

(Research) Article

Design and Construction of Automatic Mineral Water Refilling System Using *Fuzzy Logic*

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Abstract: This research discusses the design and construction of an automatic mineral water refilling system using fuzzy logic based on the ESP32 microcontroller. The background of this research is the increasing environmental pollution due to the use of disposable plastic mineral water bottles in the campus environment. The system is designed to be able to fill water containers automatically with IR sensor-based control and ultrasonic sensors to detect the presence of containers and water levels. The research method used is the *Waterfall method* which includes the planning, design, implementation, and system testing stages. The test results show that the system is able to fill water with an average effective volume of 83.2 % of the container capacity, with a safe limit for automatic stopping at a distance of less than 2 cm from the rim of the container. The implementation of Mamdani fuzzy logic allows the system to make filling decisions based on sensor conditions adaptively, resulting in efficient and accurate pump control. Thus, this system can be an innovative solution to reduce plastic waste while supporting efficient water use in the campus environment.

Keywords: Automatic Control System; ESP32; Fuzzy Logic; Ultrasonic Sensor; Water Filling.

1. Introduction

Environmental pollution is increasingly prevalent in society due to a lack of awareness and responsibility for the importance of maintaining cleanliness. The habit of littering and a lack of participation in waste management programs also worsen the daily environmental conditions. According to Law of the Republic of Indonesia Number 32 of 2009 concerning Environmental Protection and Management, factors that have the potential to threaten the environment are increasingly declining quality of life. This condition can have a serious impact on the survival of humans and also various other living creatures [1]. This is in line with the Regulation of Criminal Acts of Environmental Pollution in Indonesia. Environmental pollution is pollution that can have a negative impact directly or indirectly on humans and the sustainability of the environment. From data released by the Indonesian Central Statistics Agency (BPS), environmental pollution problems around the Indonesian region focus on air pollution, water pollution, and land pollution which are considered to have the most significant impact [2].

Based on. Air pollution is the presence of physical, chemical or biological material mixed with the air that is detrimental to human health. This air pollution is increasing due to increasing urbanization, rapid industrial development, and high emissions from motor vehicles, industrial facilities, and waste incineration processes. Which, if continuously inhaled by a person, can cause diseases and respiratory disorders such as asthma and Acute Respiratory Tract Infections [3], [4].

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Water pollution is a condition caused by the entry of chemical loads in the form of gases or other liquids that can be dissolved in pure water. Most of the causes of increasing water pollution are caused by human activities that leave behind residential waste, industrial waste, and mining [5] , [6] . As a result, there is a lack of hygienic clean water sources for washing, cooking, and cleaning the body which will cause skin diseases to diarrhea in humans [7] . Soil pollution occurs when man-made chemicals contaminate natural soil, which negatively changes the nature of the environment. The trigger for frequent soil pollution is usually due to leaks of water waste, industrial chemicals or commercial facilities that use plastic and pesticides in agriculture [8] [9] . As a result, a lot of land that should be agricultural land contains hazardous chemicals that can damage other ecosystems [2] . Based on data from the Indonesian central statistics agency, in 2021 there were 10,683 cases of water pollution, 1,499 cases of land pollution, and 5,644 cases of air pollution. which affects the environment increasingly worsens, that the increasingly declining quality of the environment has threatened the continuity of human life and other living creatures so that it is necessary to carry out serious and consistent environmental protection and management by all stakeholders (UURI No. 32 of 2009 concerning Environmental Protection and Management).

2. Literature Review

2.1. Water Refiling

Water refilling or refilled water is drinking water that has gone through special treatment stages such as chlorination to kill germs, aeration to increase oxygen levels, filtration to filter particles, and ultraviolet light irrigation as an additional method to ensure the cleanliness of the water consumed [10] . Refill drinking water is drinking water provided at drinking water depots that has gone through various processes, such as chlorination to maintain cleanliness, aeration to increase oxygen, filtration to filter dirt, and ultraviolet light irradiation as a method of killing bacteria and microorganisms [11] .

2.2 ESP 32 Microcontroller

ESP32 is a SoC (System on Chip) microcontroller device that is combined with a Wi-Fi 802.11 b/g/n module and Bluetooth version 4.2 and uses a 32bit Xtensa LX6 dual-core microprocessor [12] .

