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Implementation of Fuzzy Mamdani to Detect the Suitability of Drinking Water

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Abstract

Water is a liquid substance has no taste, smell and color. The constituent elements, there are hydrogen and oxygen with the chemical formula H2O. Because water has properties that can be used for almost anything, water is the most important substance for all forms of life (plants, animals and humans). Drinking water consumed by the public must meet quality and quantity requirements, the quality requirements of which are contained in Minister of Health Regulation no. 146 of 1990 concerning water quality requirements and supervision. The aim of this research is to design a detection tool with Arduino Mega that can measure the suitability of drinking water using a water pH sensor and TDS sensor. This methodology was prepared according needs for software and hardware, namely identification of needs, design, implementation and testing. The testing stage was divided into two, namely testing carried out on the water pH sensor with an average accuracy of 95.63% and the TDS sensor with an accuracy of 97.28%. Testing of the accuracy of the Mamdani system's fuzzy logic calculation method against manual calculations showed an average accuracy of 90.96%.

Keywords: *Arduino, Fuzzy Logic, Water pH, Total Dissolved Solid*

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INTRODUCTION

Drinking water is a basic necessity necessary for human survival. In general, all body organs need water to function properly, water is an important substance that makes up 50% - 60% of the body's composition. In the body, water has various functions, from improving digestion, maintaining body temperature balance, to helping the kidneys to clean waste from the body. Types of drinking water available on the market and their differences:

Mineral water, namely water obtained from mountain springs, so it is rich in minerals. The mineral content in water is beneficial for health, such as helping the body's metabolism, supporting kidney function, and helping the formation of cells and enzymes. Mineral water has a pH between 6 – 8.5. Demineralized water, namely water that contains almost no minerals because it has been processed many times. This type of water usually has a pH between 5 – 7.5.

Alkaline water, which is a type of water that has gone through an ionization or electrolysis process and usually contains a higher pH (8.5 – 9.97) (M. D. C. Pane, 2024).

One important factor in determining the suitability of water for human consumption is the TDS (total dissolved solid) content in the water. TDS is the amount of dissolved solids in the form of organic ions, compounds and colloids in water (WHO, 2024). The TDS value can help indicate whether the drinking water to be consumed is suitable or requires filtering, or is highly contaminated. The measurement used to measure drinking water is Parts per million (PPM). The following are the PPM value ranges for TDS 50-150: Very good for drinking. 150-250: Good for drinking. 250-300: Good enough to drink. 300-500: Bad or not good to drink. Above 1200: Very unfit to drink or dangerous (Makarim, R.F., 2024). Therefore, a tool is needed to test drinking water by classifying it into several categories. Fuzzy logic is one of the algorithm solutions used in this research. Fuzzy logic is an extension of Boolean logic which was developed by Lot Zadeh in 1965 based on the mathematical theory of fuzzy sets which is a generalization of classical set theory. By introducing the notion of degree in the verification of a condition, it allows the condition to be in a state other than true (Dernoncourt, F., 2013) (Czabanski, R., Jezewski, M., Leski, J. 2017).
Previous research, namely the application of fuzzy logic to a paddy soil suitability system based on soil pH and temperature, has been successfully carried out (Susilawati, 2019). As well as research on Clean Water Quality Analysis using Fuzzy Mamdani Logic, the results showed that it produced a value of 71.6 for PDAM and 63.3 for customer home water (Anuri, M., Sadrina, Islamadina, R., 2023). Another research is detecting water quality on the coast (Rusdin, A., Jumiyatun, 2022). Designing the detection of drinking water suitability levels using Fuzzy logic control, research conducted by Habiburrahman, M., and Fitriani E., 2024. Other research regarding the detection of drinking water suitability was carried out by Joniwarta, Priatna W., R., Asep, Alexander D, A., 2003 with the title Implementation of Fuzy Logic in an IoT-Based Mineral Water PH Control System.

