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Desain dan Implementasi *Smart Auto Feeder Fish* Berdasarkan Umur dan Ukuran Ikan dengan Metode *Fuzzy Logic*

Design and Implementation of a Smart Auto Feeder Fish System Based on Fish Age and Size Using Fuzzy Logic Method

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Abstrak

Budidaya ikan lele merupakan sektor penting dalam mendukung ketahanan pangan dan ekonomi masyarakat di Indonesia. Namun, efisiensi pemberian pakan masih menjadi tantangan utama, mengingat pakan menyumbang hingga 40% dari total biaya produksi. Penelitian ini bertujuan merancang dan mengimplementasikan sistem *Smart Auto Feeder Fish* berbasis logika *Fuzzy Sugeno* untuk mengoptimalkan pemberian pakan ikan lele berdasarkan umur dan ukuran. Sistem dirancang menggunakan mikrokontroler ESP32, modul RTC DS3231, sensor load cell HX711, keypad, LCD, serta tiga servo. Metode *fuzzy Sugeno* digunakan untuk menentukan jumlah pakan berdasarkan input linguistik umur dan ukuran ikan. Hasil pengujian menunjukkan latensi pemberian pakan rata-rata 1,27 detik (pagi) dan 1,73 detik (sore), dengan akurasi berat pakan mencapai 98,12% (pagi) dan 97,47% (sore). Sistem diuji pada dua kolam dengan 250 ikan masing-masing, menunjukkan *survival rate* lebih tinggi pada kolam dengan alat (75,60%) dibanding tanpa alat (70,40%) serta pertumbuhan panjang ikan yang lebih linear. Sistem ini terbukti efektif meningkatkan efisiensi pakan, pertumbuhan, dan kelangsungan hidup ikan lele secara otomatis dan adaptif.

Kata kunci: Budidaya ikan lele, Fuzzy Sugeno, Smart Auto Feeder

Abstract

Catfish farming plays a vital role in supporting food security and the economy in Indonesia. However, feed efficiency remains a major challenge as feed accounts for up to 40% of production costs. This study aims to design and implement a Smart Auto Feeder Fish system based on Fuzzy Sugeno logic to optimize feed distribution according to fish age and size. The system uses an ESP32 microcontroller, RTC DS3231, HX711 load cell, keypad, LCD, and three servo motors. The Sugeno fuzzy method determines feed quantity using linguistic inputs of age and size. Testing shows average feeding latency of 1.27 seconds (morning) and 1.73 seconds (afternoon), with feed accuracy reaching 98.12% and 97.47%, respectively. The system was tested in two ponds with 250 fish each. The pond with the system achieved a higher survival rate (75.60%) compared to the control pond (70.40%) and showed more linear growth patterns. The Smart Auto Feeder proves effective in improving feed efficiency, fish growth, and survival rates through automated and adaptive feeding.

Keywords: Catfish farming, Fuzzy Sugeno, Smart Auto Feeder

I. INTRODUCTION

Catfish (Clarias gariepinus) is one of the most widely cultivated freshwater commodities in Indonesia due to its rapid growth rate, ease of maintenance, wide market availability, and considerable economic value. National production data show a significant upward trend, with catfish output reaching approximately 111,579 tons in 2022, dominated by West Java with 67,167 tons, followed by regions in Sumatra and Kalimantan. This growth further accelerated in 2023, with national production rising sharply to 415,886 tons—a 272.7% increase from the previous year—indicating a strong potential for supporting national food security and local economic development.

Despite this growth, feed management remains one of the most critical challenges in catfish aquaculture. Feed constitutes up to 40% of total production costs (efishery, 2023), making feed efficiency essential to maintaining profitability and sustainability. Manual feeding methods are still commonly used; however, they are prone to inconsistencies and delays, especially when farmers manage multiple ponds. Previous studies have shown that manual feeding may experience an average delay of up to 5 seconds compared to automated systems, potentially triggering undesirable behaviours such as cannibalism due to hunger and stress.

