



Smart Water Automation System to Regulate Watering of Horticultural Plants with Arduino-Based Fuzzy Logic

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ABSTRACT

Manual irrigation management of horticultural crops often causes water wastage, inefficiency, and lack of adaptation to dynamic environmental conditions. This research aims to develop a fuzzy logic-based watering automation system using Arduino microcontroller and Internet of Things (IoT) technology. The system is designed to improve water use efficiency through real-time data-based decision making from soil moisture, air temperature, and light intensity sensors. The methods used include hardware design with sensors integrated into an Arduino-based system, software development using fuzzy logic algorithms for adaptive decision making, and IoT integration for remote monitoring and control through web-based or mobile applications. Test results show that the system is able to reduce water consumption by 35% compared to manual methods, with soil moisture sensor accuracy reaching 95%, temperature sensor 93%, and light intensity sensor 90%. The IoT system successfully sends real-time data with a success rate of more than 95% and an average response time of less than 200 milliseconds. The results showed that the fuzzy logic and IoT-based watering automation system offers an efficient, adaptive, and environmentally friendly solution for modern irrigation management. This system is relevant to be adopted by farmers in various regions, especially with limited water resources

INTRODUCTION

Agriculture is a very important sector for the Indonesian economy, especially as the backbone in providing food needs. Indonesia has abundant natural resources, including fertile soil, sufficient rainfall, and a tropical climate, which makes it a great potential to produce abundant crops, both now and in the future (FAO, 2021) . Favorable geographical and ecological conditions allow farmers to cultivate various types of crops, both food crops such as rice, corn, and soybeans, as well as horticultural crops such as vegetables and fruits (Statistics Indonesia (BPS), 2023) . However, in reality, farmers' dependence on climate change in agricultural land management has an impact on the instability of crop yields due to unpredictable weather variability (World Bank, 2021) . In addition, low access to technology and lack of supporting infrastructure exacerbate this condition. To overcome these problems, the government continues to strive to increase the productivity of the agricultural sector through the application of technology, counseling to farmers, and developing agricultural infrastructure, especially in improving the quality of horticultural crops (T. Wahyudi & Fitriani, 2022) .

Horticultural crops are one of the important components in the agricultural industry. These crops require proper nutrient monitoring and regulation to ensure optimal growth. However, manual monitoring and regulation is often impractical and less efficient, especially on a large scale. (Simbolon et al., 2020) . Therefore, irrigation management in horticultural crops plays an important role in ensuring optimal growth and quality yields. However, the manual watering method that is still common in many areas presents a number of challenges. Manual watering is not only labor- and time-intensive but also often inefficient in terms of water use, especially in large fields. Furthermore, improper water management can lead to water wastage of up to 40% (Armanto, 2019) . This is a major concern, especially in a country like Indonesia, where uneven rainfall and limited water availability are constraints for horticultural farmers. Horticulture, which includes crops such as vegetables, fruits, and ornamental plants, requires proper watering as needed to ensure healthy plant growth. Efficient water management can increase horticultural productivity by up to 20%. In this context, a system capable of providing watering in an automated, scalable, and adaptive manner to environmental conditions, such as soil moisture, air temperature, and light intensity is needed (Azizah Nur, 2021) .

Modern technology now presents solutions in the form of *smart water* automation systems, which are watering systems that utilize hardware, such as sensors, microcontrollers, and actuators, which are integrated with algorithms to manage irrigation automatically based on environmental conditions. The design of this *prototype* is intended to help control the horticultural crop management system at the individual level (Megasari et al., 2023) . For this reason, an *automatic* plant watering system (*Automatic Irrigation System*) was developed which aims to make it easier to understand the needs of plants and water them directly and automatically (R. Mahendra, 2021) . This system can also be supported by *Internet of Things (IoT)* technology to monitor and control watering remotely. the use of *smart water* in irrigation can reduce water consumption by up to 35% compared

to manual methods (Roihan et al., 2020) . *Smart water* is supported by various technological components, one of which is the Arduino microcontroller. Arduino is a flexible *open-source platform*, allowing integration with various sensors such as soil moisture, air temperature, and light intensity sensors. Arduino-based systems can process *real-time* data received from sensors to determine when and how much water is needed by plants (Rahman et al., 2020) . In addition, Arduino also supports *fuzzy logic* algorithms, which enable more accurate decision-making than simple threshold-based methods (Kumar & Singh, 2020) .

