

## Adaptive Smart Cat Feeding System Based on ESP32 Using Fuzzy Logic and IoT Monitoring

Stefina Hendrayani<sup>1</sup>, I Gede Puja Astawa<sup>2</sup>, Budi Aswoyo<sup>3</sup>

stefina@te.student.pens.ac.id<sup>1</sup>, puja@pens.ac.id<sup>2</sup>, budi@pens.ac.id<sup>3</sup>

<sup>1,2,3</sup> Politeknik Elektronika Negeri Surabaya (PENS), Surabaya, Indonesia

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### Abstract

This study presents the design and implementation of an Internet of Things (IoT)-based smart cat feeder integrating an ESP32 microcontroller, Mamdani fuzzy logic control, and a web-based monitoring interface. Unlike conventional automatic feeders with fixed schedules, the proposed system adaptively determines daily feeding portions based on cat age, body weight, and remaining food using fuzzification, rule-based inference, and centre-of-gravity defuzzification. Experimental results demonstrate that for an adult cat with medium body weight, the system generated a daily feeding target of 91 g and distributed it incrementally across feeding sessions (41.5 g, 25.5 g, 11.4 g, and 12.6 g). The system effectively prevented overfeeding by automatically blocking additional dispensing once the daily quota was reached, even when additional infrared or scheduled triggers were present. Hardware testing confirmed stable sensor readings and accurate servo actuation proportional to defuzzification outputs. The web interface provided real-time monitoring, visualisation of historical feed data, and reliable two-way configuration synchronisation. These findings confirm that the proposed system achieves adaptive portion control, reliable daily intake limitation, and stable IoT-based monitoring, offering an effective and intelligent solution for automated pet feeding applications.

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## A. Introduction

The rapid development of science and technology has had a significant impact on various aspects of human life. One of the technologies that continues to evolve is the Internet of Things (IoT), which enables smart devices to connect and communicate with each other in real time. This technology has been widely applied, including in household automation devices such as washing machines and refrigerators, thereby improving efficiency in daily activities [1,2]. In the field of pet care, particularly for cats, IoT has great potential to address the challenges owners face, as they often struggle to provide food regularly and consistently due to busy schedules.

Feeding management is a key factor influencing the health and well-being of cats. The nutritional quality of the diet, appropriate food portions, and consistent feeding schedules strongly influence a cat's growth and overall condition. Based on previous studies, innovative solutions such as automatic feeding systems can help pet owners ensure that cats receive food according to their needs without relying solely on the owner's physical presence [3,4]. Such systems can be developed using an ESP32 microcontroller integrated with a web-based interface, allowing owners to monitor and control the feeding process remotely via smart devices.

In this study, an IoT-based smart feeder equipped with a fuzzy logic decision-making method is designed and developed. This approach not only enables automatic management of feeding schedules but also optimises food portions based on parameters such as age, body weight, and feeding conditions. The system utilises an infrared sensor and a Real-Time Clock (RTC) module to support automated operation according to predefined schedules. It is expected that this research will provide a practical, adaptable solution for cat owners while advancing intelligent, efficient, and data-driven IoT technologies for pet care applications [5-7].

## B. Research Method

This study was conducted through several systematic stages: literature review, system planning, web interface design, fuzzyfication process, fuzzy rule base development, defuzzification process, system testing, and analysis and conclusion. The detailed stages are as follows:

### 1. Literature Review

Several studies have examined the development of automatic cat feeding systems that integrate Internet of Things (IoT) technology and intelligent decision-making methods. In 2024, Zain et al. developed an IoT-based smart pet feeder designed for use in cat cages [8]. Their system enables automatic feeding control, with a microcontroller as the main controller and various sensors, ensuring that food is dispensed according to predefined conditions. The study focused on system automation and remote monitoring via IoT connectivity but did not implement adaptive food-portion determination based on multiple cat-related parameters.