Inefficient feeding not only increases operational costs but may also degrade water quality due to excess feed accumulation, which negatively impacts fish health and growth. To address these issues, automated feeding technologies have been increasingly explored. The use of Real-Time Clock (RTC) modules enables accurate scheduling of feed distribution, ensuring consistency in feeding times. Moreover, determining feed quantity requires an adaptive approach that accounts for variations in fish age and size. Fuzzy Sugeno logic offers an effective solution for handling uncertain or dynamic input parameters, enabling the system to produce feed dosage outputs that reflect actual growth conditions.

However, challenges remain regarding the accuracy of feed output in automated systems. To enhance precision, integrating a load cell sensor allows real-time measurement and adjustment of feed weight, ensuring that the actual dosage aligns with the system's computed values. By combining fuzzy logic, RTC scheduling, and load cell feedback, a Smart Auto Feeder system has the potential to significantly improve feeding efficiency, reduce waste, maintain water quality, and support optimal fish growth across various developmental stages.

II. LITERATURE REVIEW

A. Catfish Farming

Catfish is widely cultivated in Indonesia because it is considered one of the leading freshwater aquaculture commodities with strong market prospects. Its main advantages compared to other freshwater fish include relatively fast growth, ease of maintenance, and simple feeding requirements (Yunus et al., 2014).

In catfish aquaculture, feed plays a crucial role, as its quality and composition directly affect fish growth and health. Catfish feed generally consists of several types, including commercial pellets, natural feed, alternative feed, and fermented feed. Commercial pellets are the most commonly used due to their nutritional composition—such as protein, fat, vitamins, and minerals—which is specifically formulated to meet the nutritional needs of fish at each growth stage. Natural feed, such as worms, larvae, and plankton, is also frequently provided to stimulate feeding activity, particularly during the early growth phase (efishery, 2023).

Feeding practices for catfish must be adjusted according to fish size and growth stage to ensure that each individual receives optimal nutrition. Each phase of catfish development—from juvenile to adult—requires different feed quantities and compositions. Such adjustments are essential to support healthy growth and improve feed utilization efficiency in catfish aquaculture (efishery, 2023). For feed allocation based shows in tabel 1.

Table 1. Feed Allocation Based on Fish Size (efishery, 2023)

Age (Days)	Body Weight (g/fish)	Length (cm)	Feed Amount (g/fish)	Frequency (times/day)
1–10	< 1	< 3	0.05	3–4
11–20	1–2	3–5	0.135	3
21–40	2–3.5	5–7	0.1925	3
41–50	3.5–5	7–9	0.23375	2–3
51–60	5–20	9–12	0.59375	2–3
61–70	20–50	12–15	1.4875	2–3
71–80	50–80	15–25	2.275	2
81–120	80–100	25–30	2.25	2
>120	>100	>30	2	2

B. Fuzzy Logic

Fuzzy logic is a reasoning system that allows degrees of membership ranging between 0 and 1, unlike classical Boolean logic, which only recognizes absolute values of 0 and 1. Variables in a fuzzy logic system are represented as fuzzy sets, which may take various shapes such as triangular, trapezoidal, Gaussian, Gaussian-bell, or sigmoid (Wahab et al., 2017).

The Sugeno fuzzy model—introduced by Michio Sugeno—shares a similar inference process with other fuzzy methods, but differs in the form of its output (consequent). In the Sugeno method, the output is not expressed as a fuzzy set; instead, it is represented as either a constant value or a linear equation. Two common types of Sugeno models are used:

1. Zero-order Sugeno Model

This model uses a constant output. Its general rule form is:
IF (x_1 is A_1) AND (x_2 is A_2) AND ... AND (x_n is A_n)
THEN $z = k$
where A_i are the fuzzy sets representing the antecedents and k is a constant output value.

