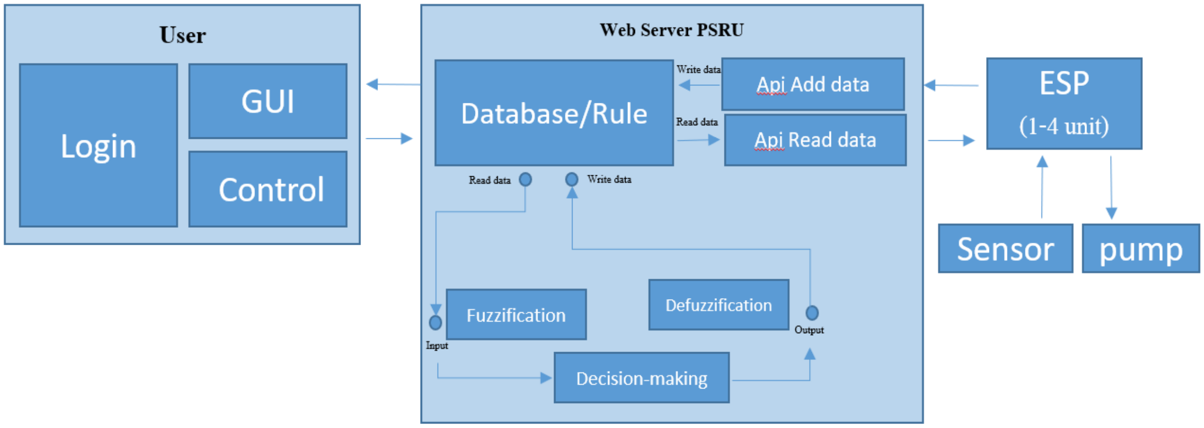

Figure 3 Fuzzy logic-based control system

The temperature, soil moisture, and suitable irrigation pattern data obtained through these real-world experiments, will be utilized in designing a fuzzy logic-based controller to extract knowledge from experts. In this research, fuzzy rules in the forms of Mamdani and Assilian (1975) are employed, as illustrated in the equations.

IF x_1 is A_1 AND … AND x_n is A_n THEN Y_1 is B_1 (1)

where x_i represents input variables, A_i represents the values of input variables or fuzzy sets of input, Y_i represents output language variables, and B_i represents the values of output language variables or fuzzy sets of output.

The firing strength value of a fuzzy rule can be calculated as shown in the Equation 2:

$$W_j = \prod_{i=1}^{n} A_i(x_i) \qquad (2)$$

where w_j is the firing strength value of the fuzzy rule j, and $A_i)x_i($ is the membership value of x_i in the fuzzy set A_i, the output of the defuzzification process can be calculated as shown in the equation:

$$COG = \frac{\int_a^b B(x)xdx}{\int_a^b B(x)dx} \qquad (3)$$

where COG represents the center of gravity or the centroid of the fuzzy set B over the interval between a to b of input variables, namely soil temperature and soil moisture, for use in the defuzzification process, the linguistic variables for the output to be used in the defuzzification process, which is the irrigation time (output variable), are defined as follows: very low (VL), low (L), medium (M), high (H) and very high (VH). These linguistic variables correspond to the output values of the defuzzification process, and their values are determined based on the calculated COG within the range of a to b.

Table 2 Soil temperature set

Soil Temperature (℃)		
Cool	Warm	Hot
20	25-30	>35

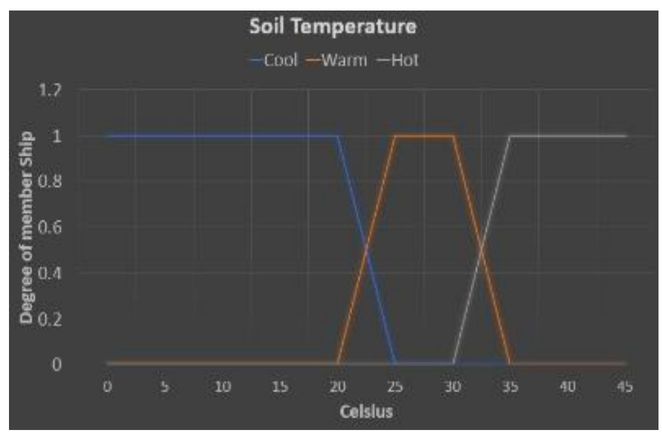

Figure 4 Soil temperature

The software design for control system development involves the use of the Arduino IDE with C/C++ language to control and read data from sensors every 120 seconds The data is transmitted wirelessly to a cloud computer for processing and then stored in a MariaDB database. Additionally,

