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Water Quality Monitoring System Based on Fuzzy Algorithm

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Abstract— **Water is one of the essential things in our life, especially for daily needs such as cooking, bathing, drinking, etc. Therefore, water quality is vital to keep humans stay healthy. The water fountain is one of the sources of water. This research designs a water monitoring device to determine the feasibility level of water produced in a water fountain using two sensors. The device measures water acidity using a pH sensor and water turbidity using a turbidity sensor. Both data measurements, water acidity, and turbidity, are processed on the Arduino nano microcontroller based on a fuzzy algorithm. The proposed fuzzy algorithm uses the Tsukamoto Fuzzy model method. The fuzzy inference system is implemented for each sensor to control the valve. There are three membership functions for the fuzzy set of pH and turbidity sensors. The model determines nine fuzzy rules that affect the solenoid valve. The solenoid valve will open if the water condition is suitable for drinking and close if the water condition is not suitable for drinking. The experimental setup is conducted for each pH and turbidity sensor. The turbidity sensor experiment used three water conditions, i.e., clean water, slightly cloud water, and dirty water. Differently, pH sensor considers three water conditions, i.e., acid, neutral, and alkaline water. Based on the result, the fuzzy inference system is determined and generates nine rules for solenoid valves as a defuzzification process. The result shows that implementing a fuzzy algorithm can be used as a filter to detect water conditions.**

Keywords— **Water monitoring, Arduino nano, fuzzy method.**

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I. Introduction

Water is a source of life that is indispensable for living things, such as daily needs, transportation, and a source of energy (Hydro Power Plant). The growth of the population affects the quality of water due to industrial and home wastewater. Therefore, water has become one of our most valuable things, and it needs special treatment to reduce water pollution. Humans require water that can be used for drinking with or without processing, i.e., ready-to-drink water. Ready-to-drink water has to be cleaned, free of bacteria, and have a neutral level of acidity. Regulation of the Minister of Health Number: 416/MENKES/PER/X/1990 describes that ready-to-drink water has some requirements, including tasteless, odorless, colorless, and not containing heavy metals. Thus, a water quality monitoring system is necessary to ensure the water is ready for consumption. If the water cannot be consumable, it needs further action to clean it.

Some researchers had been conducted water quality monitoring using satellite and remote sensing [1], [2]. The advantage of the method is that it is reliable to use in vast area, e.g., river shores and lakes. In addition, it can measure physical and biogeochemical constituents, such as transparency, chlorophyll concentration (phytoplankton), and the organic matter and mineral suspended sediments in different waterbodies compared to in situ measurements. However, this method cannot be used to determine water quality which is the source of pipelines or lakes with a lot of tree environment.

Some previous studies surveyed network communication for water quality monitoring using Wireless communication [3], [4]. From the result, it can be concluded that WSN is a promising water quality monitoring and surveillance infrastructure. The advantages come from affordability and the ability to conduct measurements remotely and in real time. Their experiments used pH, temperature, and turbidity sensors. Differently, Saravanan et al. [5] proposed Internet of Things (IoT) architecture using Arduino atmega 368 as a controller and communicating via Global System for Mobile Communication (GSM) for accessing mobile devices. The water quality parameter is used in Supervisory Control and Data Acquisition (SCADA) system. Newer research implements water quality monitoring based on IoT for the smart city [6]. Lopez et al. [7] employed IoT system for water monitoring using Zigbee, which is low-cost and has good performance.

The other research for water quality monitoring focuses on designing a sensor. Parra et al. [8] proposed a low-cost turbidity sensor using infrared light. In a different approach with [8], Yarenshenko et al. (2020) explained several types of research use biosensors [9], [10]. The sensors are implemented for online flow analysis to determine dichlorvos and methyl paraoxon in the water. The other research also used sensors for identifying and detecting organic contaminants in water [11].

Regarding data processing, many studies use AI to simulate water treatment and predict water quality without testing the water using chemical addition. Thus, the method is adequate for determining water quality in real-time [12]. The AI models include Artificial Neural Networks (ANN) used for monitoring the water pollutants in the water distribution system [13][14][15]. The other method of AI is Fuzzy Logic (FL) [16] [17]. FL has become one of the most robust techniques for analyzing water quality parameters. Oladipo et al. [18] proved that the FL algorithm effectively predicts surface water quality in low-income regions where water is from streams, ponds, and lakes. Several studies have investigated the performance of different FL methods, such as Tagaki-Sugeno FL (TSFL) [19] and the Mamdani Fuzzy Logic Model [17].

