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Implementation of Tsukamoto Fuzzy Logic in IoT Based Dam Water Level Measuring System Using Nodemcu ESP8266

[1*] Sofyan, [2] Siti Nur Asia, [3] Muh Imam Quraisy, [4] Irfan
[1] Computer Science, STMIK Kreatindo, Manokwari
[2] Information Technology, UPRI, Makassar
[3] Information Technology, University of West Sulawesi, Majene
[4] Information Systems and Technology, Muhammadiyah University of Sinjai, Sinjai
[1]sofyanarifin018@gmail.com, [2]nurasia93@gmail.com, [3] imam27@unsulbar.ac.id, [4] irfan.zaky699@gmail.com

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ABSTRACT

The measurement of dam water level is an important aspect in water resource management and flood risk mitigation. Conventional monitoring systems still have limitations in terms of accuracy, efficiency, and the availability of real-time information. This study aims to implement the Fuzzy Logic Tsukamoto method in an Internet of Things (IoT)-based dam water level measurement system using the ESP8266. The research method employed is a descriptive method, which includes system design, water level sensor data collection, data processing using the fuzzy method, and system testing. In this study, the fuzzy input variable is the water level with linguistic sets of low, medium, and high, while the output variable is the dam status with the sets of safe, alert, and danger. Based on the test results, at a water level value of 43 cm, the membership degrees obtained were $\mu\_low = 0.3$, $\mu\_medium = 1.00$, and $\mu\_high = 0.22$. The fuzzy inference process produced a crisp output value using the Tsukamoto defuzzification method of 87.45, which is categorized as an alert condition. The test results indicate that the system is capable of processing sensor data accurately and providing real-time information on water level conditions through the internet network. Therefore, the implementation of Fuzzy Logic Tsukamoto in an IoT-based system using ESP8266 can be an effective and reliable solution for monitoring dam water levels and supporting fast and accurate decision-making.

Corresponding Author:
Sofyan,
Computer Science, STMIK Kreatindo, Manokwari
Jl. Kali Bambu, Amban Village, Manokwari, West Papua
Email: sofyanarifin018@gmail.com

1. Introduction

Dams are vital infrastructure that control water resources, including irrigation, power generation, flood control, and raw water supply. Monitoring dam water levels is crucial for maintaining the safety and sustainability of dams. Delays or inaccuracies in water level information can cause serious impacts such as flooding, damage to facilities, and endanger the safety of communities downstream of the dam [1].

Water level monitoring systems are still often carried out manually or using conventional devices that have limitations in terms of accuracy, efficiency, and remote monitoring capabilities. Along with technological developments, the concept of the Internet of Things (IoT) has emerged as a solution for building monitoring systems that operate automatically, in real time, and are connected via the internet [2]

IoT technology allows data from sensors to be sent and accessed anytime and from anywhere, thereby increasing the effectiveness of dam management. One popular device used in IoT system development is the ESP8266, which is equipped with an integrated Wi-Fi module, is low-cost, and has efficient power consumption. This device is widely used in sensor-based monitoring systems due to its ability to transmit data wirelessly to a server or monitoring platform [3] However, water level data obtained from sensors is often fluctuating and contains uncertainty due to environmental influences and sensor limitations. Therefore, a data processing method capable of handling these conditions flexibly is needed. Fuzzy logic was introduced by Zadeh as an approach to representing uncertainty and human reasoning in computing systems [4].

One effective fuzzy inference method is Tsukamoto Fuzzy Logic, which produces crisp output based on linguistic rules and monotonic membership functions [5]. The Tsukamoto Fuzzy Logic method is widely used in decision-making systems due to its ability to provide more measurable and easily interpreted results compared to other fuzzy methods [6]. By applying this method to a dam water level measuring system, water conditions such as safe, alert, or dangerous can be determined more accurately based on available sensor data.

2. Literature Review

Fuzzy Logic

Professor Lotfi A. Zadeh, a professor at the University of California, was the first to coin the term "fuzzy logic" or "smart logic." The variables used must be sufficiently fuzzy to represent their fuzzy nature in their presentation. However, the equations generated from these variables must be simple, so that their computation is easy enough. Professor Lotfi A. Zadeh then presented it by determining the membership function of each variable[8]. Zadeh developed a fuzzy set to address the problem of infinite gradations. Unlike Boolean logic, Fuzzy Logic has continuous values[9].

