

Smart Irrigation System And Grow Lights For Tomato Plants Based On The Internet Of Things Using The Fuzzy Logic Method

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modern agricultural system management.

Advances in the Internet of Things (IoT) enable sensors, actuators, and internet networks to be integrated to monitor plant conditions in real time and control systems remotely [4]. However, most systems still use static control methods that are not sufficiently adaptive to environmental changes and sensor data uncertainties [5]. Therefore, there is a need for intelligent control methods capable of making flexible and accurate decisions.

Previous research has shown that the Tsukamoto Fuzzy Logic method is effective when applied to automated irrigation systems and plant environmental control. The Tsukamoto Fuzzy Logic method was applied to an IoT-based automated irrigation system for mint plants to determine the duration of irrigation based on soil temperature and humidity [6]. Additionally, a greenhouse control system for tomato plants was developed using a Raspberry Pi and fuzzy logic to automatically regulate temperature, humidity, and light intensity [7]. Other research has also shown that integrating temperature, light, and soil moisture sensors into an IoT-based greenhouse can enhance the effectiveness of real-time plant condition monitoring [8].

However, most previous studies have focused on controlling irrigation or greenhouse environments separately and have not integrated irrigation and grow light systems into a single IoT-based system with direct evaluation of plant growth under different environmental conditions. Therefore, this study developed SIGROW (Smart Irrigation and Grow Light System), an IoT-based irrigation and lighting system for tomato plants using the Tsukamoto Fuzzy Logic method. This system integrates a soil moisture sensor to control the water pump and a CJMCU-TEMT6000 sensor to control the UV LED lights, thereby not only meeting the plants' water needs but also ensuring sufficient light to support tomato plant growth. Additionally, this study evaluates the system's impact on plant growth across three distinct environmental conditions, providing a more



comprehensive analysis compared to previous research.

II. METHOD

This study employs a quantitative method with an experimental approach that involves the design, implementation, and evaluation of an Internet of Things (IoT)-based smart irrigation and UV lighting system using the Tsukamoto Fuzzy Logic method in tomato cultivation.

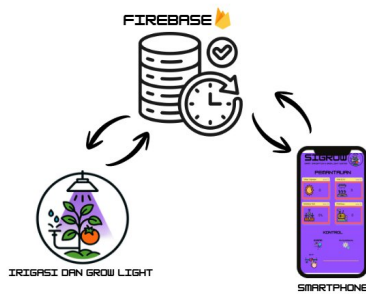


Figure 1 SIGROW IoT System Architecture.

A. Instrument Design

The design of this research setup integrates hardware into a system with the ESP32 serving as the control unit. The CJMCMU-TEMT6000 sensor and the soil moisture sensor function as “sensors,” while the UV LED and water pump act as PWM actuators that drive the system’s operations.

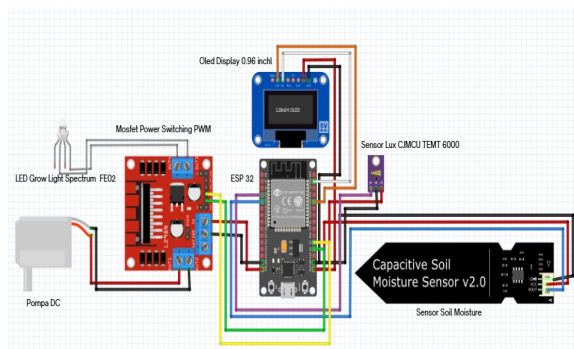


Figure 2 Component Design

B. System Block Diagram

This system collects data on light intensity and soil moisture, which is processed by the ESP32 using the Tsukamoto Fuzzy Logic method to control UV LED lights and an irrigation pump via PWM signals. The measurement data and control decisions are displayed on an OLED screen and sent to Firebase and the MIT App Inventor app for real-time IoT-based monitoring and control of tomato plant growth.

