



Analysis of the Effectiveness of the Fuzzy Sugeno and Mamdani Methods in an Arduino-Based Automatic Fish Feeder

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Abstract. The aquaculture and marine sectors are important for the economy of South Kalimantan Province with fish farming in cages as one of the contributing factors. However, the practices associated with floating net cages in the rivers of the Banjarmasin City have polluted the environment, much of which was linked to excess feeding, benzoyl-bait builds up, and drug outflow. In this case, this research designed and demonstrated automatic fish feeders powered by the Arduino board. The research focused on two fuzzy logic control methods, namely Sugeno and Mamdani, in optimizing the feeding process. These were prototype users used in swallowing prototypes as small scale tests for operational feeding, environmental and overall functional parameters of the system. The findings indicated that the control mechanisms and strategies for the feeding processes scarcities up to and culturing activities downstream wastes were achieved using both methods. But it turned out that the Sugeno method was stronger than the Mamdani's, and Australian's method was superior to Soug's in computational efficiency and strength, so there are tighter control of the computer system. This study supports the feasibility of automated feeding systems for fish farming in regards to their ability to reduce the impact on the environment while being effective in their overall operation. Takeaways from these studies may be beneficial for the introduction of Moore Strains' technology for the development of the sustainable equipment for fisheries' activities in South Kalimantan.

Keyword: Analysis Effectiveness, Fuzzy Sugeno and Mamdani Methods, Arduino-Based Automatic Fish Feeder

1 Introduction

The South Kalimantan Province gives prominence to the fisheries and marine sector with a special emphasis on fish farming in floating cages. This activity is supported by the large water area of about 1,000,000 hectares, and fish production was recorded at 26,915 tons. Floating cage fish farming is developed in the district of Hulu Sungai Utara, and Hulu Sungai Selatan, Tabalong and Banjar while floating net aquaculture is

developing in Banjar District. Among the farmers commonly raised fish is the climbing perch, snakehead, tilapia, carp, and catfish [1].

Nevertheless, fish farming using floating net cages in the rivers of Banjarmasin City is known to cause pollution as a result of fish feed, drugs used, and excretion of the fish [2], [3]. Studies show that up to nine percent of fish feed not eaten by fish can be waste to the environment especially in the dry season water bed of the river becomes richer in mass leading to the death of the fish.

In fisheries, regular and precise feedings or even using scheduling is important in increasing fish productivity and welfare. With this in mind, automatic fish feeders have become highly relevant. Meanwhile, the problem of developing sophisticated control technology is still a difficult task. One of the promising ways conceives the adequate and timely resolution of problems pertained to the fuzzy logic, which helps in decision making under uncertainty and complexity [4].

Fuzzy logic method, more specifically the Sugeno and Mamdani approaches in control systems applications are abundant as compared to the research work that is meant to prove competence between the two methods in implementation of automatic fish feeders [5], [6]. Thanks to advancements in microcontroller technology such as the Arduino, building economically viable and uncomplicated automatic fish feeders has become easier than it was before.

An Arduino is a unified ecosystem consisting of The hardware works like any ordinary microcontroller but with straightforward pin configurations, while its software is free and people can design and upload any program without extra payment [7].

This study intends to fill this gap in knowledge by studying the Sugeno and Mamdani fuzzy methods in a case-study involving an automatic fish feeder that is controlled by Arduino. The study is expected to evaluate the suitable method that facilitates integration of automatic control in all aspects of the fish feeding process and thus help in the growth of automation in the fish farming industry.

2 Literature Review

2.1 Arduino-based Automatic Fish Feeding Device

The automatic fish feeding device based on Arduino can be used for automatically feeding the fish living in aquariums, or fish ponds. It is a broad approach that integrates different concepts especially the abilities of arduino as an open source hardware, the presence of fish which will be detected by a sensor, an operable fish feeder which consists of a feed container plus motor or servo, a real time clock for the feeding schedule, C/C++ language programming by the use of arduino ide, and a power system where re-chargeable batteries or electricity adapter can be used. These concepts allow for the construction of the tool and development of many more constituents such as the

feeding schedules and the capabilities of monitoring the environmental conditions of the aquarium. This makes the maintenance of the fish easy as an adequate amount of feed is available well in advance [8].