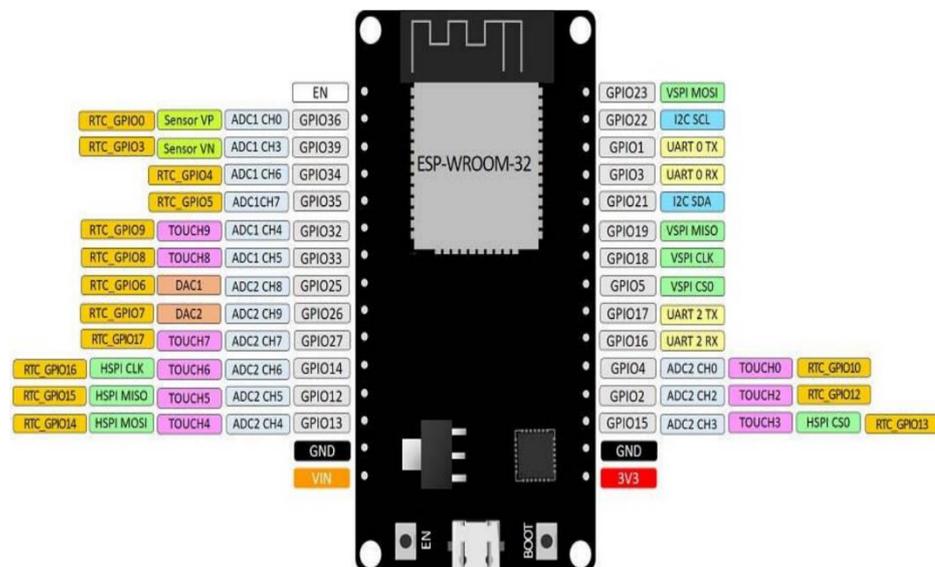


Figure 1ESP 32

To operate the ESP32 microcontroller, you can use software from the Arduino IDE. The first step is to include the library to be used in the program and create code to determine the appropriate calibration numbers. This is important so that the final results after uploading the file to the ESP32 microcontroller are close to the actual values [13] .

2.3 PLTS (Solar Power Plant)

Solar Power Plant (PLTS) is a system that plays a role in converting solar energy into electricity through Photovoltaic, where the energy of sunlight is converted into electric current by solar cells, allowing for efficient and environmentally friendly energy absorption. [14] . Photovoltaic itself is a tool that can convert solar energy (photons) into direct current electrical energy which can later be a source of direct current or converted into alternating current [15] .



Figure 2 Solar panels

Batteries are tools used to store reserve energy produced by solar panels which will later be converted into electrical energy to obtain the required electric current, either direct or alternating current [16] .

3. Method

3.1. Waterfall

method is a strategy that is implemented in order to prioritize a sequential process starting from the planning to the implementation stage, carried out in stages and in a structured manner [17] .

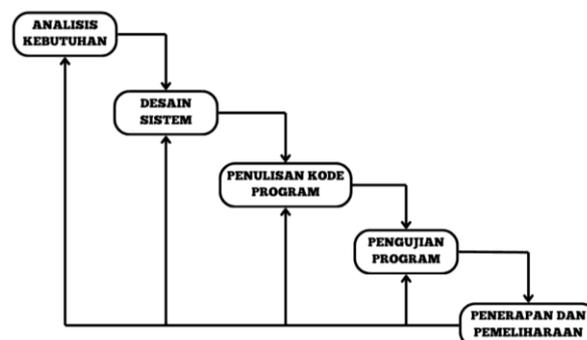


Figure 3 of the Waterfall Method

It could be said that this concept is like a continuous stream of water, where each stage reflects the need for in-depth planning, accurate modeling, meticulous implementation, and thorough testing to ensure overall quality. This analogy illustrates the importance of going through the process with an organized strategy to achieve optimal results. [17] .

3.2. Control

A control system is a mechanism or device designed to regulate, control, or direct the course of a process so that the output matches the desired setpoint value [18]. In a control system, there is a measurement process for the controlled variable using a sensor, then the measurement results are compared with the reference value. The difference between the two is called an error, and this error signal is used by the controller to determine the action that needs to be taken so that the system returns to the desired condition [19].