In this paper, we deliver water quality monitoring using the fuzzy method with the Tsukamoto model. The fuzzy approach calculates the data value from the pH and the turbidity sensor. The turbidity sensor is used to find the clarity of the ready-to-drink water, and pH sensor measures the pH of the water. The sensor data is then calculated to determine whether the water in the fountain is clean (healthy) or dirty (unhealthy). A fuzzy calculation system detects water conditions in the water fountain. If the water is dirty (unhealthy), Arduino nano will issue a signal to deactivate the solenoid valve. Thus, the water fountain will not flow. On the other hand, if the water condition is clean (healthy), then Arduino nano will signal to activate the solenoid valve. Therefore, the water fountain can flow and be ready to drink

II. MATERIAL AND METHOD

The design process Arduino-based water filter systems can be seen in Fig. 1. Lopez et al. [20] used Arduino mega version to perceive data from each sensor. This research uses Arduino nano which is cheaper than Arduino mega version.

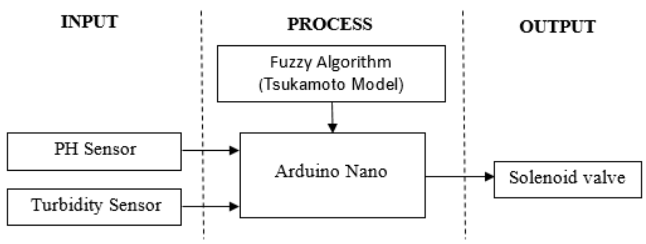

Fig. 1 Block diagram of the system

Fig. 1 shows those input from a pH sensor and a turbidity sensor. Both sensors' data inputs are processed. The Tsukamoto Fuzzy logic model is implemented to process data from the pH and turbidity sensors. The system's output is the form of control for the solenoid, whether on or off.

A. Hardware Design

The hardware design stage uses Arduino pH sensor circuit, the Arduino turbidity sensor circuit, and the Arduino solenoid valve circuit, as explained in the following lines.

1) The pH sensor detects pH levels in the water. The connection between pH sensor circuit and Arduino can be seen in Fig. 2.

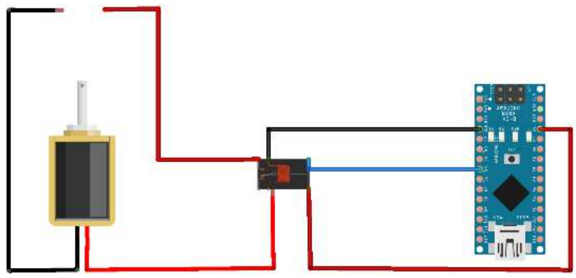

Fig. 2 pH sensor circuit

Fig. 2 is communication between pH sensor modules and Arduino using analog data, where the PO pin on the pH sensor module is connected to the analog pin A0 on Arduino nano. The power source on the pH sensor module links to the 5V pin on the Arduino nano, and the G2 pin on the pH sensor module is put on to the ground pin on the Arduino nano.

2) The turbidity sensor design circuit with Arduino can be seen in Fig. 3.

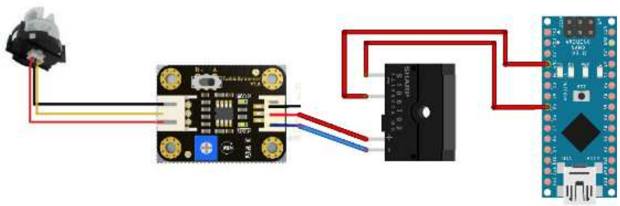

Fig. 3 Turbidity sensor circuit

Fig. 3 shows that the turbidity sensor is linked to the turbidity amplifier modules and sends the measurement data to Arduino nano.

3) Solenoid valves have the function of draining water. An additional circuit is required to run the solenoid valve, which there is a relay as the switch. The relay is used because the voltage source used to run the solenoid valve is 12 Volts, while the main voltage coming from Arduino is 5 Volts. The solenoid valve circuit design with Arduino is illustrated as shown in Fig. 4.

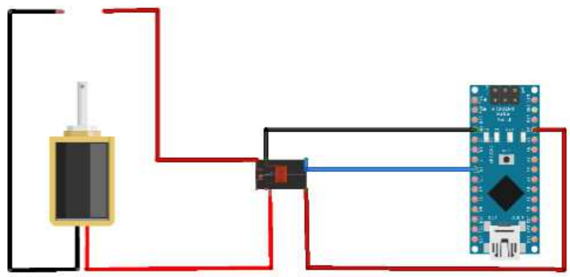

Fig. 4 Solenoid circuit

Fig. 4 is a solenoid valve circuit linked to Arduino. The solenoid valve is connected to a 12 volts power adapter and relay circuit at pin 2. The adapter is also associated with pin 1 of the relay circuit.