2.2 Fuzzy Mamdani

Fuzzy Mamdani is one of the approaches in fuzzy logic first developed by Lotfi A. Zadeh in 1975. This model is named after the name of the researcher who developed it, Ebrahim Mamdani [9]. Fuzzy Mamdani is an approach in fuzzy logic that uses “if-then” rules to connect input variables with output variables. In this model, input and output variables are defined in fuzzy sets with membership functions that determine how much a value meets the set. Each rule in the Mamdani model has two parts: a premise (if) part that specifies the input conditions, and a consequent (then) part that specifies the output to be generated. These rules are then combined using fuzzy logic operators such as AND and OR to produce a fuzzy output that will be translated into concrete values using the defuzzification method. Mamdani models are often used in control and decision-making systems to handle problems with linguistic or uncertain data [10].

Due to technical requirements of OpenType font technology, Microsoft Word’s “New Style” Equation Editor works only with fonts specially designed for mathematical typesetting. Unless you have obtained and configured new OpenType math fonts, it is highly likely that your installation of Word will use the Cambria Math font for all mathematics created with the “New Style” editor. Using the Cambria Math font for mathematics and Times Roman for your text will cause a mismatch in the visual appearance of your article, so, for consistency, we prefer authors to use the “Old Style” Equation Editor because it is straightforward to amend the size/style of the fonts it uses.

2.3 Fuzzy Sugeno

Fuzzy Sugeno, also known as the Sugeno model, is one type of approach in fuzzy logic that is often used in control systems and modeling [11]. Fuzzy Sugeno is one of the approaches in fuzzy logic that uses an “if-then” rule model to connect input variables with output variables. Unlike the Mamdani model which produces fuzzy outputs, the Sugeno model produces outputs in the form of concrete values based on linear combinations of input variables. Each rule in the Sugeno model has an “if...then...else” form, where the input variables are used to generate an output value based on a specified membership function [12]. In addition, numerical weights are applied to each rule to describe its contribution to the output value. This method is often used in control and decision-making systems to handle problems with numerical data [13].

3 Method

3.1 System Design

System Requirement

In this analysis stage, a literature study is carried out to determine the needs of the detection system to be developed. Analysis of hardware requirements includes DS18B20 temperature sensor, pH Meter, Bluetooth HC-06, Arduino Uno, and other components. While the analysis of software needs includes the Arduino IDE Program, Android IDE Program, and Xampp as an installation package. System design is divided into two stages, namely hardware and software design. Hardware design involves the use of Arduino as a sensor controller and data processing. While the software design includes the creation of monitoring applications using the Arduino IDE and Android Studio.

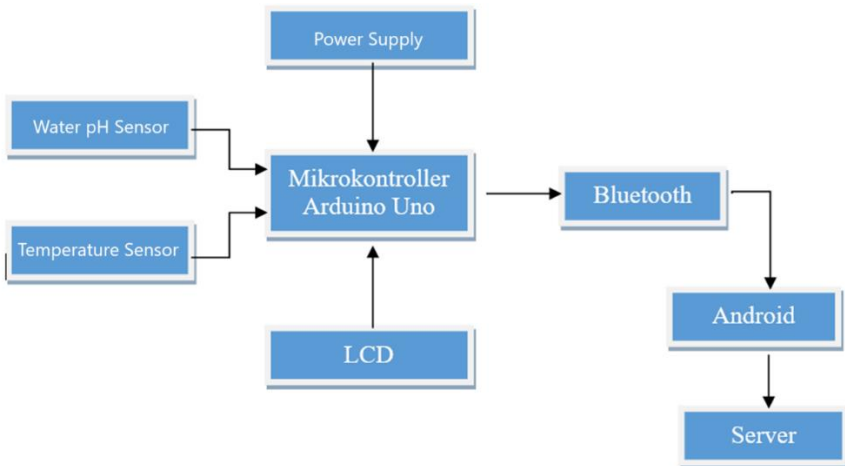


Fig. 1. Hardware design

A system architecture based on an Arduino Uno as a microcontroller, which is powered by the supply voltage to control and process the pH sensor and temperature sensor, is illustrated in Fig. 1. All these collected information is visually presented on an LCD screen placed locally and sent via wireless communication with the use of Bluetooth to an Android phone. The Android phone works as an intermediate which helps the user to see the data and sends it to a data center where a server stores and processes the information. The proposed system provides the opportunity for remote access to pH and temperature of water in the tank and also for local access.

