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Indoor Plant Watering System Based on Temperature, Humidity and Light Sensors Using Fuzzy Logic

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ABSTRACT

As one of the vegetable production centers in West Java, Indramayu Regency plays a crucial role in meeting market demand. However, farmers still face challenges in efficient use of water, time, and energy, particularly in the manual watering process. Furthermore, increasing awareness of healthy vegetable consumption without pesticide exposure encourages people to cultivate plants independently indoors. Indoor cultivation is chosen as a solution when land availability is limited and environmental conditions do not support optimal plant growth. This study aims to design and implement an automatic watering system based on Mamdani fuzzy logic for indoor cultivation of mustard greens (Brassica rapa). This system uses an ESP32 microcontroller integrated with a soil moisture sensor (Soil Moisture), a temperature sensor (DS18B20), and a light intensity sensor (GUVA-S12SD), and is equipped with a UV Growlight lamp configured to operate for 20 hours per day to support photosynthesis in conditions of low natural light. The watering process is adaptively regulated based on environmental parameters using fuzzy logic, while system monitoring and control are performed in real time via the Node-RED platform with MQTT-based data communication. Test results show that the system can efficiently adjust watering frequency and duration, support optimal plant growth, and facilitate remote monitoring. This system is considered efficient for urban agriculture and households with limited land.

INTRODUCTION

One of vegetables that are famous in Indonesia as well Lots consumed inhabitant is mustard green. Green mustard (Brassica juncea L.) is abundant consumed by residents Because have mark nutrition big. Green mustard own Lots properties for health that has protein, carbohydrate, fat, Ca, P, Fe and vitamin A, B, and C content (Slameto, 2023). Di pasaran sawi hijau mempunyai harga jual yang lumayan tinggi dibandingkan sayuran sejenisnya, seperti bayam, kacang serta sayuran lainnya (Lita, 2024). Green mustard is also a vegetables that are capable develop every year as well as have sufficient development period short from nursery until harvest time need time between 30-50 days depends from condition land as well as the treatment. There is part literature that says mustard green useful for relieves itching in the throat in sufferers cough. Not only That vegetables this is also effective for repair function kidneys, sterilize blood, treating disease head as well as expedite digestion (Pamungkas, 2025).

Plant mustard green is very tolerant to the area, air as well as weathe (Yunita et al., 2019). Mustard greens can also be used develop with good on the plains low, middle, and plain large (Nasution et al., 2020). Mustard greens are also capable develop moment season Rain or season dry season, with provisions during the dry season condition watering under control with good (Wahyudi et al., 2020). One of the factor key influencing factors development as well as results harvest mustard that is humidity soil (Rohmawati et al., 2021). Watering that is still done manually to bring up various challenges, the most important problems regarding protect consistency watering plants (Prabowo et al., 2020). During the dry season, farmers must use up more lots time for do watering, on the other hand in the dry season Rain often happens watering excessive (Putri et al., 2022). Imbalance This result significant in development plants , especially vegetables kind of mustard greens, which require humidity maximum soil (Sari et al., 2021) . Excess water can cause decay roots, whereas water shortage will limit development plants, which in the end cause loss economy for farmers (Andriani et al., 2018).

Consumption level mustard green by the community show fluctuations with trend decline in the 2016–2020 period (Suryani et al., 2021). The decline This allegedly related with decrease wide land plantation consequence over function land For need settlements and development (Wahab & Firdaus, 2020). In addition the increase preference public to consumption more vegetables safe and free residue pesticides also contribute influence pattern consumption mustard green (Putra et al., 2019). Condition the demand existence innovation cultivation mustard efficient green on land limited with still produce productivity high and quality healthy plants (Sari & Yuliana, 2020). Technology environmentally friendly farming environment and use technique cultivation that reduces use pesticide can help increase trust consumer to quality vegetables (Dewi et al., 2021). In addition the system agriculture vertical and hydroponic become solution alternative in overcome limitations land plantations (Prasetyo et al., 2022). Increased efficiency in water and nutrient use also becomes factor key in development cultivation mustard sustainable green on land limited (Rahman et al., 2020).