2. First-order Sugeno Model

This model uses a linear function of inputs as the output:
IF (x_1 is A_1) AND (x_2 is A_2) AND ... AND (x_n is A_n)
THEN $z = p_1x_1 + p_2x_2 + ... + p_nx_n + q$
where p_i are coefficients for each input variable and q is a constant.
The Sugeno fuzzy logic process generally consists of several key stages:

3. Fuzzification

In this stage, crisp input values are converted into degrees of membership within corresponding fuzzy sets. This step determines how strongly each input belongs to defined fuzzy categories, forming the basis for rule evaluation.

4. Application of Implication Functions

Each fuzzy rule is structured in the general form:
IF x is A THEN y is B,
where *A* and *B* are fuzzy sets. The antecedent may also combine multiple conditions using operators such as AND or OR, for example:
IF x_1 is A_1 AND x_2 is A_2 THEN y is B.
Common implication operators include:

- **Minimum (min):** truncates the output fuzzy set based on the degree of truth of the antecedent.
- **Product (dot):** scales the output fuzzy set by multiplying it with the antecedent degree.

5. Defuzzification

This stage translates fuzzy outputs into a crisp numerical value. In the Sugeno method, defuzzification is performed using the **Weighted Average (WA)** technique, show in equation (1):

$$WA = \frac{a_1 z_1 + a_2 z_2 + a_3 z_3 + \cdots + a_n z_n}{a_1 + a_2 + a_3 + \cdots + a_n} \quad (1)$$

where a_k represents the firing strength of rule k, and z_k represents the output (constant or linear). Membership functions represent the degree of belonging of a value within a fuzzy set, taking values from 0 to 1. These degrees are used as weighting factors to determine the influence of each rule during inference (Rahakbauw, 2015). Various membership function types may be used, such as triangular and trapezoidal functions, depending on system modeling needs.

III. RESEARCH METHOD

The research began with the visual design of the Smart Auto Feeder system, which consists of mechanical design, a system block diagram, and the interaction between components such as the ESP32, RTC DS3231, servo motors, load cell, keypad, and LCD. The system is controlled by the ESP32, which receives input on fish age and size to determine the amount of feed automatically using the Sugeno fuzzy logic method. All components operate in an integrated manner, including the RTC, which schedules feeding time; the load cell, which measures feed weight; and the servo motors, which regulate feed dispensing. Fuzzy logic is implemented to determine the feed amount based on input parameters. Fuzzy inputs include categories of age (young, juvenile, adult, mature) and size (small, medium, large), represented using triangular and trapezoidal membership functions.

The research procedure was carried out systematically through several stages, beginning with literature review, system design, and circuit development, followed by the implementation of fuzzy logic on the ESP32 and the construction of the servo-based feeding container. The system was connected to a Wi-Fi network to store data in Google Sheets automatically. Subsequent stages included load cell calibration and servo configuration so that both components operated according to signals from the fuzzy logic and RTC. The construction process involved assembling hardware components, testing modules such as the RTC, load cell, and keypad–LCD input, and developing the fuzzy algorithm based on a rule table that converts input parameters into the output feed amount.

After the device was constructed, comprehensive testing was conducted on the fuzzy algorithm, load cell accuracy, RTC scheduling, keypad input, and the integration with Google Sheets. The evaluation included comparing the performance of automatic feeding in a pond equipped with the system and a pond without the system, each containing 250 fish. Measurements of fish growth and survival rate were taken periodically. The results were analyzed to assess the effectiveness of the system in regulating feeding time and feed dosage automatically. This study also utilized independent variables such as fish age, fish size, and harvest threshold, as well as dependent variables including accuracy, error rate, feeding time, and feed weight.