System Description for Automatic Pond Monitoring and Feeding

In this system, pond monitoring and feeding are automated using sensors, a motor driven mechanism, and fuzzy logic. It comprises of:

1. **Measurement and Monitoring:** The ponds are equipped with distance, humidity, temperature and light sensors which offer feedback on pond conditions.
2. **Feed Control:** The feeding mechanism that is non available consists of a DC motor driven system suitable for dispensing feed as the speed changes according to the readings obtained from the sensors.
3. **User Interface:** The sensor values and the operational state of the system are presented by an LCD monitor, while the control is carried out by a remote Android application or web based interface.**Fuzzy Logic Control:** The control of the motor speed is made accurate by applying environmental focusing using Sugeno fuzzy logic.

Key Features

- **Reliability:** The functions of the system remain unaffected by the parameter variations of the environment.
- **Durability:** All these aspects make the components of the system effective in functionality in wet and humid areas.
- **Safety:** Provides safety for both the operator and the fish in particular from long sustained practices of the system.
- **Maintainability:** The system is very easy to maintain, and breakdowns are very easy to conduct.

This system enhances the practice of managing the pond areas, which assists in the control of the environments as well as the efficiency factor.

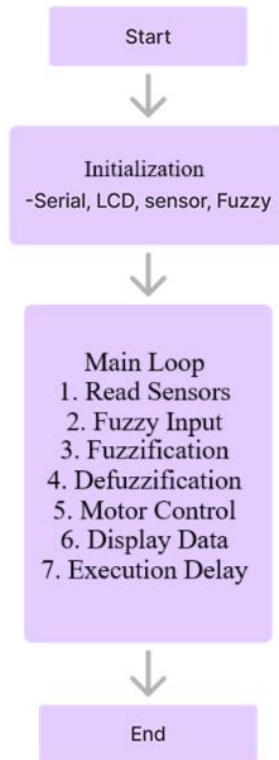


Fig. 2. Code structure

The flow chart in Fig. 2 shows the working of control system incorporating fuzzy logic. It commences the process at the Start step and proceeds to the Initialization step in which components such as Serial communication, LCD display, sensors and fuzzy system are configured. The system then proceeds to the Main Loop of the system and this comprises of the following steps: The first one will be: Read Sensors: Different sensors have been utilized for data collection. Fuzzy Input: Collected sensor data is prepared and adopted as fuzzy inputs. Fuzzification: Inputs are transformed into fuzzy sets. Defuzzification: Control outputs that are represented by fuzzy logic are kicked back to normal values. Motor Control: The voltage supplied is processed output and used to control the motor. Display Data: The values from sensors and control coefficients are brought out into the display. Execution Delay: Before commencing the next iteration, the system will delay for some moment. In the end, the system ends at the End step. In order to conduct such a design, consideration is given to possible use of fuzzy logic control principles so that constant monitoring is being done in a period of control.

Determination of Fuzzy Variables and Rules

Estimation of Input Variables:

1. Water Temperature: It records the temperature of the fish pond water as this is important in fish metabolism and feed requirement. Range: 0°C to 50°C [14].
2. Water pH: Measures the relative acidity of the water (pH). When unable to obtain the desired level of pH, fish health and feeding proficiency can be impaired. Range: 0 – 14 [15].

The input variables of the automatic regulating machine aquaculture system shall be considered in the form of fuzzy sets [16], [17]:

1. Water Temperature: Low which is below 20 degrees, moderate which ranges from 20 degrees to 30 degrees and high which is above 30 degrees can be used to modulate feeding as a function of fish mostly activity levels.
2. Water pH: Acidic which is below 6, neutral which is between 6 and 8 and alkaline which is above 8 which can regulate feeding based on water quality in addition to the fish health.

The Feed Amount can be rated on three levels. The first one is Low which is 0-25% of total feed capacity and is given when fish have less appetite. Then there is a Moderate Feed which is 25-75% of total feed capacity, suitable for moderate feeding requirements. The last one is High and is rated between 75-100%. This feed is whenever high activity is observed in fishes and the requirement of feed is high.

The Fuzzy Rules generation starts with the following rules.