Tsukamoto fuzzy logic

Tsukamoto fuzzy logic has the advantage of a simpler inference model, but can produce better prediction results by extending monotonic reasoning. The Tsukamoto fuzzy logic method uses the Center Average Defuzzifier formula in the defuzzification process, which is explained in the formula equation below.

$$z = \frac{\sum(\alpha\_p_i * z_i)}{\sum \alpha\_p_i}$$

Description:
z = defuzzification result
α_p = predicate alpha value (obtained from the minimum value of the membership function constraints)
zi = crisp value of the conclusion result (z)
i = number of fuzzy rules used [10].

Internet Of Things

IoT is a system that connects real-world objects such as machines, vehicles, household appliances, electronic devices, and sensors—into a digital network that can collect, send, and receive information to support decision-making and specific actions [11]. IoT (Internet of Things) is a technological concept that connects various physical devices to the internet network so that these devices are able to collect, send, and exchange data automatically without requiring direct human interaction[12]. The IoT infrastructure consists of existing networks and the internet and its development. This infrastructure offers object identification, sensor identification, and connection capabilities that form the basis for the development of autonomous collaborative services and applications, also characterized by a high degree of autonomy for data capture, event transfer, network connectivity, and interoperability [13].

NodeMCU ESP8266

NodeMCU is a microcontroller module that has been equipped with a Wifi module, where in the NodeMCU an ESP8266 chip has been embedded specifically for connecting to the internet, this NodeMCU is open source whose functions and uses are almost the same as Arduino [14]. NodeMCU is an electronic board based on the ESP8266 chip with the ability to run microcontroller functions and also internet connections (WiFi). There are several I/O pins so that it can be developed into a monitoring or controlling application on an IOT project. NodeMCU ESP8266 can be programmed with the Arduino compiler, using the Arduino IDE. The physical form of the NodeMCU ESP 8266, there is a USB port (mini USB) so that it will make it easier to program it, is shown in Figure 1 [15].

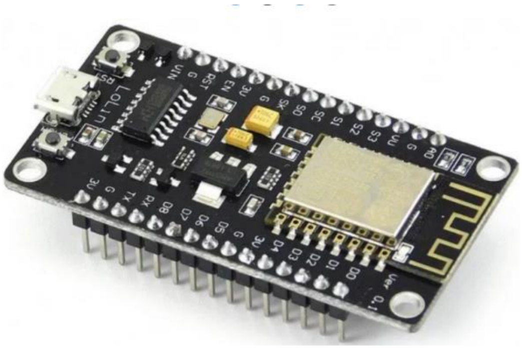

Figure 1. Nodemcu EPS8266

Sensor Ultrasonic

The HC-SR04 ultrasonic sensor is a sensor that can be used to measure the distance between objects with the HC-SR04 sensor. The HC-SR04 ultrasonic sensor consists of 4 pins, namely Vcc, Trigger, Echo and Ground [16]. An ultrasonic sensor is a sensor that converts physical quantities in the form of sound or noise into electrical quantities. This sensor will generate ultrasonic waves through an object called a piezoelectric [16]. The principle of measuring distance using the HC-SR04 ultrasonic sensor is, when a trigger pulse is given to the sensor, the transmitter will start emitting ultrasonic waves, at the same time the sensor will produce a TTL output with an upward transition indicating that the sensor starts calculating the measurement time, after the receiver receives 7 reflections generated by an object, the time measurement will be stopped by producing a TTL output with a downward transition, is shown in Figure 2 [18].

Figure 2. Ultrasonic Sensor

Buzzer

Buzzer is an electronic component that functions to convert electrical vibrations into sound vibrations. Basically, the working principle of the Buzzer is almost the same as a loud speaker, so the Buzzer also consists of a coil attached to the diaphragm and then the coil is supplied with current so that it becomes an electromagnet, the coil will be pulled in or out, depending on the direction of the current and the polarity of the magnet [19]. The Buzzer is an electronic component that can produce sound vibrations in the form of sound waves. The Buzzer will produce sound vibrations when given a certain amount of electrical voltage according to the specifications of the shape and size of the electronic buzzer itself, is shown in Figure 3 [20].


