Smart Agriculture Water System Using Crop Water Stress Index and Weather Prediction

Jason Timotius Purwoko[1], Taurean Orlin Wingardi[2], and Benfano Soewito[3*]
[1−3]Computer Science Department, BINUS Graduate Program – Master of Computer Science,
Bina Nusantara University
Jakarta 11480, Indonesia
Email: [1]jason.purwoko@binus.ac.id, [2]taurean.wingardi@binus.ac.id, [3]bsoewito@binus.edu

***Abstract*—Water is essential for crops to grow well. However, overwatered or underwatered plants hinder growth and produce less fruit than plants with sufficient watering. Using the Internet of Things (IoT), agriculture can be controlled to achieve the best condition for plants to grow. The research aims to develop a watering system based on Crop Water Stress Index (CWSI), soil moisture content, and weather prediction. By evaluating CWSI and soil moisture content, the research makes a smart watering system that efficiently monitors water concentration in a plant. However, there is a flaw in the watering system that water from the rain makes the plant overwatered. So, using weather prediction can delay irrigation to save water and produce a better stress index result. Next, the research compares the watering system using four pots: (1) weather prediction, CWSI, and soil moisture watering system; (2) CWSI and soil moisture watering syste;, (3) soil moisture watering system; (4) manual irrigation watering system to get the best watering system by water consumption and CWSI. The results show a significant difference by using CWSI. It gets a 42.7754% smaller CWSI value by using CWSI value in making watering decisions. By adding weather prediction, the research saves water consumption by 21.9% compared to CWSI and soil moisture watering systems. These results show that weather prediction and CWSI are vital for IoT plant watering systems.**

***Index Terms*—Smart Agriculture Water System, Crop Water Stress Index (CWSI), Weather Prediction**

I. Introduction

ONE of the factors that affect plant growth and development is water. Water is a food ingredient for plants to carry out the process of photosynthesis, where the water will be converted into carbohydrates as a source of plant energy. In practice, there are various ways for plants to get water, such as rainwater, watering, and irrigation techniques. With some of these techniques, the water content obtained by the plant can hinder the plant's growth less or more. In addition, additional labor is needed if the farmer must manually water the plants with water.

In the growth of a plant, several variations of the water limit are needed. For example, peppers have an average water requirement of 600–900 mm. It can even reach 1,250 mm for some peppers with a long growing time. However, peppers are very sensitive to water requirements. If it experiences water shortages/excesses, it will produce fewer fruits than a well-nourished pepper [1].

An idea is formed to create an automatic watering system using automatic sprinklers. The irrigation system can be customized to water the plants in several hours. Unfortunately, this idea has the disadvantage that if it rains, the plants will get enough water from the rain which causes the plant to get too much water and leads to an overwatered plant. Adding input in the automatic watering system can produce better water concentration for plants to grow. Hence, using the given input, the watering decision can be controlled to water the plants if the water in the plants runs low.

To deal with this problem, a smart agriculture system which is a watering system in the agricultural process, becomes even more efficient. Smart agriculture system is the application of the Internet of Things (IoT) in agriculture. Research on smart agriculture systems has been done by making irrigation systems and monitoring systems for plants using temperature, soil moisture, and infrared sensors. Raspberry PI creates a system that sprinkles water on the plants if the sensors detect that the plant experiences a lack of water [2].

Next, in manufacturing smart agriculture systems, there are three approaches that can be used to create a watering system: weather-based, soil-based, and plant-based [3]. The weather-based approach is the application of an irrigation system using the weather so that rain or clear weather can be detected using a hygrometer to perform a watering command. Meanwhile, the soil-based approach applies an irrigation system using soil. It uses soil moisture and temperature sensors. A

Received: April 08, 2022; received in revised form: June 24, 2022; accepted: June 24, 2022; available online: March 17, 2023.
*Corresponding Author

plant needs water based on the soil moisture level of the plant. Moreover, the plant-based approach is the application of irrigation systems based on the plant's needs that can be obtained using infrared sensors to observe the plant's temperature. The plant-based approach method uses the Crop Water Stress Index (CWSI) as a reference limit used when plants need water.

These three approaches use sensors as a tool to get data. The data are processed to obtain CWSI values and soil moisture content, where CWSI indicates the water content in the plants. Meanwhile, soil moisture content shows the water content in the soil. In addition, there are data from the temperature sensor, which can be used as a reference for rain occurrence. Usually, the temperature drops when it rains. CWSI, soil moisture content, and temperature data are used in fuzzy logic to determine whether the plant needs irrigation. Fuzzy logic can determine the watering decision based on the three approaches mentioned.

The limitation of using one of the approaches is that every approach has weaknesses. It cannot be covered when the research uses only one of the approaches. For example, a soil-based approach to making an irrigation system does not calculate the weather as in a weather-based approach. Hence, the water concentration in the plants will almost be likely to become overwatered. The other example is the soil-based approach, which cannot accurately predict a plant's water requirement as every plant has its water requirement and is not just dependent on soil moisture.