1. Rule 1: IF Water Temperature is Cold AND Water pH is 7 Neutral A, THEN Feed Amount: Low
2. Rule 2: IF Water Temperature is Moderate AND Water pH is Alkaline A, THEN Feed Amount: Moderate
3. Rule 3: IF Water Temperature is Hot August A AND Water pH is Acidic, THEN Feed Amount: High.

3.2 Implementation

Implementation of Sugeno Fuzzy Method

Fuzzification of Data Input

In the fuzzification process, raw input data is transformed into fuzzy numbers using a membership function provided. The input variables for this system are as follows: Water Temperature: This represents the temperature of the pond water. Water pH: This represents the measure of acidity or alkalinity of the pond water.

The output variable of the system is the decision to increase the provision of feed to the fish based on these inputs. Constant fuzzy sets for water temperature and pH were defined so as to have some variation and allow adaptive feeding decisions to be made.

Discrepancy Resolution

Fuzzification, in this case, introduces boundaries and distinctions that allow for more categories to be made in order to mitigate uncertainty. For example, establishing such

suitable relations as “sugar softness = a lack of (hardness)” employing the theoretical analogies comes as no surprise. A typical rule-based representation of fuzzy logic where it is used for resolution might go this way:

IF Water Temperature is Low AND Water pH is Moderate,
THEN Feed Amount = $a * \text{Temperature} + b * \text{pH} + c$ to be determined.

The method in this way aids the system in the sensing of environmental parameters and alters the feeding amounts in real time.

Fuzzy Sets of Outputs

The output fuzzy sets assist with the proper calculations of the feed amount, which assists the machine translators in achieving the desired results. Such a mapping of the consequence of the fuzzy logic rule logic is done via a function:

Feed Amount = $0.5 * \text{Water Temperature} + 0.3 * \text{Water pH} + 10$.

This function offers a simple way of determining the amount of feed that is suitable in relation to the provided input variables assuring the amount of feed required is ideal to the current conditions of the pond.

Reminding of Variables and Algorithms Once Employed

The introduced variables, which include water temperature and pH, possess a significant extent of contribution to the operation of the system. Such inputs, folded through the Sugeno fuzzy rules, help to achieve effective feed control.

```
float fuzzySugeno(float temperature, float ph) {
    return 0.5 * temperature + 0.3 * ph + 10;
}
```

FIGURE 3. Code Structure for Sugeno Fuzzy Rules

Figure 3 shows the code for the microcontroller to implement Sugeno fuzzy rules and calculate the output based on the consequent function A microcontroller such as an Arduino could be used in the application in order to execute the feed mechanisms in accordance with the Sugeno fuzzy logic principles. For instance, the microcontroller interprets the information provided and sets the motor speed for feed distribution and therefore the system is able to run on its own and adapt itself. This integration shows the benefits of automation with microcontrollers and fuzzy logic for optimal fish feeding management furthering the goal of this project.

Implementation of Mamdani Fuzzy Method

The Resolution of Variables and Fuzzy Sets

The Fuzzy System operates using some input variables and a fuzzy set(s) defined prior to reaching decisions:

Input Variables:

- a. Water Temperature: These specific variables analyze water temperature within the pond and its impact on fish metabolism and eating habits. In fuzzy terms, water temperature is then divided into fuzzy sets (ie. Low, Moderate, High)
- b. Water pH: These variables measure the proportion of acid and base in water as this is one factor affecting the health of the aquatic animal. The pH levels are described in fuzzy rating according to the three ranges of pH (eg acid, neutral and alkaline).

Output Variable:

Feed Amount: In this case, the system determines the most suitable amount of fishfeed depending on the input variables. Feed amount is within the broad fuzzy sets of: low, medium and high.

This step verifies that environmental factors are correctly modeled in the system for precise feeding regulation.

Fuzzy Rule Formulation

Fuzzy rules describe how input variables interact with the output variable. These rules combine inputs using AND or OR logical connectors.

Rule: IF Water Temperature is Moderate AND Water pH is Neutral,
THEN Feed Amount is Moderate.

These principles are applied in the fuzzy inference mechanics as rules that give meaning to the fuzzy input values through their corresponding output. The system makes use of a number of such rules to deal with diverse circumstances hence allowing flexible and situational specific feeding behavior.