Figure 3. Buzzer

ThingSpeak

ThingSpeek is a cloud-based Internet of Things (IoT) platform used to collect, store, visualize, and analyze real-time data from various devices or sensors. This platform was developed by MathWorks and is widely used in academic research and IoT system development. ThingSpeak enables devices such as the ESP8266, ESP32, Arduino, and Raspberry Pi to send sensor data via HTTP or MQTT protocols to a cloud server. The received data is stored in the form of channels, where each channel can have up to eight data fields. The data can then be visualized in the form of graphs, tables, or analyzed using MATLAB Analytics which is integrated directly in ThingSpeek, is shown in Figure 4[21].

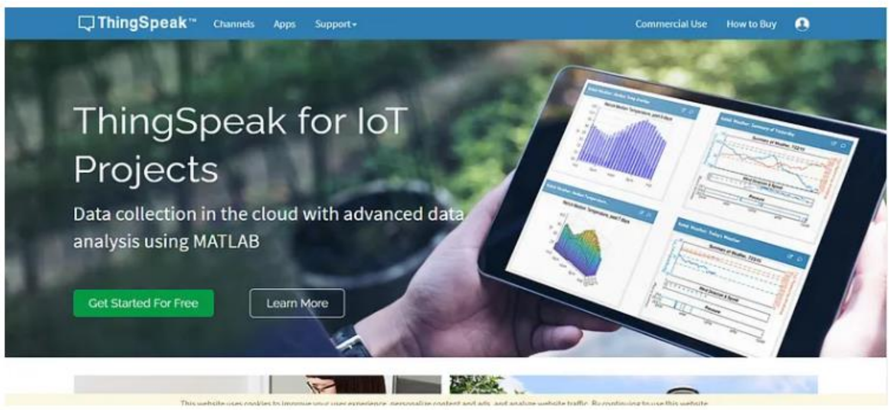

Figure 4. ThingSpeek

3. Methodology

A. Method

The method used in this research is a descriptive method. The descriptive method is a method in researching a group of people, an object, a method that presents a problem by collecting data presented to describe the characteristics of a condition or object of research and drawing conclusions to be made [7]. The descriptive method is used to describe the design process, implementation, and performance of an IoT-based dam water level measuring system using ESP8266 and the Tsukamoto fuzzy logic method. Data obtained from the results of sensor and system testing are analyzed to determine the level of accuracy, reliability, and ability of the system in determining water level conditions. Based on the results of the analysis, conclusions are then drawn to answer the research problems and achieve the stated objectives.

B. System Block Diagram

In the block diagram design of this system, there are several hardware components that are interconnected and work in an integrated manner, as shown in Figure 5 below. Each component has its own function in supporting the overall system performance. The water level sensor acts as an input device that functions to detect and measure the water level of the dam. The measurement data from the sensor is then sent to the ESP8266 microcontroller which functions as the system control center. This microcontroller is responsible for processing sensor data, running the Tsukamoto Fuzzy Logic algorithm, and managing the process of sending data via the internet network, the system block diagram can be seen in Figure 5 shown below.

