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Fuzzy-based Nutrient System for Chili Cultivation in Urban Area

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ABSTRACT

The right level of nutrients is crucial for chilli cultivation as the crop requires different nutrient levels at different growth stages. The current fertiliser supply needs many human resources, which is time-consuming. Thus, an automatic nutrient controlling system giving the exact amount of fertiliser based on Fuzzy logic and IoT technology is proposed in this paper. The proposed system uses Hostinger platform to monitor water level, electrical conductivity (EC) and pH values in real-time. Fuzzy membership functions and rules decide the precise amount of nutrients to chilli plants based on the EC value and water level at each growth stage. The Fuzzy membership functions are designed according to the nutrients requirement in each chilli's phenological stage. The proposed system results are compared with the traditional approach, where fertilisers are supplied manually every week. The experiment results showed that the proposed system could meet the precise and automatic fertiliser addition requirement, eliminate human intervention and ensure the plants grew well.

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1. INTRODUCTION

According to United Nations Population Division, the world population increases as time goes by, and it is expected to reach 9.7 billion by 2050. With this, the demand for food is expected to increase drastically by 2050 [1]. Hence, crop production needs to be increased to meet the critical demand. It is well known that crop production is highly related to the total amount of nutrients provided to plants, where the right amount of nutrients at the right phenological stage can enhance crop production and quality [2]. The index of salt concentration is used as an indication of nutrients in the solution. It is measured through electrical conductivity (EC) generated by ions produced when fertiliser is dissolved in water. The optimum EC value is significant as a low EC value leads to malnutrition in plants [3]–[7]. In the conventional way of measuring nutrient content, farmers use a handheld EC meter to measure EC values routinely to ensure the EC values are at the optimum range, which is tedious and inconvenient [4]. Furthermore, some farmers only rely on their experience to add fertiliser to nutrient solutions [1], which is sometimes inaccurate and even affects the plant's growth with slight changes in EC value for plants sensitive to EC [8].

IoT has helped achieve better crop management, resource management, cost-effective crop and field monitoring [9]–[11]. IoT technology has been explored intensively in the agriculture field. In [12], Perwiratama et al. used IoT in a smart hydroponic farming system that provides climate and nutrient information. The authors concluded that IoT could help humans do menial tasks in agriculture, thus reducing human labour. In [13], Puranik et al. introduced an IoT-based water management system for a farm. The system checks the soil moisture and irrigates automatically according to the soil moisture. The authors concluded that IoT in agriculture provides convenience and time efficiency to farmers. In [14], the authors claimed that the proposed IoT system eases monitoring and controlling the nutrient solution’s water level and EC value for an NFT system. The system also promotes healthy plant growth based on a relative growth rate. This statement is supported by C. Hairu et al.[15], which also uses IoT to monitor surface temperature and moisture content inside a low-cost urban greenhouse in real-time. Studies have shown that fertiliser utilisation can be efficient with the implementation of the Internet of Things (IoT) [8], [16]. Compared to traditional farming methods, IoT requires minimum human intervention, and provides faster access and time efficiency [13], [17].

Utilising Fuzzy classifier for controlling EC levels has received significant attention [18]. In [19], Mashumah et al. designed Fuzzy logic control for the Nutrient Film Technique (NFT)-based hydroponic system. The setpoint value of the EC was predicted via HSV (Hue, Saturation, Value) Histogram. The authors claimed that the Fuzzy logic control could provide nutrients following the age of the plant with an error rate of 8.9%. In [20], a Fuzzy logic-based program that provides an appropriate amount of fertiliser to soil was proposed. The Fuzzy decision is based on season, nitrogen, phosphorus, and potassium levels for the use of rice in inbred light soil. A two-phase fuzzy-based approach was proposed in [21] to predict soil nutrients, where the pH value of soil was predicted in phase one, depending on the previous time-series pH value of the soil by using the Fuzzy model. Then the regression model was employed in phase two to predict soil nutrients based on the predicted pH value. The result analysis showed that the experimental results outperformed statistical parameters. In [22], Fuzzy logic determined the nutrient level of the soil based on the features extracted from the captured images. Puno et al. [23] applied Fuzzy Logic to maintain water and nutrients at the NFT system’s optimum level. Yolanda et al. [24] also used fuzzy logic methods to control the EC values in the NFT system. Apart from monitoring and controlling all parameters remotely, the system took around 101 seconds to restore the lowest EC value to be ideal and approximately 89 seconds to restore the highest EC value to an ideal condition.

Inspired by the previous studies, a Fuzzy-based fertiliser controlling system with an IoT technology for remote monitoring is proposed in this study. The Fuzzy membership functions and rules that decide the amount of fertiliser to be pumped into the mixing tank, are designed based on the chili plant’s phonological stage, EC, and water level values, as explained in the following section. The rest of the paper is organised as follows; the sytem structure and process are presented in section 2; the mathematical modelling in section 3; results and discussion in section 4; and conclusions and further studies in the last section.