B. Software Design

The software design stage for each component explains the programming of the pH sensor, turbidity sensor, solenoid valve, and Fuzzy logic calculation based on the Tsukamoto model. The system flowchart can be seen in Fig. 5.

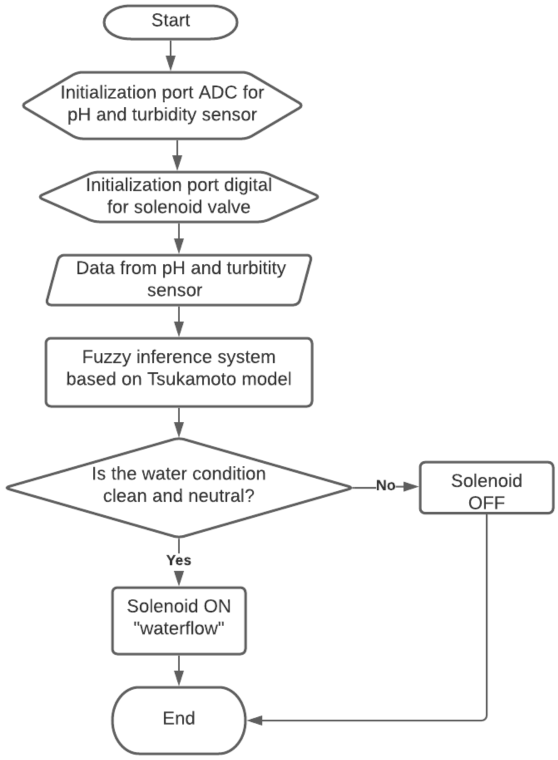

Fig. 5 System flowchart

The system flowchart as in Fig. 5 describes the system starting with initialization ADC and digital port for pH sensor, turbidity sensor, and solenoid valve. Using fuzzy inference system, the solenoid valve conditions determine whether the solenoid valve is on or off. If the water condition is clean and neutral, then the solenoid will turn on, and if the other conditions are reached, the solenoid will turn off. The program design stage for each component, starting from the pH sensor, turbidity sensor, and solenoid valve to the calculation of the Tsukamoto fuzzy logic, can be explained as follows.

1) The pH sensor calculation begins with obtaining 10 data from the ADC sensor, then calculates the average data from the ADC pH sensor. After that, the average data with 5 volts reference voltage is divided by the ADC bit value, i.e., 10 bits (210) is 1024. The calculation yields the electric voltage value. The conversion from electric voltage to pH value is by multiplying the value of the electric voltage from the ADC calculation with a neutral pH value of 7. Then the multiplication is subtracted with the calibration value. The calibration value is used so that the value calculated by the pH sensor is the same as a result on litmus paper.

2) The turbidity sensor process obtains the ADC turbidity sensor data and converts the ADC value into electric voltage. The results of turbidity sensor measurement will appear on the Arduino sketch monitor series as water turbidity level conditions.

3) The solenoid will run by giving a voltage of 5 volts or logic HIGH and a voltage of 0 volts or logic LOW in the relay circuit. The relay circuit is not active when the Arduino output is HIGH or 5 Volt logic. Therefore, the solenoid valve voltage is 0 volts, and the solenoid valve status is off. In contrast, the relay circuit is active when Arduino output is LOW or 0 Volt logic. After that, the voltage measured on the solenoid valve is 12 volts, and the solenoid valve status is on. It can be concluded that Arduino output must be a LOW or 0-volt logic on digital port 5 to activate the solenoid valve.

In this research, fuzzy logic starts with fuzzy set determination. There are three membership functions for the fuzzy set of pH sensors, i.e., acid, neutral, and base. The membership functions can be modeled as

For acid membership,

$$\mu PH_{acid}(x) = \begin{cases} 0\,; & x \geq 7 \\ \frac{7-x}{7-6}\,; & 6 < x < 7 \\ 1\,; & x \leq 6 \end{cases} \tag{1}$$

For neutral membership,

$$\mu PH_{neutral}(x) = \begin{cases} 0\,; & x \leq 6 \; atau \; x \geq 8 \\ \frac{x-6}{7-6}; & 6 < x < 7 \\ \frac{8-x}{8-7}\,; & 7 \leq x < 8 \end{cases} \tag{2}$$

For alkaline membership,

$$\mu PH_{alk}(x) = \begin{cases} 0\,; & x \leq 7 \\ \frac{x-7}{8-7}\,; & 7 < x < 8 \\ 1\,; & x \geq 8 \end{cases} \tag{3}$$

The turbidity sensor membership functions are clear water, slightly cloudy water, and dirty water with the following member functions. The functions can be seen as follows.