Microcontroller Program Code

The brain of the system, such as an Arduino, performs the functions of receiving input data as well as fuzzification and defuzzification procedures as follows:

- a. Fuzzy Inference: The min-max method analyzes input values obtained by the fuzzy membership functions to evaluate the truth degree to each rule.
- b. Defuzzification: The centroid approach is used to change the defuzzified output into a sharp value which computes with precision the appropriate feed volume for the motorized feeding mechanism.

This program makes use of sensor information within the framework of fuzzy logic rules and supervises the feeding elements when they are in action.

System Integration

The stage of system integration seeks to combine all the hardware and software components so that the system can operate concurrently. It is important to ensure the coordinated operation of the sensors, the microcontroller, and the motor in order to automate the feeding depending on the environmental data available.

- a. **Sensor and Actuator Setup:** A temperature sensor and a pH sensor are attached to the analog pins on the Arduino, while the feeder motor controlled by the motor driver is connected to the PWM (pulse-width modulation) pins.
- b. **Data Communication Between Components:** The system operates in real time in which sensor measurements are taken with a minimal time lapse of a few seconds: an interval within which the microcontroller reading results from the sensors via PCB, analyzes the data using fuzzy models outputs, and then the results are sent to control the actuator which is a DC motor.
- c. **Data Validation and Output Process:** As soon as the sensors detect the alterations in temperature and pH, the fuzzy system is expected to alter the output, in terms of motor rotation speed, since the output must follow the inputs instantaneously. And here the test for integration ensures that no gross delay due to processing occurs and that the environmental input can be delivered within the reasonable time frames.

Testing and Adjustment

Once integrated, the system was tested for validation of the fuzzy implementation in terms of its design and functional requirements. Two fuzzy methods (Sugeno and Mamdani) were put into effect with the objective to compare system’s response to same conditions. The system was subjected to the field tests for 5 days during which water temperature, pH as well as feed output were recorded and analyzed.

Table 1. Fuzzy Test Result

Day	Temperature (°C)	pH	Sugeno Output (%)	Mamdani Output (%)	Comment
1	24	7.0	50	55	Output is stable
2	26	6.5	60	65	Sugeno is more aggressive
3	29	8.0	75	70	Mamdani is more conservative
4	31	7.5	85	80	Both methods respond quickly
5	25	6.0	55	60	Output is stable

Table 1 summarizes the results of fuzzy logic tests, showing the relationship between water temperature, pH levels, and the calculated feed outputs using Sugeno and Mamdani methods. The comments highlight notable differences or similarities in the outputs of the two methods

Prototype Test Result

The testing of prototypes in various simulated environmental conditions shows the working of both the Sugeno and Mamdani fuzzy inference methods in regards to feed levels as shown on Table 2. In normal conditions, it is shown that both methods manage to deliver moderate feed output which is expected. Under high temperatures, both

methods recommend an increase in feed, the expected output. Under low pH conditions, the output is stable as was expected. On bright light conditions, both of the methods propose a decrease in feeds, which is the expected output. At last, when in a dark surrounding both methods increase the feeds. It can be deduced from these results that both Sugeno and Mamdani methods can be effective in adjusting the feed levels as per environmental extremes.

Table 2. Prototype Test Result

Test Condition	Expected Output	Sugeno Result	Mamdani Result
Normal	Moderate Feed	Moderate Feed	Moderate Feed
High Temp	Increase Feed	Increase Feed	Increase Feed
Low pH	Stable Feed	Stable Feed	Stable Feed
Bright Light	Decrease Feed	Decrease Feed	Decrease Feed
Dark Environment	Increase Feed	Increase Feed	Increase Feed

4 Result and Discussion

4.1 Data on the Test of the Prototype

For this research study, data was collected in order to ascertain the performance of the fuzzy logic automatic fish feeding system which uses Sugeno and Mamdani methods of control. Such data is obtained from the testing of the fish feeder prototype over a period of days under different temperature and pH level conditions. The need for data collection is to find out the working of the two fuzzy methods in controlling feeding and in comparison with the reference system. In the course of prototype testing, a good number of variables were recorded including the water temperature, the pH level of water, feed amount and the accuracy of the sensor. Table 3 shows the test lasted for seven days and samples were taken once in every day under different weather conditions.

