Indonesian Journal of Data and Science

Volume 6 Issue 1
ISSN 2715-9936
https://doi.org/10.56705/ijodas.v6i1.229

Research Article

Sugeno Fuzzy Logic for IoT-based Chicken Farm Drinking Water Quality Monitoring

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Received 17 December 2024; Accepted 10 March 2025; Published 31 March 2025

Abstract:

Introduction: The quality of drinking water plays a crucial role in the health and productivity of broiler chickens. In Indonesia, many poultry farms still rely on manual water testing using litmus paper, which may yield inaccurate results. This study aims to develop an Internet of Things (IoT)-based system integrated with the Sugeno fuzzy logic method to monitor and assess the quality of drinking water for broiler chickens in real time. **Methods**: An IoT prototype was developed using an ESP32 microcontroller, pH and turbidity sensors, and a cloud-based mobile application. Water quality data from 1,975 samples were collected over three days from a broiler farm in East Kalimantan using water sourced from a former mining lake. The system applies the Sugeno fuzzy inference system with 15 expert-defined rules to classify water quality into four categories: Very Good, Good, Bad, and Very Bad. Performance was evaluated using a Confusion Matrix. **Results**: The system achieved a classification accuracy of 96.76%, precision of 97.52%, recall of 98.79%, and F1-score of 98.15%. The results demonstrate the system's effectiveness in identifying water quality, with the majority of predictions falling into the correct class. The system also successfully transmitted real-time data to an Android application for monitoring purposes. **Conclusions**: The integration of IoT and Sugeno fuzzy logic provides a reliable, accurate, and scalable solution for real-time water quality monitoring in poultry farming. This system enhances decision-making for farmers, supports animal welfare, and can be further developed to include additional environmental parameters for broader livestock health monitoring.

Keywords: Broiler Chicken, Fuzzy Sugeno, IoT, pH, Turbidity.
Dataset link: https://docs.google.com/spreadsheets/d/1Az8ufBFfiGjS-tu3pcJ-DF4Cf7eO6mV-3pB2oduroFg/edit?usp=drive_link

1. Introduction

One of the technological revolutions that has changed the way we interact with our surroundings is the Internet of Things (IoT) [1], [2]. Internet of Things (IoT) is a technology that allows objects in the surrounding environment to be connected to the internet. the surrounding environment to connect to the internet [3]–[5]. IoT is able to provide services in order to interact with hardware that has been connected to the internet network. The intended interaction is the process of transferring and receiving data from the user to the device or vice versa [4]–[6]. IoT is very helpful in everyday life, so it provides many benefits for many fields. One of them is the field of animal husbandry.

The most common poultry livestock in Indonesia is broiler chicken poultry. Chickens have many breeds, one of the breeds in Indonesia is broiler chickens (broilers) whose cultivation is fast, usually ready to slaughtered when they are just 28-45 days. The rapid growth of chickens does not always go smoothly because the health of chickens can be disrupted or infected with disease. The object of this research is a farm in East Kalimantan Province, Indonesia. Like other farms in East Kalimantan, Sunardi's farm uses water sources from former mining basins, or so-called ex-mining lakes. These basins are left because of illegal mining and unclear government regulations regarding reclamation. Many people use these basins to watering plants or livestocks.

Water is one of the most important things for the chicken body. The largest constituent component in the chicken body is water which reaches 60-85% of all parts of its body. From the results of the interview for this study on Sunardi's farm, the chicken drinking water from the former mining lake was collected for several days and then checked for the ph of the water. Checking water still uses litmus paper. The level of accuracy of litmus paper measurement results cannot be up to the value of one digit behind the comma which increases the possibility of reading errors in pH values. Therefore, the existence of iot technology plays an important role in water quality for broiler livestock.