In 2022, Khoiroh et al. proposed an automatic cat feeding system integrated with a Real-Time Clock (RTC) module to control feeding schedules and a mobile application (Blynk) for manual feeding control [3]. The system applied fuzzy logic to evaluate sensor accuracy, including ultrasonic sensors for measuring food levels in the storage container and load-cell sensors for measuring food weight. Although

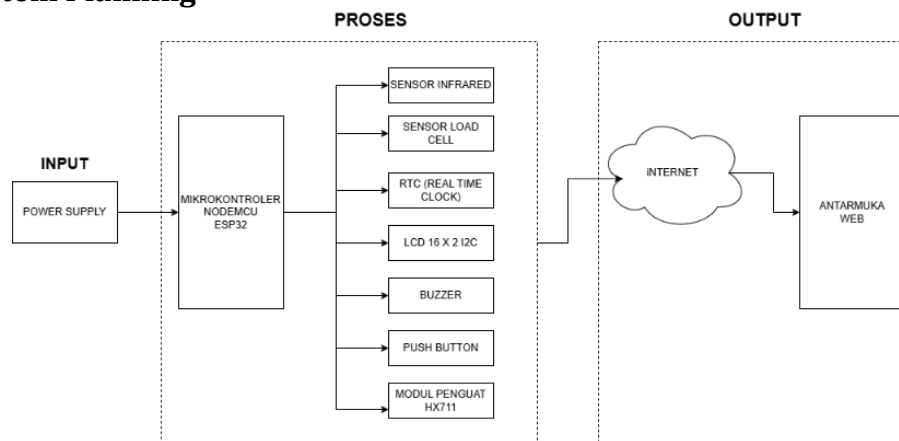
fuzzy logic was utilised, the study mainly emphasised sensor accuracy and monitoring functions rather than adaptive portion control based on comprehensive feeding conditions.

Another related study was conducted by Rahayu and Khoir in 2021, who developed an IoT-based automatic cat feeder controlled via the Telegram application [9]. Their system enables pet owners to dispense food and remotely monitor its availability via ultrasonic sensors. This approach provides convenience for users who are frequently away from home; however, the feeding portion is still determined manually or via predefined settings, without intelligent adaptation to the cat's condition.

Furthermore, Sadad et al. analysed the application of fuzzy logic in an automatic cat feeding system for the distribution of dry food in 2023 [10]. Their study aimed to determine appropriate food portions for cats based on age and body weight, using feeding guidelines from cat food manufacturers. The fuzzy logic design included the formation of fuzzy sets, rule bases, inference models, and defuzzification processes with trapezoidal membership functions. While the results demonstrated that food portions could be adjusted according to predefined ranges, the system was not fully integrated with real-time IoT-based monitoring and control.

Based on the reviewed studies, most existing systems either emphasise IoT-based monitoring and remote control or employ fuzzy logic with limited integration and adaptability. Therefore, this research proposes an IoT-based smart cat feeder that integrates fuzzy logic for adaptive food-portion determination and a web-based interface for real-time monitoring, scheduling, and evaluation, thereby addressing the limitations identified in previous studies.

## 2. System Planning



**Figure 1.** System Design Block Diagram

This system is designed for automatic monitoring and feeding and consists of three main parts: input, processing, and output.

1. Input collects data from the environment and user interaction using infrared sensors (object detection), load cells (food or cat weight), RTC (accurate time), and push buttons (manual input).
2. Processing uses the NodeMCU ESP32 microcontroller as the core, handling sensor data via the HX711 amplifier and applying fuzzy logic to determine

feeding time and portion sizes. With Wi-Fi capability, the ESP32 transmits processed data to the Internet, enabling IoT-based monitoring.

- Output includes a 16x2 I2C LCD for local display, a buzzer for sound alerts, and a web interface for real-time remote monitoring and schedule adjustment.

Overall, this ESP32 IoT-based smart feeder provides convenience for cat owners by automating feeding schedules, ensuring proper portions, and notifying when food stock is low. Its modular design makes it flexible, efficient, and adaptable for various pets or similar applications.

### Flowchart System

This flowchart describes the workflow of an ESP32-based automatic cat feeding system. The process begins with hardware initialisation and reading the tare value from EEPROM, followed by receiving the selected cat profile data from the website. The system then checks the feeding triggers, which include a manual push button, object detection by an IR sensor, and a scheduled feeding time using an RTC module. When one of these triggers is activated, the system reads the food container status and calculates the required food portion using fuzzy logic. Based on the calculation result, the servo opens to dispense the food. After feeding is completed, the feeding data is sent to the website, and the system returns to standby mode to repeat the process.