METHODS

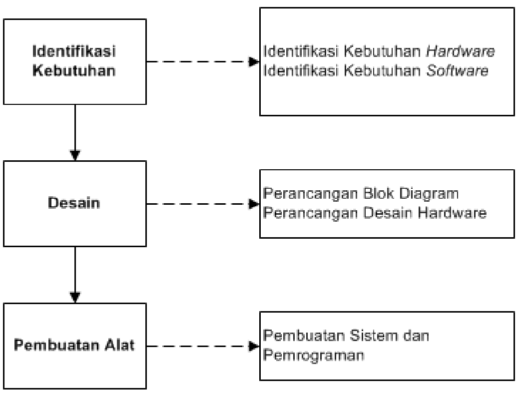

Figure 1. System Planning

Identify Needs

In the first stage, we will identify what needs are needed to make a tool to detect the suitability of drinking water, both hardware and software requirements.

The main hardware used as input, process and output includes a water pH sensor, a TDS sensor as system input, an Arduino ATMega 2560 microcontroller as a tool for processing the results of the sensor input, and an LCD as a display of the output of the process results. Meanwhile, the software used to create a drinking water suitability detection program is Arduino IDE.

Table 1 Hardware and Software Requirements

Hardware Requirements	Software Requirements
a. Mikrokontroler *Arduino ATMega 2560* b. Sensor pH Air c. Sensor TDS d. LCD 16x2 e. Kabel *Jumper Male to Female*	a. Arduino IDE b. *Proteus 8 Professional* c. *Windows 8 64-bit* d. *Processor Intel® Coleron®* n3050 e. Minimal RAM 2GB

Design

At the design stage, namely making block diagrams and designing tool designs using Proteus 8 Professional software. This stage aims to serve as a reference for designing a tool to detect the suitability of drinking water.

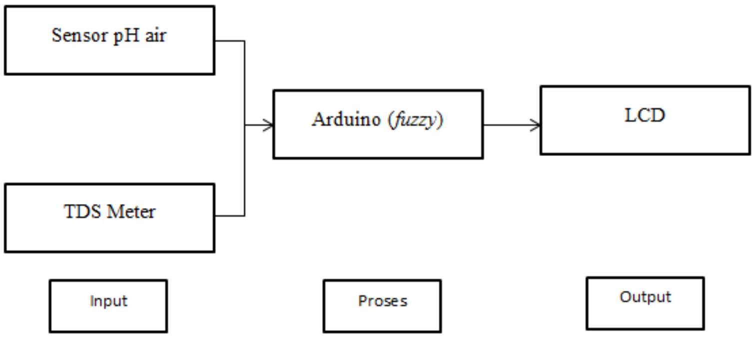

Figure 2 Block Diagram

In Figure 2, the block diagram of the system that will be created consists of input, process and output. In the data input process, this drinking water suitability detection tool uses a water pH sensor and a TDS sensor. Next, the input data is processed in the Arduino ATMega 2560 microcontroller using the fuzzy Mamdani model algorithm to produce an output of drinking water suitability.

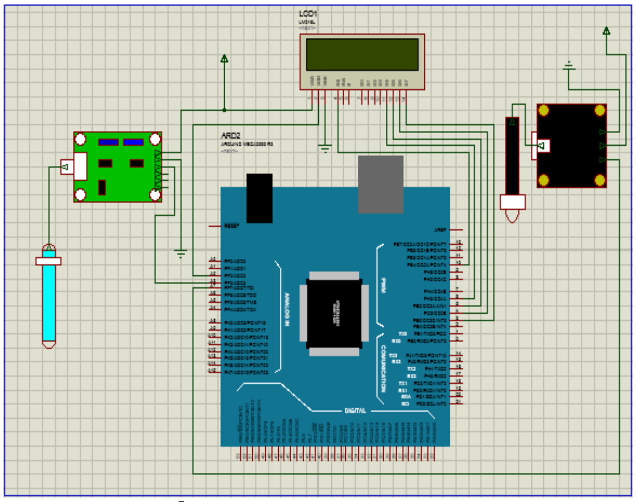

Figure 3 Tool Design Design

Tool making

At this stage, the suitability of drinking water will be detected using the fuzzy mamdani method in accordance with the tool design. At this stage, the suitability of drinking water will be detected using the fuzzy mamdani method in accordance with the tool design.