The fuzzy logic implemented in the Smart Auto Feeder system is used to determine the feed amount precisely based on two main parameters: fish age and fish size. The fuzzy system uses the Sugeno method, which produces output in the form of constant values according to predefined rules (rule base). The fuzzy process begins by receiving input on fish age and size through the keypad, followed by *fuzzification*, which converts the crisp input values into degrees of membership within linguistic categories such as young, juvenile, adult, mature for age, and small, medium, large for size. The system then applies inference based on twelve fuzzy rules designed to determine the optimal feed amount in grams.

The resulting fuzzy output is then *defuzzified* using the Sugeno weighted average method, producing the final feed amount to be dispensed by the system. This fuzzy logic implementation ensures that the feeding process is more adaptive to the growth needs of the fish, minimizes feed wastage, and improves overall efficiency in automated feeding. For membership function Values for Fish Age show in figure 1. and membership fungction Values for Fish Size show in figure 2. For Fuzzy Rules for the Smart Auto Feeder System show in tabel 2.

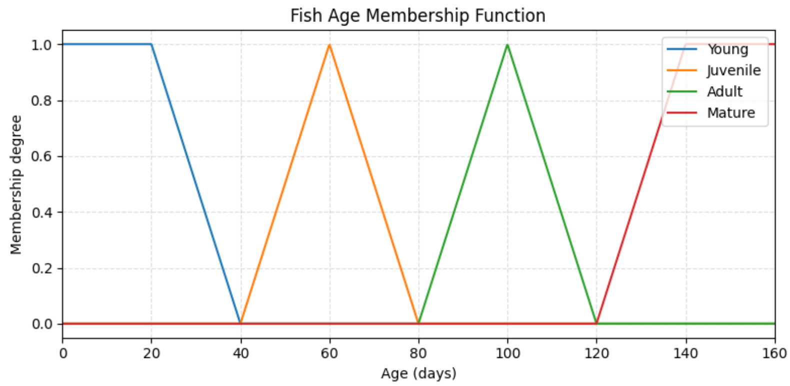

Figure 1. Membership Values for Fish Age

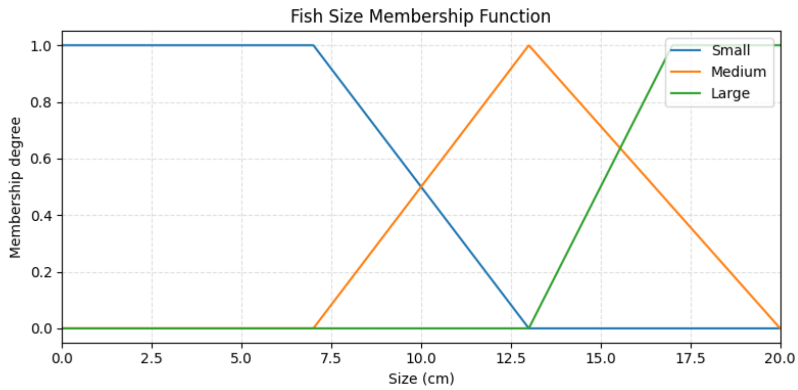

Figure 2. Membership Values for Fish Size

Table 2. Fuzzy Rules for the Smart Auto Feeder System

No.	Fish Age	Fish Size	Feed Amount (grams)
1	Young	Small	0.05
2	Young	Medium	0.135
3	Young	Large	0.1925
4	Juvenile	Small	0.23375
5	Juvenile	Medium	0.625
6	Juvenile	Large	1.4875
7	Adult	Small	2.275
8	Adult	Medium	2.25
9	Adult	Large	2
10	Mature	Small	2
11	Mature	Medium	2
12	Mature	Large	2

IV. RESULTS AND DISCUSSION

The design of the Smart Auto Feeder Fish system based on the Sugeno Fuzzy Logic method resulted in an integrated device housed within an 18 cm × 11 cm component box. This enclosure was designed to accommodate the ESP32 microcontroller, HX711 module, keypad, LCD, and RTC module. The device is equipped with three servo motors, each performing a specific function: Servo 1 opens the feed container according to the predetermined schedule, Servo 2 activates when the feed falling from Servo 1 onto the load cell meets the fuzzy logic rules corresponding to fish age and size, and Servo 3 distributes the feed into the pond.