The research overcomes the problem from the explanation described by proposing a watering system for plants using a combination of the three approaches: weather-based, soil-based, and plant-based approaches. Using these three approaches is expected to help farmers get better water quality conditions in farming, so the fruit from the plants is more abundant. Based on the background, the two formulated problems are how to combine the three approaches to provide the right water for plants and how much water savings are by using the system offered.

The research aims to combine several existing approaches, such as weather-based, soil-based, and plant-based approaches, to cover the shortcomings of other approaches. It can obtain a better irrigation system by evaluating the total water used for watering plants and the CWSI value. Another objective is to create an irrigation system for red peppers that can be used in an agriculture system so that these plants can provide better yields. The benefits of the research include reducing the potential for overwatering when planting plants by using the proposed system and creating irrigation systems that can adjust the plant's water needs based on weather, soil moisture, and plant conditions.

II. Literature Review

Several tools are needed to make a smart agriculture system, such as sensors, microcontrollers, and processors. Sensors can detect a parameter, such as temperature, humidity, or light intensity, in the form of an electrical or optical signal [4]. Sensors are often used in IoT-based applications as input parameters to decide on the application. Decisions made by an IoT system have various types depending on the input parameters provided by the sensor. For example, using a light sensor can make an embedded system to predict the condition of the room, whether the room is too dark or too bright so that the system can adjust the lighting in the room [5]. Then, in the manufacture of IoT systems, it cannot be separated from the processor. The processor used in the IoT system must be energy efficient because the processor must process data all the time when the IoT system runs [6].

The Raspberry Pi is a small computer that is only the size of a credit card running an operating system called Raspbian, which is based on Debian [7]. It is explained that on the Raspberry Pi, there is a General-Purpose Input/Output (GPIO) pin that can function to receive or send signals from the device, which is used to connect, such as a switch or room temperature sensor [8]. This GPIO pin can be programmed using the python programming language.

Next, there are several methods to create a smart agriculture system: weather-based, soil-based, and plant-based. Weather-based approach regulates water requirements in plants by looking at the weather as an input parameter [9]. This parameter input can be obtained from the weather forecast. Meanwhile, the soil-based approach gets water requirements from the plant's soil moisture [10]. The soil moisture can be obtained from the soil moisture sensor, which is planted 4 cm below the soil surface. Then, the plant-based approach obtains water requirements by calculating the CWSI value [11].

The CWSI is a technique to measure the stress level of water needs in plants. CWSI is introduced as the theoretical formula to measure the water stress index in a plant using an infrared thermometer [12]. The CWSI measurement method compares the room temperature (land) with the plant's temperature. Later, it will get the stress level of a plant. In previous research [13], there is an empirical CWSI formula, as shown in Eq. 1. It shows $(T_c - T_a)_m$ as the difference between canopy temperature (plant temperature) and air temperature, $(T_c - T_a)_{L.L}$ as a lower baseline for the difference between canopy temperature and air temperature for a plant, and $(T_c - T_a)_{U.L}$ as an upper baseline for the difference between canopy temperature and air temperature for a plant.

$$\text{CWSI} = \frac{(T_c - T_a)_m - (T_c - T_a)_{L.L}}{(T_c - T_a)_{U.L} - (T_c - T_a)_{L.L}}. \quad (1)$$

Then, the lower baseline has been formulated in Eq. (2) [14]. It has a and b as a linear regression equation of $y = ax + b$. It shows a as the intercept and b as the slope. Meanwhile, the Vapor Pressure Deficit (VPD) is the difference in the amount of moisture in the air and the total moisture in the air collected in a saturated condition in an air space. Then, the formula for determining the upper baseline of a plant is in Eq. (3) [14]. The Vapor Pressure Gradient (VPG) indicates the difference in total air moisture in saturated conditions for plants with temperatures between T_a and $T_a + a$. The value results from the CWSI calculation have a range of values between 0 and 1. It shows 0 for the plant in good and sufficient condition and 1 for poor water conditions and the affected plant being stressed by water.

$$(T_c - T_a)_{L.L} = a + b \text{ VPD}, \quad (2)$$

$$(T_c - T_a)_{U.L} = a + b \text{ VPG}. \quad (3)$$

The upper baseline and lower baseline CWSI of each plant have different values in this case. The research cites the values of the upper baseline and lower baseline from previous research [15]. It evaluates the CWSI value in red peppers, with the upper baseline value of $0.005 * \text{VPD} + 2.86$. Meanwhile, the lower baseline value has $-1.10 * \text{VPD} + 0.49$. Then, the temperature difference between plant temperature and air temperature calculates CWSI. For example, if the plant temperature and air temperature differences are close to 3, the plant is called water shortage. Conversely, if the difference in plant temperature and air temperature is close to the lower baseline where the line value is $-1.10 * \text{VPD} + 0.49$, the plant is well-watered. In addition, if the plant is far below the lower baseline, the plant is said to have excess water.