2. SYSTEM STRUCTURE AND PROCESS

The proposed study was conducted at the Faculty of Engineering, Universiti Putra Malaysia, and the experiments were performed on 28 chilli plants in a greenhouse in an urban area. The nutrient solution is provided to plants through drip irrigation, from a nutrient mixing tank, as shown in Figure 1. The nutrient mixing tank mixes water from the tap and the concentrated fertiliser A and B solutions from fertiliser tanks. Raspberry Pi is the microcontroller that controls the irrigation, where Fuzzy membership functions and rules perform the decision.

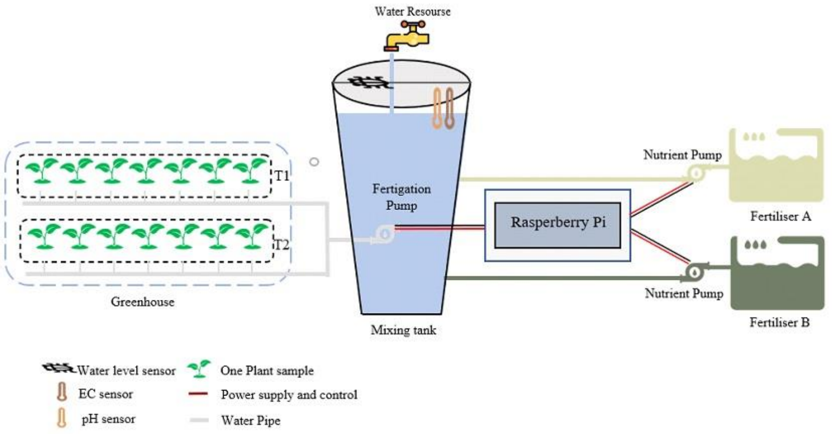


Figure 1. The experimental setup

The process involved can be categorised into three main parts, namely, 1) sensing and actuation, 2) processing, and 3) cloud and data display, as illustrated in Figure 2. The sensing part consists of three sensors, namely ultrasonic sensor (HC-SR04), EC sensor (A1005) and pH sensor (H-101 pH electrode). These sensors measure the water level, EC and pH values in the mixing tank. The decision produced by the Fuzzy system in the Raspberry Pi is executed by actuators, which are the WP-4000, HJ-541 and R385 DC pumps. Both WP-4000 and HJ-541 pumps are placed in the mixing tank, while the R385 DC pump is placed in the fertiliser tank. Water is supplied to chilli plants through the WP-4000 pump that operates at the voltage of 220-240V, with a power of 40 Watts. The HJ-541 pump operates at the same voltage but is used to stir the water in the mixing tank, to ensure the water and the concentrated fertilisers A and B, pumped by the R385 DC pump, mix well in the mixing tank before irrigating plants. The Raspberry Pi controls all the water pumps through relays.

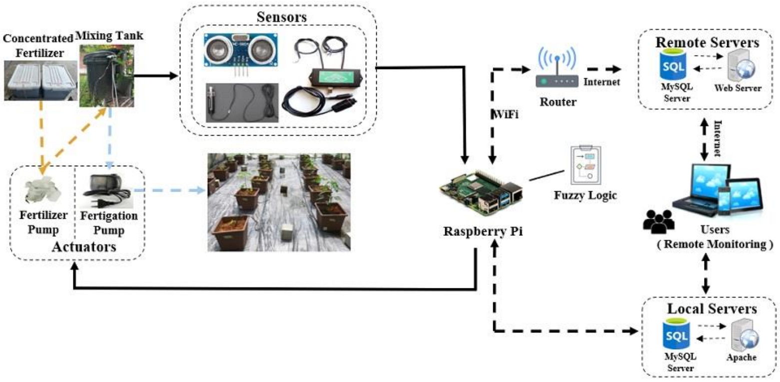


Figure 2. Overall process.

In the processing stage, the amount of fertilisers A and B to be pumped into the mixing tank are based on the plant's phenological stage [25][26], as shown in Table 1. If the EC value in the mixing tank is lower than the optimum range, the adding of fertilisers and stirring process will continue until the EC value reaches the optimum level.

Table 1. EC value according to plant's stages [25][26].

Chilli stage	Seedling state	Vegetative state	Flowering state	Fruiting state
Week	1	2-5	6-11	12 - end of season
EC values (mS/cm)	1.5-1.8	2.0-2.3	2.4-2.8	2.8-3.2

The process in the processing part is illustrated in Figure 3 and Figure 4. The first step is to stir the solution in the mixing tank, followed by the sensor reading. All sensor data would be checked for validity before further processing. In our developed IoT system, the system will alert the user by sending an email if the water level or pH in the nutrient mixture tank is at an extreme level, either extremely low or extremely high, allowing users to take quick action. After the sensor reading, the system will check the plant's phenological stage, where the decision performed by the Fuzzy method to add the amount of concentrated fertilisers A and B into the mixing tank is based on the phenological stage. Figure 4 shows the process performed by the fuzzy logic controller. EC inputs on specific phenological stage and water level values are passed to a fuzzifier, translating real-valued inputs into fuzzy values. The pH value of the solution in the mixing is measured only for monitoring purposes, as the pH value in the mixing tank is always at the optimum level for chilli plant growth based on our observation. An inference engine applies a fuzzy reasoning mechanism based on the designed Fuzzy sets and rules to obtain a fuzzy output. Each element in the Fuzzy sets is mapped to [0,1], with 0 representing absolute falseness and 1 representing whole truth, based on expert knowledge. The Fuzzy rules are in the form of "if-then" rules. Then, a defuzzifier translates the output into a crisp value that transforms into the duration of irrigation in seconds, executed by the actuators. This process is performed weekly and this is based on the recommendation by Yue et al [14], where excessive nutrient leads to slow growth, or plants can even die.