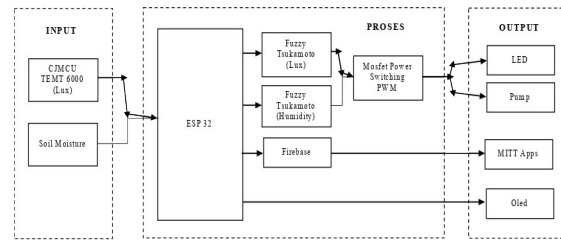


Figure 3 Architectural Block Diagram

C. System Flowchart

This system flowchart illustrates the sequence of processes, starting with initialization, followed by a check of the Wi-Fi and Firebase connections. If the connections are successful, the system reads data from the light sensor CJMCMU-TEMT6000 and the soil moisture sensor, then determines the operating mode. In automatic mode, the data is processed using the Fuzzy Tsukamoto method to generate a PWM signal that controls the LED and pump, while in manual mode, control is performed via the app. Sensor data and system status are displayed on the OLED screen and sent to Firebase for monitoring purposes.

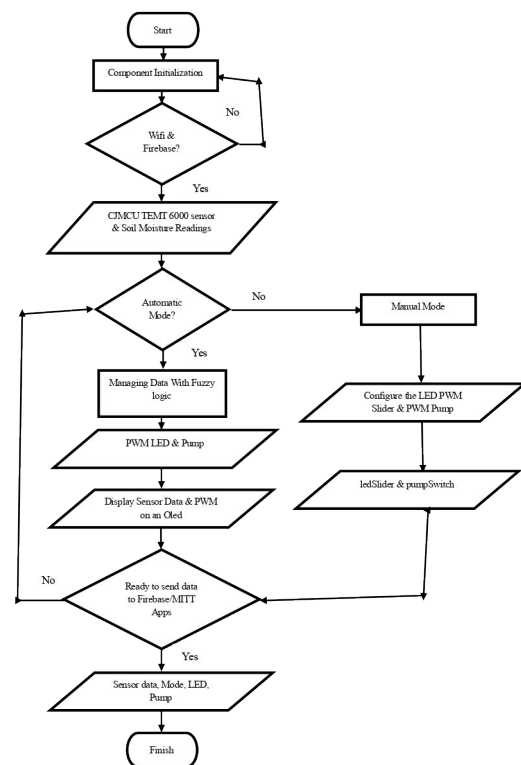


Figure 4 System Flowchart

D. Fuzzy Logic Design

This system uses the Tsukamoto fuzzy method, which begins with a fuzzification process, followed by rule-based inference, and concludes with a defuzzification process to produce an accurate decision.

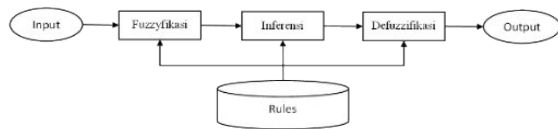


Figure 5 Block Diagram of a Fuzzy Logic System

1. Determination of Variables and Membership Functions

Determine the variables and membership functions by grouping the inputs and outputs into linguistic categories. The LUX variable is classified into Dark, Overcast, and Bright to control the LED PWM, while the SOIL variable is divided into Dry, Damp, and Wet to control the pump PWM. Each category has a specific range of values used in calculating membership degrees in the Tsukamoto fuzzy method.

Table 1 Membership Degree Data

Variable	Criteria	Value Range
Lux	Dark	0 – 1500
	Overcast	1000 – 2500
	Bright	2000 – 4000
Soil	Dry	0 – 40
	Damp	30 – 70
	Wet	60 – 100
LED UV PWM	Bright	180 – 255
	Medium	100 – 200
	Dim	0 – 100
Pump PWM	Long	180 – 255
	Medium	100 – 200
	Short	0 – 100

2. Fuzzification Process

Fuzzification is the first step in converting raw data from light and humidity sensors into membership degrees using linguistic representations—such as Dark to Bright and Dry to Wet—through the use of triangular or trapezoidal curves.