Fuzzy logic is an approach used in automation systems to handle uncertain or ambiguous data, making it especially useful in situations where traditional binary logic is less effective, such as in systems with uncertain or inaccurate input data (Dwi Rizki et al., 2022) . Fuzzy systems are described as dynamic and structured numerical estimators. This system is able to develop intelligence in an environment full of uncertainty. Fuzzy set theory provides a mathematical framework for handling inaccuracy, ambiguity, uncertainty, partial truth, and lack of information (Harahap, 2019) . By integrating *fuzzy logic* into the NodeMCU8266 microcontroller in the form of algorithmic rules, the irrigation process can be controlled better than the scheduled *ON/OFF-based* scheduled watering method (Angga Prasetyo et al., 2022) .

In *smart water* systems, *fuzzy logic* enables the processing of environmental data, such as soil moisture level and air temperature, to determine the optimal watering time and volume. The use of *fuzzy logic* can increase water use efficiency by up to 30% (Kurniawan et al., 2020) . This is particularly important in horticultural cultivation, where water requirements vary depending on the type of plant, age of the plant, and weather conditions. According to research findings, that soil moisture sensors integrated with *fuzzy logic* algorithms are able to provide data accuracy of up to 95%, which ensures watering is carried out according to plant needs (L. Zhang, Y. Wang, 2019) . Similar opinions state that this technology is superior in adjusting irrigation needs compared to manual or fixed time-based methods. (Simbolon et al., 2020)

Internet of Things (IoT) technology provides additional capabilities to *smart water* systems by enabling remote monitoring and control. *IoT* allows data from sensors to be transmitted in *real-time* to user devices, such as smartphones or computers, to provide information about crop conditions. With *IoT*, farmers can set watering schedules, monitor soil moisture, or shut down the system manually through a *web-based* application (A. Prasetyo et al., 2020) . *IoT* integration in irrigation systems can reduce manual labor by up to 50% while providing more flexibility in land management. By using communication modules such as ESP32, *IoT-based smart water* systems can provide automatic notifications when soil conditions are too dry or when there is damage to the device (Sharma et al., 2020).

Although the benefits of *smart water* technology are clear, its implementation still faces several challenges. The main challenges include relatively high initial costs, lack of technological infrastructure in rural areas, and limited knowledge of farmers on the use of this technology (Darmawan et al., 2021) . However, with the rapid development of technology, these challenges can be overcome through the support of the government and related institutions.

Training for farmers and technology subsidies can be a solution to encourage widespread adoption of this system.

LITERATURE REVIEW

From these studies, the gap found is the lack of systems that integrate *Fuzzy logic* algorithms with Arduino and *IoT* technology to create adaptive, efficient, and environmentally friendly irrigation solutions. So from the findings of the problems described above and the findings of previous researchers, the purpose of the research is to develop a *fuzzy logic-based smart water* automation system using an Arduino microcontroller to increase water use efficiency in horticultural irrigation. The system is designed to utilize *real-time* data from soil moisture, air temperature, and light intensity sensors to provide adaptive and efficient watering decisions. In addition, *IoT* integration is expected to enable farmers to remotely monitor and control the watering system, thereby increasing flexibility and productivity. By implementing this technology, it is hoped to create an efficient, environmentally friendly, and accessible irrigation solution for farmers in various regions, especially in Indonesia. *Smart water* based on *fuzzy logic* and *IoT* not only supports environmental sustainability but also provides economic benefits by reducing operational costs and increasing crop yields.