At the cloud and data display stage, the data is send to the cloud database and displayed on the developed website, namely http://chillifertigationsystem.hol.es/login.php, to enable users to monitor the information remotely. The data from the sensors are displayed hourly. The website was developed using HTML, PHP, and CSS language code, which includes a login page, homepage, and a page for displaying collected data. The user is required to register an account to access the website.

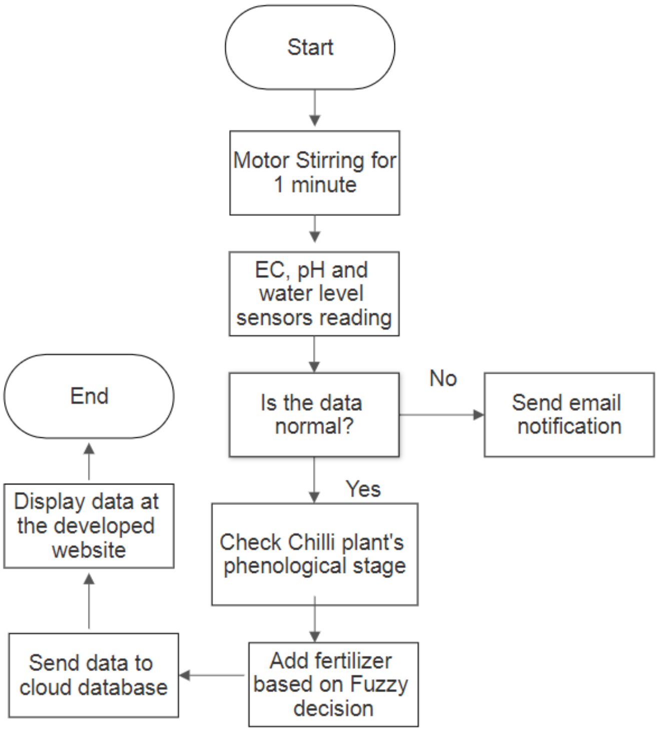


Figure 3. Flow chart representing the processing part.

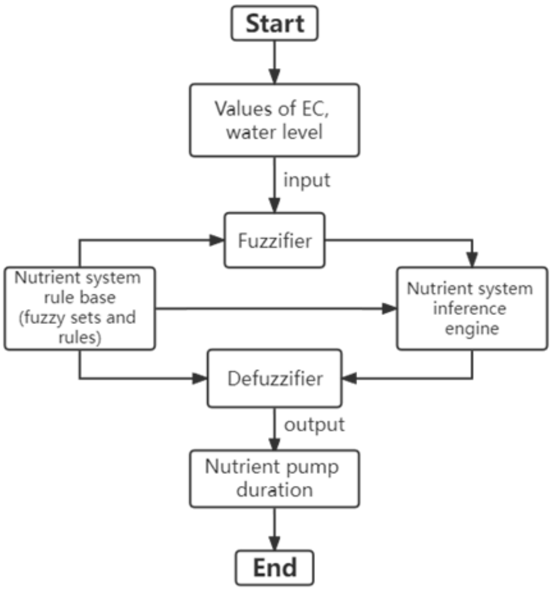


Figure 4. Fuzzy logic controllers in the processing part.

3. MATHEMATICAL MODELLING

3.1. Fuzzy membership functions

As mentioned previously, the EC range for each plant's phonological stage is different. Thus, the Fuzzy sets of EC and the output pump duration are different for each phenological stage, as shown in Figure 5 to Figure 8. The EC fuzzy sets are expressed as "low", "optimal" and "high", while the fuzzy sets for the output that is the duration of A and B fertilisers will be pumped into the mixing tank are expressed as "stop", "short", "medium" and "long". The membership functions' specific values are decided based on sensor calibration, expert knowledge and experience in chilli cultivation.