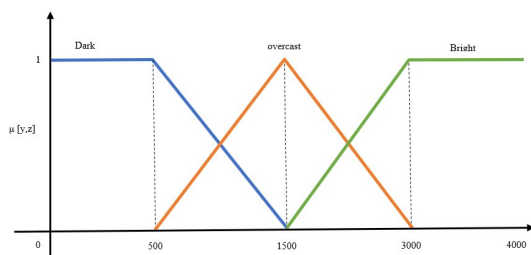


Figure 6 Lux Variable Membership Curve

On the CJMCU-TEMT60000 (Lux) sensor, data is classified as Dark, Overcast, and Bright within a range of ± 0 –4000 Lux.

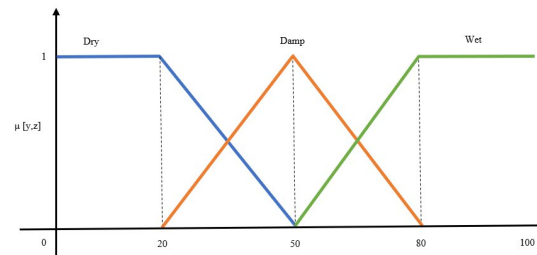


Figure 7 Soil Variable Membership Curve

As for soil moisture, moisture levels are categorized as Dry, Moist, and Wet on a scale of 0–100%.

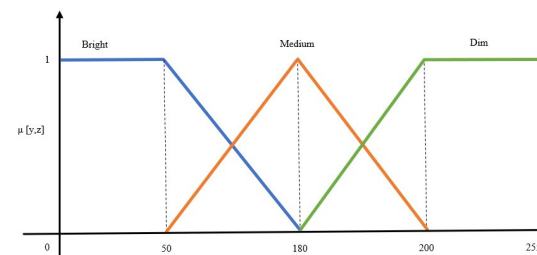


Figure 8 Membership Curves for the UV LED

In the output results, the PWM value (0–255) serves as a control for the LEDs, which are grouped into the categories Dim, Medium, and Bright.

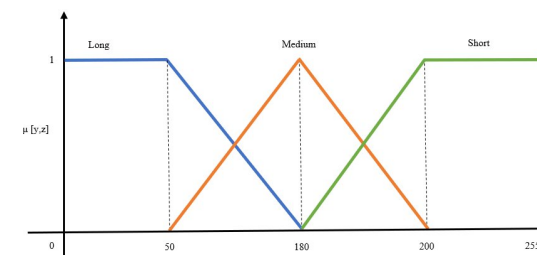


Figure 9 Membership Curves for the Pump

PWM values (0–255) control the pumps, which are grouped into the categories Short, Medium, and Long. These levels convert numerical data into linguistic variables that form the basis for reasoning in the Tsukamoto fuzzy system.

3. The Inference Process

The inference process is the stage in which decisions are made based on a combination of inputs using a rule base. In this system, there are nine rules that link the Lux and Soil Moisture conditions using the AND operator.

Table 2. Fuzzy Logic Rules

Rules	Light Sensor	Soil Sensor	PWM (Light)	Pump (Water)
1	Dark	Dry	Bright	Long
2	Dark	Damp	Bright	Medium
3	Dark	Wet	Bright	Short

4	Overcast	Dry	Medium	Long
5	Overcast	Damp	Medium	Medium
6	Overcast	Wet	Medium	Short
7	Bright	Dry	Dim	Long
8	Bright	Damp	Dim	Medium
9	Bright	Wet	Dim	Short

4. Defuzzification Process

These conclusions were converted into discrete values using the weighted average method in Fuzzy Tsukamoto. Each predicate value α was multiplied by the corresponding rule output, and then averaged to produce a PWM value (0–255) that controls the intensity of the UV LED and the operation of the pump according to environmental conditions.

$$Z = \frac{\sum(\alpha_i \times z_i)}{\sum \alpha_i} \quad \#(1)$$

E. Test Scenario

This study was conducted in a home environment using three tomato plants as test subjects. Plant A was placed indoors and controlled using the SIGROW system; plant B was placed on a terrace without direct exposure to environmental conditions; and plant C was placed in an open area and exposed directly to the weather. These three plants were used to compare the effects of SIGROW application on tomato plant growth.