For dirty water,

$$\mu TR_{dirty}(x) = \begin{cases} 0\,; & x \geq 3{,}34 \\ \frac{3{,}34-x}{3{,}34-3{,}28}\,; & 3{,}28 < x < 3{,}34 \\ 1\,; & x \leq 3{,}28 \end{cases} \tag{4}$$

For slightly cloudy water,

$$\mu TR_{slighty}(x) = \begin{cases} 0\,; & x \leq 3{,}28 \; or \; x \geq 3{,}36 \\ \frac{x-3{,}28}{3{,}34-3{,}28}\,; & 3{,}28 < x < 3{,}34 \\ \frac{3{,}36-x}{3{,}36-3{,}34}\,; & 3{,}34 \leq x < 3{,}36 \end{cases} \tag{5}$$

For clean water,

$$\mu TR_{clean}(x) = \begin{cases} 0\,; & x \leq 3{,}34 \\ \frac{x-3{,}34}{3{,}34-3{,}28}\,; & 3{,}34 < x < 3{,}36 \\ 1\,; & x \geq 3{,}36 \end{cases} \tag{6}$$

The next step is to determine the basic fuzzy rules. The rules have been defined in Table 1.

TABLE I
FUZZY RULES

Fuzzy Rules						
k1	IF	pH = acid	AND	Turbidity = Dirty water	THEN	Solenoid OFF
k2	IF	pH = acid	AND	Turbidity = Slightly cloudy water	THEN	Solenoid OFF
k3	IF	pH = acid	AND	Turbidity = Clean water	THEN	Solenoid OFF
k4	IF	pH = neutral	AND	Turbidity = Dirty water	THEN	Solenoid OFF
k5	IF	pH = neutral	AND	Turbidity = Slightly cloudy water	THEN	Solenoid OFF
k6	IF	pH = neutral	AND	Turbidity = Clean water	THEN	Solenoid ON
k7	IF	pH = alkaline	AND	Turbidity = Dirty water	THEN	Solenoid OFF
k8	IF	pH = alkaline	AND	Turbidity = Slightly cloudy water	THEN	Solenoid OFF
k9	IF	pH = alkaline	AND	Turbidity = Clean water	THEN	Solenoid OFF

Based on the fuzzy rules in Table 1, the condition of the pH sensor and turbidity sensor will be processed, and the resulting value is then used to activate and deactivate the solenoid valve. The condition is obtained based on the level of water acidity combined with the level of clarity. After that, nine water conditions can be determined from the six rules.

The defuzzification process uses the Tsukamoto method, which multiplies the weight of each fuzzy rule with the resulting solenoid valve in an active condition, and the value is 1. If the solenoid valve is not active, then the value is 0.1. Based on the Tsukamoto method, a table for defuzzification can be explained in Table 2.

TABLE II
DEFUZZIFICATION OF SOLENOID VALVE

		pH		
		acid	**neutral**	**alkaline**
Turbidity	Dirty Water	Solenoid OFF	Solenoid OFF	Solenoid OFF
	Slightly cloudy water	Solenoid OFF	Solenoid OFF	Solenoid OFF
	Clean Water	Solenoid OFF	Solenoid ON	Solenoid OFF

The defuzzification process results in a value, which if the solenoid valve in the predetermined rule is greater than or equal to 0.50, then the solenoid valve will turn on, and the valve opens so that water flows, and vice versa if the solenoid valve value is less than 0.50, then the solenoid valve will shut off, and the valve will close, so that water cannot flow out.

III. RESULTS AND DISCUSSION

The experiments include pH sensor testing, turbidity sensor testing, solenoid valve testing, and overall system testing. The experiment of pH sensor is by comparing the measurement results of the pH sensor with litmus paper, as shown in Fig. 6.