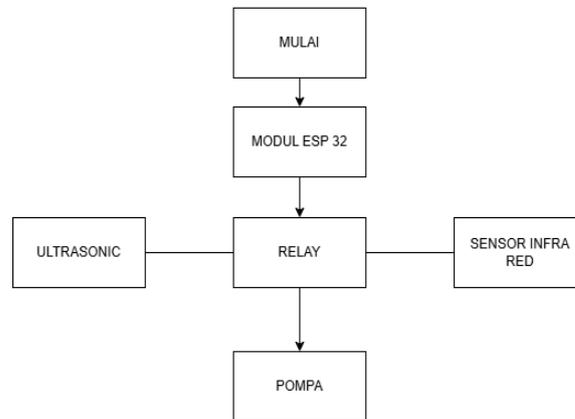


Figure 4Control System Diagram

In other words, the control system is designed to ensure the stability, reliability, and performance of the process automatically without requiring constant human intervention. In the context of this research, the author chose the ESP32 microcontroller to control the system as a whole. The ESP32 was chosen with the aim of managing the system efficiently to prevent instability disturbances automatically. The ESP32 microcontroller was chosen as the optimal solution to ensure that the system automation process runs smoothly and effectively, without the presence of humans constantly interfering in the control of the entire process.

3.3. Power

The hybrid PLTS system with PLN is a power generation system that integrates Solar Power Plants (PLTS) with the PLN (State Electricity Company) electricity network to create an efficient, reliable, and sustainable energy supply [20]. This system is designed so that the electrical energy generated from solar panels can be used together with electrical energy from the PLN network, so that users can save electricity consumption from PLN without losing the continuity of power supply when solar intensity is low [21].

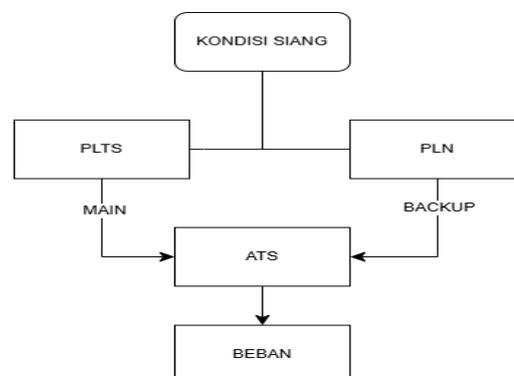


Figure 5Power System Diagram for Daytime Conditions

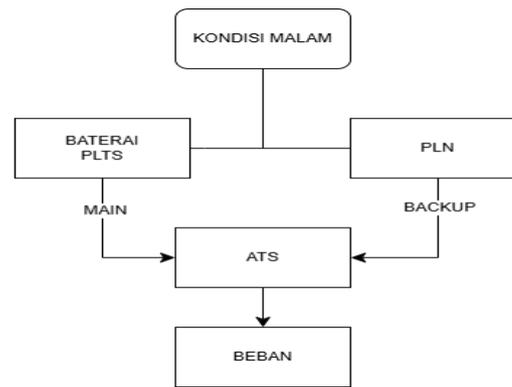


Figure 6 Power System Diagram for Night Conditions

In essence, a hybrid solar power system with PLN operates by combining two energy sources, namely energy from solar modules and from the PLN network which is regulated by a hybrid inverter. During periods of high solar radiation, priority is given to energy from solar panels to meet the electricity needs of homes or industries [22]. The extra energy produced can be channeled to the PLN network through an energy export-import mechanism, provided the system supports grid-tied functions. If solar energy is insufficient, such as at night or in cloudy weather conditions, the system automatically switches to power supply from PLN [23]

3.4. gamInstrument Fuzzy Mamdani

Fuzzy logic was developed by the famous figure, namely Professor Lotfi Aliasker Zadeh in 1965, where *fuzzy* logic in general is a method that calculates a variable and converts it into a number [24]. A similar thing was emphasized [25]. *Fuzzy* logic is an approach that uses several stages by classifying them into several relevant groups for problem solving.

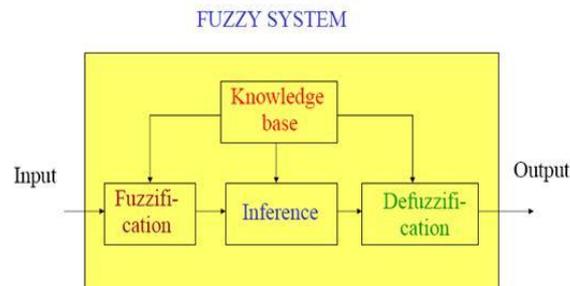


Figure 7 Fuzzy System

3.5. Fuzzification

At this stage, calculations are carried out for each numerical value that will be interpreted into linguistic form, in this case the form of variables such as IR1, IR2, Ultrasonic Sensor, will be identified to find out how each variable has a value.