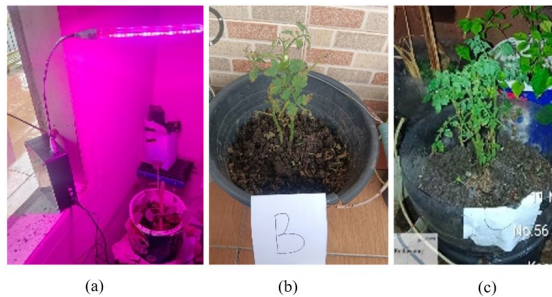


Figure 10 Three Tomato Plant Samples (a) Plant A (b) Plant B (c) Plant C

III. RESULTS AND DISCUSSION

A. Design Results

This Smart Irrigation and Grow Light System design integrates IoT components and technologies, with the ESP32 serving as the main control unit. The system operates using light and soil moisture sensors as data sources, while UV LEDs and a pump function as actuators controlled by the Tsukamoto Fuzzy Logic method. The system runs automatically, is responsive, and connects in real-time to Firebase for monitoring. The SIGROW app for Android, developed using MIT App Inventor, serves as an interface to display data (light, humidity, PWM) and adjust modes and intensity, allowing users to easily monitor and control the system via their smartphones.

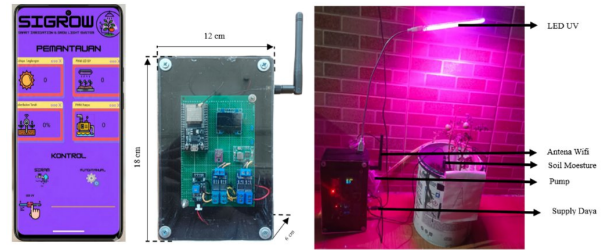


Figure 11 SIGROW Prototype and Application

B. Test Results

1. Sensor Accuracy

Sensor accuracy testing is performed by comparing sensor readings with those of a reference instrument through error calculations and accuracy assessments.

$$Error = |Reference Value - Sensor Value| \quad \#(2)$$

$$\%Error = \frac{|Reference Value - Sensor Value|}{Reference Value} \times 100\% \quad \#(3)$$

$$Accuracy = 100\% - \%Error \quad \#(4)$$

Table 3. Comparison of Lux Sensor Accuracy

No.	CJMCU-TEMT 600	Lux Meter AS803	ERROR (%)	Accuracy (%)
1.	762	739	3,10%	96,90%
2.	858	820	4,60%	95,40%
3.	967	947	2,10%	97,90%
4.	1297	1294	0,20%	99,70%
5.	1825	1819	0,30%	99,60%
6.	2152	2147	0,20%	99,70%
7.	2566	2450	4,70%	95,20%
8.	2879	2898	0,70%	99,70%
9.	3578	3570	0,20%	99,70%
10.	3810	3897	2,20%	97,70%
Average			1,83%	98,15%

Test results show that the CJMCU-TEMT6000 light sensor has an average error rate of 1.83% and an accuracy rate of 98.15%, making it a highly reliable choice for measuring light intensity.

Table 4. Soil Sensor Accuracy Testing

No.	Soil Moisture (%)	Analog 3-in-1 Soil Meter (%)	ERROR (%)	Accuracy (%)
1.	47	48	2,10%	97,90%
2.	50	51	2%	98%
3.	57	55	3,60%	96,40%
4.	61	60	1,70%	98,30%
5.	70	72	2,80%	97,20%
6.	77	79	2,50%	97,50%
7.	82	82	0%	100%
8.	86	84	2,40%	97,60%
9.	91	90	1,10%	98,90%

10.	95	92	3,30%	96,70%
Average			2,15%	97,85%

On the other hand, the soil moisture sensor showed an average error rate of 2.15% with an accuracy rate of 97.85%. Although there were some slightly larger deviations, these values still fell within acceptable tolerance limits. Overall, both sensors proved to be sufficiently reliable and suitable as data sources in the Tsukamoto Fuzzy system for controlling lighting and irrigation.