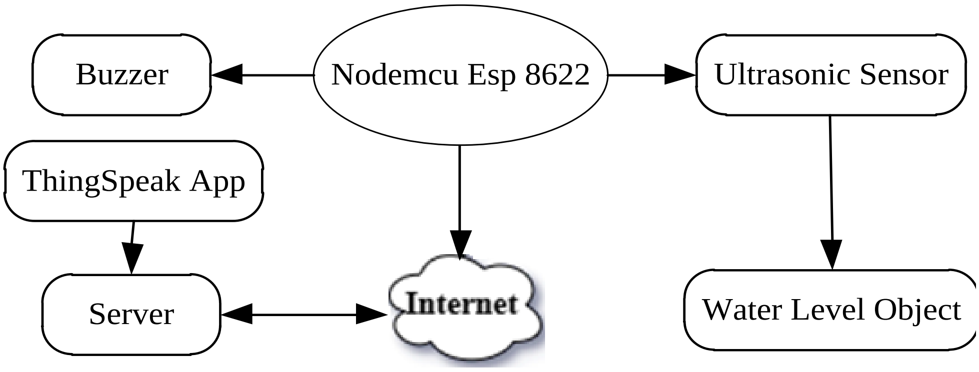

Figure 5. System Block Diagrams

C. System Flowchart Design

The workflow of the IoT-based dam water level monitoring system using the Tsukamoto Fuzzy Logic method. The process begins from the Start stage, then the system checks the ON switch condition as a marker whether the device is activated or not; if the switch is not active then the process is immediately Finished. After the system is active, initialization and reading of the water level sensor value are carried out, which functions to obtain real-time water level data. The sensor value is then processed through the fuzzification stage, which is converting the crisp value into a fuzzy membership degree. Next, rule formation (fuzzy rules) and fuzzy inference are carried out to determine the condition of the dam based on the established rules. The inference results are then processed in the Tsukamoto defuzzification stage to produce a crisp output value. This final value is then evaluated based on certain thresholds, namely values ≤ 50, ≤ 80, and ≤ 100, which represent safe, alert, and dangerous conditions, respectively. If the value is still within the safe or alert limit, the system will display the dam water level value, while if the value reaches the dangerous limit, the system will activate the buzzer as an early warning. This flow shows that the system is not only able to monitor water levels in real-time, but also provides automatic warning responses to support minimizing the risk of flooding, the results of the system flowchart design can be seen in Figure 6 shown below.

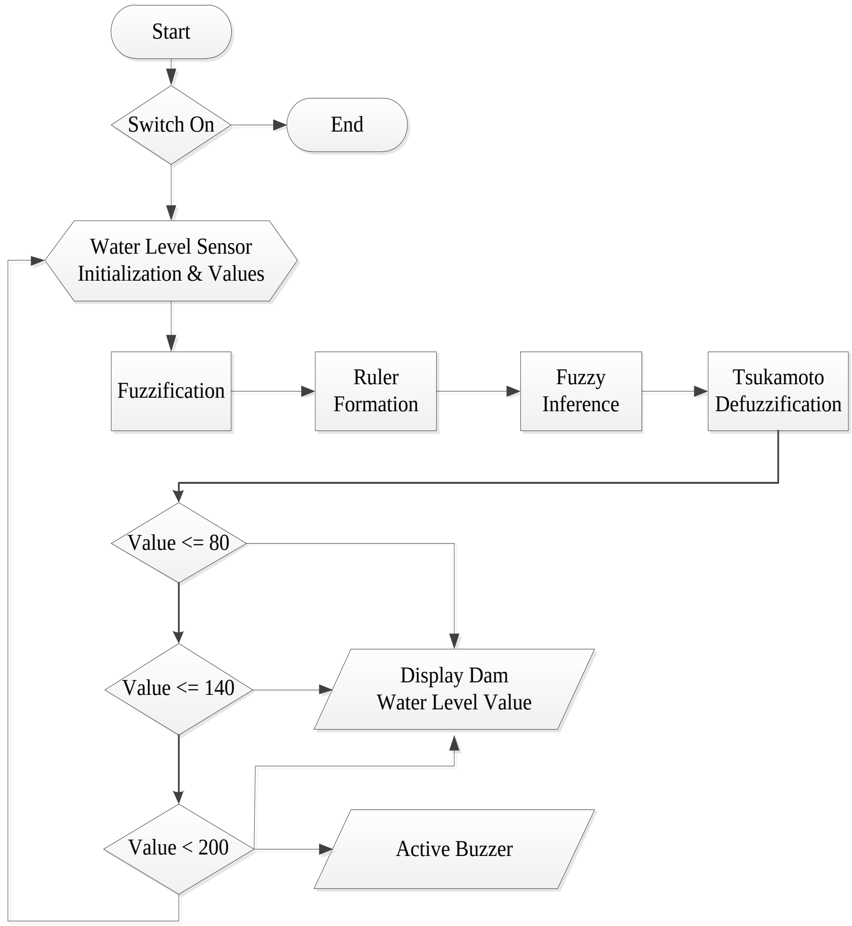

Figure 6. System Flowchart

4. Results and Discussion

A NodeMCU-based water level monitoring system was developed through hardware design that utilizes an HC-SR04 ultrasonic sensor to detect the distance of the water surface, which is connected to a NodeMCU ESP8266 microcontroller as the main processing unit. The microcontroller is programmed using the Arduino IDE to be able to read sensor data periodically and in real-time, then convert the distance measurement results into water level values. The data is then processed using the Tsukamoto Fuzzy Logic method to determine the condition of the dam more flexibly based on the designed fuzzy rules. The fuzzy processing stages include fuzzification, application of inference rules, and defuzzification to produce a clear output value that represents the status of the dam, such as safe, alert, or danger. Information from the measurement results and data processing is then sent via a Wi-Fi connection to an Internet of Things (IoT) platform, such as ThingSpeak, so that it can be monitored remotely in the form of graphic visualizations and real-time status. In addition, this system can be developed with an early warning feature in the form of a buzzer or notification, which will be activated automatically when the fuzzy decision results indicate certain conditions or when the water level exceeds the set limit, so that the system is able to support flood risk mitigation more quickly and effectively, the design results can be seen in Figure 7 shown below.