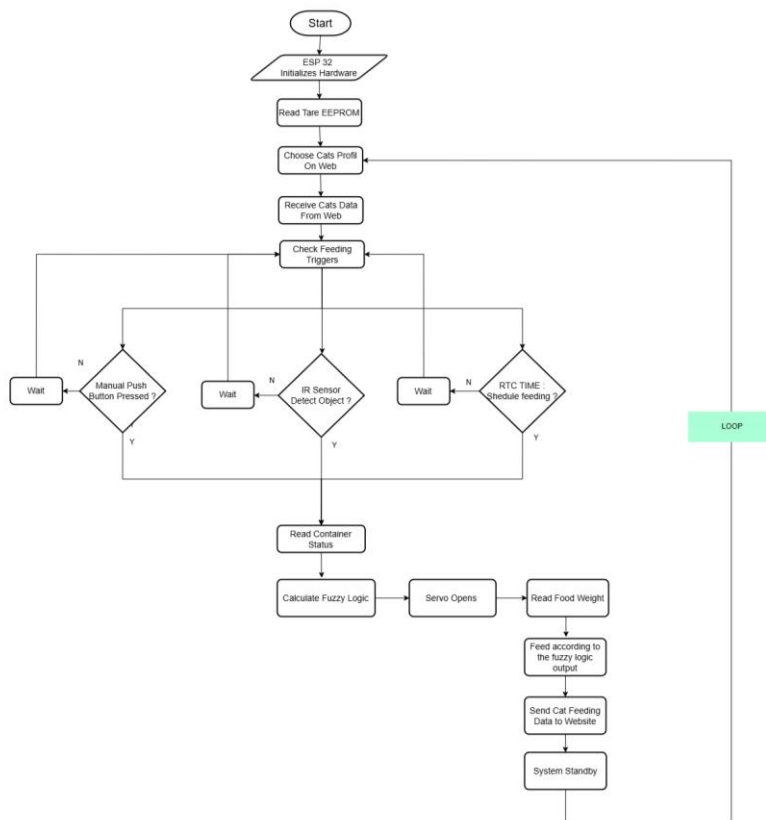
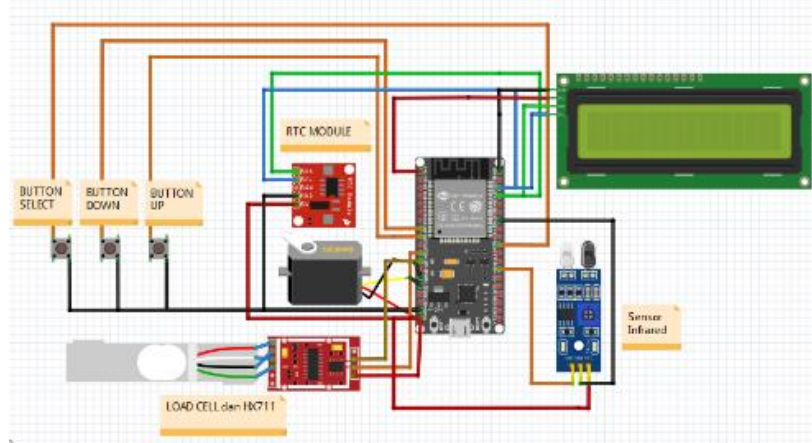


Figure 2. Flowchart System

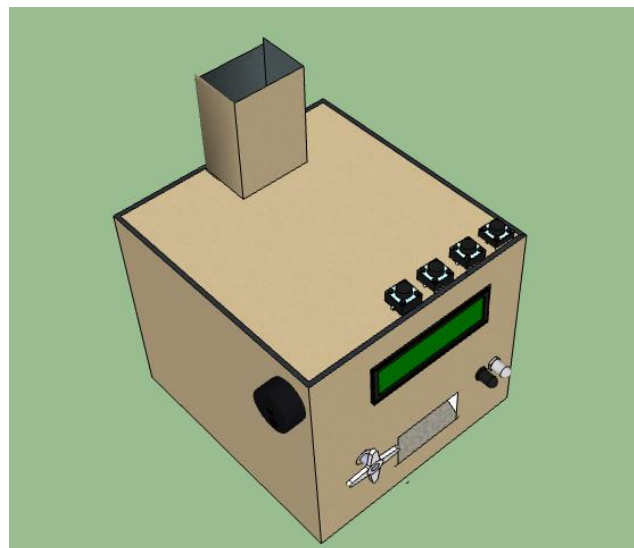
### Hardware and Prototype Design

The hardware system is designed to support automatic, scheduled, and adaptive feeding. It consists of an ESP32 microcontroller, infrared sensor, load cell with HX711 module, RTC DS3231, servo motor, LCD 16×2 I2C, push buttons, and a buzzer[10-15],[16]. The complete hardware circuit design is shown in Figure 3. All sensors and actuators are connected to the ESP32 in accordance with the designed circuit to ensure stable data acquisition and control. The load cell measures the weight of dispensed food in real time, while the RTC provides accurate scheduling for feeding operations.