2. Tsukamoto Fuzzy Logic Rules

Testing of the Tsukamoto fuzzy rule showed that the system is capable of producing outputs that correspond to combinations of light intensity and soil moisture inputs.

Table 5. Results of the Tsukamoto Fuzzy Logic Rules Test

No.	Lux	Lux Criteria	soil (%)	Soil Criteria	UV PWM	Pump PWM	Rules
1.	384	Dark	23	Dry	231	193	Meets rule 1
2.	610	Dark	52	Damp	216	122	Meets rule 2
3.	483	Dark	88	Wet	224	30	Meets rule 3
4.	1407	Overcast	16	Dry	165	214	Meets rule 4
5.	1577	Overcast	62	Damp	154	97	Meets rule 5
6.	1910	Overcast	91	Wet	133	23	Meets rule 6
7.	2542	Bright	21	Dry	93	201	Meets rule 7
8.	2835	Bright	57	Damp	74	109	Meets rule 8
9.	3123	Bright	83	Wet	56	43	Meets rule 9

3. IoT Response

The IoT response test was conducted to measure the communication speed between the ESP32 and the MIT App Inventor app over the internet.

Table 6. IoT Response Testing Data Using Wi-Fi

No.	Device Response to MIT App (Seconds) Wi-Fi				
	Feature	Test 1	Test 2	Test 3	Average
1.	Mode (MANUAL/AUTO)	4,28	2,91	2,69	3,29
2.	LED Slider	3,13	2,73	1,49	2,45
3.	Pump Switch	2,02	1,66	2,11	1,93
4.	Lux	2,39	2,01	2,93	2,44
5.	Soil	2,19	2,32	2,24	2,25
6.	PWM LED	2,45	2,1	3,14	2,56
7.	PWM Pump	2,25	2,48	2,3	2,34

Table 7. IoT Response Testing Data Using a Hotspot

No.	Device Response to MIT App (Seconds) Hotspot
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	Feature	Test 1	Test 2	Test 3	Average
1.	Mode (MANUAL/AUTO)	5,21	4,83	5,07	5,03
2.	LED Slider	3,92	3,64	3,48	3,68
3.	Pump Switch	3,41	3,22	3,35	3,32
4.	Lux	3,87	3,69	4,02	3,86
5.	Soil	3,75	3,81	3,66	3,74
6.	PWM LED	4,05	3,88	4,11	4,01
7.	PWM Pump	3,79	3,93	3,84	3,85

Although latency at critical points increased, the system remained stable and successfully performed real-time monitoring and control without any issues.

C. Comparative Growth Analysis

1. Height Comparison

Plant A, equipped with an irrigation system and grow lights, showed gradual growth from 0 cm, 1 cm, 0.5 cm, to 3.5 cm. During the testing period with high rainfall intensity, this plant continued to receive a stable supply of artificial light in the bright category (around 231 PWM) and stable soil moisture in the moist category (around 74%), allowing its growth to be maintained even indoors. Plant B, which was watered without direct exposure, experienced the fastest growth from 0 cm, 9 cm, 13 cm, then decreased to 7 cm. Meanwhile, Plant C, which was exposed to a natural environment, grew steadily and continued to increase from 2 cm, 5 cm, 7 cm, to 8 cm.