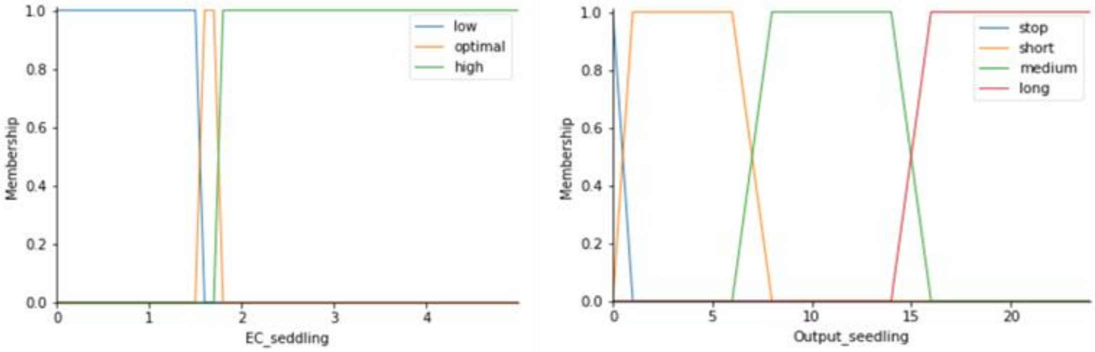


Figure 5. EC and output membership functions at the seedling

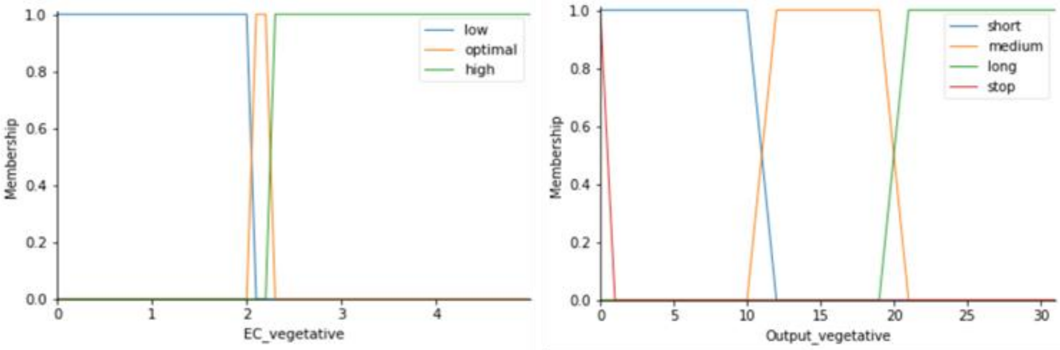


Figure 6. EC and output membership functions at the vegetative stage

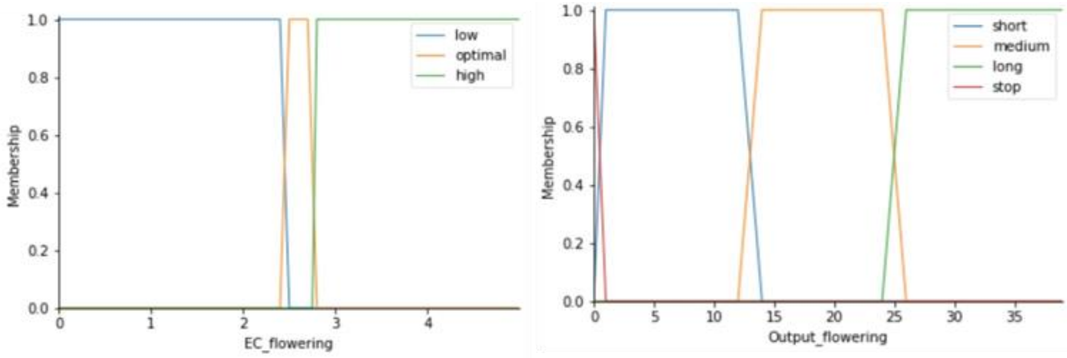


Figure 7. EC and output membership functions at the flowering stage

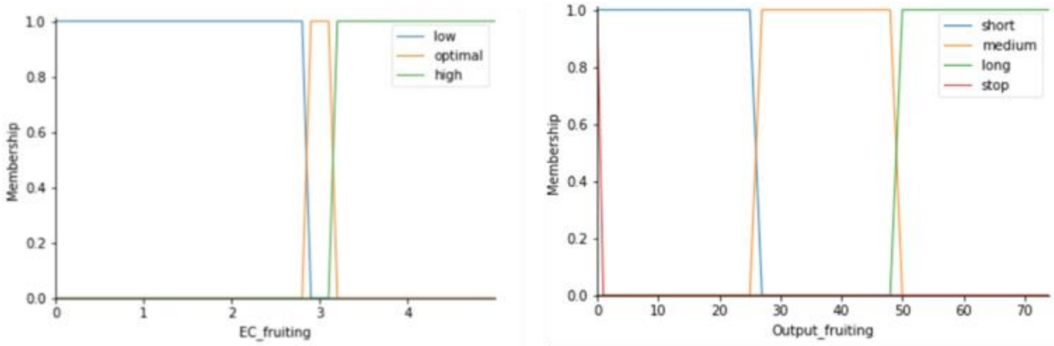


Figure 8. EC and output membership functions at the fruiting stage

Nevertheless, the water level setpoint is similar for all the growth stages of plants, where the water level membership functions are expressed as “low”, “optimal” and “high”, as shown in Figure 9. The range defined by each Fuzzy set is based on the sensor calibration data.