The design of the IoT tool uses a pH sensor and turbidity sensor whose results will be read from the two sensors and then processed by a microcontroller. There are several parameters that can be used as a measure of water quality. In this study using two parameters as a measure of water quality, namely pH and turbidity. This research applies the Sugeno fuzzy method to assess the level of water quality based on the parameters that have been mentioned.

2. Method:

In this research, the author describes the stages of research that are passed systematically in order to provide a clear and structured picture.

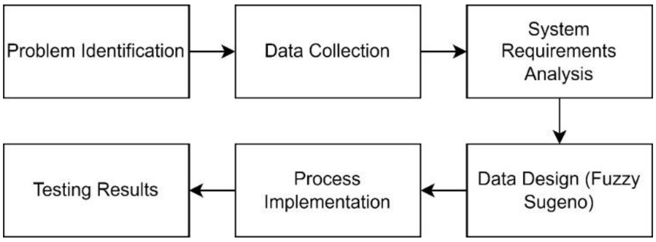

Figure 1. Stages of research implementation

Figure 1 illustrates the sequence of steps in conducting research using fuzzy logic, the explanation of **Figure 1** is as follows:

a. Problem Identification
According to [7], research and problem formulation is one of the most important aspects in conducting research in any field. Drinking water provided to farmed chickens must meet certain quality standards to keep the chickens healthy and productive. One of the key parameters is the pH of the water. The optimal pH value for chicken drinking water is in the range of 6 to 8. Changes in pH can be caused by various factors, such as fouling, feed residues that dissolve in water, or other contamination. Therefore, a system is needed that can monitor the pH level of chicken drinking water.

b. Data Collection
The data collection stage is the process of gathering relevant information or facts to answer research questions or solve problems [8]. Collecting data that will be used as research variables [9].

c. System Requirements Analysis
Analyze the needs of the water quality monitoring system to be built [1], [10]. This stage includes analyzing what devices are needed in the process of designing and building the system.

d. Data Design (Fuzzy Sugeno)
Determining the data that will be used as input and output. Input data will pass through several stages in the fuzzy logic process which will determine the output [11].

e. Process Implementation
Designing an IoT device and assembling its components so that they are well integrated to form a control system that can monitor water quality. This system will produce outputs in accordance with the objectives set, such as information on pH and water turbidity that can be used to make decisions regarding water quality.

f. Testing Results

Evaluate the system by testing the results obtained and comparing with the standard.

3. Results and Discussion

System Specification

There are several system requirements, that can be seen in Table 1 and Table 2.

Table 1. Hardware Specifications

No	Hardware	Description
1	Laptop	RAM 4 GB and above, Windows 10 and above
2	Mikrokontroler	Using ESP32
3	Turbidity Sensor	Using Turbidity Sensor (Water Turbidity) SEN0189
4	pH Sensor	Using PH-4502
5	OLED	LCD OLED 0.96 inchi IIC 128X64 Pixel I2C
6	Adapter	Using 5V
7	Kabel	Using *jumper*
8	*Push Button*	For *on/off* sistem

Table 2. Software Specification

No	Perangkat Lunak	Keterangan
1	IDE	For Writing scripts
2	Matlab	Used for method testing
3	Library	A collection of program code
4	Kodular	As an IoT interface
5	Antares	Server, Database

Sugeno Fuzzy Logic Implementation

The data collected will be processed using the Fuzzy Sugeno method to determine water quality. Based on Figure 2, there are 2 variables to determine water quality, namely, water pH and water turbidity. pH and turbidity act as inputs and will be processed using a Fuzzy Inference System with the Sugeno method [12]–[14].