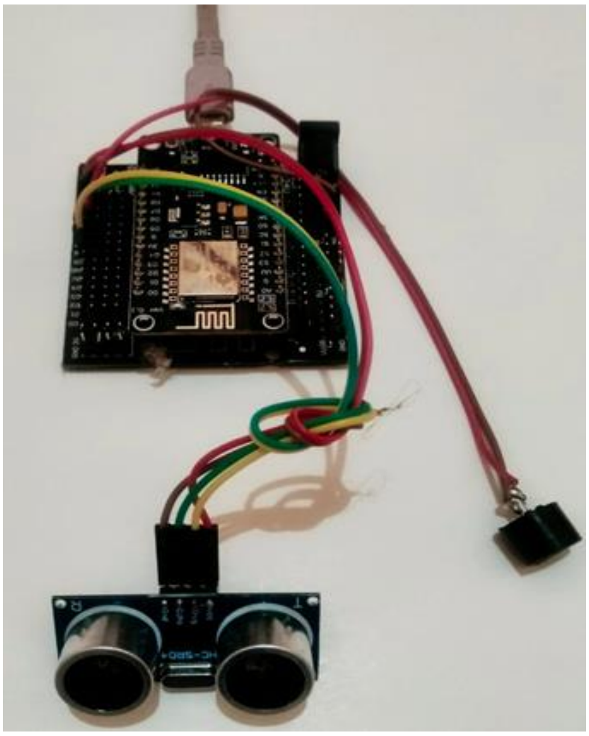

Figure 7. Hardware Circuit

The hardware implementation includes the design, assembly, and connection stages of the system's main components, including an ultrasonic sensor, a NodeMCU ESP8266 microcontroller, a buzzer, and several other supporting modules as needed. This process is structured to ensure each component is properly connected and functions optimally. The ultrasonic sensor detects the distance to the water surface, while the NodeMCU serves as a control center that processes sensor readings and manages data communication. Other supporting modules, such as a power supply and output devices, are used to maintain system stability. The purpose of this hardware development is to produce a device capable of accurately reading water levels and transmitting these data in real-time over the internet. Thus, the resulting device can be used as an efficient water level monitoring system, and the implementation results can be seen in Figure 8 below.