Fuzzy logic can judge the grayness of relative values. Fuzzy logic is necessary because each plant has different water requirements, and the level of water demand cannot be described through a crisp set (represented by a value of 0 or 1). In a fuzzy logic, there are three main processes: fuzzification, fuzzy inference, and defuzzification [16]. Fuzzification is the process of converting crisp sets to fuzzy sets to be even fuzzier. For example, membership of CWSI data with a value of (0–1) is grouped into small, medium, and large groups. Next, the fuzzy inference is the process of making fuzzy rules for each grouping of existing data. For example, in small CWSI values, an irrigation system must be carried out for watering plants. So, each group has its rules, and there may be rules that are the same as others. Meanwhile, defuzzification is the process of changing the fuzzy into a crisp set. In this case, by using the rules and memberships that have been made, a result (0–1) is obtained. For example, 0 indicates that the irrigation process has not occurred, and 1 indicates that the irrigation process has occurred.

There are several studies related to the research. First, the previous researchers use Arduino and soil moisture, temperature, humidity, and pH as a parameter to make a smart IoT for plants. Their research concludes that plants with IoT systems grow faster based on the number of leaves, plant height, and flower buds than conventional irrigation systems [17]. Second, a smart agriculture watering system has been made using Arduino as the microcontroller and CWSI and soil moisture as a parameter to determine watering decisions. The smart irrigation system can reduce electrical energy and water consumption compared to manual and time-based irrigation by 67.35% and 59.61%, respectively [3]. Third, a plant monitoring and watering system is made using a fuzzy set. The previous researchers set the duration of watering plants by paying attention to air humidity, air temperature, and soil moisture. The system can provide results in using water that is more efficient by 37.76% than the manual watering method [18]. Fourth, a smart irrigation system is created by looking at soil moisture and air humidity values. The system will water the plant if the value of soil moisture or air humidity has reached the value determined by the farmers. It is said that the placement of the soil moisture sensor should be near the plant roots to obtain more accurate soil moisture data [19]. Last, a smart irrigation system is made using soil moisture, air temperature, and air humidity sensors that are controlled using an Arduino. The irrigation will be carried out if the soil moisture value obtained is below the predetermined limit. It concludes that water use can be saved by using the system that is made [20].

III. Research Method

A. Proposed Watering System Architecture

The pepper is paired with sensors to determine the plant's water needs, as shown in Fig. 1. The sensors are infrared temperature, temperature, humidity, and soil moisture sensors (resistive). The infrared temperature sensor is used to get the canopy temperature to perform CWSI calculations. Meanwhile, the temperature and humidity sensors get the air temperature and humidity,

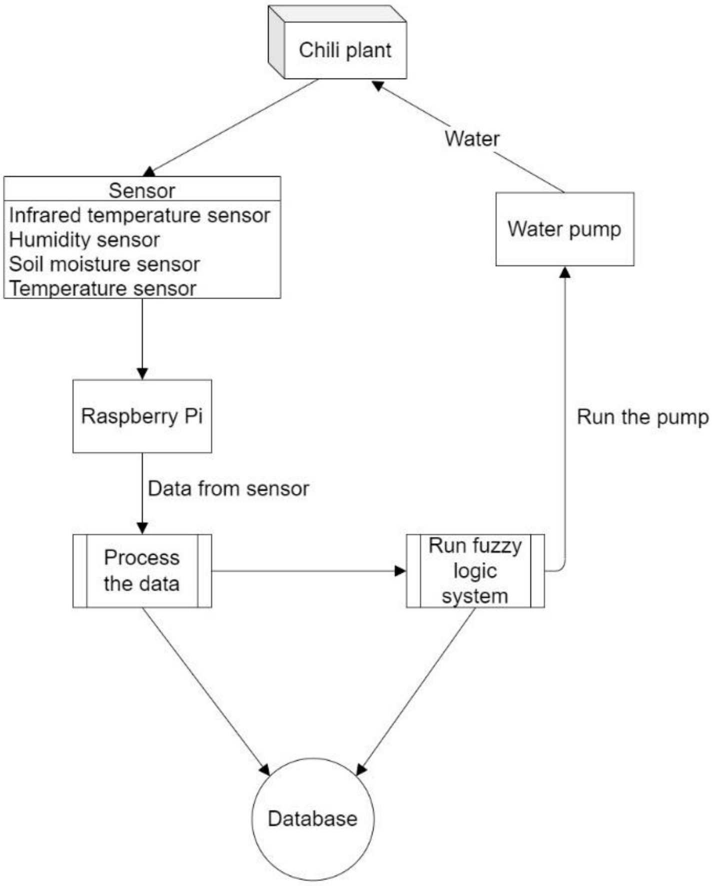

Fig. 1. Proposed watering system architecture.

which is used to find the VPD to perform CWSI calculations. Soil moisture sensor (resistive) calculates soil moisture content which is useful for measuring the water content in the soil. Data from the sensor are sent to Raspberry Pi and processed to calculate CWSI and soil moisture content. CWSI and the soil moisture content values are categorized based on fuzzy membership (fuzzification) to determine the fuzzy rule. This fuzzy rule will later be defuzzified to get a crisp set value of 0, 1, and 2. It shows 0 if irrigation is not needed. Meanwhile, a value of 1 indicates Raspberry pi will look for the weather forecast on the Weather API. The Weather API sees the situation in the next one hour, whether it will rain or not. If it rains, the irrigation process will be canceled. Meanwhile, if it does not rain for the next one hour, the irrigation process will be carried out. Then, a score of 2 indicates irrigation should be carried out without checking the weather forecast due to the condition of the plants being short of water. The irrigation process will signal the pump to water the plant.