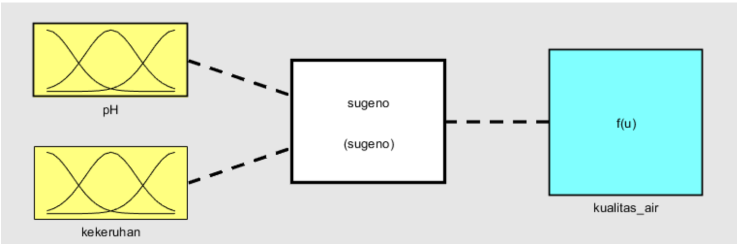

Figure 2. Sugeno Fuzzy Logic Design

A fuzzy set is a collection of values that represent a certain condition or state in a fuzzy variable [15], [16]. The following is the determination of the fuzzy set in the water quality monitoring system [17]:

a. Input Variable

Table 3. Input Variable Set

Function	Variable	Set	Universe Speaker
Input	pH	*Strong Acid*	0 – 5.5 pH
		Acid	5 – 6.5 pH
		Normal	6 – 8 pH
		Alkali	7.5 – 9 pH
		Strong Alkali	8.5 – 14 pH
	Turbidity	*Not Turbid*	0 – 5 NTU

Function	Variable	Set	Universe Speaker
		Turbid	4 – 25 NTU
		Very Turbid	24 – 30 NTU

Based on **Table 3**, a graph of the pH and turbidity variables can be drawn.

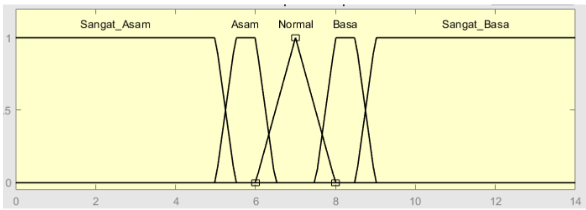

Figure 3. pH Variable Set Graph

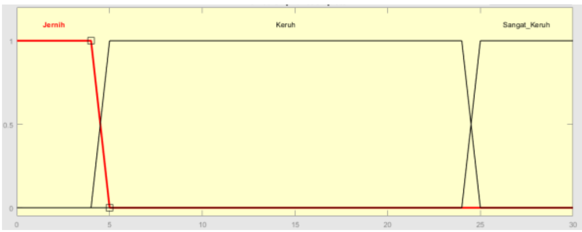

Figure 4. Turbidity Variable Set Graph

b. Output Variable

Fuzzy rules for the water pH control system based on the results of interviews at Broiler Farms there are 15 rules, namely:

Table 4. Fuzzy Rules Based on Interview

No	Code	Condition
1	R1	If *(pH is Normal)* and *(Turbidity* is *Not Turbid)* then *(kualitas_air* is *Sangat_Good)*
2	R2	If *(pH is Normal)* and *(Turbidity* is *Turbid)* then *(kualitas_air* is *Good)*
3	R3	If *(pH is Normal)* and *(Turbidity* is *Sangat_Turbid)* then *(kualitas_air* is *Sangat_Bad)*
4	R4	If *(pH is Acid)* and *(Turbidity* is *Not Turbid)* then *(kualitas_air* is *Good)*
5	R5	If *(pH is Acid)* and *(Turbidity* is *Turbid)* then *(kualitas_air* is *Bad)*
6	R6	If *(pH is Acid)* and *(Turbidity* is *Sangat_Turbid)* then *(kualitas_air* is *Sangat_Bad)*
7	R7	If *(pH is Alkali)* and *(Turbidity* is *Not Turbid)* then *(kualitas_air* is *Good)*
8	R8	If *(pH is Alkali)* and *(Turbidity* is *Turbid)* then *(kualitas_air* is *Bad)*
9	R9	If *(pH is Alkali)* and *(Turbidity* is *Sangat_Turbid)* then *(kualitas_air* is *Sangat_Bad)*
10	R10	If *(pH is Sangat_Acid)* and *(Turbidity* is *Not Turbid)* then *(kualitas_air* is *Sangat_Bad)*
11	R11	If *(pH is Sangat_Acid)* and *(Turbidity* is *Turbid)* then *(kualitas_air* is *Sangat_Bad)*
12	R12	If *(pH is Sangat_Acid)* and *(Turbidity* is *Sangat_Turbid)* then *(kualitas_air* is *Sangat_Bad)*
13	R13	If *(pH is Sangat_Alkali)* and *(Turbidity* is *Not Turbid)* then *(kualitas_air* is *Sangat_Bad)*
14	R14	If *(pH is Sangat_Alkali)* and *(Turbidity* is *Turbid)* then *(kualitas_air* is *Sangat_Bad)*
15	R15	If *(pH is Sangat_Alkali)* and *(Turbidity* is *Sangat_Turbid)* then *(kualitas_air* is *Sangat_Bad)*