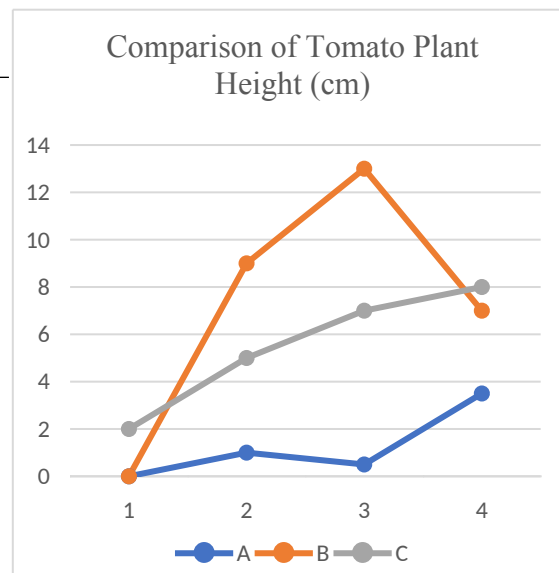


Figure 12 Comparative Height Analysis Graph

2. Comparison of Leaf Segments

Plant A, which was grown with an irrigation system and grow lights, showed fluctuating changes in leaf area from 2.65 cm², 1.25 cm², and 0.1 cm², then increased sharply to 4.9 cm². Plant B, which was watered without direct exposure, experienced the most significant changes: from 1.3 cm², 0.45 cm², a

good UV light exposure and soil moisture maintained at around 77%, ensuring that growing conditions remained optimal.

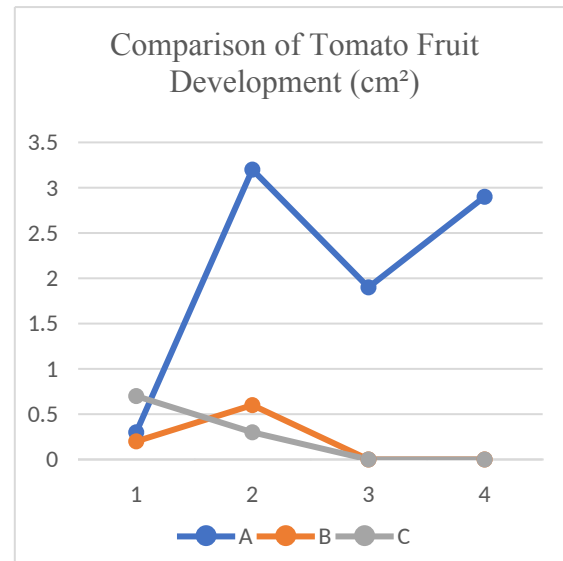


Figure 15 Comparative Analysis of Fruit Development

Plant B, which was watered without direct exposure, showed limited growth from 0.2 cm² to 0.6 cm², then remained at 0 cm² until the final observation, likely due to exposure to strong winds. Meanwhile, Plant C, which was directly exposed to the natural environment, showed only initial growth of 0.7 cm² and 0.3 cm², and then did not experience further fruit development in subsequent observations due to continuous rainfall, which caused the fruit to wither.

IV. CONCLUSION

This study successfully designed an IoT-based smart irrigation and plant lighting system using the ESP32 and Tsukamoto Fuzzy Logic, which operates automatically, stably, and in real-time for tomato cultivation. The CJMCU-TEMP6000 light sensor demonstrated an accuracy rate of 98.15%, while the soil moisture sensor demonstrated an accuracy rate of 97.85%. Fuzzy logic testing showed that all 9 rules operated according to lux and soil moisture conditions, resulting in adaptive PWM control of the UV LED and pump. IoT response via Wi-Fi had a latency of 1.93–3.29 seconds, while via a hotspot it was 3.32–5.03 seconds; however, it remained stable for remote monitoring and control. In the growth test, Plant A, which used this system, showed the best results with an average height of 20.5 cm and successfully bore fruit, while Plant B only grew leaves without fruit, and Plant C failed to bear fruit due to weather factors. These results prove that the IoT system with Fuzzy Tsukamoto is more effective than manual methods or natural environments in maintaining the growth and productivity of tomato plants.