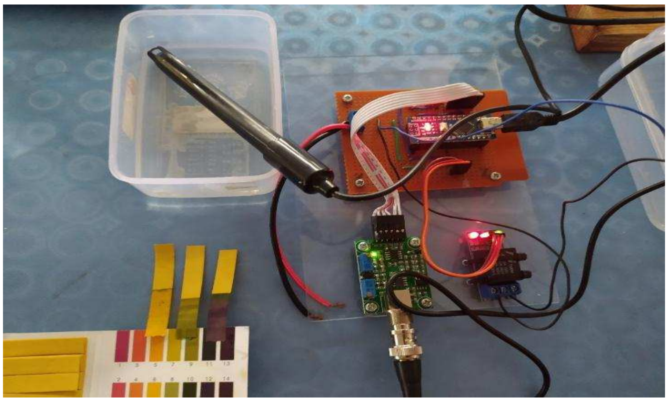

Fig. 6 Experimental setup of sensor pH

Fig. 6 shows that the data from the pH sensor is similar to litmus paper in neutral conditions. To test the sensor for measuring low pH, the experiment mixes mineral water and vinegar to obtain acidic conditions. The sensor measures pH of 4, which is the same as in the litmus paper. The other experiment combines lime and mineral water to determine alkaline conditions. The results prove that the sensor's data is the same as litmus paper. Both results from a data sensor and litmus paper is pH 13. All of the results can be seen in the Arduino sketch monitor series in Fig. 7.

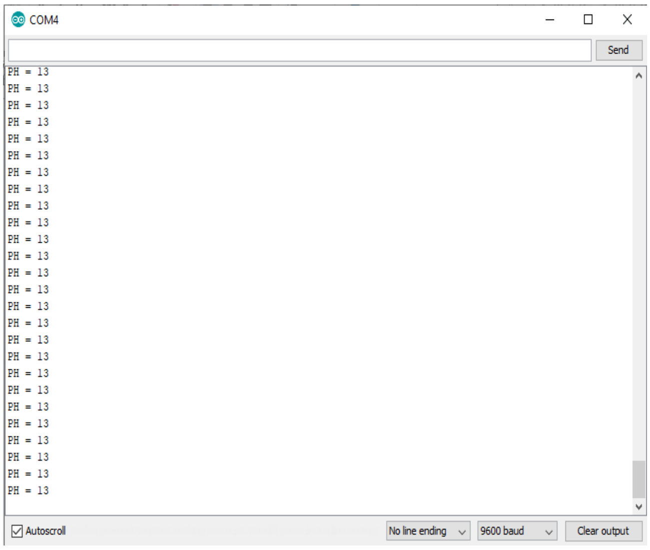

Fig. 7 Result of sensor data measurement for pH acid and alkaline

Turbidity sensor experiments are conducted by flowing water through the sensor. There are three types of water, i.e., clear mineral water, slightly cloudy mineral water, and colored water with a slightly dark color. The water is assumed as the water fountain conditions in the Air Force Academy. This result can be seen in Fig. 8. Fig. 8 shows the sensor measures the water conditions for clear mineral water. The result of mineral water being a bit cloudy and cloudy can be seen in Fig. 9.

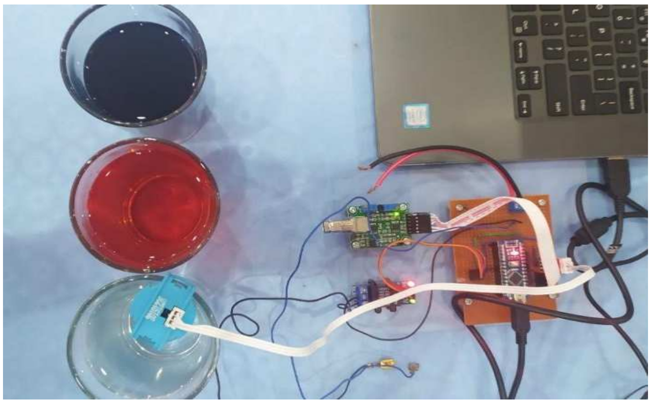

Fig. 8 Experimental setup of turbidity sensor for clean and slightly cloud water

Fig. 9 illustrates the water in a bit cloudy and cloudy mineral water condition. It can be seen from the data that an average calculation is carried out to determine voltage in the three water conditions, i.e., clear water, slightly cloudy water, and cloudy water. The average calculation can be seen in Table 3.