There are some aspect development plants in the method cultivation plants inside room. Light is one aspects that can influence the development process plants inside room in line with Nguyen et al.'s (2019) statement that chlorophyll absorb photon light for energy in the photochemical process. Overcoming problem lack intensity light until Can use light artificial with LED growlight as radiation replacement light sun for the process of photosynthesis plants. LED growlight capable avoid occurrence disturbance physiological in plants in room as well as capable pressing disease that attacks plant so that Can reduce loss moment harvest (Slameto , 2023).

From the presentation above we design A capable tool do watering plants mustard in a way automatic using a humidity sensor land and temperature sensor land. In the planning tool This able carry out watering plant mustard greens planted in polybags automatic based on values humidity land as well as temperature land so that plant mustard green capable develop optimally (Pamungkas , 2025). System This no only reduce power manual labor but also ensuring more water usage effective. System automatic This allow planters for control frequency as well as duration watering based on information generated by sensors, so that ensure plant get the right amount of water at the right time (Pasinggi & Yafet, 2019).

Test This done in the room around Faculty of Engineering, Wiralodra University, Indramayu. Research done inside room use radiation light growlight that has been determined it's on for 20 hours a day. The system automatic This allow planters for control frequency as well as duration watering based on information generated by sensors, so that ensure plant get the right amount of water at the right time (Pasinggi & Yafet, 2019).

Study This aim for designing system watering automatic based on temperature and humidity sensors land that is capable monitor condition environment in real-time and process the data use fuzzy logic method to produce decision accurate watering in accordance plant water needs. System This designed with build fuzzy sets, rule base rules and mechanism inferences that are dynamic determine duration or intensity watering based on variation mark temperature and humidity.

In addition, research it also integrates lighting artificial using LED growlights 6 watt power with duration 20 hours of use per day to in One device integrated. This integration allows lighting and watering Work in a way coordinated under control fuzzy logic system so that support efficiency growth plant in a way overall.

Design results This expected become prototype system agriculture automatic which can implemented in scale House ladder and agriculture small. With implementation control intelligent fuzzy logic based system This offer solution efficient automation in use energy and water. In addition, technology This designed for make things easier farmer and urban farming actors in manage plant without manual intervention in the watering and lighting processes. Research this also has potential become runway in development system agriculture economical and adaptive precision to change condition environment.

METHOD

This study used a Fuzzy Inference System (FIS) with the Mamdani approach to regulate watering for mustard greens. The system was tested directly on mustard greens, using information and parameters obtained from previous needs identification. This approach allows the system to make more adaptive watering decisions based on weather conditions and soil moisture.

The membership function for weather temperature consists of three linguistic variables: cold (0–16°C), normal (14–26°C), and hot (24–100°C). Meanwhile, for soil moisture, the linguistic variables used are dry (0–40%), humid (30–70%), and wet (60–100%). The watering duration has three linguistic variables: stop (0 seconds), short (1–2 seconds), and long (1–5 seconds). With this combination of linguistic variables, the system is able to make watering decisions that are more responsive to varying conditions.

The Mamdani Fuzzy Approach uses the min-implication function to form basic fuzzy rules based on input variables. In this study, the AND (&) operator is used to connect each input. The defuzzification process is carried out to convert the fuzzy output into a crisp output. The centroid method was chosen as the defuzzification method, with an equation that calculates the central area of the membership function curve. The final value of $\bar{y}$ from the defuzzification results determines the level of automatic watering duration to maintain optimal soil moisture.

The design and fabrication of the tool were carried out after analyzing the system requirements. The ESP-32 microcontroller was programmed to process soil temperature and humidity data obtained from sensors (such as Soil Moisture and DS18B20). This data was input to the FIS, which then produced an output in the form of watering duration. The microcontroller then triggered a relay in active high mode to turn on the mini pump for the specified duration. Furthermore, the ESP-32 was connected to the Node-RED platform via MQTT-based communication protocol for easy monitoring and control.

The Node-RED platform interface is designed to monitor and control smart irrigation systems in real time via a computer or smartphone. Node-RED connects through a free MQTT broker like hivemq.com. The Node-RED dashboard features widgets such as historical graphs of sensor readings, gauges for displaying soil moisture and temperature, and manual control buttons for testing the water pump. Integration between devices is achieved through MQTT virtual topics, allowing all system components to function synchronously.