- 1) IR1 membership function
 $\mu_{\text{Aktif High}}(x) = 1$
 $\mu_{\text{Aktif Low}}(x) = 0$
- 2) IR2 membership function
 $\mu_{\text{Aktif High}}(x) = 1$
 $\mu_{\text{Aktif Low}}(x) = 0$
- 3) Ultrasonic sensor membership function

$$\mu_{\text{Tinggi}}(x) = \begin{cases} 1; & x \leq 3 \\ \frac{5-x}{5-3}; & 3 < x < 5 \\ 0; & x \geq 5 \end{cases}$$

$$\mu_{\text{Sedang}}(x) = \begin{cases} 0; & x \leq 5 \\ \frac{(x-5)}{(6,5-5)}; & 5 < x < 6,5 \\ \frac{(8-x)}{(8-6,5)}; & 6,5 \leq x < 8 \\ 0; & x \geq 8 \end{cases}$$

$$\mu_{\text{Rendah}}(x) = \begin{cases} 0; & x \leq 8 \\ \frac{(x-8)}{(12-8)}; & 8 < x < 12 \\ 1; & x \geq 12 \end{cases}$$

With this calculation, it is stated that if it is below 3cm then the variable that will light up is high, conversely if it is above 3cm but below 8cm a decision can be made between high and medium, and if it is above 12cm then low will be taken.

3.6. Fuzzy Inference

After carrying out *the fuzzyfication* process on each variable, *fuzzy rules were found*, the details of which can be seen in the table below.

Table 1 Fuzzy Rules

Rules	IF IR1	AND IR2	AND	ULTRA SONIC	THEN	PUMP	INFORMATION
R1	IF 0	AND 0	AND	-	THEN	0	Off no cup
R2	IF 1	AND 0	AND	-	THEN	0	Cup detected
R3	IF 1	AND 1	AND	>8	THEN	1	Start charging
R4	IF 1	AND 1	AND	5-8	THEN	1	Continue filling
R5	IF 1	AND 1	AND	<5	THEN	0	Off Stop filling
R6	IF 0	AND 1	AND	-	THEN	0	Off Cup not detected
R7	IF 1	AND 1	AND	<4-5	THEN	0	Off safety cup full

The inference stage is part of a *fuzzy logic system* where the process in it extracts data carefully, in this system the drawing of conclusions is based on each applicable rule, in the Mamdani inference method it consists of two stages, namely implication and composition.

At this stage, the rules are arranged which will be used to form implications to link each input and output variable to process data processing.

- Rule 1
IF : IR1 = 0 AND IR2 = 0 AND Ultrasonic = none
THEN: OFF
 $[R1] = \text{Min}(\mu_{IR1}(x), \mu_{IR2}(x), \mu_{Ultrasonic}(x))$
 $[R1] = \text{Min}(\mu_{IR1}(0), \mu_{IR2}(0), \mu_{Ultrasonic}(\text{none}))$
 $[R1] = \text{Min}(0, 0, 0)$
 $[R1] = 0.163$
- Rule 2
IF : IR1 = 1 AND IR2 = 0 AND Ultrasonic = None
THEN: OFF
 $[R2] = \text{Min}(\mu_{IR1}(x), \mu_{IR2}(x), \mu_{Ultrasonic}(x))$
 $[R2] = \text{Min}(\mu_{IR1}(1), \mu_{IR2}(0), \mu_{Ultrasonic}(\text{none}))$
 $[R2] = \text{Min}(1, 0, 0)$
 $[R2] = 0.163$
- Rule 3
IF : IR1 = 1 AND IR2 = 1 AND Ultrasonic = low
THEN: ON
 $[R3] = \text{Min}(\mu_{IR1}(x), \mu_{IR2}(x), \mu_{Ultrasonic}(x))$
 $[R3] = \text{Min}(\mu_{IR1}(1), \mu_{IR2}(1), \mu_{Ultrasonic}(R))$
 $[R3] = \text{Min}(1, 1, 20)$
 $[R3] = 0.837$