The defuzzification process takes the fuzzy values obtained from the fuzzy rules as input and produces a firm value in the domain of the fuzzy set as output [18], [19]. The Sugeno method performs defuzzification by calculating the weighted average value [20], [21]. Based on **Table 4** using the following formula [22]–[25]:

$$Z^* = \frac{\sum \mu_i z_i}{\mu_i} \tag{1}$$

Description:
Z^*= Weight Average Value
μ_i= a i-th Prediction
z_i= i-th Consequent

Installation and Application

This stage is the process of connecting the microcontroller with the pH and turbidity sensors and some other hardware requirements as in **Table 1**. In **Figure 5**, you can see the circuit of the chicken drinking water quality monotoring system.

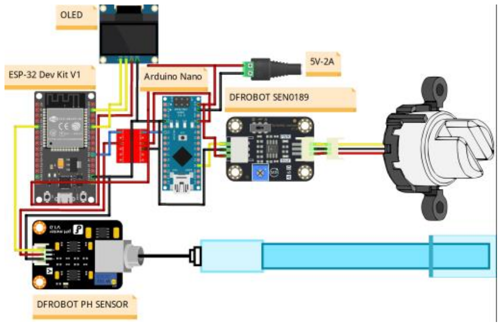

Figure 5. Monitoring System Schematic

The implementation results of this scheme can be seen in **Figure 6**.

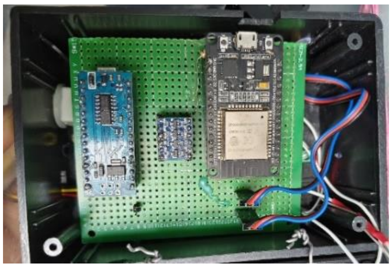

Figure 6. Hardware Implementation

Then the installation of the IoT device of the chicken drinking water quality monitoring system is placed on the water reservoir for data acquisition.

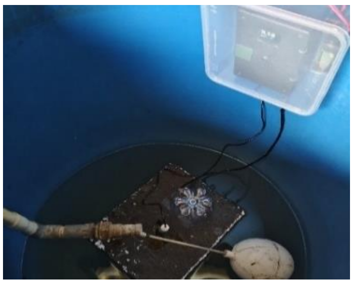

Figure 7. IoT Device Installation

The software used is the Arduino IDE using additional libraries needed such as libraries for pH and water turbidity sensors and libraries for wifi modules.

Figure 8. Coding on Arduino IDE

Based on **Table 2**, the application of the android application display using the Kodular platform can be seen in **Figure 9**.

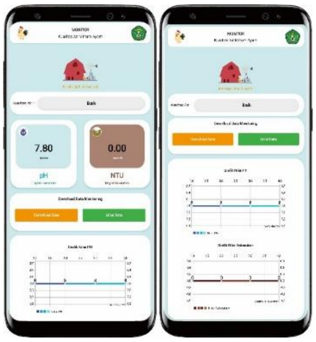

Figure 9. Application of Android Display

Sensor Result Data

After installation and application have been successfully carried out, the data collected can be seen in **Table 5**.