The keypad is used to input system settings, while the LCD displays system information such as status, schedule, and measured feed weight. The feed container utilizes an FF23 aluminum funnel, along with an additional FF15 funnel placed above Servo 2 to channel the feed accurately toward the load cell. The system frame is constructed from aluminum profiles, providing structural stability and durability. The final design implementation of the Smart Auto Feeder is shown in Figure 3.

Figure 3. Final design implementation of the smart auto feeder.

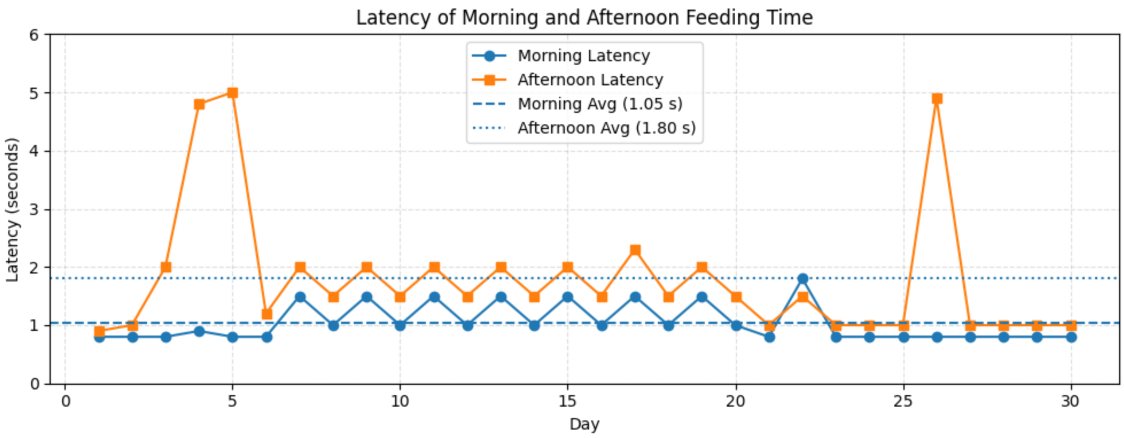

Figure 4. The latency graph smatt auto feeder performs during 30-day test.

The latency graph in figure 4. shows that the Smart Auto Feeder performs consistently with minimal delay during the 30-day test. Morning latency is highly stable, averaging 1.05 seconds, with values mostly between 0.8–1.2 seconds, indicating reliable system response and minimal environmental influence.

Afternoon latency, while generally within the **1.0–2.0 second** range, displays several spikes—especially on Days 4, 5, and 26—caused by external factors such as sensor fluctuations or environmental changes. Even with these outliers, the average afternoon latency remains acceptable at **1.80 seconds**.

Overall, morning sessions demonstrate better stability than afternoon sessions, but both remain within operational limits. These results confirm that the Smart Auto Feeder activates promptly and consistently, supporting timely feeding and contributing to healthier and more predictable fish growth.