- Rule 4
 IF : IR1 = 1 AND IR2 = 1 AND Ultrasonic = Medium
 THEN: ON
 $[R4] = \text{Min} (\mu IR1 (x), \mu IR2 (x), \mu Ultrasonic(x))$
 $[R4] = \text{Min} (\mu IR1 (1), \mu IR2 (1), \mu Ultrasonic(S))$
 $[R4] = \text{Min} (1, 1, 5)$
 $[R4] = 0.500$
- Rule 5
 IF : IR1 = 1 AND IR2 = 0 AND Ultrasonic = High
 THEN: OFF
 $[R5] = \text{Min} (\mu IR1 (x), \mu IR2 (x), \mu Ultrasonic(x))$
 $[R5] = \text{Min} (\mu IR1 (1), \mu IR2 (1), \mu Ultrasonic(T))$
 $[R5] = \text{Min} (1, 1, 4)$
 $[R5] = 0.202$
- Rule 6
 IF : IR1 = 0 AND IR2 = 1 AND Ultrasonic = none
 THEN: OFF
 $[R6] = \text{Min} (\mu IR1 (x), \mu IR2 (x), \mu Ultrasonic(x))$
 $[R6] = \text{Min} (\mu IR1 (1), \mu IR2 (0), \mu Ultrasonic(None))$
 $[R6] = \text{Min} (1, 1, 0)$
 $[R6] = 0.202$
- Rule 7
 IF : IR1 = 1 AND IR2 = 1 AND Ultrasonic = <5
 THEN: OFF
 $[R7] = \text{Min} (\mu IR1 (x), \mu IR2 (x), \mu Ultrasonic(x))$
 $[R7] = \text{Min} (\mu IR1 (1), \mu IR2 (1), \mu Ultrasonic(< 5))$
 $[R7] = \text{Min} (1, 1, 4)$
 $[R7] = 0.202$

At the composition or aggregation stage, the rules that have been compiled and obtained results will be recorded for later decision making whether the value is included in the decision yes or no. For the ON composition there is a contribution of rules 3 and 4 where the symmetric peak output is at 0.837, and for the OFF composition there is a contribution of Rules 1, 2, 5, 6, 7 with a symmetric peak at a value of 0.202.

3.7. Defuzzification

The defuzzification stage is the final stage which combines the contribution values that have been recorded in the *fuzzy inference process*, where the data that has been divided based on OFF and ON contributions will be calculated to find out the value of the pump craps which will be ON if it is at a certain value and will be OFF if it is at a certain value too.

$$Pompa = \frac{Aoff * Coff + Aon * Con}{Aoff + Aon} \dots\dots\dots$$

(1)

It is known:

The highest value OFF = 0.8

The highest value ON = 0.2

Centeroid value = 0.5

then the value of;

$$\begin{array}{l}
 Aoff = \frac{1}{2} x \text{Centeroid } x \text{ off} \\
 Aoff = \frac{1}{2} x 0,5 x 0,8 \\
 Aoff = 0,2 \\
 Coff = \frac{1}{3} \text{Ceteroid} = 0,1
 \end{array}
 \left|
 \begin{array}{l}
 Aon = \frac{1}{2} x \text{Centeroid } x \text{ on} \\
 Aom = \frac{1}{2} x 0,5 x 0,2 \\
 Aon = 0,05 \\
 Con = 0,5 + \frac{2}{3} \text{Ceteroid} = 0,8
 \end{array}
 \right.$$

So when all the values are known, the value of the pump is;

$$\begin{aligned}
 Pompa &= \frac{Aoff * Coff + Aon * Con}{Aoff + Aon} \\
 Pompa &= \frac{(0,2) * (0,1) + (0,05) * (0,8)}{0,2 + 0,05} \\
 Pompa &= \frac{0,02 + 0,04}{0,25} \\
 Pompa &= \frac{0,06}{0,25} \\
 Pompa &= 0,24
 \end{aligned}$$

So the result of the system defuzzification is recorded as 0.24 which indicates that the ON and OFF values are at that number. When the value is below 0.24, the system operates at 0 and when the value is above 0.24, the system operates at 1.