B. *Research Workflow*

Figure 2 is the research workflow for the research. In the workflow, there are several steps. It consists of getting data from the sensor, rain prediction to decide whether the plant gets watered, and a decision using fuzzy logic.

The sensors used in the research are as follows:

- Room temperature and humidity sensor. The type of room temperature and humidity sensor used in the research is DHT22. Based on the specifications, the sensor uses a capacitive humidity sensor and thermistor to measure the surrounding air and output a digital signal. The data generated by this sensor has units of Celsius for room temperature and Relative Humidity (RH) for air humidity [21].
- Soil moisture sensor. The soil moisture sensor used is a resistive type. This sensor is used to take the value of soil moisture. The wetter the soil is, the greater value will be given by this sensor.
- Infrared temperature sensor. The research uses an infrared temperature sensor with the GY906 MLX90614 type to get the temperature in certain

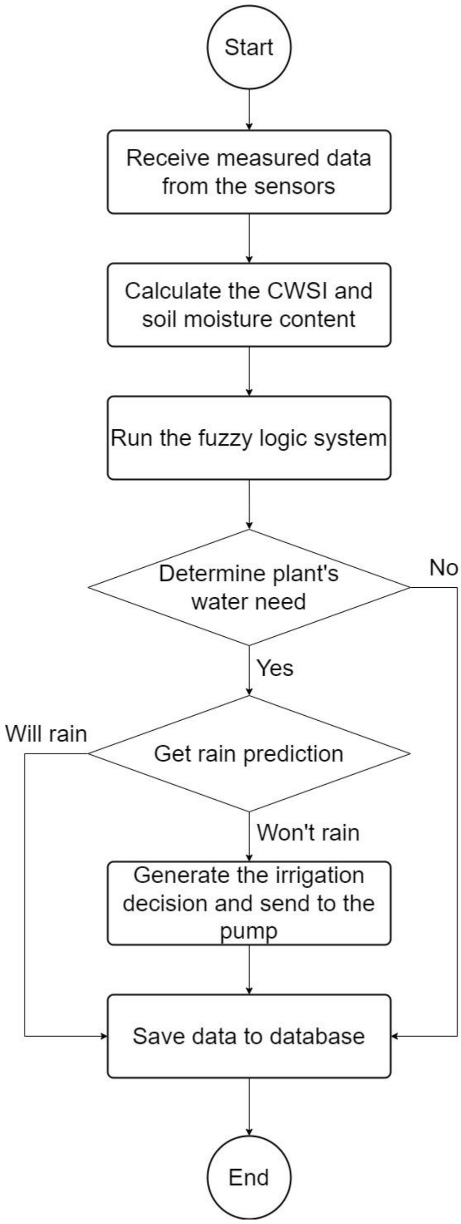

Fig. 2. Research workflow.

fields. The temperature range that the sensor can measure is -70°C–380°C for object temperature. This sensor can also measure room temperature at 40°C–125°C [22].

- Waterflow sensor. The type of water flow sensor used is YF-S401. This sensor is used to measure the amount of water that has been used in each pot. According to the specifications, this sensor detects water flow according to the number of square wave signals given by the sensor. The sensor can measure 1 liter of water as much as 5880 square wave signals [23].

The research uses weather forecast because the results of predictions of weather conditions and real weather conditions in previous research do not have a significant difference [24]. So, the research uses the weather forecast API from openweathermap.org [25] because the data are easy to obtain without manually creating a weather prediction system using sensors. This API can provide weather predictions for the next one hour and weather conditions in real-time. The Uniform Resource Locator (URL) to call the API is as

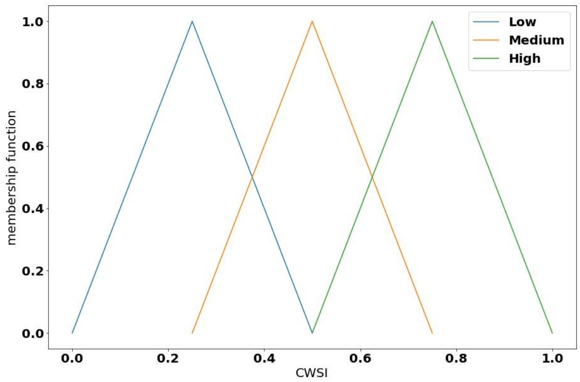

Fig. 3. Crop Water Stress Index (CWSI) membership function.