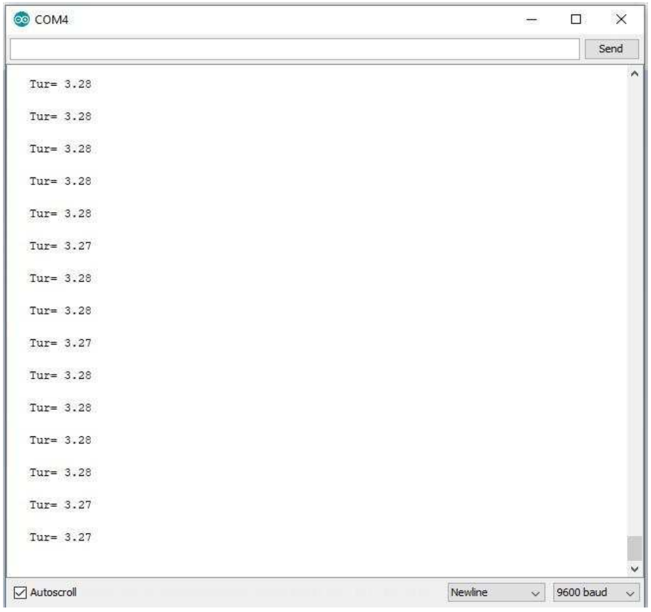

Fig. 9 Result of turbidity sensor on a serial monitor for slight cloud and dirty water

Based on the data, the turbidity sensor obtains voltage for clear water above 3.36 Volts, a bit cloudy water is at a voltage between 3.29 Volts to 3.35 Volts, and cloudy water is at a voltage less than 3.28 Volts. The data will be used to determine the fuzzy Tsukamoto model calculation for the overall test. The solenoid valve functions as a filter; when the water is determined unhealthy, the solenoid valve will automatically close the water flow, but when the water is considered healthy, the solenoid will drain the water. Solenoid valve testing can be illustrated in Fig. 10.

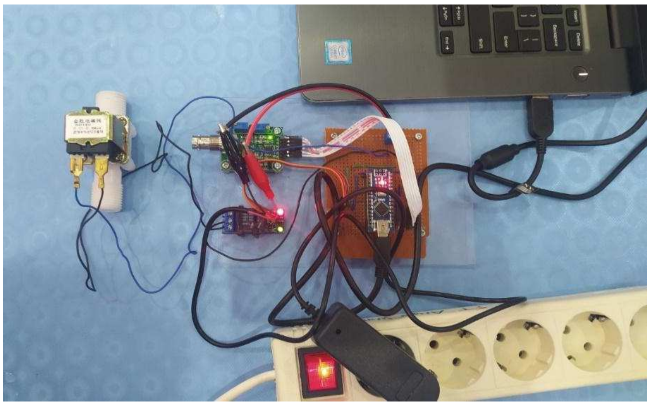

Fig. 10 Experimental setup for solenoid valve

Fig. 10 shows that the solenoid is conducted by giving a voltage of 5 Volts or logic HIGH and a voltage of 0 Volts or LOW logic in the relay circuit. The fuzzy set for pH sensor membership is obtained based on previous pH sensor testing results. The data from the pH sensor test results have been accumulated to produce a fuzzy set graph, as in Fig. 11.

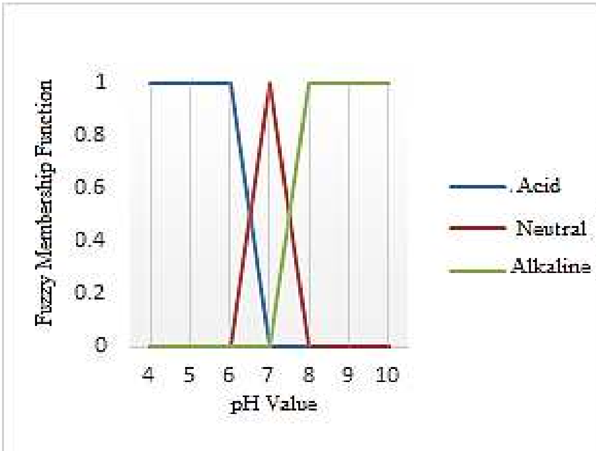

Fig. 11 Fuzzy membership function of pH sensor

Fig. 11 shows there are three membership functions, i.e., acid, neutral and alkaline. The middle point is the neutral membership, where the pH neutral is 7, ranging from pH 6.5 to pH 7.5. While the acid membership has a pH less than 6, and the alkaline membership has a pH above 8.

The fuzzy set for turbidity sensor membership is based on turbidity sensor testing. The fuzzy membership function of turbidity sensors is as in Fig. 12. Fig. 12 is a fuzzy set for a turbidity sensor that is divided into three membership functions. The memberships are clean water, slightly cloudy water, and dirty water.