Table 3. Prototype Test Result

Day	Temperature (°C)	pH	Sugeno Output (%)	Mamdani Output (%)	Temperature Sensor Accuracy (°C)	pH Sensor Accuracy	Feed Waste Sugeno (g)	Feed Waste Mamdani (g)
1	24	7.0	50	55	±0.5	±0.2	5	7
2	26	6.5	60	65	±0.4	±0.1	4	6
3	29	8.0	75	70	±0.6	±0.3	3	5

4	31	7.5	85	80	± 0.5	± 0.3	2	4
5	25	6.0	55	60	± 0.4	± 0.2	4	6
6	28	7.0	70	65	± 0.3	± 0.2	3	5
7	27	7.5	65	60	± 0.4	± 0.2	3	4

The results and findings provide very interesting insights related to feed output and wastage as well as the sensor accuracy. It was observed that on the fourth day, the water temperature at 31°C and pH of 7.5, the system using Sugeno technique had feeding output of 85% which was higher than the Mamdani system which had a feeding output of 80%. This means that the Sugeno is fairly quick and aggressive in putting conditions for fish to optimal level.

In addition, less feed wastage was reported under the Sugeno method especially on day 4 where only 2 grams of waste was recorded compared to 4grams for the –Mamdani method. This indicates that the feeding amount recommended by the Sugeno is closer to what fish actually require, thus preventing over-feeding under those conditions.

The temperature and pH sensors performed as intended without any failures and the temperature accuracy error was ± 0.5 degrees while the pH, a lesser accuracy error of ± 0.3 was recorded. Also the system in itself had no major breakdowns which had the potential to affect the operation.

To sum up, the findings collectively emphasize the advantages of the Sugeno method with regards to feed optimization and the reliability and stability of the system is not compromised.

4.2 Reference System Data

Data obtained from the reference system has been undertaken by fish farmers under manual feeding methods. It has set a standard time interval for fish feeding on a self-imposed principle without regard to temperature and pH situations.

Table 4. Reference System Data (Manual Feeding)

Day	Temperature (°C)	pH	Manual Feed (%)	Feed Waste (%)
1	24	7.0	60	10
2	26	6.5	60	8
3	29	8.0	60	7
4	31	7.5	60	12
5	25	6.0	60	9
6	28	7.0	60	8
7	27	7.5	60	10

Table 4 summarizes the results of manual feeding tests, showing that under the control unit, a manual member of the survey population feeds the fish 60% of the total expected

pH automatically without considering temperature fluctuations. The higher feed losses caused by ice cubes are temperatures outside the optimal range.

In manual feeding systems feed wastage by day (day 4) was 12 grams, while its Sugeno counterpart only managed a fraction of 2 grams, and Mamdani 4 grams. Such figures point to the sufficiency of the finished feeding system automatic based on fuzzy logic.

4.3 Comparison

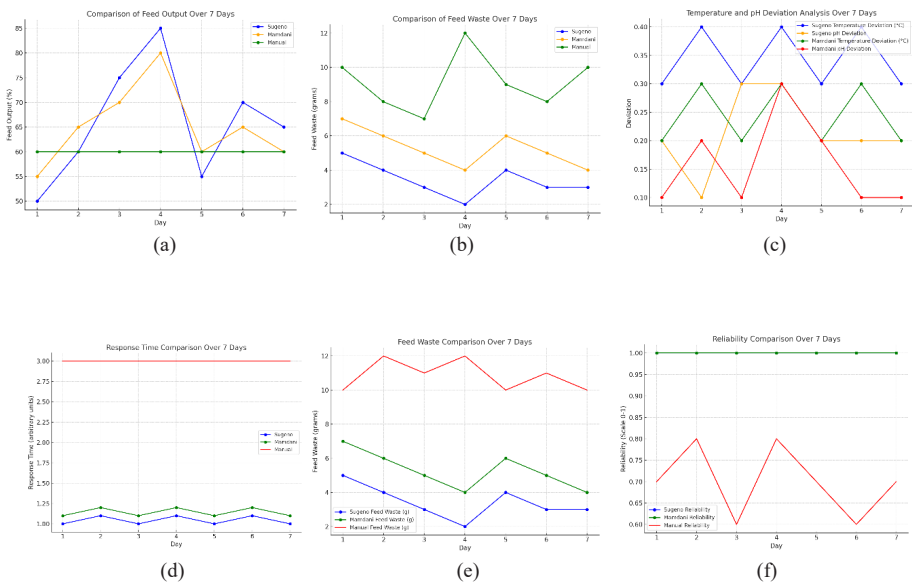


Fig. 4. Comparison result. (a) Comparison of Feed Waste Effectiveness, (b) Comparison of Feed Waste Efficiency, (c) Temperature and pH Sensor Accuracy Comparison, (d) Response Speed Comparison, (e) Efficiency Comparison, (f) Feed System Reliability.