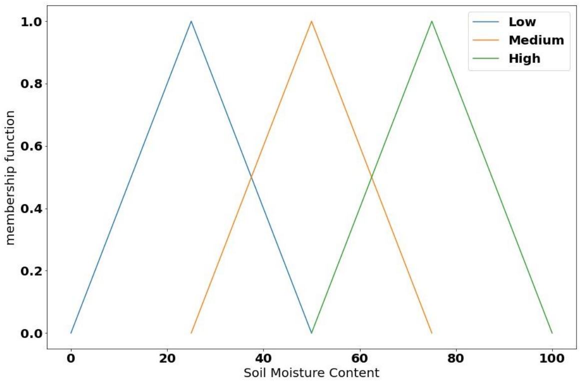

Fig. 4. Soil moisture content membership function.

follows. Then, the output from this API is a JavaScript Object Notation (JSON) file of weather forecast data.

https://api.openweathermap.org/data/2.5/onecall?lat={lat}&lon={lon}&exclude={exclude}&appid={API key}
{lat}: Geographical coordinate in latitude
{lon}: Geographical coordinate in longitude
{exclude}: Excluding search criteria (current, minutely, hourly, daily, alerts)
{API key}: Credential from OpenWeather

The CWSI value range is from 0 to 1. It is made into three membership functions which are low, medium, and high, as shown in Fig. 3. The low category has a CWSI value range from 0.0 to 0.5. The low category means that the plant is not stressed or has little stress on the plant's water needs. The medium category has a CWSI value range from 0.25 to 0.75, indicating that the plant has a medium stress level to the plant's water needs. Then, the high category has a CWSI value ranging from 0.75 to 1.0, implying that the plant is very stressed and needs water [3].

Soil moisture content with a value of 0–100% is

TABLE I
FUZZY RULE.

CWSI	Soil Moisture Content		
	Low	Medium	High
Low	1	1	0
Medium	2	1	0
High	2	1	0

also made into three membership functions which are low, medium, and high, as seen in Fig. 4. The low category has a soil moisture value ranging from 0% to 50%. It indicates that the soil moisture in the plant is in dry conditions. Meanwhile, the medium category has a soil moisture value ranging from 25% to 75%, showing that the soil moisture in the plant is in normal conditions. Then, the high category has a soil moisture value ranging from 75% to 100%. It indicates that the soil moisture in the plant is in a wet condition [3].

The fuzzy rules in Table I are made to get a crisp set of 0, 1, and 2. It shows 0 for the plant in sufficient water conditions, so there is no irrigation. Then, a value of 1 for the plant means that it can be watered but must be checked against the weather if it will rain soon, so there is no need to irrigate the plant. Additionally, a value of 2 is for the urgent need for water, and the irrigation process is carried out regardless of weather conditions.

When the soil moisture content is in the high category, the decision is not to irrigate the plants because of the wet soil moisture conditions. Meanwhile, if the soil moisture content is in the medium category, it needs to check the weather forecast for the next one hour before irrigating the plants. If it rains, the plants will not be watered. If it does not rain, the plants will be watered. When the CWSI and soil moisture content are in a low category, the decision is the same as the soil moisture content in the medium category because the plants are not in a condition of lacking water. When the CWSI is in the medium or high category, and the soil moisture content is in a low category, the decision is to irrigate the plant due to dry soil moisture conditions and the plant's condition that lacks water.

There is a total of 11 days to experiment irrigation process for 4 pots as a comparison from plant-soil-weather-based methodology, plant-based methodology, soil-based methodology, and manual irrigation. The experiment can be seen in Fig. 5. In the experiment, the research compares water use (liter) and stress index (CWSI) for each pot. In manual irrigation, the plant is watered every day at a specific time. Meanwhile, in soil-based methodology, the plant is watered if the soil status is low. Then, for plant-based methodology, the plant is watered based on the membership function

Fig. 5. Experiment picture.

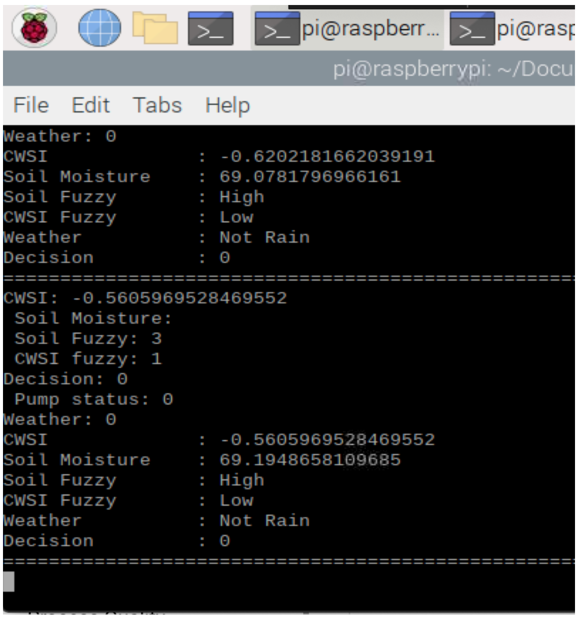

Fig. 6. The example of output.

without checking the weather API. Some parameters will be saved in the database, such as humidity, temperature, CWSI, soil moisture, weather, fuzzy decision, pump status, and liters of water used as measuring tools.