REFERENCES

- [1] D. Z. Nisa and D. P. Astuti, "Sistem Penyiraman Tanaman Tomat Otomatis Berbasis Arduino Uno Dan Panel Surya," *Power Elektron. J. Orang Elektro*, vol. 12, no. 1, p. 44, 2023, doi: 10.30591/polektron.v12i1.4648.
- [2] A. Algiffary and T. Sutabri, "Indonesian Journal of Computer Science," *Indones. J. Comput. Sci.*, vol. 12, no. 2, pp. 284–301, 2023, [Online]. Available: <http://ijcs.stmikindonesia.ac.id/ijcs/index.php/ijcs/article/view/3135>
- [3] X. Liu, R. Shi, M. Gao, R. He, Y. Li, and H. Liu, "Growth of tomato and cucumber seedlings under different light environments and their development after transplanting," *Front. Plant Sci.*, vol. 14, no. July, pp. 1–15, 2023, doi: 10.3389/fpls.2023.1164768.
- [4] Muhammad Zikri, Muhammad Fikry, and Rizki Suwanda, "Rancang Bangun Smart Greenhouse Otomatis Berbasis Internet of Things Dengan Kontrol Rule-Based Untuk Optimalisasi Pertumbuhan Tanaman Tomat," *Rabit J. Teknol. dan Sist. Inf. Univrab*, vol. 10, no. 2, pp. 693–700, 2025, doi: 10.36341/rabit.v10i2.6435.
- [5] Thariq Almajidi, Arief Ika Uktoro, and Suparman, "Perancangan Sistem Monitoring dan Kontroling Intensitas Cahaya pada Greenhouse Berbasis IoT dan Web Dashboard," *Agroforetech*, vol. 3, no. 02, pp. 1278–1286, 2025.
- [6] I. M. Dwi Andika Saputra, A. Sjamsjiar Rachman, and G. Wahyu Wiriasto, "Perancangan Sistem Penyiraman Otomatis Dan Monitoring Tanaman Daun Mint Menggunakan Logika Fuzzy Tsukamoto Berbasis Internet of Things," *JATI (Jurnal Mhs. Tek. Inform.)*, vol. 9, no. 2, pp. 2663–2669, 2025, doi: 10.36040/jati.v9i2.13148.
- [7] J. K. Unsrat, "Purwarupa Sistem Pengendalian Greenhouse Tanaman Tomat," vol. XIII, no. 2, pp. 309–318, 2024.
- [8] N. A. Prasetyo, A. Pracoyo, and Sungkono, "Pengkondisian Suhu, Cahaya Dan Kelembaban Tanah PadaPrototype Green House Untuk Bawang Merah Berbasis Iot," *J. Ilm. Sain dan Teknol.*, vol. 2, no. 11, pp. 349–357, 2024.
- [9] M. Aji, G. Darmawan, A. Bhawiyuga, and S. R. Akbar, "Rancang Bangun Sistem Penyiraman Tanaman Tomat Menggunakan Wireless Sensor Network dengan Metode Fuzzy Logic," *J. Pengemb. Teknol. Inf. dan Ilmu Komput.*, vol. 6, no. 12, pp. 6029–6038, 2022, [Online]. Available: <http://j-ptiik.ub.ac.id>
- [10] M. A. Hadi Sirad, "Optimasi Sistem Pembangkit Listrik Tenaga Angin Dan Pembangkit Listrik Tenaga Diesel Berbasis Fuzzy Logic," *PROtek J. Ilm. Tek. Elektro*, vol. 6, no. 2, pp. 102–106, 2019, doi: 10.33387/protek.v6i2.1254.
- [11] T. Mekatronika, J. Teknik, E. Politeknik, and N. Sriwijaya, "SISTEM KONTROL FUZZY LOGIC ALAT PENYIRAMAN OTOMATIS PADA TANAMAN TOMAT DAN KAKTUS mana akan terjadi penyiraman secara Mikrokontroler ESP32 Soil Masture Sensor (Sensor Kelembapan Tanah Soil Moisture sensor adalah sensor kelembapan yang dapat mendeteksi pe," vol. 16, no. Ii, pp. 23–31, 2023.