Table 3 Soil moisture content set

Soil moisture content, %		
Dry	Humid	Damp
<40	50-70	>80

Table 4 Fuzzy rules

Fuzzy Rule		Watering Time (minute)
ST	SM	
Cool	Dry	M
Cool	Humid	L
Cool	Damp	VL
Warm	Dry	H
Warm	Humid	M
Warm	Damp	L
Hot	Dry	VH
Hot	Humid	H
Hot	Damp	M

User interfaces for systems A and B are designed to connect and display information through a web application using PHP and MariaDB. The main system homepage (Home) consists of four main menus: 1) Pump: This menu allows users to command and view the status of the water pump. 2) Sensor: Here, users can monitor the status of sensors. 3) Graph: This section displays detailed data in both graphical and tabular formats, providing users with comprehensive information. This software design combines hardware control using Arduino, data transmission to the cloud, and a web-based interface for user interaction and data visualization.

Step 4: implementation: The research team proceeded to implement the developed system in a real-world setting and conducted extensive usability testing. This was carried out in Nakhon Thai District, Phitsanulok Province. During this phase, the system underwent refinement to enhance its efficiency and was prepared for any necessary error corrections.

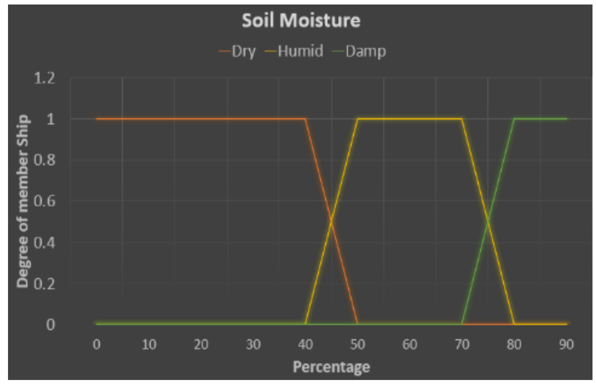

Figure 5 Soil moisture content

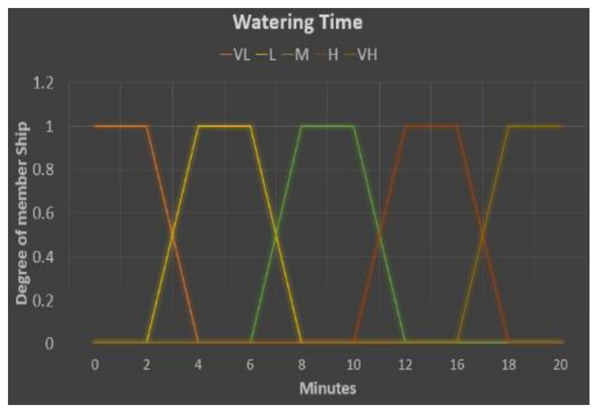

Figure 6 Watering time

Figure 7 Graphic user interface of the system

3 Results and discussion

Displaying the user interface is a representation of the system that has been developed and improved, both in systems A and B. It connects and presents data through a web application using PHP and MariaDB. The main screen of the system's operation is as follows:

The home page of the system consists of four main menus: pump, which controls and displays the status of the water pumps; Sensor, which shows the sensor status; and graph, which displays detailed data in both graphical and tabular formats. The pump menu (as shown in Figure 8) allows entry of commands and views of the status of the water pumps for Group A, Group B, and Group C. Group A represents the newly planted durian trees with IoT technology inside the greenhouse. Group B is the newly planted durian trees with IoT technology outside the greenhouse, and Group C represents the newly planted durian trees with automatic watering. The pumps can be manually controlled from this page which indicates if the pumps are currently running. The Graph menu displays detailed data in both graphical and tabular formats for Group A and Group B. It shows humidity data at intervals of 120 second, collected over 24 hours. Documentation in the form of .csv or .pdf files can be copied and printed from this menu. This study can be appropriately compared to that of Hadkhuntod and Sangkudluo (2020) who using PHP language and MariaDB to develop smart farm fish feeding system based on IoT, and Obma et al. (2023) who using PHP language and MySQL to develop water quality for ornamental fish tank using IoT technology.

The fuzzy logic obtained from the designed fuzzy rules is used in the system's diagnostic process. The input variables consist of two parameters: soil temperature (ST) and soil moisture (SM), while the output variable is the watering time (WT), expressed in IF-THEN rules. For example, IF ST is Cool AND SM is Dry THEN CV is M, where CV represents the watering time's category (e.g., M represents "Medium") .