IV. Results and Discussion

The experiment has been conducted for 11 days. The data are taken every 5 minutes for each existing pot. Data values, such as CWSI, soil moisture, fuzzy, decision, pump status, and weather, are stored in the database and displayed. The data are obtained using sensors, such as soil moisture, infrared sensors, and the weather API for weather data. The experimental location is in Indonesia, with a latitude of 6.16 and a longitude of 106.75. The example can be seen in Fig. 6.

The CWSI calculation uses an empirical formula, as shown in Eq. (1). It starts by measuring the upper baseline and lower baseline used. Hence, the CWSI formula can be utilized using that information. Then, VPD is also calculated. The calculations are shown as follows.

$$(T_c - T_a)_{L.L} = -1.10 * \text{VPD} + 0.49,$$
$$(T_c - T_a)_{U.L} = 0.005 * \text{VPD} + 2.86,$$

$$\text{CWSI} = \frac{(T_c - T_a)_m - (-1.10 * \text{VPD} + 0.49)}{0.005 * VPD + 2.86 - (-1.10 * \text{VPD} + 0.49)} = \frac{(T_c - T_a)_m + 1.10 * \text{VPD} - 0.49}{1.105 * VPD + 2.37},$$

$$\text{VPD} = 610.78 * e^{\left(\frac{T_a}{T_a + 238.3} * 17.2694\right)} * \left(1 - \frac{RH}{100}\right).$$

The CWSI value obtained indicates that the plant is not stressed by water because the CWSI value is 0.02, categorized as low in the fuzzy system. Relative humidity (RH) is the percentage of air humidity taken

TABLE II
DATABASE IN THE RESEARCH.

RH	Tc	Ta	CWSI	Timestamp
77.3	28.39	28.8	0.02	2022-1-15 8:59:51
78.1	28.37	28.8	0.01	2022-1-15 8:59:59
77.6	28.37	28.7	0.04	2022-1-15 9:00:07

from DHT22 sensors. RH of 77.3% is categorized as moderately humid. Then, T_c is the plant temperature taken from infrared temperature sensor, pointed to the leaves of the plant. Meanwhile, T_a is the room air temperature taken from DHT22 sensor. For example, the calculation is as follows to calculate the CWSI values for the timestamp 2022-01-15 08:59:51 in Table II.

$$\text{VPD} = 610.78 * e^{\left(\frac{28.8}{28.8+238.3} * 17.2694\right)} * \left(1 - \frac{77.3}{100}\right),$$
$$\text{VPD} = 610.78 * e^{(1.8621)} * 0.227,$$
$$\text{VPD} = 892.4771 Pascal = 0.8924771\ KPa,$$

$$\text{CWSI} = \frac{(T_c - T_a)_m + 1.10 * VPD - 0.49}{1.105 * \text{VPD} + 2.37},$$
$$\text{CWSI} = \frac{(28.39 - 28.8) + 1.10 * \text{VPD} - 0.49}{1.105 * \text{VPD}\ + 2.37},$$
$$\text{CWSI} = \frac{-0.41 + 1.10 *\ \text{VPD} - 0.49}{1.105 * VPD + 2.37},$$
$$\text{CWSI} = \frac{-0.9 + 1.10 * \text{VPD}}{1.105 * \text{VPD} + 2.37},$$
$$\text{CWSI} = \frac{-0.9 + 1.10 *\ 0.8924771}{1.105 *\ 0.8924771 + 2.37},$$
$$\text{CWSI} = \frac{-0.9 + 0.98172481}{2.37 + 0.9861871955},$$
$$\text{CWSI} = \frac{0.08172481}{3.3561871955} = 0.02.$$

Table III shows a comparison between the experimental pots: pot 1 with soil moisture, CWSI, and weather as watering parameters, pot 2 with soil moisture as a watering parameter, pot 3 with soil moisture and CWSI as watering parameters, and pot 4 with a random watering system. The random watering system is manual watering. The soil moisture in pot 1, pot 2, and pot 3 has the same value, but pot 4 has drier soil moisture. It shows that better soil moisture can be obtained using the sensor, as seen from the soil moisture values obtained in pot 1, pot 2, and pot 3, namely 66.18%, 68.36%, and 66.06%, respectively. Meanwhile, the plants that do not use sensor input, pot 4, only have a value of 54.69%.

The best CWSI values (close to 0) are achieved by pots 1 and 3. Meanwhile, pots 2 and 4 are stressed against water. As seen from the CWSI data for pot 2, the value is 0.70. Then, in pot 4, it has 0.92. Comparing pots 1 and 2, the average CWSI for pot 1 is 0.30, and pot 2 is 0.70. It means that using CWSI as a parameter, the CWSI value of pot 1 is 42.78% better than pot 2. It implies that using only soil moisture or manual watering is ineffective for plant development because the plants are often stressed against water using both methods. CWSI can be used as a watering parameter to get a lower stress index value.

TABLE III
THE RESULT OF POTS COMPARISON.