System testing and implementation were conducted in two stages: hardware and software testing. Hardware testing verified the performance of the sensors, pumps, and ESP-32 connections, while software testing assessed the accuracy of the Mamdani Fuzzy algorithm and the stability of MQTT communication. The trial was conducted for 7 days, recording soil temperature and humidity data for analysis against a fuzzy system reference. After testing, the system was fully implemented in a real-world environment, with fuzzy parameters adjusted based on initial observations. Monitoring was conducted through the Node-RED dashboard, allowing users to control watering adaptively and efficiently.

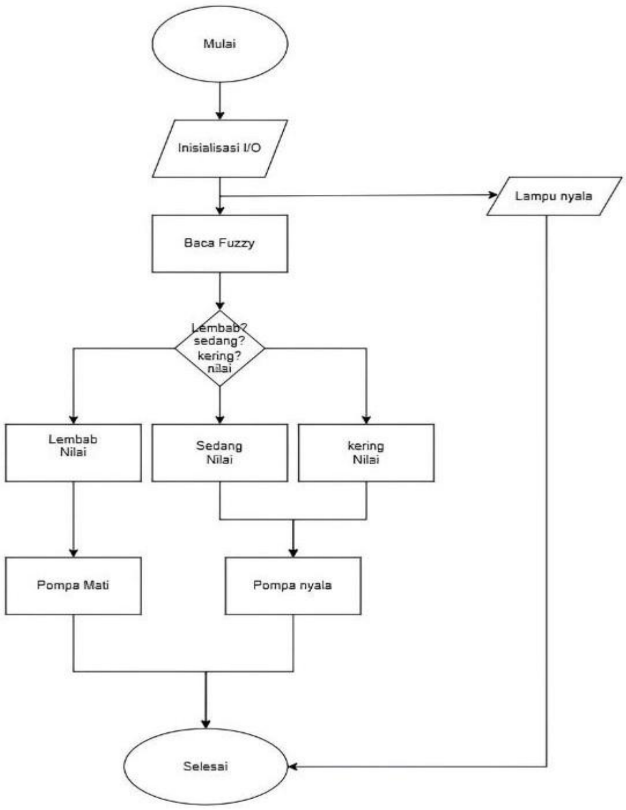

Figure 1. Automatic Watering System Test Results

Source: Data taken from testing

RESULTS AND DISCUSSION

The system was tested using soil moisture and temperature sensors integrated with an ESP32 microcontroller. The data obtained was analyzed to understand the relationship between soil moisture, soil temperature, and the duration of automatic watering generated by the Mamdani fuzzy method-based system. The test lasted for 7 days. Information on soil moisture and soil temperature was collected each time the device watered. On days 1 and 7, intensive recording was conducted to obtain an overview of changes in soil conditions. The table displays the results of observations of soil moisture and soil temperature on those days using a Confusion Matrix.

Table 1. Dry Soil Primary Data

No	Temperature	Humidity	Pump Status	Prediction
1	29	0%	Long (5 seconds)	in accordance
2	28	16%	Long (5 seconds)	in accordance
3	33	39%	Just a moment (3 seconds)	It is not in accordance with
4	31	10%	Long (5 seconds)	in accordance
5	28	7%	Long (5 seconds)	in accordance
6	32	38%	Just a moment (3 seconds)	It is not in accordance with
7	28	31%	Long (5 seconds)	in accordance
8	32	5%	Long (5 seconds)	in accordance
9	30	18%	Long (5 seconds)	in accordance
10	31	2%	Long (5 seconds)	in accordance

Source: Data taken from direct testing results by researchers (2025)

Information:
TP = 8
Wrong Prediction = 2 (damp)

Table 2. Primary Data for Moist Soil

No	Temperature	Humidity	Pump Status	Prediction
1	29	58%	Just a moment (2 seconds)	in accordance
2	30	62%	Just a moment (1 second)	in accordance
3	31	67%	Long (5 seconds)	It is not in accordance with
4	32	49%	Just a moment (2 seconds)	in accordance
5	28	54%	Just a moment (2 seconds)	in accordance
6	31	64%	Just a moment (1 second)	in accordance
7	29	68%	Just a moment (1 second)	in accordance
8	30	53%	Just a moment (2 seconds)	in accordance
9	27	47%	Just a moment (2 seconds)	in accordance
10	28	42%	Just a moment (2 seconds)	in accordance