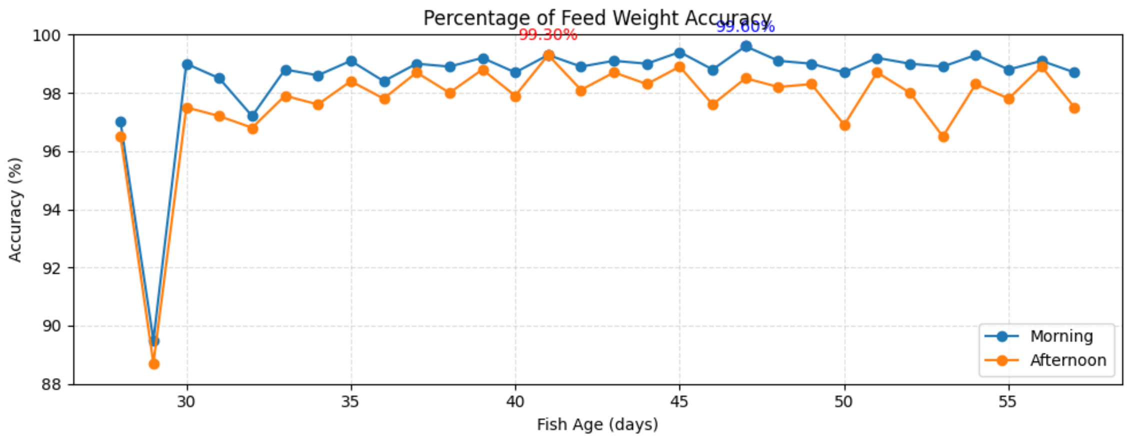

Figure 5. Graf smart auto feeder maintains consistently high feed weight accuracy

The graph in Figure 5 shows that the Smart Auto Feeder consistently maintained high feed weight accuracy for both morning and evening feeding sessions, with morning and evening data compared to the system's feed weight setpoint, generally remaining above 97% across the fish age range of 28–57 days. Morning accuracy was slightly more stable and higher, often reaching 98–99.5%, indicating that the system performs optimally under morning environmental conditions.

A single significant drop occurs around Day 29 for both sessions, which aligns with the journal's explanation that early operational fluctuations or uneven feed distribution can momentarily affect load cell readings. However, the system quickly stabilizes again, demonstrating reliable performance.

Overall, the results confirm that the feeder's fuzzy logic and load cell integration effectively ensure precise feed dispensing, minimize waste, and support consistent fish growth.

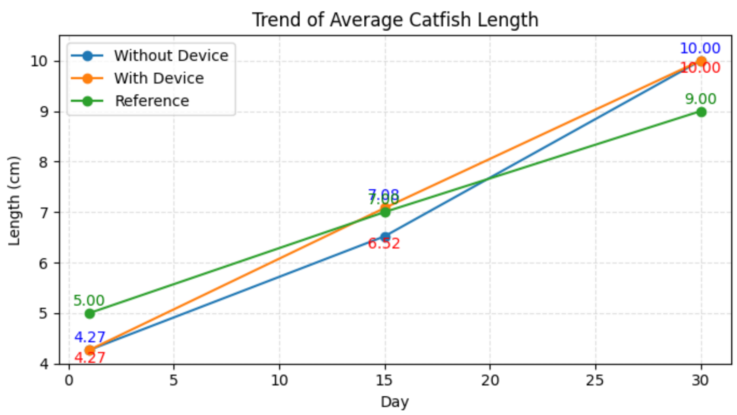

Figure 6. Growth trend graph catfish using smart autofeeder compared to without the device.

The growth trend graph figure 6. shows a clear improvement in average catfish length when using the Smart Auto Feeder compared to the pond without the device. At Day 15, fish in the automated pond reach 7.08 cm, which is higher than both the fish without the device (6.52 cm) and the reference growth (7.00 cm). By Day 30, fish in both conditions reach 10.00 cm, but the fish with the device exhibit a more stable and consistent growth trajectory throughout the period.

The pond without the device shows slower early growth and greater variation, suggesting less consistent feeding. The reference line remains between the two treatments, indicating that the Smart Auto Feeder supports growth that meets or exceeds standard benchmarks.

Overall, the results demonstrate that automated feeding improves early and mid-phase growth performance, providing more uniform nutrition delivery and supporting healthier development of catfish.