Fuzzy testing is carried out by inserting water with four conditions that can be seen in Fig. 13 shows that four water conditions were tested on the designed tool. The first glass contains mineral water, the second glass contains mineral water mixed with dyes, the third glass has mineral water mixed with vinegar, and the fourth glass contains mineral water mixed with lime.

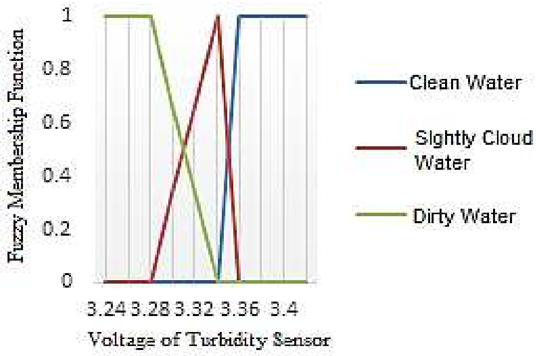

Fig. 12 Fuzzy membership function of turbidity sensor

In the experiment, each water is inserted into a series of pipes that have been installed with pH sensors, turbidity sensors and solenoid valves. In Fig. 14, it can be seen that the result of pH sensor is as in the following lines. Neutral water has 7.12 of pH with 3.48 Volts of turbidity sensor voltage, and the solenoid valve is ON.

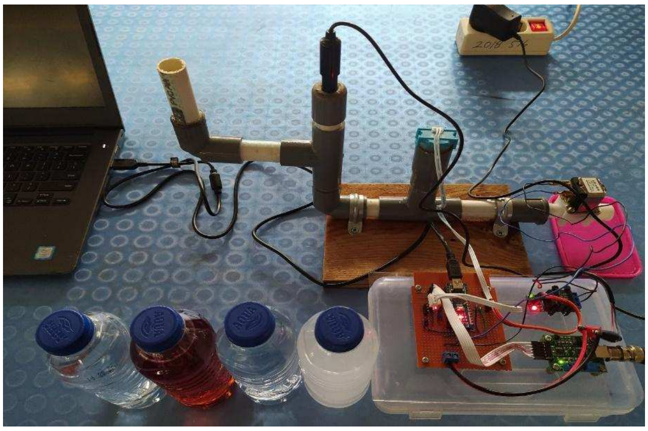

Fig. 13 Overall testing using four water conditions; (1) Mineral Water, (2) Colored Mineral Water (3) Mineral Water with Vinegar, and (4) Mineral Water with Lime.

The results are obtained in the serial monitor from the first condition, as shown in Fig. 15.

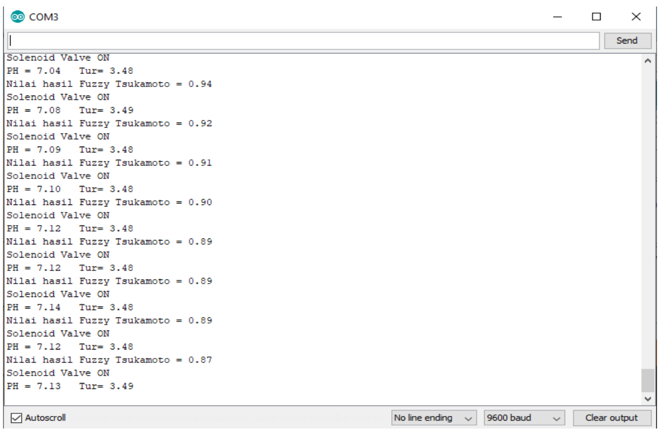

Fig. 14 Result of mineral water

The second condition is when mineral water mixed with dye is inserted into a series of pipes. The results can be seen in Fig. 15.