- [12] D. I. Kabupaten *et al.*, "Alat Pendeteksi Intensitas Cahaya Untuk Pembibitan Tomat Ceri (Cerasiforme) Hidroponik Menggunakan Ldr (Light Dependent Resistor) Berbasis Sms Gateway Light Intensity Detection Tool for Selecting Hydroponic Tomato Certies Using Light Dependent Resistors B".
- [13] J. Xu, B. Gu, and G. Tian, "Review of agricultural IoT technology," *Artif. Intell. Agric.*, vol. 6, pp. 10–22, 2022, doi: 10.1016/j.iaia.2022.01.001.
- [14] J. Zheng, P. Gan, F. Ji, D. He, and P. Yang, "Growth and energy use efficiency of grafted tomato transplants as affected by LED light quality and photon flux density," *Agric.*, vol. 11, no. 9, 2021, doi: 10.3390/agriculture11090816.
- [15] Tundo, Sodik, K. Setiawan, and R. F. Aula, "Penerapan IoT dengan Algoritma Fuzzy dan Mikrokontroler ESP32 dalam Monitoring Penyiraman," *J. Indones. Manaj. Inform. dan Komun.*, vol. 5, no. 3, pp. 2915–2924, 2024, doi: 10.35870/jimik.v5i3.977.
- [16] S. M. A. Mandal, and D. Singh, "Integrated Remote Power Control System for Conserving Energy in IOT," vol. 19, pp. 196–185, 2024, doi: 10.29007/tmg6.
- [17] M. R. Ariwibowo, L. A. Setiawan, and A. Iman, "Sistem Pemantau Kelembapan Tanah Dan Debit Air Pada Tanaman Cabai Menggunakan Esp32 Berbasis Internet of Things," *J. Inform. dan Tek. Elektro Terap.*, vol. 13, no. 2, pp. 963–969, 2025, doi: 10.23960/jitet.v13i2.6382.
- [18] M. N. Kartika and B. Kurniasih, "Pengaruh Irigasi Tetes dan Mulsa terhadap Pertumbuhan Tajuk Tanaman Tomat (*Solanum lycopersicum* L.) di Lahan Kering Gunungkidul," *Vegetalika*, vol. 10, no. 1, p. 31, 2021, doi: 10.22146/veg.55590.
- [19] R. N. Hidayat, F. Idris, and J. Juhaeriyah, "A Comparative Analysis of Sugeno and Tsukamoto Fuzzy Logic for Temperature Stability in SCAMIS," *Protek J. Ilm. Tek. Elektro*, vol. 12, no. 3, pp. 182–189, 2025, doi: 10.33387/protek.v12i3.10514.
- [20] R. Murugan, R. Narayanamoorthi, A. Emara, and Y. Y. Ghadi, "Fuzzy Logic Controlled Pulse Density Modulation Technique for Bidirectional Inductive Power Transfer Systems," *IEEE Access*, vol. 12, no. March, pp. 55184–55200, 2024, doi: 10.1109/ACCESS.2024.3388491.
- [21] M. Imbalo Zaki Hasibuan and T. Triase, "IMPLEMENTASI SISTEM DATABASE NoSQL SECARA REALTIME MENGGUNAKAN FIREBASE REALTIME DATABASE PADA APLIKASI OURTICLE," *SIBATIK J. J. Ilm. Bid. Sos. Ekon. Budaya, Teknol. dan Pendidik.*, vol. 2, no. 1, pp. 1–24, 2022, doi: 10.54443/sibatik.v2i1.489.
- [22] S. Edriati, L. Husnita, E. Amri, A. A. Samudra, and N. Kamil, "Penggunaan Mit App Inventor untuk Merancang Aplikasi Pembelajaran Berbasis Android," *E-Dimas J. Pengabd. Kpd. Masy.*, vol. 12, no. 4, pp. 652–657, 2021, doi: 10.26877/e-dimas.v12i4.6648.