Table 5. Data Acquisition Results

No.	Date	Hour	PH	Turbidity
1	28/10/2024	0:00:23	8.57	5.74
2	28/10/2024	0:01:27	8.68	0.03
3	28/10/2024	0:02:28	8.54	0.03
4	28/10/2024	0:03:31	8.64	0.00
5	28/10/2024	0:04:34	8.57	0.03
6	28/10/2024	0:05:36	8.52	0.03
7	28/10/2024	0:06:39	8.55	0.03
8	28/10/2024	0:07:41	8.63	0.00
9	28/10/2024	0:08:44	8.54	0.00
10	28/10/2024	0:09:46	8.62	0.00
⋮	⋮	⋮	⋮	⋮
1966	30/10/2024	23:19:29	5.38	0.03
1967	30/10/2024	23:20:31	5.25	5.74
1968	30/10/2024	23:21:34	5.27	0.03
1969	30/10/2024	23:22:37	5.38	0.00
1970	30/10/2024	23:23:39	5.45	0.03
1971	30/10/2024	23:24:43	5.05	0.03
1972	30/10/2024	23:25:45	5.44	0.00
1973	30/10/2024	23:26:49	5.32	0.00
1974	30/10/2024	23:27:59	5.08	0.03
1975	30/10/2024	23:28:53	5.25	0.00

The data obtained consists of 1975 data collected over three days with 24 hours. Data was collected at this time because there are several factors that affect the pH and turbidity conditions in the water reservoir. These factors include impurities that enter when filling water into the reservoir from the remaining sediment in the previous reservoir. The data graph of the monitoring results can be seen in **Figure 10**.

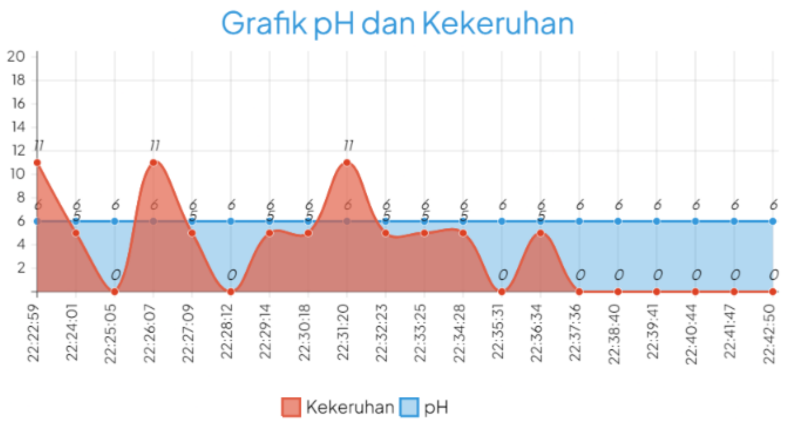

Figure 10. Monitoring Data Graph of pH and Turbidity

Application of Fuzzy Logic

Based on **Table 5** data number 389 with a pH value of 6.49 and a turbidity value of 11.46, Then, the application of Sugeno Fuzzy logic can be generated as follows:

a. Fuzzification

Fuzzification result and rule implementation can be seen in **Table 6** and **Table 7**.

Table 6. Fuzzification Result

Variable	Set	Result
pH	*Strong Acid*	0
	Acid	0,02
	Normal	0,49
	Alkali	0
	Strong Alkali	0
Turbidity	*Not Turbid*	0
	Turbid	1
	Very Turbid	0

Table 7. Rule Implementation Result

Rule	a - predicate
[R1]	0
[R2]	0,49
[R3]	0
[R4]	0
[R5]	0,02
[R6]	0
[R7]	0
[R8]	0
[R9]	0
[R10]	0
[R11]	0
[R12]	0
[R13]	0
[R14]	0
[R15]	0

b. Defuzzification

Calculation is conducted to determine the percentage of membership values between *"Bad"* and *"Good"* conditions. Based on **Table 4**, the value of the output set BA = 0.6 and *"Bad"* = 0.4. The calculation process can be seen in **Table 8**.