	Pot Description	Average CWSI	Average Soil Moisture	Total used water (Liter)
Pot 1	Soil Moisture + CWSI + Weather Approach (Proposed Method)	0.30	66.18	2.02
Pot 2	Soil Moisture	0.70	68.35	4.82
Pot 3	Soil Moisture + CWSI	0.16	66.06	2.58
Pot 4	Random Watering System	0.92	54.69	9.56

Next, pot 4 gets the most water during the experiment of 9.56 liters but the CWSI value is better than pot 2 which uses soil moisture by getting 4.82 liters of water. It is because pot 4 gets a lot of water at a certain time compared to soil moisture. On average, it is always wet because it is watered whenever the soil moisture reaches dry conditions. Therefore, when calculating the average of CWSI, pot 2 is better at 0.70, compared to pot 4 at 0.91. In pot 2, the CWSI value is more stable than in pot 4, which uses more water but is only irrigated once a day.

The results from pots 1 and 3 indicate that with soil moisture and CWSI, they get better CWSI results. However, the use of water used by pot 3 is more wasteful when compared to pot 1. Pot 3 uses 2.58 liters, while pot 1 uses 2.02 liters. Pot 1 saves 21.9% of water compared to pot 3. With average CWSI values that are not much different (0.30 for pot 1 and 0.16 for pot 3), weather can be used as a variable to reduce water use in the irrigation process. It can save water use even though the CWSI value is not better than CWSI and soil moisture (pot 3).

Table IV compares the previous studies with the research. According to the research, adding weather prediction can reduce water consumption by 78.92% compared to other studies, which get 37.76% [18] and 51.11% [3]. The resulting soil moisture indicates that the soil is not too wet or dry compared to other studies. Then, a better CWSI value is also obtained, indicating that the plant gets less stress than in other previous studies to maximize plant growth.

TABLE IV
STATE OF THE ART.

	Previous Research [18]	Previous Research [3]	The Research
Methodology	Temperature, humidity, soil moisture, fuzzy logic	CWSI, soil moisture, fuzzy logic	CWSI, soil moisture, weather prediction, fuzzy logic
Water saved compared to manual watering	37.76%	51.11%	78.92%
Average soil moisture	77.5%	60%	66.18%
Average CWSI	-	0.45	0.30

V. Conclusion

Fuzzy logic can be used to combine the input parameters, so the three approaches can be combined. Soil-based approach sends data in the form of soil moisture. Meanwhile, the weather-based approach has data in the form of weather predictions, and the plant-based approach sends data in the form of the plant's temperature. By combining several input parameters, a watering system can be made that complements the weaknesses of each approach.

The water consumption in a watering system can be reduced by up to 21.9% using the weather. That means the weather can be used as a reference for a system to automatically make decisions in watering a plant. It is suitable for countries with a rainy season, such as Indonesia. Water savings can be done in the process of watering plants during the rainy season. In addition to weather factors, CWSI plays an important role as an indicator of the development of a plant. The CWSI value of each plant is different and has advantages and disadvantages.

The research limitation is that the data taken are noisy data. So, it results in less accurate decision-making in the system. Solar radiation sensors can be used to calculate CWSI values to get more precise results, so it makes a better watering decision for the system to reduce noise in the data. For future research, an irrigation system using CWSI can be made from the start until the end (seedling-sprout-plant-produced fruits), and the CWSI value affects the level of fruit produced in a plant. Moreover, different plants also have different CWSI upper baseline and lower baseline. In addition, it is also possible to develop a system for plants so that the CWSI value is maintained in rainy conditions and does not experience overwatered conditions by the rainwater.

References

[1] Food and Agriculture Organization of the United Nations, "Pepper." [Online]. Available: https://www.fao.org/land-water/databases-and-software/crop-information/pepper/en/#c236442

[2] K. Anusha and U. B. Mahadevaswamy, "Automatic IoT based plant monitoring and watering system using Raspberry Pi," *International Journal of Engineering and Manufacturing*, vol. 8, no. 6, pp. 55–67, 2018.

[3] C. Jamroen, P. Komkum, C. Fongkerd, and W. Krongpha, "An intelligent irrigation scheduling system using low-cost wireless sensor network toward sustainable and precision agriculture," *IEEE Access*, vol. 8, pp. 172 756–172 769, 2020.

[4] T. A. Khoa, M. M. Man, T. Y. Nguyen, V. Nguyen, and N. H. Nam, "Smart agriculture using IoT multi-sensors: A novel watering management system," *Journal of Sensor and Actuator Networks*, vol. 8, no. 3, pp. 1–22, 2019.

[5] N. Hossein Motlagh, M. Mohammadrezaei, J. Hunt, and B. Zakeri, "Internet of Things (IoT) and the energy sector," *Energies*, vol. 13, no. 2, pp. 1–27, 2020.

[6] Z. Wang, Y. Liu, Y. Sun, Y. Li, D. Zhang, and H. Yang, "An energy-efficient heterogeneous dual-core processor for Internet of things," in *2015 IEEE International Symposium on Circuits and Systems (ISCAS)*. Lisbon, Portugal: IEEE, May 24–27, 2015, pp. 2301–2304.