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Masukkan nilai IR1 (0 / 1): 1
Masukkan nilai IR2 (0 / 1): 1
Masukkan jarak Ultrasonic (cm): 4.9

IR1=1.0 | IR2=1.0 | Ultrasonic=4.9 cm
Hasil defuzzifikasi = 0.238
? POMPA: OFF

Masukkan nilai IR1 (0 / 1): 1
Masukkan nilai IR2 (0 / 1): 1
Masukkan jarak Ultrasonic (cm): 5

IR1=1.0 | IR2=1.0 | Ultrasonic=5.0 cm
Hasil defuzzifikasi = 0.500
? POMPA: ON
    
```

Figure 8 Defuzzification Results

As can be seen in Figure 8, the results of defuzzification using MATLAB software show that the maximum value of off in the system is 0.238 which is below 0.24, while for the ON condition it is above the value of 0.24.

4. Results and Discussion

By using 15 cups of different sized sauce, and taking measurements first to describe each size, which will then be used to compare the data after filling.

Table 2 Water Filled Data

No	Container Specifications			Charging Time	Water Filled			Percentage (%)
	Cm	Cm ³	ml		Cm	Cm ³	ml	
1.	15	592.9	593	7.1	13.0	473.1	473.1	79.8
2.	15.5	612.7	613	7.4	13.5	492.7	492.7	80.4
3.	16	632.5	633	7.7	14.0	512.2	512.2	81.0
4.	16.5	652.3	652	8.0	14.5	531.8	531.8	81.5
5.	17	672.0	672	8.3	15.0	551.3	551.3	82.0
6.	17.5	691.8	692	8.6	15.5	570.9	570.9	82.5
7.	18	711.6	712	8.9	16.0	590.5	590.5	83.0
8.	18.5	731.4	731	9.2	16.5	610.1	610.1	83.4
9.	19	751.1	751	9.4	17.0	629.7	629.7	83.8
10.	19.5	770.9	771	9.7	17.5	649.3	649.3	84.2
11.	20	790.6	791	10.0	18.0	669.0	669.0	84.6
12.	20.5	810.4	810	10.3	18.5	688.6	688.6	85.0
13.	21	830.2	830	10.6	19.0	708.2	708.2	85.3
14.	21.5	850.0	850	10.9	19.5	727.9	727.9	85.6
15.	22	869.7	870	11.2	20.0	747.5	747.5	86.0

Table 2 explains the identification of containers, which range in diameter from 15cm to 22cm. The container has a top diameter of 9cm and a bottom diameter of 5cm. When the container is filled with water, the measured volume will not equal its full capacity. This is due to a 2cm limiter system before the water reaches the rim of the container. This system

automatically stops filling when the water reaches the full limit. The purpose of this system is to prevent excessive water pouring that can occur during filling. This makes using this container easier and more practical to fill without worrying about overflowing.

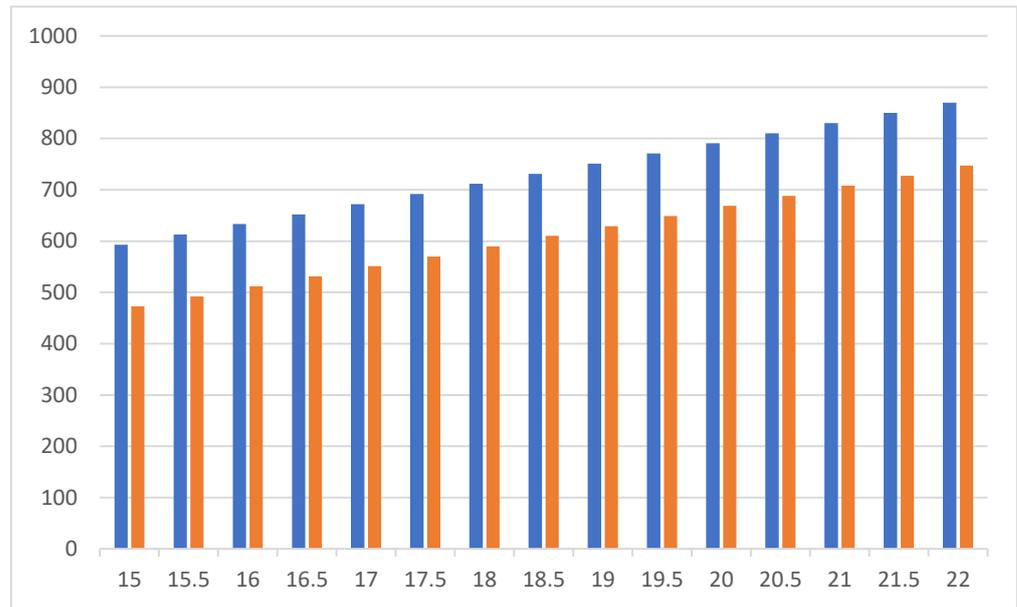


Figure 9 Comparison Diagram

The data presented in Figure 9 shows the comparison of the total water required by the container with the actual filling results. The data is presented as a percentage. The average water filling of the total container volume is 83.2 % , with a minimum percentage filled of 79.8% and a maximum percentage filled of 86%. With an average filling exceeding 80%, this indicates that the filling system is running well and optimally. The container filling has met the ideal percentage to ensure sufficient water and not excess. The closer the filling percentage is to 100%, the more efficient the water use. Maintaining the filling percentage in the range of 80-90% will help in better managing water use. Therefore, the water filling results that reached an average of 83.2 % indicate that filling is optimal and can be maintained to maintain the sustainability of efficient water use.