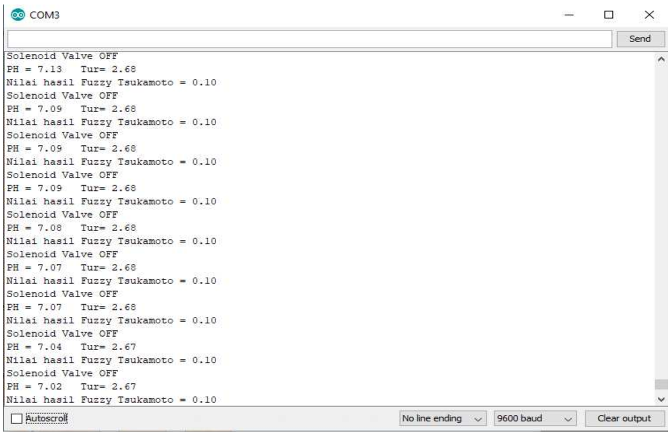

Fig. 15 Result of mineral water mixed with dyes

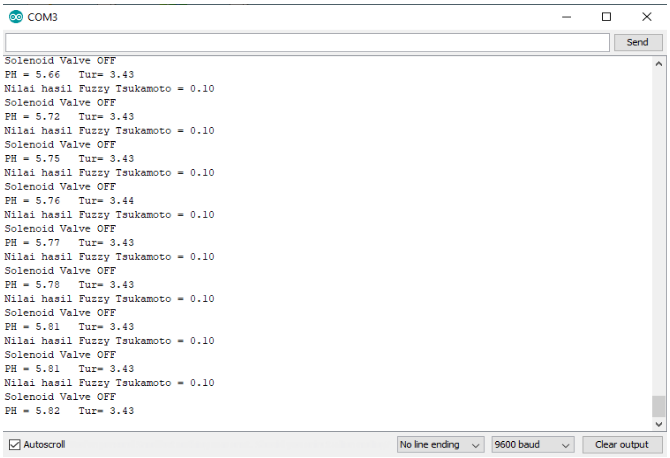

Fig. 16 Result of mineral water mixed with vinegar

From Fig. 15, it can be seen that the measurement result of pH sensor is 7.04 on neutral water and the turbidity sensor is about 2.68 Volts. Therefore, the solenoid valve is OFF.

The third condition is mineral water mixed with vinegar water. The water is inserted into a series of pipes. The measurement results are obtained in the serial monitor, as shown in Fig. 16. From Fig. 16, it can be seen that the results of the pH sensor on acidic water are 5.77, the turbidity sensor is 3.43 Volts, and then the solenoid valve is OFF. The fourth condition is mineral water mixed with lime water inserted into a series of pipes. The results on the serial monitor are shown in Fig. 17.

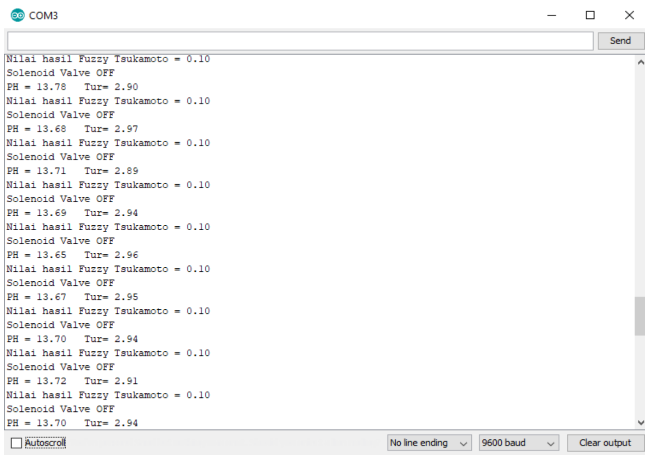

Fig. 17 Result of mineral water mixed with lime

Fig. 17 shows that the measurement of pH sensor on alkaline water is 13.65, the turbidity sensor is 2.94 Volts, and the solenoid valve is OFF. The comprehensive test on four water conditions gives the results in Table 3. From Table 3, it can be analyzed that an Arduino-based water filter system with the proposed fuzzy rule runs well. Although the overall test of each sensor produces an error of around 0.02-0.06, it does not affect the fuzzy calculation. System success indicates the solenoid is ON when the water is in normal pH and clear conditions. In the other conditions, the system determines the solenoid condition OFF.

TABLE III
OVERALL TEST RESULT

Water Condition	**Sensor pH (pH)**	**Turbidity Sensor (Volt)**	**Solenoid Valve Status**
Pure mineral Water	7.12	3.48	Solenoid ON
Mineral water + Dyes	7.08	2.68	Solenoid OFF
Mineral water + Acid	5.77	3.43	Solenoid OFF
Mineral Water + Lime	13.45	2.94	Solenoid OFF

IV. CONCLUSION

It can be concluded that the calculation of sensor data processed using fuzzy methods can be implemented as water filtering. The solenoid valve is only open when the water conditions are feasible to drink, and it is closed when the water conditions are not feasible to drink. Both of the valve conditions are based on the rules of the proposed fuzzy. The result proves that the fuzzy method of the Tsukamoto model can be used in the monitoring of water filters in water fountains.

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