[7] S. Kumar and A. Jasuja, "Air quality monitoring system based on IoT using Raspberry Pi," in *2017 International Conference on Computing, Communication and Automation (ICCCA)*. Greater Noida, India: IEEE, May 5–6, 2017, pp. 1341–1346.

[8] N. S. Yamanoor and S. Yamanoor, "High quality, low cost education with the Raspberry Pi," in *2017 IEEE Global Humanitarian Technology Conference (GHTC)*. San Jose, USA: IEEE, Oct. 19–22, 2017, pp. 1–5.

[9] J. Cao, J. Tan, Y. Cui, and Y. Luo, "Irrigation scheduling of paddy rice using short-term weather forecast data," *Agricultural Water Management*, vol. 213, pp. 714–723, 2019.

[10] R. Sui, "Irrigation scheduling using soil moisture sensors," *Journal of Agricultural Science*, vol. 10, no. 1, pp. 1–11, 2017.

[11] H. Kirnak, H. A. Irik, and A. Unlukara, "Potential use of Crop Water Stress Index (CWSI) in irri-

gation scheduling of drip-irrigated seed pumpkin plants with different irrigation levels,” *Scientia Horticulturae*, vol. 256, pp. 1–8, 2019.

[12] R. D. Jackson, S. B. Idso, R. J. Reginato, and P. J. Pinter Jr, “Canopy temperature as a crop water stress indicator,” *Water Resources Research*, vol. 17, no. 4, pp. 1133–1138, 1981.

[13] A. Khorsand, V. Rezaverdinejad, H. Asgarzadeh, A. Majnooni-Heris, A. Rahimi, S. Besharat, and A. A. Sadraddini, “Linking plant and soil indices for water stress management in black gram,” *Scientific Reports*, vol. 11, no. 1, pp. 1–19, 2021.

[14] G. Yuan, Y. Luo, X. Sun, and D. Tang, “Evaluation of a crop water stress index for detecting water stress in winter wheat in the North China Plain,” *Agricultural Water Management*, vol. 64, no. 1, pp. 29–40, 2004.

[15] S. M. Sezen, A. Yazar, Y. Daşgan, S. Yucel, A. Akyıldız, S. Tekin, and Y. Akhoundnejad, “Evaluation of Crop Water Stress Index (CWSI) for red pepper with drip and furrow irrigation under varying irrigation regimes,” *Agricultural Water Management*, vol. 143, pp. 59–70, 2014.

[16] O. Nelles, *Nonlinear system identification: From classical approaches to neural networks, fuzzy models, and gaussian processes*. Springer, 2020.

[17] J. H. Gultom, M. Harsono, T. D. Khameswara, and H. Santoso, “Smart IoT water sprinkle and monitoring system for chili plant,” in *2017 International Conference on Electrical Engineering and Computer Science (ICECOS)*. Palembang, Indonesia: IEEE, Aug. 22–23, 2017, pp. 212–216.

[18] N. Abdullah, N. A. B. Durani, M. F. B. Shari, K. S. Siong, V. K. W. Hau, W. N. Siong, and I. K. A. Ahmad, “Towards smart agriculture monitoring using fuzzy systems,” *IEEE Access*, vol. 9, pp. 4097–4111, 2020.

[19] T. Kassanuk, M. Mustafa, P. Panse, R. Sivanand, K. Phasinam, and T. Santosh, “An Internet of things and cloud based smart irrigation system,” *Annals of the Romanian Society for Cell Biology*, vol. 25, no. 4, pp. 20 010–20 016, 2021.

[20] N. A. M. Leh, M. S. A. M. Kamaldin, Z. Muhammad, and N. A. Kamarzaman, “Smart irrigation system using Internet of things,” in *2019 IEEE 9th International Conference on System Engineering and Technology (ICSET)*. Shah Alam, Malaysia: IEEE, Oct. 7, 2019, pp. 96–101.

[21] T. P. Satya, U. Y. Oktiawati, I. Fahrurrozi, and H. Prisyanti, “Analisis akurasi sistem sensor DHT22 berbasis Arduino terhadap Thermohygrometer Standar,” *Jurnal Fisika dan Aplikasinya*, vol. 16, no. 1, pp. 40–45, 2020.

[22] Melexis, “Datasheet for MLX90614,” 2019. [Online]. Available: https://www.melexis.com/en/documents/documentation/datasheets/datasheet-mlx90614

[23] Github, “YF-S401 Datasheet,” 2020. [Online]. Available: https://github.com/microrobotics/YF-S401/blob/main/YF_S401_datasheet.pdf

[24] Z. Chao, F. Pu, Y. Yin, B. Han, and X. Chen, “Research on real-time local rainfall prediction based on MEMS sensors,” *Journal of Sensors*, vol. 2018, pp. 1–9, 2018.

[25] OpenWeather, “One Call API 2.5.” [Online]. Available: https://openweathermap.org/api/one-call-api