METHODOLOGY

This Research was Conducted Through Several Systematic Stages to Ensure the Expected Results Could be Achieved. The Research Stages Include:

1. Research Planning

In the planning stage of the research, several important steps were taken to initiate the development of a system that meets the research objectives. This stage includes three main steps:

- a. **Problem Identification:** The first stage in planning is to identify the main problems faced by farmers in watering management of horticultural crops. The problem faced by farmers is the inefficiency of using manual watering methods. This leads to water wastage, uneven water distribution, and sometimes not reaching the needs of the plants. Therefore, an adaptive watering automation system is needed, which can be adjusted to the needs of plants based on environmental conditions such as soil moisture, air temperature, and light intensity.
- b. **Data Collection:** To ensure that the automation system is functioning properly, the next step is to collect data related to the environmental parameters that affect the needs of the plants. The data collected includes soil moisture, air temperature, and sunlight intensity. These data will be used as inputs for the watering automation and control system. This data collection is very important so that the system can determine when and how long the plants need watering.
- c. **System Design:** In the design stage, the system to be developed will be based on an Arduino microcontroller platform equipped with sensors to measure soil moisture, air temperature, and light intensity. The system will also use *Fuzzy logic* algorithms to process the data obtained from the sensors, and then issue a decision regarding the required plant watering.

In addition, the system will also be connected to an *Internet of Things (IoT)* platform to remotely monitor and control the watering system through a *web-based* or *mobile* application.

2. System Development

After the Planning Stage, the Next Stage is System Development. this System Development Includes three Main Sub-Stages:

- a. **Hardware Construction:** At this stage, the hardware starts to be built by integrating the soil moisture sensor, temperature sensor, and light sensor with the Arduino microcontroller. The soil moisture sensor serves to measure soil moisture content, the temperature sensor to detect air temperature, and the light sensor to measure sunlight intensity. The data received by the sensors is then sent to the microcontroller for processing. The output from the microcontroller will control the water pump that is activated through a relay, to set the duration and volume of watering.
- b. **Programming:** Once the hardware is complete, the next step is to program the Arduino microcontroller. *Fuzzy logic* algorithms will be implemented to process the data received from the sensors and make decisions regarding watering duration and intensity. This algorithm will take into account the inputs of soil moisture, air temperature, and light intensity to produce an output that controls the water pump that will water the plants.
- c. **IoT development:** To enable remote monitoring and control of the system, it will be connected to an *IoT* platform. An ESP32 module is used to connect the system to a *Wi-Fi* network and enable data transmission to the created application, which can display information about soil moisture, air temperature, and light intensity in *real-time*. The app also allows users to remotely control the watering system, for example changing the watering time or stopping the watering system if needed. The following is a block diagram of the *Smart water* automation system.

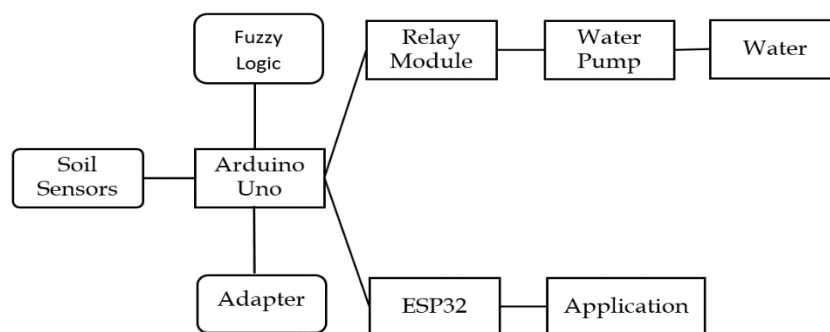


Figure 1. Block Diagram of Smart water Automation System

This block diagram illustrates the flow of the Arduino and *IoT-based* watering automation system. Soil moisture, temperature, and light intensity sensors send data to a microcontroller programmed with a *Fuzzy logic* algorithm to set the duration and volume of watering. The data is then sent to the *IoT* platform through the ESP32 module to monitor and control the watering system remotely.