Figure 4 shows the comparison analysis takes into considerations how fuzzy-based systems (Sugeno and Mamdani) can easily be accepted in preference to manual feeding. Sugeno allows for the optimization of feed settings based on temperature and pH parameters, such that on day 4 there was waste of only 2 grams. Mamdani is however a bit conservative but manages to be more efficient than the manual feeding method in terms of waste reduction. The yields from manual feeding in which a fixed

amount of feed is offered every day has the problem of either wasting a high amount above 8 grams daily in most cases 12 grams due to overfeeding or wasting above 8 grams daily due to underfeeding.

Fuzzy systems outperform classical and conventional systems since it has sensor deviations of ± 0.5 °C; ± 0.3 pH for pH thus achieving satisfactory accuracy, high environmental dynamic response and highly efficient fuzzy system especially type Sugeno. Cost wise and in terms of operational complexity, manual feeding has some advantages however it is rigid and lacks the needed accuracy. Hence, for the fuzzy systems that can maintain low feed wastage and improve fish welfare (Sugeno), the initial higher capital cost is justified.

4.4 Analysis of Fuzzy Effectiveness

In controlling fish feeding, fuzzy logic is further evaluated in the study through Sugeno and Mamdani methods and how it improves the effectiveness of the control fish feeding. The Sugeno method also exhibits good results since it can achieve very high feed outputs in optimal conditions of high temperature and neutral pH. The fact that it has some linear properties makes it fast acting to changes ensuring that fish growth is maximized and wastage is minimized. On the other hand, the Mamdani method is not defined either but is more timid and hence can only be applied to the environments where the changes are not abrupt and requires feed changes to be gradual at all times so as to avoid excessive feed.

In exchange, it can be said that the introduction of fuzzy logic in the system increases its efficiency compared to manual fish feeding. Real time corrections enhance feeding efficiency and conserve the amount of waste, while the artificial intelligence gives fuzzy algorithms that help to make decisions which are ideal in the rapidly changing environments.

5 Conclusion

The analysis and evaluation of the implemented fuzzy logic-based fish feeding system (Sugeno and Mamdani) led to key conclusions. First, the developed fuzzy systems achieved better efficiency than the manual feeding. Due to incorporating feed amount changes according to temperature and pH data, these systems waste about 3-5 grams a day, while the manual system wastes about 8-12 grams. Not only does this efficiency improve the environmental performance but it also decreases overall costs of the operation.

In terms of accuracy, the fuzzy systems outperformed the competition with sensor precision averages of ± 0.5 °C for temperature and ± 0.3 pH. In particular, the Sugeno method was much quicker to respond when conditions were better such as higher temperature and neutral pH, it was also aggressive when providing a response.

However, the Mamdani method was much slower in terms of response which was useful in steady environments that require stability.

The prototype further demonstrated consistency during a week-long experiment as sensor readings and motor control were reliable and steady causing the uninterrupted performance of the system over time. On the other hand, the manual feeding system, which supplies every day the same amount of feed, was less successful as it did not cater to the fish's real demands resulting in poor feeding practices and increased waste as well as health risks to the fish.

Eventually, the Sugeno method has revealed to be optimal for dynamic and varying environmental conditions, meanwhile the Mamdani method demonstrated its appropriateness towards stable environments. Manual feeding was still, of course, surpassed by both in terms of accuracy and flexibility of feed administration along with its control over the provision of feed to the fishes.

To conclude, the fuzzy logic system, through particularly the Sugeno method, is the best option in terms of effectiveness, precision and reliability when considering the fish feeding optimization, reduces losses to waste to great extent and addresses changes of the conditions more efficiently than the manual systems.

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