Table 8. Calculation of Percentage of Output Membership Value

Distance between values *"Good"* dan *"Bad"*	$\mathbf{0.6 - 0.4 = 0.2}$
Contribution of each value	- Distance from defuzzification result (0.59) to *"Good"* (0.6) is : $0.6 - 0.59 = 0.01$ - Distance from defuzzification result (0.59) ke *"Bad"* (0.4) is : $0.59 - 0.4 = 0.19$
Percentage contribution	- Percentage for value *"Good"*: $\frac{0.19}{0.2} \times 100\,\% = 95\%$ - Percentage for value *"Bad"*: $\frac{0.01}{0.2} \times 100\,\% = 5\%$

Based on **Table 8**, the percentage for the *"Good"* membership value is 95% while the *"Bad"* membership is 5%. This means that the pH value of 6.49 and Turbidity of 11.46 the quality of chicken drinking water is *"Good"*.

Table 9. Water Condition Determination Using Sugeno Fuzzy Method

No.	Date	Hour	PH	NTU	Water Quality
1	28/10/2024	0:00:23	8.57	5.74	*Bad*
2	28/10/2024	0:01:27	8.68	0.03	*Good*
3	28/10/2024	0:02:28	8.54	0.03	*Good*
4	28/10/2024	0:03:31	8.64	0.00	*Good*
5	28/10/2024	0:04:34	8.57	0.03	*Good*
6	28/10/2024	0:05:36	8.52	0.03	*Good*
7	28/10/2024	0:06:39	8.55	0.03	*Good*
8	28/10/2024	0:07:41	8.63	0.00	*Good*
9	28/10/2024	0:08:44	8.54	0.00	*Good*
10	28/10/2024	0:09:46	8.62	0.00	*Good*
⋮	⋮	⋮	⋮	⋮	⋮
1966	30/10/2024	23:19:29	5.38	0.03	*Good*
1967	30/10/2024	23:20:31	5.25	5.74	*Bad*
1968	30/10/2024	23:21:34	5.27	0.03	*Good*
1969	30/10/2024	23:22:37	5.38	0.00	*Good*
1970	30/10/2024	23:23:39	5.45	0.03	*Good*
1971	30/10/2024	23:24:43	5.05	0.03	*Very Bad*
1972	30/10/2024	23:25:45	5.44	0.00	*Good*
1973	30/10/2024	23:26:49	5.32	0.00	*Bad*
1974	30/10/2024	23:27:59	5.08	0.03	*Very Bad*
1975	30/10/2024	23:28:53	5.25	0.00	*Very Bad*

Table 9 displays all data with water quality conditions that have been determined using the Fuzzy Sugeno method.

Test Results

Testing the Fuzzy Sugeno method in this study using Confusion Matrix, testing is based on the results of predicting water quality conditions using 1975 data obtained from the pH and turbidity monitoring system for chicken drinking water on October 28, 2024 to October 30, 2024. The test results can be seen in **Table 10**.

Table 10. Testing Results of Sugeno Fuzzy Method

	Prediction

Confusion Matrix		*Very Good*	*Good*	*Bad*	*Very Bad*
Actual	***Very Good***	142	12	0	0
	Good	0	1149	25	0
	Bad	0	0	530	0
	Very Bad	0	0	27	90

Table 10 shows that there are four classes used in method testing, *"Very Good"*, *"Good"*, *"Bad"*, *"Very Bad"*.

4. Conclusion

This research has yielded several key conclusions. Firstly, the developed IoT device successfully transmits data to the server, which is then displayed on the Android application. Secondly, the Fuzzy Sugeno method was effectively implemented to determine the quality of chicken drinking water. Thirdly, the determination of chicken drinking water quality was achieved using a set of 15 fuzzy rules. Finally, system testing, conducted using the Confusion Matrix method, demonstrated excellent performance, with results showing an accuracy of 96.76%, precision of 97.52%, recall of 98.79%, and an F-score of 98.15%.

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