An example of how these fuzzy rules can be applied is described here: Suppose the soil temperature is 32 ℃, and the soil moisture is 30%. We can calculate the degree of membership for the watering time (WT) based on the following rules:

w_1 = IF ST is Cool (0.5) AND SM is Dry (1.0) THEN CV is M (0.5)

w_2= IF ST is Warm (0.5) AND SM is Dry (1.0) THEN CV is H (0.5)

For rule w_1, the degree of membership for WT is M, which has a membership value of 0.5. Similarly, for rule w_2, the degree of membership for WT is H, with a membership value of 0.5. Now, we can perform defuzzification to find the *COG* using the formula:

COG = (0.5 ×9)+(0.5 ×13)/(0.5+0.5) = 11

This means that if the weather has a temperature of 23 ℃, and the soil has a moisture level of 30%, the recommended watering time is 11 minutes.

In summary, fuzzy logic is used to determine the appropriate watering time based on input parameters like soil temperature and moisture. The rules and membership functions help categorize the watering time, and *COG*, is calculated to provide a specific recommendation for the given conditions.

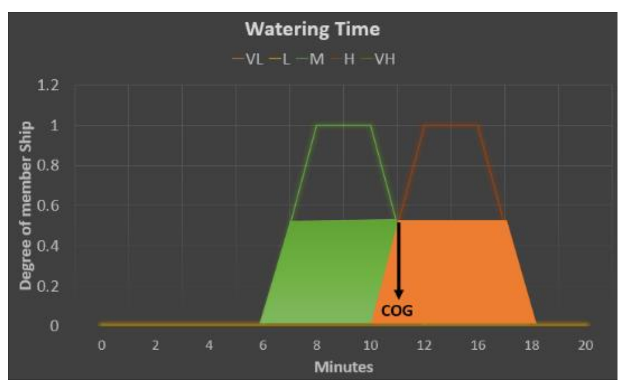

Figure 8 Finding the center of gravity

The study, which employed One-way ANOVA and utilized a DC Power Meter for measuring power consumption and a water flow meter for quantifying water usage in tree irrigation, yielded the following outcomes:

Table 5 Comparison of differences in growth

Plant growth	Group	N	Mean	S.D.	F	Sig.
Height (cm)	A	4	177.50	1.92	35.97	.000
	B	4	160.25	7.68		
	C	4	145.50	4.80		
Brunch (amount)	A	4	73.25	9.60	36.16	.000
	B	4	52.50	8.35		
	C	4	25.75	5.12		
Leaf (amount)	A	4	157.50	21.42	69.84	.000
	B	4	87.50	6.81		
	C	4	45.25	6.85		

Table 6 Comparison of growth between groups

Plant growth	Group (I)	Group (J)	Mean Difference	Sig.
Height)cm(	A	B	17.25*	.000
		C	32.00*	.001
	B	A	-17.25*	.004
		C	14.75*	.000
	C	A	-32.00*	.004
		B	-14.75*	.005
Brunch)amount(	A	B	20.75*	.000
		C	47.50*	.005
	B	A	-20.75*	.001
		C	26.75*	.000
	C	A	-47.50*	.001
		B	-26.75*	.000
Leaf)amount(	A	B	70.00*	.000
		C	112.25*	.000
	B	A	-70.00*	.002
		C	42.25*	.000
	C	A	-112.25*	.002
		B	-42.25*	.000

Note: *The mean difference is significant at the 0.05 level.

From Tables 5 and 6, it is observed that: The height of Group A is the highest (Mean=177.50, S.D.=1.92), followed by Group B (Mean=160.25, S.D.=7.68), and Group C has the lowest height (Mean=145.50, S.D.=4.80). Group A has the highest number of branches (Mean=73.25, S.D.=9.60), followed by Group B (Mean=52.50, S.D.=8.35), and Group C has the lowest number of branches)Mean=25.75, S.D.=5.12). The leaf amount of Group A is the highest (Mean=157.50, S.D.=21.42), followed by Group B (Mean=87.50, S.D.=61.81), and Group C has the lowest leaf amount (Mean=45.25, S.D.=6.85). All these group differences are statistically significant at the 0.05 level. When comparing between groups, Group A ranks the highest, followed by Group B and Group C, in terms of height, the number of branches, and leaf amount. Group A can control the environment to meet the plant's requirements, resulting in the highest growth. Group B, with no temperature or humidity control, ranks second. Group C have timed watering, which may be an adequate or correct volume of water in certain periods, coupled with unfavorable environmental conditions, led to inferior growth as compared to Groups A and B. This study can be appropriately compared to that of Srinil et al. (2021) who applied a fuzzy logic control to IoT for melon cultivation, and compared the melon weight and sweetness outcomes to human expert-led cultivation. The results showed no statistically significant difference in melon yields between the two groups. However, environmental conditions inside and outside the greenhouse were not tested, and thus, differences in these aspects remain unexplored. Additionally, the research by Shahzadi et al. (2020) employed a similar comprehensive approach using IoT devices but for smart homes to assist the visually impaired in navigation and the research by Assawakanchana et al. (2022) using IoT devices and mobile applications but for children left in cars or kindergarten vans and the research by Muhammad et al. (2022) using IoT monitoring system but for fresh cassava chip.