**Figure 3.** Hardware circuit diagram

The physical design of the system prototype is illustrated in Figure 4. The components are arranged vertically inside a 3D-printed casing. The upper section serves as a food container, while the lower section houses a servo-controlled gate that regulates the flow of food into the feeding bowl atop the load cell.



**Figure 4.** Prototype design of the automatic cat feeder

## Analysis

Test results are analysed to evaluate system performance, sensor detection accuracy, and the responsiveness of data transmission to the web interface. The conclusion drawn from this analysis is that the designed automatic clothesline prototype is effective and reliable. The main hardware components used in the proposed smart cat feeder system are summarised in Table 1.

**Table 1.** Main Device Specifications Used

No	Component	Type	Main Specifications	Reference
1	ESP32	NodeMCU ESP32	Dual-core 32-bit microcontroller with integrated Wi-Fi and Bluetooth, operating voltage 3.3 V DC, multiple GPIO pins, programmable via Arduino IDE	[10]
2	Infrared Sensor	IR Obstacle Sensor	Object detection using infrared reflection, digital output, operating voltage 3.3–5 V DC	[14]
3	Load Cell	Weight Sensor	Strain gauge-based weight measurement sensor, high accuracy for gram-level measurement	[16]
4	HX711 Module	Load Cell Amplifier	24-bit ADC, high precision signal amplification for load cell sensors	[16]
5	RTC Module	DS3231	Real-time clock with battery backup, high timing accuracy	[12]
6	Servo Motor	SG90 / Equivalent	PWM-controlled actuator for food dispensing mechanism, operating voltage 4.8–6 V DC	[11]
7	LCD Display	16×2 I2C LCD	Alphanumeric display with I2C interface, low pin usage	[13]
8	Buzzer	Piezoelectric Buzzer	Audio alert indicator, low power consumption	[17]
9	Push Button	Tactile Switch	Manual input control, Normally Open (NO) type	[18]

## 3. Web Interface Design

The web interface functions as a monitoring and control platform for the automatic cat feeding system. It provides real-time information on the active cat profile, feeding records, food weight data, and fuzzy logic results. The interface also displays a food consumption graph for each feeding event, allowing users to analyse feeding patterns. In addition, menus for profile management, feeding schedule configuration synchronised with the RTC, and feeding history visualisation are provided to support efficient system monitoring and flexible scheduling.

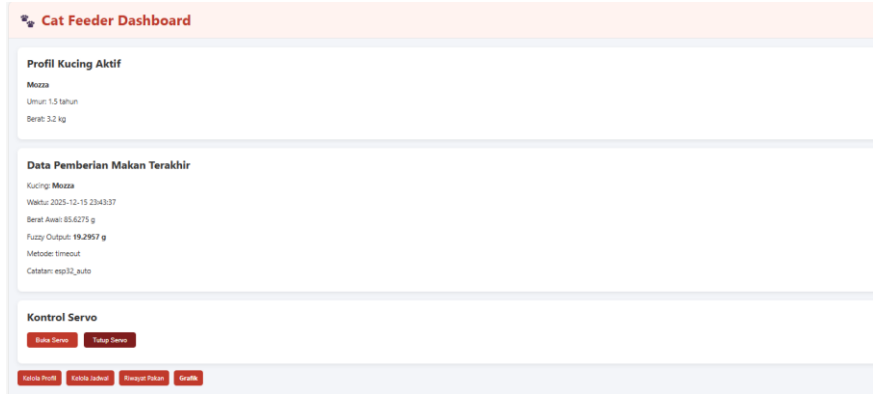


Figure 5. Web Interface Design

#### 4. Fuzzyfication Process

Fuzzy logic is widely used in control systems to handle uncertainty by converting crisp input values into fuzzy membership functions [17-19]. In this study, a fuzzy logic approach is applied to control an automatic dry cat feeding system using cat age, body weight, and remaining food as input variables. These inputs are processed through fuzzification and fuzzy inference based on predefined IF-THEN rules. Cat age, measured within a range of 0 to 15 years, is classified into three linguistic categories: Kitten, Adult, and Senior using triangular membership functions, as presented in Table I.