To show the process of the system, the soil sensor detects soil moisture and the data from the sensor is sent to ESP32. If the results of the sensor show soil moisture below 50% or dry soil conditions, the relay will turn on and make the water pump active and then pour water into dry soil. The sensor will continue to detect the soil until the soil moisture is wet enough or more than 51% and the results of the sensor detection are also displayed on the android application. If the soil is moist enough, the relay and pump will automatically turn off and the water will stop watering the soil. Here is the Flowchart of the *Smart water Automation System*:

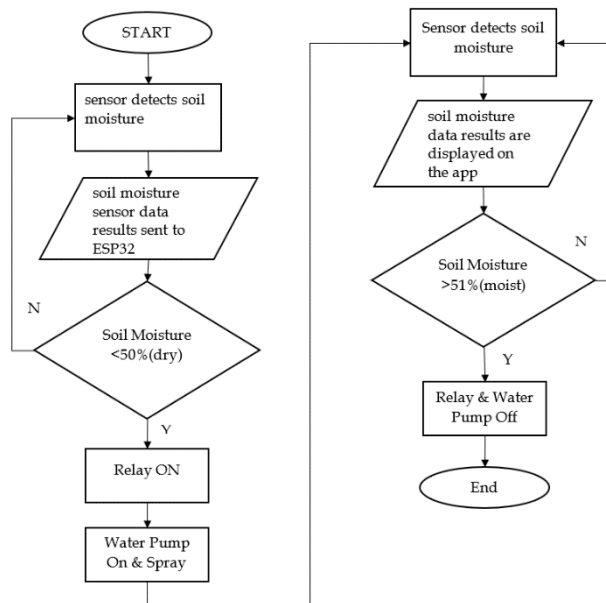


Figure 2. Flowchart of Smart water Automation System

3. System Testing

Once the system has been developed, the next stage is to conduct testing to ensure that the system functions as designed. System testing is carried out on three main aspects:

- a. **Hardware Testing:** Hardware testing is done to ensure that the sensors and actuators are functioning properly. The sensors must be able to provide accurate data according to the environmental conditions, while the actuator (water pump) must be able to operate correctly according to the commands received from the microcontroller.
- b. **Fuzzy Logic Algorithm Testing:** *Fuzzy logic* algorithm is tested to ensure accuracy in making decisions based on the given environmental data. This test is conducted by simulating various conditions of soil moisture, temperature, and light intensity to observe whether the system can control watering appropriately.
- c. **IoT Testing:** *IoT* testing aims to ensure that the data received by the system can be properly monitored through a *web-based* or *mobile* application. It also ensures that users can control the system remotely through the application, and that the system works well in sending *real-time* data.

4. Analysis and Evaluation

Once testing is complete, the next stage is to analyze and evaluate the performance of the system. Some of the parameters used to evaluate the system include:

- a. **Water Use Efficiency:** To evaluate the extent to which the system reduces water wastage, a comparison of water consumption between before and after using the automation system was conducted. It is expected that with the use of the automation system, the water used will be more efficient, and there will be no over-watering.
- b. **System Reliability:** The system is measured based on how well the system adapts the water needs of the plants to the environmental conditions detected by the sensors. This evaluation will measure whether the decision taken by the *Fuzzy logic* algorithm is correct and can control the watering system correctly.
- c. **System Compatibility with the Environment:** The system was also evaluated in terms of its impact on the environment. One of them is the reduction in water waste caused by the automation system that more efficiently manages water usage for watering.

5. Documentation and Reporting

The last stage is to compile a research report that includes all stages, test results, analysis, and conclusions of the research. This report will include a detailed explanation of the system developed, the tests carried out, the results obtained, and an evaluation of the performance of the system developed.