Table 7 DC consumption and watering amount

Plant growth	Group	N	Mean	S.D.	F	Sig.
Electric current (amp/day)	A	90	64.09	18.87	873.67	.000
	B	90	4.47	.86		
	C	90	6.00	.00		
Water (lite/tree/time)	A	120	5.53	.84	1268.20	.000
	B	120	9.45	1.51		
	C	120	12.00	.00		

Table 8 Comparison of DC consumption and watering amount

Plant growth	Group (I)	Group (J)	Mean Difference	Sig.
Electric current (amp/day)	A	B	59.62*	.000
		C	58.09*	.000
	B	A	-59.62*	.000
		C	-1.53	.349
	C	A	-58.09*	.000
		B	1.53	.349
Water (lite/tree/time)	A	B	-3.92*	.000
		C	-6.47*	.000
	B	A	3.92*	.000
		C	-2.55*	.000
	C	A	6.47*	.000
		B	2.55*	.000

Note: *The mean difference is significant at the 0.05 level.

From Tables 7 and 8, it can be observed that: Electricity consumption (amps/day) for Group A is the highest (Mean=64.09, S.D.=18.87), followed by Group B (Mean=4.47, S.D.=0.86), and Group C has the lowest electricity consumption (Mean=6.00, S.D.=0.00). Group A requires the highest electricity consumption as it needs to control the environment the most. Water (liters/tree/time) for Group C is the highest (Mean=12.00, S.D.=0.00), followed by Group B (Mean=9.45, S.D.=5.53), and Group A has the lowest water consumption (Mean=5.53, S.D.=0.84). There are statistically significant differences among these groups at the 0.05 level. A comparison of DC consumption shows that Group A is significantly higher than B and C, but Groups B and C do not statistically differ from each other. This is because the fuzzy logic process was designed to make decisions based on expert knowledge from the combined moisture and temperature sensors, with 5 levels of input. Group A, which has complete control over the environment, can conserve water the most. Group C, with a predetermined schedule and water quantity, experiences no change in DC and water consumption. This aligns with the research of Kumar et al. (2012) where fuzzy logic was used to improve software efficiency and the research of Firouzi et al. (2020) where fuzzy logic was used to improve the plausibility of the low-level intelligence concerning reducing latency and more accurate prediction and the research of Reddy et al. (2023). where fuzzy logic was used to enhance security in IoT. Results of this: Trust prediction accuracy (99%), energy consumption (53%), malicious node detection (98%), computation time (61 S), latency (1.7 ms), and throughput (9 Mbps).

4 Conclusion

An IoT, fuzzy logic-based system was developed for controlling the growth of young durian trees under optimal conditions. The system comprised four main menus to control water (the Pump control system), a Sensor display of the status of all sensors, and a Graph display, which presents detailed data in both graph and table formats for water pump control and status. The system provides operational control of water consumption and environmental conditions. Tests were carried out on three groups of seedlings: newly planted durian seedlings cultivated in a greenhouse (Group A) ; newly planted durian seedlings grown outside the greenhouse with IoT watering control (Group b), and newly planted durian seedlings outside the greenhouse with automatic watering (Group C).

The results of the study on growth efficiency using One-way ANOVA statistics reveal that growth, as measured by plant height, branch count, and leaf count, significantly differs among the three groups. Group A has the highest values, followed by Group B and Group C, with statistically significant differences. The study of DC electric current usage found that Group A consumes the most electricity, significantly more than Groups B and C. Groups C and B do not statistically differ in their electricity consumption. The efficiency of plants grown using an IoT greenhouse system is highest in Group A but comes at the cost of higher electricity consumption. However, it helps in conserving water for plant irrigation. In contrast, Group B, which uses IoT outside the greenhouse, consumes less electricity and conserves more water compared to traditional cultivation. Moreover, the application of fuzzy logic for control further enhances watering efficiency, as it closely simulates human decision-making, providing reasonably precise water allocation rules based on various factors. The results of these experiments will be useful in informing the future cultivation of durian trees in this, and similar, areas of Thailand, which will enhance the economic prospects of these areas.

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