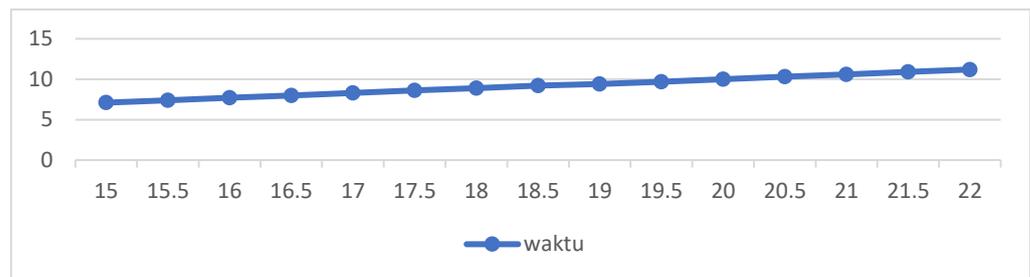


Figure 10 Container Filling Diagram

Figure 10 shows a graph showing the relationship between the time required to fill a container and its height. The graph shows that the higher the container, the greater the volume of water required and the longer the filling time . The apparatus used in this experiment is 15 cm high, and the pump used is capable of filling the container at a rate of 4 L per minute. From the recorded data, the time required to fill a 15 cm high container ranges from 7.1 seconds to 11.2 seconds. This shows that even though the pump has a constant water flow rate, the time required to fill the container will vary depending on the size and height of the container.

Table 3 Water Filling Analysis Data Using the *Fuzzy Method*

No	Tall	INPUT			OUTPUT
		IR1	IR2	Ultrasonic	Pump
1.	15	1	1	15	1
2.	15.5	1	1	15.5	1
3.	16	1	1	16	1
4.	16.5	1	1	16.5	1
5.	17	1	1	17	1
6.	17.5	1	1	17.5	1
7.	18	1	1	18	1
8.	18.5	1	1	18.5	1
9.	19	1	1	19	1
10.	19.5	1	1	19.5	1
11.	20	1	1	20	1
12.	20.5	1	1	20.5	1
13.	21	1	1	21	1
14.	21.5	1	1	21.5	1
15.	22	1	1	22	1

Table 3 shows the test results demonstrating the application of *fuzzy logic* to the system. The monitored indicators include IR1, IR2, and an ultrasonic sensor as inputs, while the output is a pump that discharges water. In this monitoring, when the result is on (ON), the value is 1, while if it remains off (OFF), the value is 0. All tests in table 3 were successfully implemented, in accordance with the rules set out in table 1 regarding *fuzzy rules*. This confirms that the device operates according to its initial purpose, which is to provide water automatically by applying *fuzzy logic*.

5. Conclusion

Based on the results of the research that has been conducted, an automatic mineral water refilling system based on fuzzy logic has been successfully designed and implemented. The use of an ESP32 microcontroller as the main controller allows automatic water pump regulation based on IR and ultrasonic sensor data. The test results show that the system is able to fill water up to an average of 83.2 % of the container capacity without spilling, and stops filling automatically when the water approaches the maximum limit. The Mamdani fuzzy logic applied to the system is able to optimize the decision-making process between the ON and OFF conditions of the pump with a defuzzification value of 0.24 as the operating threshold. Thus, this system is considered efficient, adaptive, and has the potential to be widely applied in public water refilling systems to reduce the use of single-use plastic bottles.

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