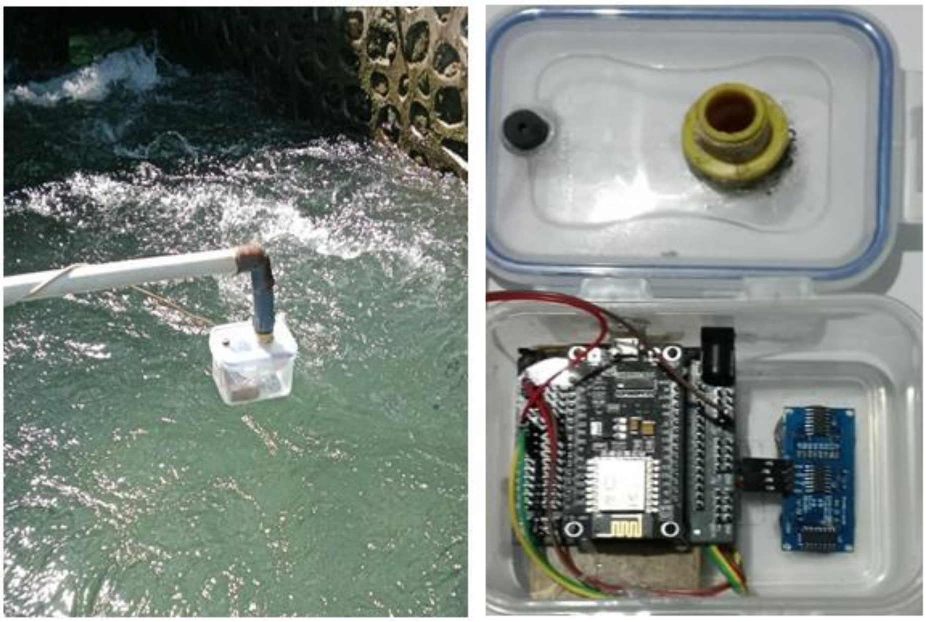

Figure 8 Dam Water Level Measuring Hardware

The results of real-time dam water level monitoring are displayed through the ThingSpeak platform. Showing a water level value of 43, which is the result of processing water level sensor data using an IoT-based system. This value represents the condition of the dam water level at the time of measurement and is generally in the safe or safe category approaching alert, according to the results of the Tsukamoto Fuzzy Logic method defuzzification. Meanwhile, on the right side, a time graph is displayed showing changes in the dam water level over time. The graph shows a fairly significant water level condition at certain times, which can be caused by environmental factors such as rainfall or incoming water discharge. Overall, this display proves that the system is able to send and display water level data continuously and in real-time via the internet, thus facilitating the monitoring process and decision-making in dam management, the results of the ThingSpeak application implementation can be seen in Figure 9 shown below.

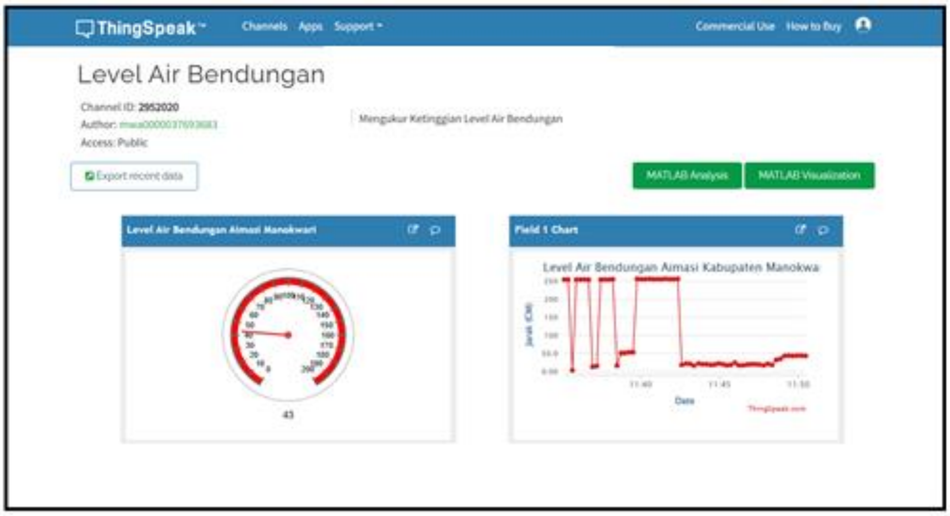

Figure 9 ThingSpeek Software

Based on the results of the tests that have been carried out and observed, the membership function values range from Low values from 0 to 40 cm, Medium values from 40 to 200 cm and High values above 160 cm, thus forming 3 fuzzy variables that can be modeled into a membership graph, as can be seen in Figure 8.

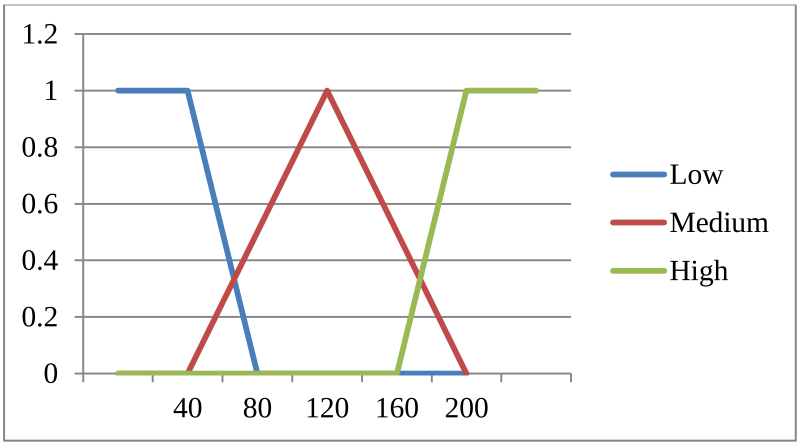

Figure 10 Membership Graph

Fuzzification Process

The fuzzification process is the initial stage in a fuzzy logic system that functions to convert crisp input values into membership values in the form of fuzzy sets. In other words, numerical data from sensors, such as water level (e.g., 43 cm), is not directly processed as an exact number, but is first converted into linguistic values such as low, medium, or high with membership degrees between 0 and 1.