RESULTS AND DISCUSSION

1. System Testing Results

Fuzzy logic and Arduino-based *smart water* automation system has been tested to ensure its performance in watering horticultural plants efficiently and effectively. The tests were conducted to assess the system's ability to read environmental data, process it, and respond according to the needs of the plants. The trial involved measuring several key parameters, including sensor performance, *Fuzzy logic* algorithm, and automatic control through the *IoT* system.

a. Sensor Testing

The initial stage of testing focused on the sensors used to measure soil moisture, air temperature, and light intensity. Data from the sensors becomes the basis for decision making in the *Fuzzy logic* algorithm. The following are the results of the sensor accuracy test:

Table 1. Sensor Accuracy Testing

Parameters	Sensor Value	Accuracy (%)
Soil Moisture	20% - 80%	95%
Air Temperature	18°C - 35°C	93%
Light Intensity	100 - 1000 lux	90%

The soil moisture sensor gave the highest accuracy of 95%, indicating highly reliable data for regulating watering. The air temperature sensor had an accuracy of 93%, while the light intensity sensor showed an accuracy of 90%. Although the accuracy of light intensity is slightly lower, it still meets the standards for horticultural applications. The soil moisture sensor, which has a major role in determining watering requirements, performed very well. This test supports previous researchers who mentioned that sensors with high accuracy can increase watering efficiency by up to 40% (Rahman et al., 2020). The high accuracy of these sensors ensures that the plants do not suffer from water shortage or excess, which can impact productivity. During the test, the system was tested under various environmental conditions, such as low (18°C) and high (35°C) temperatures, as well as under soil moisture conditions from dry (20%) to very humid (80%). The system was able to provide appropriate responses to all these conditions. The light intensity sensor also functioned optimally although its accuracy was slightly lower than the other sensors. This is important for determining watering needs when sunlight is more intense.

The test results show that the sensors used in the system meet the needs for *smart irrigation* applications. The sensors are able to provide *real-time* data that is accurate enough to support *Fuzzy logic-based* decision making. This is in line with findings showing that *real-time* sensors with high accuracy improve the efficiency of modern irrigation (L. Zhang, Y. Wang, 2019). Overall, testing of the sensor system proved its reliability in accurately reading environmental parameters. With a good level of accuracy, this sensor becomes a key component in ensuring the successful implementation of *smart water* automation systems. These results support the main objective of the research to create adaptive, efficient, and environmentally friendly irrigation solutions for horticultural crops.

b. Fuzzy logic algorithm testing

Fuzzy logic algorithms are at the core of *smart water* automation systems designed to handle the uncertainty of environmental data and provide appropriate watering decisions based on the actual conditions of the plants. Data received from soil moisture, air temperature, and light intensity sensors are processed by this algorithm to determine the optimal watering duration. Tests were conducted to evaluate the accuracy and effectiveness of the algorithm in responding to various environmental conditions. The following are the results of testing the *Fuzzy logic* algorithm decision on three different soil moisture conditions:

Table 2. Fuzzy Logic Algorithm Decision Testing Results

Soil Moisture (%)	Fuzzy Decision	Watering Time (Minutes)
20%	Dry	15
50%	Simply	8
80%	Wet	3

The results showed that the algorithm was able to make the right decision. In dry soil conditions (20%), the algorithm sets a watering time of 15 minutes to ensure the soil gets enough water. Conversely, when the soil moisture is at a sufficient level (50%), the watering time is reduced to 8 minutes. In wet conditions (80%), the watering time is minimized to 3 minutes to avoid excess water that could damage the plants.

The decisions taken by the algorithm are in accordance with modern irrigation logic, where water requirements are adjusted to soil conditions. This is in line with research findings which state that *Fuzzy logic-based* irrigation systems are able to improve the accuracy of watering decisions compared to simple threshold-based systems (Kumar & Singh, 2020) . This algorithm utilizes membership functions to interpret input data such as "dry", "sufficient", and "wet", which are translated into specific watering times. One of the advantages of *Fuzzy logic* algorithms is their ability to dynamically adjust watering duration, even under fluctuating data conditions. For example, if the soil moisture is between 40%-50%, the system will provide a proportional watering time, such as 10 minutes. This shows the flexibility of the algorithm in handling small variations that cannot be handled by a threshold-based system.