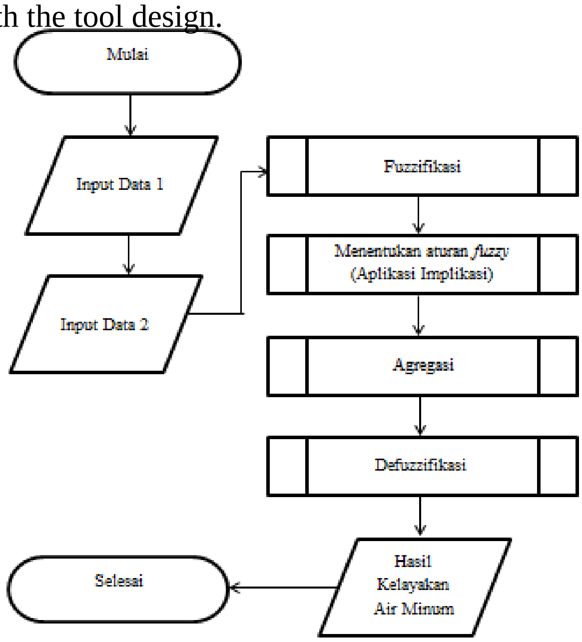

Figure 4 System Flowchart

Figure 4 explains how the system can detect the suitability of drinking water using the fuzzy mamdani method. First of all, the system will detect data 1, namely from the water pH sensor, and data 2, namely data from the TDS sensor. Then the input of these two data is processed on the Arduino ATMega 2560 microcontroller using the fuzzy mamdani method. To start the fuzzy mamdani process, it starts with Fuzzification, namely determining the degree of membership. The fuzzy sets used in this research are as follows:

PH; consists of three fuzzy sets, namely; ACID, NEUTRAL, and BASE

TDS; consists of three fuzzy sets, namely; VERY GOOD, GOOD, NOT GOOD.

Quality; consists of three fuzzy sets, namely; VERY WORTH IT, WORTH IT, and NOT WORTH IT.

Next, apply the implications or determine the appropriate rules using the min method for each rule. There are 9 rules that will be used in forming an implication function in this fuzzy method, including:

[R1] If the ACID PH and TDS are VERY GOOD, Then the Quality is DECENT.

[R2] If the ACID PH and TDS are GOOD, then the quality is DECENT.

[R3] If the ACID PH and TDS are NOT GOOD, then the quality is NOT WORTH IT.

[R4] If the PH is NEUTRAL and the TDS is VERY GOOD, then the quality is VERY DECENT.

[R5] If the PH is NEUTRAL and the TDS is GOOD, then the quality is VERY DECENT.

[R6] If the PH is NEUTRAL and the TDS is NOT GOOD, then the quality is NOT WORTH IT.

[R7] If the pH is BASED and the TDS is VERY GOOD, then the quality is DECENT.

[R8] If the pH is BASED and the TDS is GOOD, then the quality is DECENT.

[R9] If the pH is BASED and the TDS is LESS GOOD, then the quality is NOT WORTH IT.

The next stage is Aggregation, or composition of all the rules, the method used is the max method. The final stage is defuzzification, in defuzzification using the centroid method. The following is the calculation formula for defuzzification using the centroid method:

$$y* = \frac{\sum y\mu R(y)}{\sum \mu R(y)}$$

Field Test

Once the system is really working well, the next step is a field test or testing of the drinking water suitability detector. This testing stage aims to determine the effectiveness of the tool that has been created. Testing was carried out in three stages, namely testing the water pH sensor, testing the TDS sensor, and testing the tool that had been implemented by Fuzzy Mamdani.

Water pH Sensor Testing

Water pH sensor testing is carried out using a solution filled with buffer powder. This test was carried out using two buffer powders, namely buffer powder with a pH value of 4.01 and buffer powder with a pH value of 6.80, 100 samples were taken from each test result. The purpose of testing this water pH sensor is to determine the error level in the water pH sensor.

TDS Sensor Testing

At the TDS sensor testing stage, it is carried out using a TDS meter as a parameter. The results of this test were taken as many as 100 samples. The purpose of testing the TDS sensor is to determine the error level in the TDS sensor.

Fuzzy Mamdani Testing on Tools

At this testing stage, it is carried out using various solutions/liquids, namely solutions/liquids that have different pH and TDS levels. The results of this test will reveal two outputs, the first is the defuzzification output, and the second is the rule output. The purpose of this test is to find out whether the two outputs match. This test was carried out 10 times.