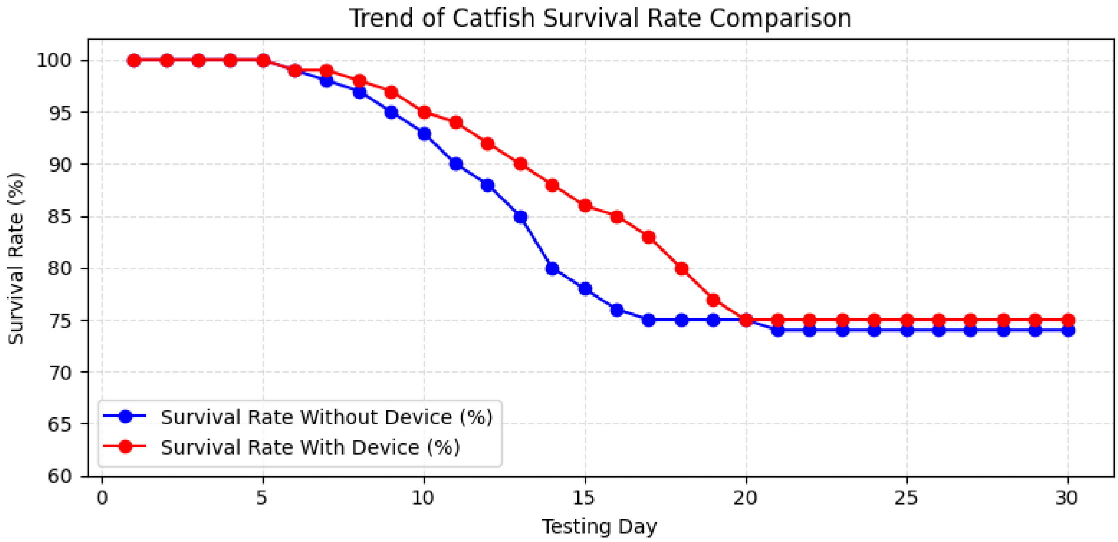

Figure 7. Survival rate graph between the smart auto feeder and without the device.

The survival rate graph figure 7. shows a clear difference in fish survival between the pond using the Smart Auto Feeder and the pond without the device. Fish in the automated pond maintain a higher survival rate throughout the early and middle stages of the 30-day observation period. Mortality begins around the same time for both ponds, but the decline is slower and less severe when the device is used.

By Day 20 onward, the pond without the device stabilizes at around **74%**, while the pond with the device stabilizes slightly higher at **75.6%**, reflecting better overall fish endurance. The improved survival rate in the automated pond indicates that consistent feeding timing and accurate feed portions help reduce stress, competition, and underfeeding—factors that contribute to mortality in the manually fed pond.

Overall, the results demonstrate that automated feeding enhances fish survival by ensuring more stable and predictable feeding conditions.

V. CONCLUSION

This study demonstrates that the Smart Auto Feeder Fish system based on the Sugeno Fuzzy Logic method effectively improves the feeding process and overall performance of catfish cultivation. The latency results show that the system consistently activates with minimal delay, particularly during morning feeding sessions, indicating reliable and stable operation. Afternoon sessions exhibit occasional fluctuations, but the system remains within acceptable performance limits.

The feed weight accuracy analysis confirms that the integration of fuzzy logic and load cell measurement provides highly precise feed dispensing, with accuracy levels generally above 97% for both morning and afternoon feedings. This precision contributes directly to better feeding consistency and reduced waste.

Growth trend results show that fish fed using the Smart Auto Feeder experience more consistent and slightly enhanced growth compared to manually fed fish, particularly during early and mid-growth phases. Additionally, the survival rate analysis indicates that the automated feeding system supports higher fish survivability, stabilizing at 75.6% compared to 74% in the pond without the device.

Overall, the findings confirm that the Smart Auto Feeder enhances feeding efficiency, promotes healthier and more uniform fish development, minimizes operational inconsistencies, and supports improved survival outcomes. These results highlight the system's potential as a practical and effective solution for modern aquaculture management. Future research should include neural network-enabled systems to improve load cell accuracy.

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