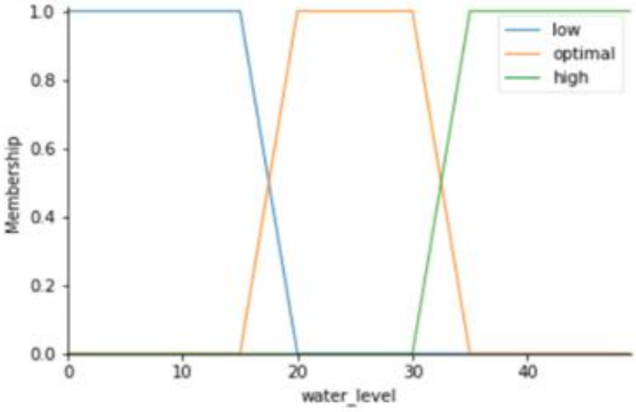


Figure 9. Water level membership functions at all chili crop stages.

3.2. Fuzzy rules

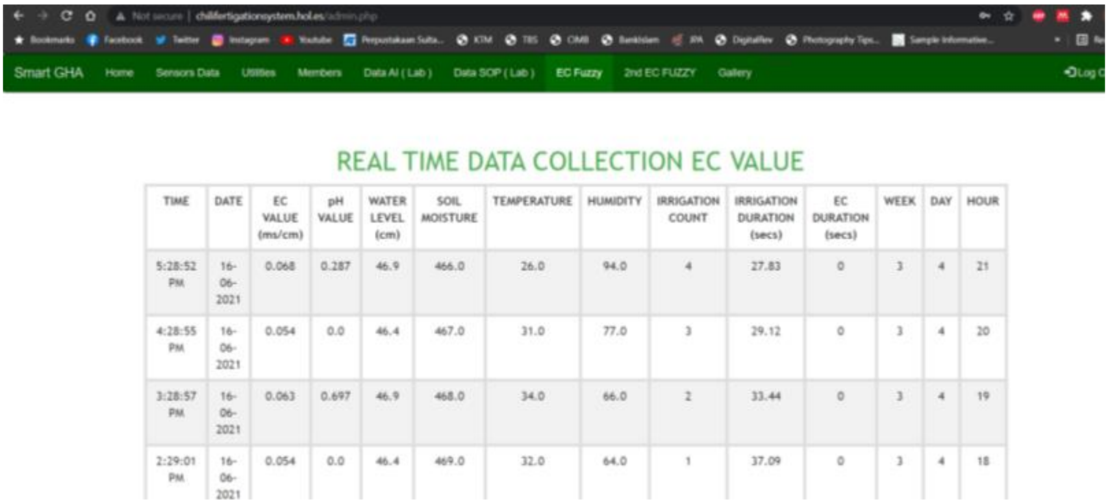
The Fuzzy rules used in the experiments are shown in Table 2. In the case where the EC value is high, the decision by the fuzzy operation is no fertilisers are pumped into the mixing tank. The same action is performed when the EC value is at the optimum level and the water level is optimal or high. The time allocated for long is 75 seconds, where the reading in the mixing tank will be reached up to 3.5 mS/cm, which is the maximum EC value. The allocated output range for the duration of the working pump is based on the EC sensor calibration.

Table 2. The Fuzzy Rules

No	EC	Water level	Output
1	low	low	medium
2	low	optimal	long
3	low	high	long
4	optimal	low	stop
5	optimal	optimal	stop
6	optimal	high	short
7	high	low	stop
8	high	optimal	stop
9	high	high	stop

4. Results and discussion

The experiments were performed on 28 chilli plants in a greenhouse, and the data collection was performed for 11 weeks, where the data includes all the sensor data and plant growth measurement. The measured parameters are average plant height, average leaf width, average leaf length, average stem perimeter, and average plant crown. The collected data are displayed on http://chillifertigationsystem.hol.es/, in the table as shown in Figure 10. The EC values trend during the 11 weeks is shown in Figure 11.



REAL TIME DATA COLLECTION EC VALUE

TIME	DATE	EC VALUE (ms/cm)	pH VALUE	WATER LEVEL (cm)	SOIL MOISTURE	TEMPERATURE	HUMIDITY	IRRIGATION COUNT	IRRIGATION DURATION (secs)	EC DURATION (secs)	WEEK	DAY	HOUR
5:28:52 PM	16-06-2021	0.068	0.287	46.9	466.0	26.0	94.0	4	27.83	0	3	4	21
4:28:55 PM	16-06-2021	0.054	0.0	46.4	467.0	31.0	77.0	3	29.12	0	3	4	20
3:28:57 PM	16-06-2021	0.063	0.697	46.9	468.0	34.0	66.0	2	33.44	0	3	4	19
2:29:01 PM	16-06-2021	0.054	0.0	46.4	469.0	32.0	64.0	1	37.09	0	3	4	18