RESULTS AND DISCUSSION

Table 2 Test Results at pH parameter 4.01

Electrical Voltage (v)	**Results**	**pH value**	**|(y-y*)/y|**
	y	y*	
14,350	4.52	4.01	0.112831858
14,348	4.52	4.01	0.112831858
14,319	4.51	4.01	0.110864745
14,327	4.51	4.01	0.110864745
14,331	4.52	4.01	0.112831858
14,269	4.49	4.01	0.106904232
14,086	4.43	4.01	0.094808126
13,947	4.38	4.01	0.084474886
13,939	4.38	4.01	0.084474886
13,989	4.4	4.01	0.088636364

So the accuracy level obtained is 91.901% or has an error rate of 8.098%.

Table 3 Test results at pH parameter 6.86

Electrical Voltage (v)	**Results**	**pH value**	**|(y-y*)/y|**
	y	y*	
1,8948	6.63	6.86	0.034690799
1,8956	6.63	6.86	0.034690799
1,8864	6.6	6.86	0.039393939
1,8889	6.61	6.86	0.037821483
1,8940	6.63	6.86	0.034690799
1,8953	6.63	6.86	0.034690799
1,8956	6.63	6.86	0.034690799
1,9106	6.69	6.86	0.025411061
1,9238	6.73	6.86	0.019316493
1,9741	6.91	6.86	0.007235890

So the accuracy level obtained is 99.36652492% or has an error rate of 0.633475079%.

Table 4 TDS Sensor test results

No	**Results** Y	**Parameter y***	**|(y-y*)/y|**
1	47	44	0.0638298
2	47	44	0.0638298
3	47	44	0.0638298
4	45	44	0.0222222
5	43	44	-0.0232558
6	47	44	0.0638298
7	41	44	-0.0731707
8	43	44	-0.0232558
9	49	44	0.1020408
…			
100	29	44	-0.5172414

So the accuracy level obtained is 97.280188% or has an error rate of 2.7198121%.

Table 5 Testing Accuracy of Mamdani Fuzzy Logic Calculations

No	***Input***		***Output***		**Decision**	***Rule***
	TDS (*ppm*)	pH	Defuzzifikasi Sistem	Defuzzifikasi Manual		
1	3.79	5.69	4.41	4.46	Layak	R1
2	92.45	5.83	4.19	4.34	Layak	R1
3	100.77	6.17	4.59	3.64	Layak	R1
4	169.67	5.67	4.00	4.67	Layak	R2
5	214.49	5.70	4.04	4.61	Layak	R2
6	231.44	5.67	4.01	4.67	Layak	R2
7	262.41	5.96	4.34	5.18	Layak	R2
8	276.48	5.73	4.39	5.06	Tidak Layak	R3
9	282,78	4.68	4.7	5.3	Tidak Layak	R3

10	281.20	4.57	4.68	5.25	Tidak Layak	R3

Table 5 shows the results of testing the accuracy of Mamdani's Fuzzy Inference System (FIS) calculations. The error rate obtained using MAPE is 9.04% with an accuracy rate of 90.96% and the accuracy of the decision to run the rule is 100%. It is said to be 100% because in 10 trials the system can execute the correct decision according to the rules created.

Figure 5 Circuit of detection tools

Based on the results of testing and implementation between software and hardware, it shows that the system built can work as planned. The system is able to apply the Mamdani fuzzy logic method for measuring TDS and pH.
The implementation of the fuzzy logic Mamdani method is shown in the testing subchapter where the TDS measurement is 3.79 and pH 5.69, the system will display a notification or status of "Appropriate" on the LCD and serial monitor. The Mamdani fuzzy inference system process is as follows:

1. **Fuzzification**

The first step in the fuzzification process is the formation of fuzzy sets. The fuzzy set in this research is as follows:

a. Fuzzy set of TDS Variables

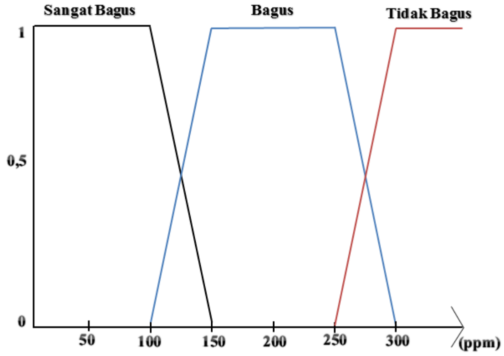

Figure 6 Fuzzy Set of TDS Variables

The membership function for representation in Figure 6 uses the following equations:

$$\mu \text{Very Good}(x) = \begin{cases} 1, & x \leq 100 \\ \dfrac{150 - x}{50}, & 100 \leq x \leq 150 \\ 0, & x \geq 150 \end{cases}$$

$$\mu good(x) = \begin{cases} 0, & x \leq 100 \; atau \; x \geq 300 \\ \dfrac{x - 100}{50}, & 100 \leq x \leq 150 \\ \dfrac{300 - x}{50}, & 250 \leq x \leq 300 \\ 1, & 150 \leq x \leq 250 \end{cases}$$

$$\mu Not\ Good(x) = \begin{cases} 0, & x \leq 250 \\ \dfrac{x - 250}{50}, & 250 \leq x \leq 300 \\ 1, & x \geq 300 \end{cases}$$

a) Linear Representation of Ascending Linear Curves (Very Good)

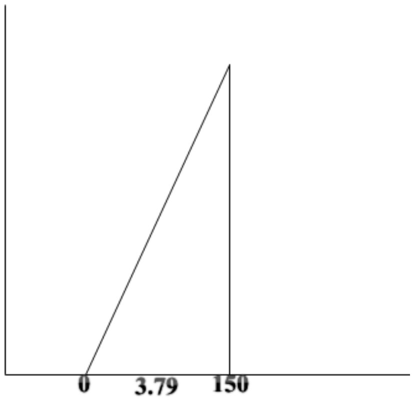

Figure 7 Degrees of Membership for Very Good

The crisp input TDS variable of 3.79 ppm goes straight into membership which is very good because it is based on the rule if x≤100=1.

Fuzzy Set of pH Variables

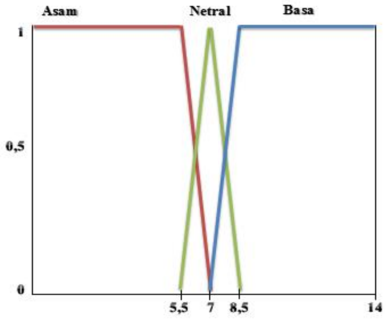

Figure 8 Fuzzy Set of pH Variables

The membership function for representation in Figure 8 uses the following equations:

$$\mu Asam(x) = \begin{cases} 1, & x \leq 5,5 \\ \frac{7 - x}{1,5}, & 5,5 \leq x \leq 7 \\ 0, & x \geq 7 \end{cases}$$

$$\mu Netral(x) = \begin{cases} 0, & x \leq 5,5 \\ \frac{x - 5,5}{1,5}, & 5,5 \leq x \leq 7 \\ \frac{8,5 - x}{1,5}, & 7 \leq x \leq 8,5 \\ 0, & x \geq 8,5 \end{cases}$$

$$\mu Basa(x) = \begin{cases} 0, & x \leq 7 \\ \frac{x - 7}{1,5}, & 7 \leq x \leq 8,5 \\ 1, & x \geq 8,5 \end{cases}$$

The next step is to determine the membership function of the variable pH crisp input 5.69.

a) Ascending Linear Curve Representation (Neutral)

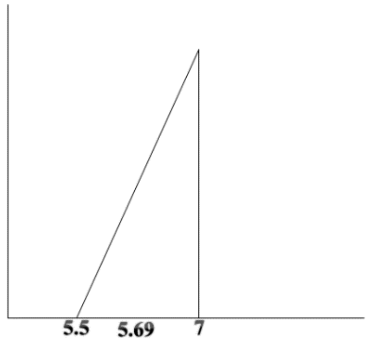

Figure 9 Membership Degrees for Neutral

$$al(x) = \begin{cases} 0, & x \leq 5,5 \\ \frac{x - 5,5}{1,5}, & 5,5 \leq x \leq 7 \\ \frac{8,5 - x}{1,5}, & 7 \leq x \leq 8,5 \\ 0, & x \geq 8,5 \end{cases}$$

$$\mu Basa(x) = \begin{cases} 0, & x \leq 7 \\ \frac{x - 7}{1,5}, & 7 \leq x \leq 8,5 \\ 1, & x \geq 8,5 \end{cases}$$