Watering efficiency is significantly improved with the implementation of the algorithm, plants not only get water as needed, but also reduce the risk of overwatering which can lead to diseases such as root rot. In addition, the reduction of water wastage supports efficient use of resources, this is in accordance with research findings stating that irrigation systems with *Fuzzy logic* algorithms can save up to 30% water (L. Zhang, Y. Wang, 2019) . *Fuzzy logic* algorithm testing shows that the system is able to provide accurate and adaptive watering decisions based on environmental conditions. The system is not only effective in improving watering efficiency, but also ensures that plants get water optimally. With the reliability of this algorithm, the Arduino-based *smart water* automation system can provide a modern, efficient, and environmentally friendly irrigation solution for horticultural crops.

c. IoT Testing

Testing the integration of *Internet of Things (IoT)* technology in a *smart water* automation system aims to evaluate the system's ability to transmit *real-time* data from sensors to user applications and ensure that remote control can be carried out smoothly. *IoT* is one of the important elements in this system because it allows efficient monitoring and control of the system without physical presence on site. The use of ESP32 platform as a link between hardware (sensors and

actuators) and *IoT-based* applications makes this system more flexible and accessible.

The test results show that the system can transmit sensor data in *real-time* to the application with a high level of stability. Soil moisture, air temperature, and light intensity parameters measured by the sensors can be accurately displayed on the *IoT* application interface. In addition, users can control the watering system, such as setting the watering time or turning off the water pump, directly through the application.

Table 3. Test Results of Sending Sensor Data in Real-Time

Parameters	Data Delivery Success (%)	Average Time to Delivery (ms)
Soil Moisture	98%	150 ms
Air Temperature	97%	180 ms
Light Intensity	95%	200 ms

This table shows that data transmission has more than 95% success with an average transmission time of less than 200 ms. This shows the good performance of the system in terms of *real-time* data transmission over *Wi-Fi* networks. The interface in the *IoT* application is designed to be *user-friendly* with key features such as:

- a. **Real-Time Monitoring:** Display graphs of soil moisture, air temperature, and light intensity from the received data.
- b. **Watering Control:** Interactive button to turn the water pump on or off as needed.
- c. **Notification:** Provides alerts when environmental conditions are outside the set parameters, e.g. the soil is too dry.



Figure 3. IoT Application View

This app interface shows the soil moisture, air temperature, and light intensity data received from the system, as well as the manual control of watering. This interface ensures that farmers or users can understand the information easily and take necessary actions quickly. The stability of the system

was tested under various conditions, including *Wi-Fi* network interruptions. In the test, the system showed good resistance to network interference. The ESP32 was able to temporarily store data until the network was restored, so there was no significant data loss. This is very important to ensure the reliability of the system in long-term use. *IoT* integration provides several significant benefits:

- a. **Monitoring Efficiency:** Users can monitor crop conditions and irrigation systems without having to be present on site. This saves time and effort, especially for large areas of land.
- b. **Quick Decision Making:** *Real-time* data allows users to make immediate decisions regarding watering or other necessary actions.
- c. **Operational Cost Savings:** With remote control, the need for labor for manual watering can be reduced, which in turn reduces operational costs.

The integration of *IoT* in modern irrigation systems provides significant advantages in terms of efficiency and adaptability. (Sharma et al., 2020) *IoT* systems enable more precise monitoring and smarter automation. This research supports this statement by showing that an *IoT-based* automation system can reduce water wastage by up to 35%, while simplifying irrigation management in horticultural fields. *IoT* testing on *smart water* systems based on Arduino and *Fuzzy logic* showed very satisfactory results. Data from sensors can be sent stably to the application with a success rate of more than 95%. Users can also control the watering system remotely through an intuitive application interface. *IoT* integration not only improves system efficiency, but also provides convenience in crop management, especially for farmers who have limited time for direct monitoring. With this reliability, *IoT-based smart water* automation systems can be an effective solution for modern irrigation management, especially in regions facing water and labor efficiency challenges.