$$\text{Low [X]} \begin{cases} 1 & X \leq 40 \\ \dfrac{80-X}{60} & 40 \leq X \leq 80 \\ 0 & X \geq 80 \end{cases}$$

$$\text{Medium [X]} \begin{cases} 1 & X = 120 \\ \dfrac{X-40}{120} & 40 \leq X \leq 120 \\ \dfrac{200-X}{120} & 120 < X < 200 \\ 0 & 100 < X \leq 200 \end{cases}$$

$$\text{High [X]} \begin{cases} 1 & X \geq 200 \\ \dfrac{X-160}{180} & 160 < X < 200 \\ 0 & X \leq 160 \end{cases}$$

$$\begin{aligned} \text{Low}[60] &= (80-60)/60 \\ &= 0{,}3 \\ \text{Medium}[120] &= (120-40)/(200-120) \\ &= 1{,}00 \\ \text{High}[180] &= (180-160)/180 \\ &= 0{,}22 \end{aligned}$$

Ruler Formation

A formation rule is a rule or method used to connect predetermined fuzzy variables in a decision-making system. In the Fuzzy Tsukamoto method, rules are formed in the form of monotonic IF–THEN statements, so that each rule produces a crisp output value through an inference process. The fuzzified input variables are processed based on their degree of membership in each fuzzy set, then matched with the designed rules. Each rule will produce an α-predicate value (fire strength) that indicates the level of truth of the rule. Furthermore, the Tsukamoto method uses a monotonic output membership function to obtain a crisp output value from each rule, which is then combined using a weighted average method. Thus, the formation rule in Fuzzy Tsukamoto plays a very important role because it determines the logical relationship between input and output variables, and influences the level of accuracy of the decision results produced by the fuzzy system.

[R1] If the water level is low, then the status is safe.
[R2] If the water level is medium, then the status is alert.
[R1] If the water level is high, then the status is dangerous.

Fuzzy Inference

The fuzzy inference reasoning process in a fuzzy logic system is used to generate decisions based on IF–THEN rules and the membership degree values of the input variables. At this stage, the fuzzified input values will be evaluated against each rule to obtain the α-predicate value (the degree of truth of the rule). Furthermore, in the Fuzzy Tsukamoto method, each rule produces a crisp output through a monotonic membership function, then all outputs are combined using a weighted average to obtain the final decision result.

[R1] If the water level is low, then the status is safe.

α- predicate$_1$ = 0,3

$$\mu safe(z) = \frac{60-z}{60}$$

$$0.3 \ \frac{60-z}{60}$$

$$0,3 \quad * 60 = 18$$

$$z1 \quad = 42$$

[R2] If the water level is medium, then the status is alert.

α- predicate$_1$ = 1,00

$$\mu standby\ (z) = \frac{z-40}{40}$$

$$1,00 \ \frac{z_2 - 40}{40}$$

$$1,00 \quad * 40 = 40$$

$$z_2 \quad = 80$$

[R1] If the water level is high, then the status is dangerous.

α- predicate$_1$ = 0,22

$$\mu danger\ (z) = \frac{z-160}{160}$$

$$0,22 \ \frac{z3-160}{160}$$

$$0,22 \quad *160 = 35,2$$

$$z3 \quad = 195,3$$

Defuzzification

$$z= \frac{(0,3 \times 42)+(1x80)+(0.22x195,3)}{0,3+1+0,22}$$

$$z= \frac{135,56}{1,55} \ 87,45$$

5. Conclusion

1. An Internet of Things (IoT)-based dam water level measuring system using the ESP8266 was successfully designed and implemented to monitor water levels in real time.
2. The Tsukamoto Fuzzy Logic method can be effectively applied to process continuous and uncertain water level data, thus enabling more accurate dam status determination.
3. The fuzzy input variables, consisting of water levels with linguistic sets of low, medium, and high, and the output variables, consisting of dam statuses of safe, alert, and danger, effectively represent the dam's condition.

4. The fuzzy calculation results at a water level of 43 cm yielded membership degrees of μ_low = 0.3, μ_medium = 1.00, and μ_high = 0.22, with a crisp output value of 87.45, categorizing it as an alert state.
5. The system is capable of transmitting and displaying water level and dam status information in real time via the internet, facilitating remote monitoring.
6. Implementation of this system has the potential to support fast and accurate decision-making in dam management and flood risk mitigation.

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