Figure 10. Data display page

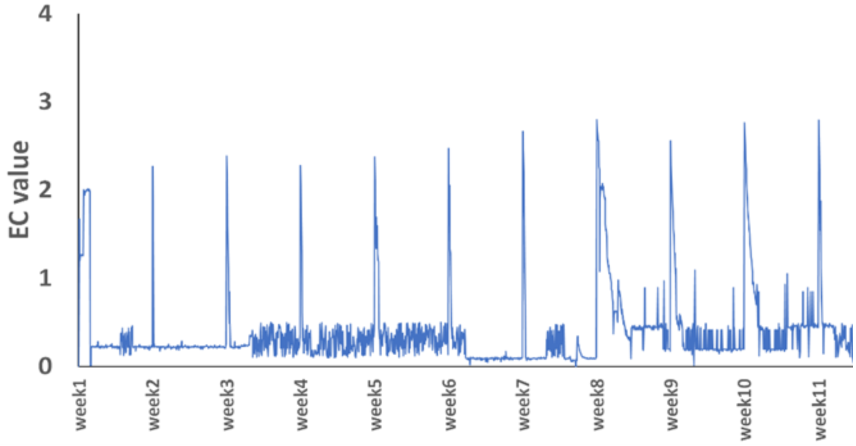


Figure 11. EC values trend.

The graph shows that the EC reading decreased gradually before adding the fertiliser. However, a drastic increase can be observed after the A and B fertilisers were pumped into the mixing tank. The trend is approximately similar every week as the fertiliser is only pumped into the mixing tank once a week. The fertilisers are only added once a week based on the findings in [14], where these fertiliser greatly influenced plant growth, where some plants died, and some had shown slow growth when A and B fertilisers were frequently given, such as more than once a week. The plants grown in the proposed system is compared with those developed using the traditional method, where the fertilisers were added manually every week. The system's performance is observed through plant growth measurement with 11 weeks of data shown in Figure 12 and the relative growth rate(RGR) calculated using equation (1) [12] is shown in Figure 13.

$$RGR = \frac{\ln S2 - \ln S1}{T2 - T1} \times 100\% \qquad (1)$$

where S2 is the final measurement at $T2$; S1 is the initial measurement at $T1$; $T2$ is day 77 for the last measurement taken; $T1$ is day 1 for the initial measurement taken.

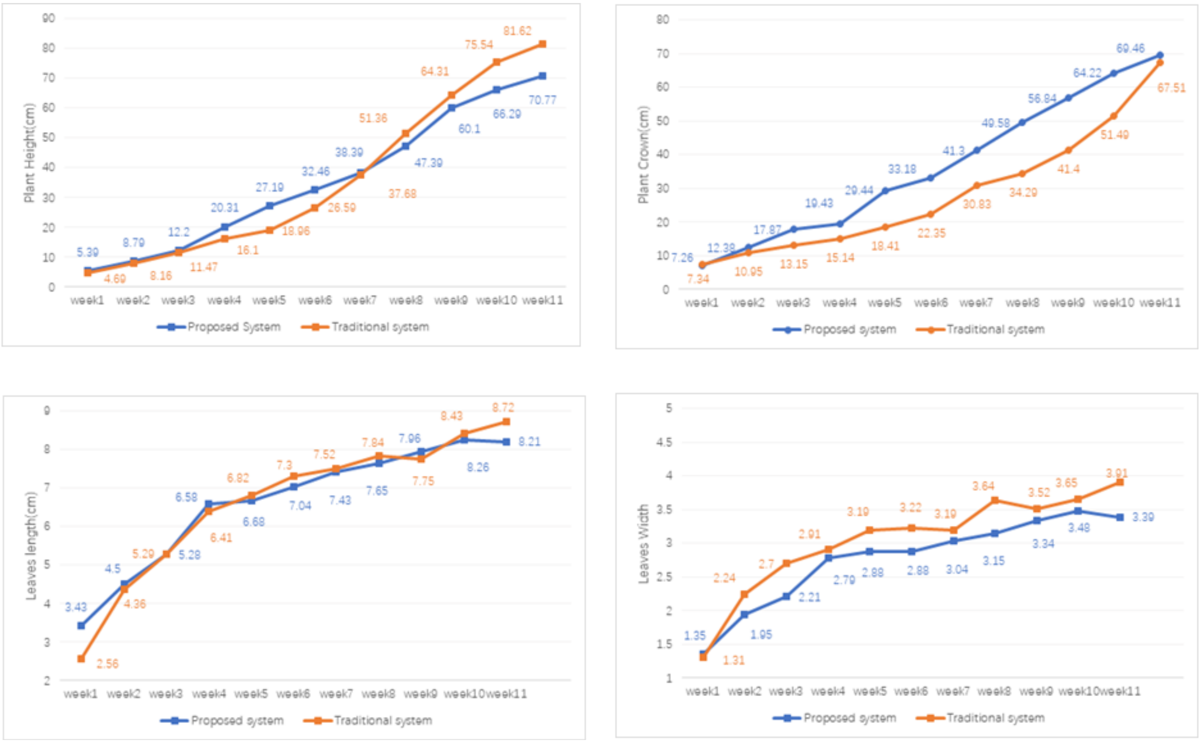


Figure 12. Comparison of average plant measurement for all growth parameter

The results showed that the performance of the proposed system is approximately similar to the traditional method. However, the plant crown from the proposed system is growing faster than the traditional system. In terms of plant leaves, the plant leaves in the first five weeks grew faster than the rest weeks. This showed that the proposed system gave better performance because the first few weeks are the most crucial phase of plants, and fuzzy logic worked significantly. The plant RGR of the plant parameters, as shown in Figure 13, is less than 0.5%, indicating a minor influence on plant growth between the two systems. Even though the performance of the plant growth is approximately similar, the proposed system has many advantages compared to the traditional method, where the system eliminates the requirement of closed monitoring by human labour with the utilisation of a few economical devices; it allows users to monitor the sensor data in real-time remotely and provides an accurate fertiliser supply on different plant growth stages