The next step is to determine the membership function of the variable pH crisp input 5.69.

b) Descending Linear Curve Representation (Acid)

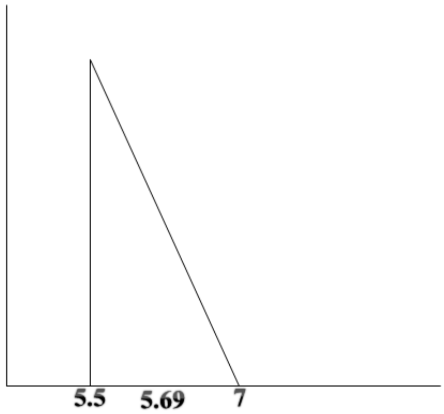

Figure 10 Membership Degrees for Acids

The calculation is as follows:

$$\frac{(b-x)}{(b-a)}\ ; a < x \leq b$$

and a=5.5 , b=7 , x=5.69

$$\frac{7-5.69}{7-5.5} = 0.8733$$

2. Application Implications

After knowing the membership values of TDS and pH, the next process is the application of the implication function using the Min method for each rule.

Rule 1

If the pH is Acid and TDS is Very Good then the notification is Eligible

Min [0.8333 ; 1] = 0.8333

Rule 2

If the pH is acidic and the TDS is good then the notification is appropriate

Min [0.8333 : 0] = 0

Rule 4

If the pH is Neutral and the TDS is Very Good then the notification is Very Appropriate

Min [0.19 ; 1] = 0.19

Rule 5

If the pH is Neutral and the TDS is Good then the notification is Very Appropriate

Min [0.19 ; 0] = 0

3. Aggregation or Composition Rules

The method used to perform composition between all rules is the max method.

Very Eligible [0 ; 0.19] = 0.19

Worth [0 ; 0.8333] = 0.8333

1. Defuzzification

In the defuzzification process, the centroid (Center of Area) method is used:

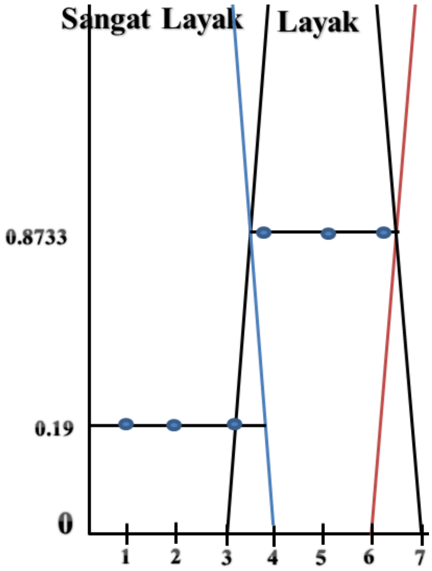

Figure 11 Defuzzification of the Centroid Method

$$*= \frac{\sum y\mu R(y)}{\sum \mu R(y)}$$

$$y* \quad = \frac{\big((1+2+3)*0.19\big)+((4+5+6)*0.8733)}{(3*0.19)+(3*0.8733)}$$

$$y*= \frac{14.2395}{3.1899}$$

$$y*= 4.46$$

Manual calculations produce a feasibility value of 4.46, while the system produces a feasibility value of 4.41. and the accuracy of rule processing decisions is 100%. Based on these results, it can be decided that at an input TDS of 3.79 ppm and pH 5.69 the system will display a notification "Appropriate" on the serial monitor.

CONCLUSION

Based on what was discussed previously, the test results of the drinking water suitability detection system using Fuzzy Mamdani obtained an accuracy value of 90.96% and an error value of 9.04%.

SUGGESTION

From the results of the research carried out, suggestions are given for further research references:

It is hoped that in further research other methods can be applied in implementing the fuzzy inference system, namely the Sugeno fuzzy method and the Tsukamoto fuzzy method.

Adding other chemical parameters in determining indicators of drinking water suitability

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