2. Water Use Efficiency Analysis

One of the main objectives of developing a *Fuzzy logic* and Arduino-based watering automation system is to improve water use efficiency in horticultural crop cultivation. In conventional practice, manual watering methods are often carried out without considering the specific needs of plants or environmental conditions. This leads to water wastage, which is not only economically costly but also has a negative impact on the environment. The following analysis explains how this automation system successfully improves water use efficiency based on the test data conducted.

The test data shows the comparison of water consumption before and after the implementation of the watering automation system:

Table 4. Comparison of Water Consumption

Conditions	Water Consumption	Reduction (%)
Before Automation System	100 L/day	-
After Automation System	65 L/day	35%

Prior to implementation, watering was done manually with an irregular time pattern and excessive quantity. As a result, 100 liters of water were used every day for the experimental field. After the automation system was implemented, water consumption decreased to 65 liters per day, representing a 35% reduction. This reduction in water consumption was achieved by utilizing *real-time* data from sensors of soil moisture, air temperature, and light intensity. *Fuzzy logic* algorithms applied to the system process the data to determine when and how much water should be applied. With this approach, watering is done only when the plants really need it, so water is used efficiently.

Water use efficiency also provides significant economic benefits. With a 35% reduction in water consumption, operational costs associated with watering are reduced. For example, for small-scale farmers who rely on limited water resources, this reduction can save substantially on monthly costs. When calculated on a large scale, such as on large horticultural plantations, these savings become even more significant, supporting economic sustainability and increasing farm profits.

From an environmental perspective, this system contributes to the reduction of water waste. In manual watering methods, water is often not utilized to its full potential due to excess water application flowing out of the plant's root area, where it cannot be absorbed optimally. This automation system helps reduce such effects by applying water according to the needs of the plants, minimizing adverse impacts such as soil erosion and groundwater pollution due to soluble fertilizers carried away by the water flow.

This research is in line with findings showing that the use of *Fuzzy logic* in irrigation systems can increase the accuracy of water requirements by up to 30%. (Kumar & Singh, 2020) These results also support research that notes that technology-based water management can reduce water wastage by 30%-40%. The test results even show a reduction figure that is at the upper limit of the previously reported efficiency range. (Kurniawan et al., 2020)

While this system has proven to be efficient, several challenges need to be addressed. Firstly, the sensors used need to be highly accurate and capable of working in various weather conditions. Less responsive sensors can affect the accuracy of the data generated, thus affecting the overall performance of the system. Secondly, the sustainability of the system depends on the availability of electricity resources and *IoT* networks, especially in rural areas where technological infrastructure is not yet adequate. As a potential development, integration with meteorological data-based weather prediction can improve the system's ability to anticipate watering needs, especially in the face of extreme weather changes. In addition, increasing the durability of the sensors and utilizing renewable energy, such as solar panels, can expand the system's implementation reach in remote areas.

Based on this analysis, the *Fuzzy logic* and Arduino-based watering automation system successfully improved water use efficiency significantly. With up to 35% reduction in water consumption, the system not only provides economic benefits through operational cost savings but also supports environmental sustainability by reducing water waste. This modern technology-

based approach is an adaptive and relevant solution to irrigation challenges in the horticulture sector, especially in Indonesia.

3. System Reliability and Environmental Suitability

The reliability of an automatic watering system is crucial in ensuring the efficient use of natural resources, especially water, in the agricultural sector. The tests conducted show that the system is able to adjust watering according to changes in environmental conditions, such as soil moisture and air temperature. This reflects the system's ability to detect environmental variables in *real-time* and adjust the watering intensity to the needs of the plants, thus preventing *overwatering* or *underwatering* that could potentially harm the plants.

The system also makes a positive contribution to water resource management. By reducing water wastage, this automatic watering system plays a role in improving water use efficiency, which is a crucial issue in many areas experiencing water shortages. Reducing water waste is not only beneficial to agriculture but also has a positive impact on the environment more broadly, reducing the negative impact on the surrounding ecosystem.