Source: Data taken from the results of direct testing by researchers (Pamungkas, 2025)

Information:
TP = 9
Wrong Prediction = 1 (Dry)

Table 3. Primary Data on Wet Land

No	Temperature	Humidity	Pump Status	Prediction
1	29	100%	Stop (0 seconds)	in accordance
2	32	97%	Stop (0 seconds)	in accordance
3	28	77%	Stop (0 seconds)	in accordance
4	29	84%	Stop (0 seconds)	in accordance
5	28	69%	Just a moment (1 second)	It is not in accordance with
6	27	78%	Stop (0 seconds)	in accordance
7	33	75%	Just a moment (1 second)	It is not in accordance with
8	32	90%	Stop (0 seconds)	in accordance
9	31	80%	Stop (0 seconds)	in accordance
10	27	99%	Stop (0 seconds)	in accordance

Source: Data taken from direct testing results by researchers (2025)

Information:
TP = 8
Wrong Prediction = 2 (damp)

Table 4. Engineering Fusion Matrix

	Pred: Dry	Pred: Moist	Pred: Wet
Actual: Dry	8	2	0
Actual: Moist	1	9	0
Actual: Wet	0	2	8

Source: Data taken from direct testing results by researchers (2025)

Table 5. Accuracy

Total data = 30
Amount Correct = 8+9+8 =25
Accuracy = 25 / 30 = 83.3%

Source: Data taken from direct testing results by researchers (2025)

Testing of the Mamdani fuzzy logic-based automatic irrigation system demonstrated that the system can provide adaptive irrigation responses to variations in soil temperature and humidity. The assessment was conducted across three categories of soil conditions: dry, damp, and wet.

1. Dry Soil Conditions

In the primary dry soil condition information, the system performed well with a success rate of 80% (8 out of 10 information matches). The system consistently activated the pump for a long duration (5 seconds) when the detected humidity was below 40%, which corresponds to the fuzzy membership limit for the "dry" category. However, there were two information that were predicted as "moist" while still within the "dry" range according to the fuzzy parameters (humidity 38% and 39%). This may be due to the influence of high temperature (32–33°C), which implicitly lowered the "dry" membership degree in the fuzzy and increased the contribution of "moist" in the inference process, resulting in a shorter pump duration (3 seconds). This error did not disrupt the overall fuzzy logic, but it did impact the system's final decision.

2. Moist Soil Conditions

In the humid category (40–70% humidity), the system correctly predicted 9 out of 10 data points (90%). The pump operated for a moderate duration (1–2 seconds), according to the predetermined fuzzy rules. One error occurred when the humidity reached 67% but the system only flushed for 1 second, which was considered inadequate to maintain optimal humidity levels. However, humidity values close to the upper limit of the humid category allowed the system to issue the minimum duration according to the interpolation on the fuzzy membership graph.

3. Wet Soil Conditions

For wet conditions, the system
showed an accuracy of 80% (8 out of 10 correct information), where most of the data indicated that the pump was inactive (0 seconds) when humidity exceeded 80%, in accordance with the fuzzy rules. Two data points faced mispredictions, namely humidity of 69% and 75%, which were still considered to require short watering (1 second). Both values are at the bottom of the "wet" category, which allows for overlapping fuzzy membership between "damp" and "wet", so the system provides an intermediate decision.

CONCLUSION

Fuzzy Mamdani can respond to environmental conditions based on soil moisture and temperature sensor readings using an ESP32 microcontroller. Testing was conducted for 7 days with a total of 30 test data divided into 3 main categories: dry, humid, and wet. The test results showed that the system had an accuracy rate of 83.3%, with 25 correct predictions from 30 test information. Prediction errors mostly occurred at the boundary points between fuzzy categories, such as humidity values of 38–39% (dry-humid) and 69–75% (humid-wet). Nevertheless, the system can always activate the water pump automatically with the appropriate watering duration, which is long (5 seconds) for dry soil, longer (1–2 seconds) for moist soil, and off (0 seconds) for wet soil. This proves that the applied Mamdani fuzzy method can provide adaptive watering results and is close to ideal conditions based on actual environmental data, so it is suitable for small-scale farming, especially indoors (indoor farming), especially for busy farmers or individuals who want healthy vegetables free from excess pesticides.

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