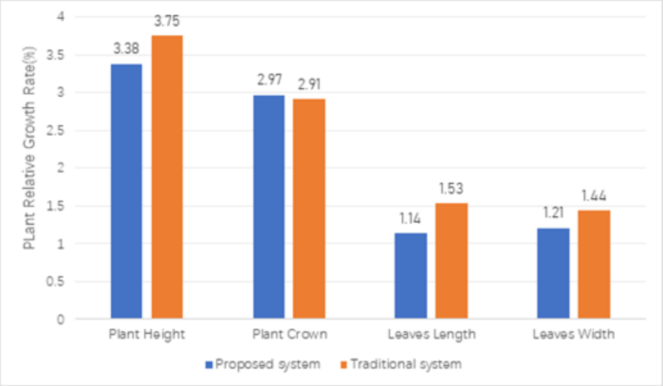


Figure 13. RGR for all the plant growth parameters

5. CONCLUSIONS

An intelligent IoT-based nutrient monitoring and controlling system proposed in this paper provides many advantages such as ensuring an accurate fertiliser supply on different plant growth stages, allowing remote monitoring in real-time and most importantly eliminating the need for human intervention that is time-consuming and costly. In terms of the chilli plant growth performance, the results have shown that the performance of the proposed system is approximately similar to the traditional approach. However, the intelligent and automatic process offered by the proposed system has made the execution of the farming activities becomes effective and economical. In future, the proposed system can be further improved by adding surveillance cameras to automatically capture plant images that can be used to develop an automated pest detection system or automated plant growth measuring system.

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REFERENCES

[1] D. Frona, S. Janos, and M. Harangi-Rakos, "The challenge of feeding the world," *MDPI J. Sustain.*, no. 11, p. 5816, 2019.

[2] S. Charumathi, R. M. Kaviya, J. Kumariyarasi, R. Manisha, and P. Dhivya, "Optimisation and Control of Hydroponics Agriculture using IOT," *Asian J. Appl. Sci. Technol.*, vol. 1, no. 2, pp. 96–98, 2017, [Online]. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2941105.

[3] R. M. A. Machado and R. P. Serralheiro, "Soil salinity: Effect on vegetable crop growth. Management practices to prevent and mitigate soil salinisation," *Horticulturae*, vol. 3, no. 2, 2017, doi: 10.3390/horticulturae3020030.

[4] C. Hidayat, M. R. Pahlevi, B. F. Taufiqqurahman, and M. A. Ramdhani, "Growth and Yield of Chili in Nutrient Film Technique at Different Electrical Conductivity," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 288, no. 1, pp. 1–5, 2018, doi: 10.1088/1757-899X/288/1/012034.

[5] X. Ding *et al.*, "Electrical conductivity of nutrient solution influenced photosynthesis, quality, and antioxidant enzyme activity of pakchoi (Brassica campestris L. Ssp. Chinensis) in a hydroponic system," *PLoS One*, vol. 13, no. 8, pp. 1–15, 2018, doi: 10.1371/journal.pone.0202090.

[6] S. S. Sheikh, A. Javed, M. Anas, and F. Ahmed, “Solar Based Smart Irrigation System Using PID Controller,” *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 414, no. 1, 2018, doi: 10.1088/1757-899X/414/1/012040.

[7] Herman and N. Surantha, “Intelligent monitoring and controlling system for hydroponics precision agriculture,” *2019 7th Int. Conf. Inf. Commun. Technol. ICoICT 2019*, pp. 1–6, 2019, doi: 10.1109/ICoICT.2019.8835377.

[8] T. Sangeetha and P. Ezhumalai, “Enhanced and cost-effective techniques used for plant growth in vertical agriculture,” *Mater. Today Proc.*, no. xxxx, 2020, doi: 10.1016/j.matpr.2020.11.557.

[9] H. Benyezza, M. Bouhedda, and S. Rebouh, “Zoning irrigation smart system based on fuzzy control technology and IoT for water and energy saving,” *J. Clean. Prod.*, vol. 302, p. 127001, 2021, doi: 10.1016/j.jclepro.2021.127001.

[10] D. Shinde and N. Siddiqui, “IOT Based Environment change Monitoring Controlling in Greenhouse using WSN,” in *2018 International Conference on Information, Communication, Engineering and Technology, ICICET 2018*, 2018, pp. 1–5, doi: 10.1109/ICICET.2018.8533808.