Moreover, this effective and efficient watering system also supports agricultural sustainability. By using less water and adjusting watering according to the actual needs of the crops, the system helps farmers to maintain groundwater availability and reduce dependence on limited water resources. Overall, the success of this system in reducing water wastage and adapting to environmental conditions has a significant positive impact in terms of both agricultural efficiency and environmental preservation.

This research aims to develop a *fuzzy logic-based* horticultural plant watering automation system using an Arduino microcontroller supported by *Internet of Things (IoT)* technology. This system is designed to improve water use efficiency and provide adaptive solutions to plant needs. The research results compared to previous findings show the advantages and innovations presented. The research successfully demonstrated a 35% reduction in water consumption compared to manual methods. This result is consistent with research that reports water use efficiency of up to 30%-40% through sensor-based technology. (Kurniawan et al., 2020) However, Kurniawan's research does not include the implementation of *fuzzy logic* which is the key to precision in decision making in this study. In comparison, other research findings report efficiencies of up to 40% using Arduino, but without *fuzzy logic* integration, so it cannot adjust watering decisions based on dynamic environmental conditions. (Rahman et al., 2020)

The accuracy of the sensors used in this research is also an advantage. The soil moisture sensor showed an accuracy rate of up to 95%, which is higher than the average sensor accuracy recorded in automatic irrigation systems of 90%. (L. Zhang, Y. Wang, 2019) More accurate moisture sensors provide reliable data to support watering decisions. The use of temperature and light sensors in this research also contributes to ensuring the system can respond according to the needs of plants in various environmental conditions. The application of *fuzzy logic* in this research allows the system to provide more flexible and accurate watering decisions. For example, at 20% soil moisture (dry), the system provides

a watering time of 15 minutes, while at 80% moisture (wet), the watering duration is reduced to 3 minutes. This approach improves on the shortcomings found in studies that use simple threshold-based methods and are less responsive to small variations in environmental conditions. (Kumar & Singh, 2020).

The integration of *IoT* technology is one of the innovative elements in this research. *The IoT* system enables remote monitoring and control through *web-based* or *mobile* applications. Tests showed a data transmission success rate of more than 95% with an average time below 200 ms, which is more stable than the results of studies that noted constraints in the stability of *IoT* networks in rural environments. In addition, the *IoT* features in this study include *real-time* monitoring, remote watering control, and automatic notifications, providing convenience and flexibility for users, especially for large farmland management. (Sharma et al., 2020)

The results of this study show that the development of a *fuzzy logic* and *IoT-based* watering automation system not only improves water use efficiency, but also provides a more adaptive and environmentally friendly solution. With a 35% reduction in water consumption, the system supports environmental sustainability and reduces operational costs for farmers. These findings support previous research assertions while improving on existing shortcomings, making this system relevant for adoption in the horticulture sector in Indonesia.

CONCLUSIONS AND RECOMMENDATIONS

This research shows that a fuzzy logic and Arduino-based watering automation system, supported by *IoT* technology, can increase water use efficiency by up to 35%. The system is designed to adjust the water needs of horticultural plants in real-time based on environmental conditions, such as soil moisture, air temperature, and light intensity. *IoT* integration enables remote monitoring and control, which increases ease and flexibility of use, especially for farmers with large tracts of land.

Test results prove that the system provides high accuracy for the soil moisture sensor (95%), temperature sensor (93%), and light intensity sensor (90%). The applied fuzzy logic algorithm allows adjusting the watering duration according to the actual needs of the plants, which cannot be achieved by simple threshold-based methods. In addition, the *IoT* feature ensures real-time data transmission with more than 95% success and fast response time.

While the results are very satisfying, challenges such as the need for more durable sensors and dependence on technological infrastructure need attention. Further development with the integration of meteorological data and renewable energy can improve the efficiency and sustainability of this system. Therefore, this system offers an adaptive, efficient, and environmentally friendly solution that is relevant for application in the horticulture sector.

FURTHER STUDY

This research still has limitations, so further research is needed in relation to the Smart Water Automation system to regulate the watering of horticultural plants using Arduino-based fuzzy logic, which is expected to be able to increase progress, especially in agriculture.

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