[11] E. R. Kaburuan, R. Jayadi, and Harisno, “A Design of IoT-based Monitoring System for Intelligence Indoor Micro-Climate Horticulture Farming in Indonesia,” *Procedia Comput. Sci.*, vol. 157, pp. 459–464, 2019, doi: 10.1016/j.procs.2019.09.001.

[12] R. Perwiratama, Y. K. Setiadi, and Suyoto, “Smart hydroponic farming with IoT-based climate and nutrient manipulation system,” *Proceeding - 2019 Int. Conf. Artif. Intell. Inf. Technol. ICAIIT 2019*, pp. 129–132, 2019, doi: 10.1109/ICAIIT.2019.8834533.

[13] V. Puranik, Sharmila, A. Ranjan, and A. Kumari, “Automation in Agriculture and IoT,” *Proc. - 2019 4th Int. Conf. Internet Things Smart Innov. Usages, IoT-SIU 2019*, pp. 29–34, 2019, doi: 10.1109/IoT-SIU.2019.8777619.

[14] S. J. Yue, C. Hairu, M. Hanafi, S. M. Shafie, and N. A. Salim, “IoT Based Automatic Water Level and Electrical Conductivity Monitoring System,” *Proceeding - 2020 IEEE 8th Conf. Syst. Process Control. ICSPC 2020*, no. December, pp. 95–100, 2020, doi: 10.1109/ICSPC50992.2020.9305768.

[15] C. Hairu, M. Hanafi, S. M. Shafie, W. F. F. Ilahi, and S. Mashohor, “Remote Monitoring of Surface Temperature and Moisture Content in Urban Greenhouse,” *Proceeding - 2020 IEEE 8th Conf. Syst. Process Control. ICSPC 2020*, no. December, pp. 101–105, 2020, doi: 10.1109/ICSPC50992.2020.9305786.

[16] A. P. Montoya, F. A. Obando, J. A. Osorio, J. G. Morales, and M. Kacira, “Design and implementation of a low-cost sensor network to monitor environmental and agronomic variables in a plant factory,” *Comput. Electron. Agric.*, vol. 178, no. August, p. 105758, 2020, doi: 10.1016/j.compag.2020.105758.

[17] R. S. Krishnan *et al.*, “Fuzzy Logic based Smart Irrigation System using Internet of Things,” *J. Clean. Prod.*, vol. 252, p. 119902, 2020, doi: 10.1016/j.jclepro.2019.119902.

[18] I. A. Lakhiar, G. Jianmin, T. N. Syed, F. A. Chandio, N. A. Buttar, and W. A. Qureshi, “Monitoring and control systems in agriculture using intelligent sensor techniques: A review of the aeroponic system,” *J. Sensors*, vol. 2018, pp. 1–18, 2018, doi: 10.1155/2018/8672769.

[19] S. Mashumah, M. Rivai, and A. N. Irfansyah, “Nutrient Film Technique based Hydroponic System Using Fuzzy Logic Control,” *Proceeding - 2018 Int. Semin. Intell. Technol. Its Appl. ISITIA 2018*, no. 1, pp. 387–390, 2018, doi: 10.1109/ISITIA.2018.8711201.

[20] J. J. I. Haban, J. C. V. Puno, A. A. Bandala, R. Kerwin Billones, E. P. Dadios, and E. Sybingco, “Soil fertiliser recommendation system using fuzzy logic,” *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2020-Novem, pp. 1171–1175, 2020, doi: 10.1109/TENCON50793.2020.9293780.

[21] R. Singh, R. Kaur, and A. Singla, “Two phase fuzzy based prediction model to predict Soil nutrient,” *PDGC 2018 - 2018 5th Int. Conf. Parallel, Distrib. Grid Comput.*, pp. 80–85, 2018, doi: 10.1109/PDGC.2018.8745759.

[22] J. C. V. Puno, A. A. Bandala, E. P. Dadios, and E. Sybingco, “Vision System for Soil Nutrient Detection Using Fuzzy Logic,” *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2018-Octob, no. October, pp. 617–622, 2019, doi: 10.1109/TENCON.2018.8650242.

[23] J. C. V. Puno, J. J. I. Haban, J. D. Alejandrino, A. A. Bandala, and E. P. Dadios, “Design of a nutrient film technique hydroponics system with fuzzy logic control,” *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2020-Novem, pp. 403–408, 2020, doi: 10.1109/TENCON50793.2020.9293749.

[24] D. Yolanda, L. Arief, T. A. Sundara, M. Deza, and D. Oktavia, “Control of Electrical Conductivity for NFT Hydroponic Systems using Fuzzy Logic and Android Environment,” *2018 Int. Conf. Inf. Technol. Syst. Innov. ICITSI 2018 - Proc.*, pp. 508–514, 2018, doi: 10.1109/ICITSI.2018.8695923.

[25] Malaysia Hydroponics AB powder fertiliser (10L/50L/100L) - Special Mixture. Accessed at http://malaysiahydroponics.com/malaysia-hydroponics-powder-chili.html

[26] Chilli life cycle. Can be accessed at http://www.majlisilmu.gov.bn/Shared%20Documents/Pameran/2018/WEEK%205%20Life_Cycle.pdf