Table 1. Input Variable Cat Age

Category	Age (year)	MF
Kitten	0 – 1	[0 0 1]
Adult	1 – 7	[1 4 7]
Senior	7 – 15	[7 11 15]

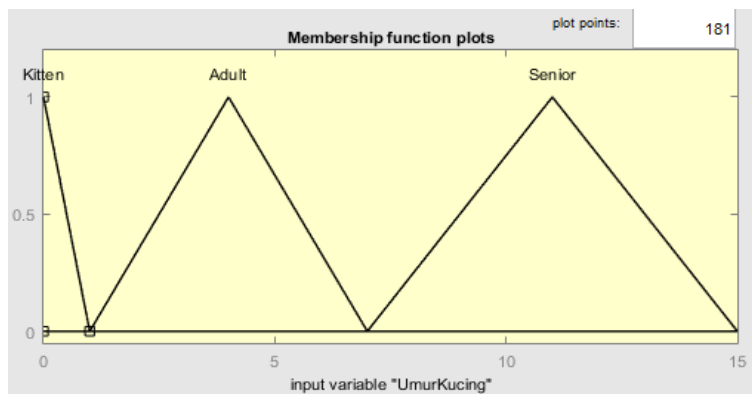


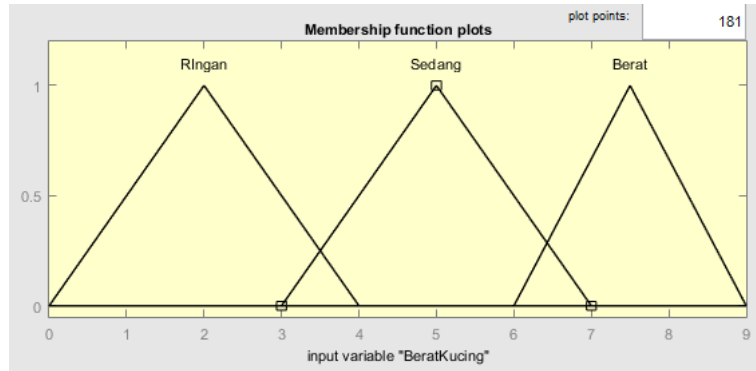
Figure 6. Cat Age Membership Function Graph

The Cat Weight variable is an input to the fuzzy system representing the cat's physical condition based on its body weight. The weight is measured in kilograms (kg) within a range of 1–9 kg. This variable is classified into three linguistic categories: Light, Medium, and Heavy, each represented by a trapezoidal

membership function to allow smooth transitions between categories. The category divisions and membership functions are shown in Table II.

**Table 2.** Input Variable Cat Weight

Category	Weight (kg)	MF
Light	0 – 4	[0 2 4]
Medium	3 – 7	[3 5 7]
Heavy	5 – 8	[6 7.5 9]

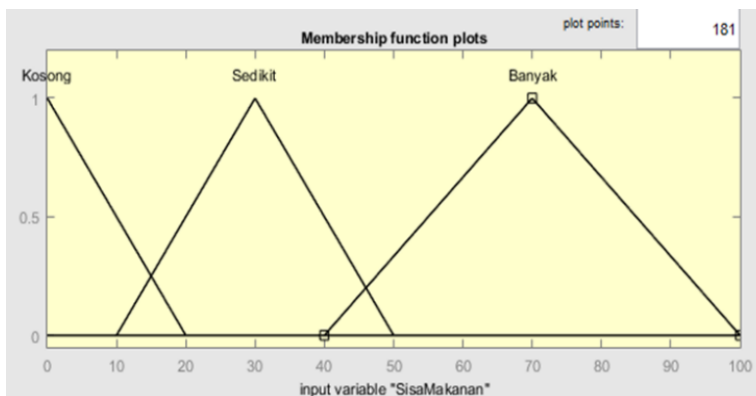


**Figure 7.** Cat Weight Membership Function Graph

The Remaining Food variable is an input to the fuzzy logic system representing the amount of dry food remaining in the container, measured in grams using a load-cell sensor. It is classified into three linguistic categories: *Empty*, *Low*, and *High*, each represented by a triangular membership function, as shown in Table III.

**Table 3.** Input Variable: Remaining Food

Category	Range (grams)	MF
Empty	0 – 20	[0, 0, 20]
Low	10 – 50	[10, 30, 50]
High	40 – 100	[40, 70, 100]



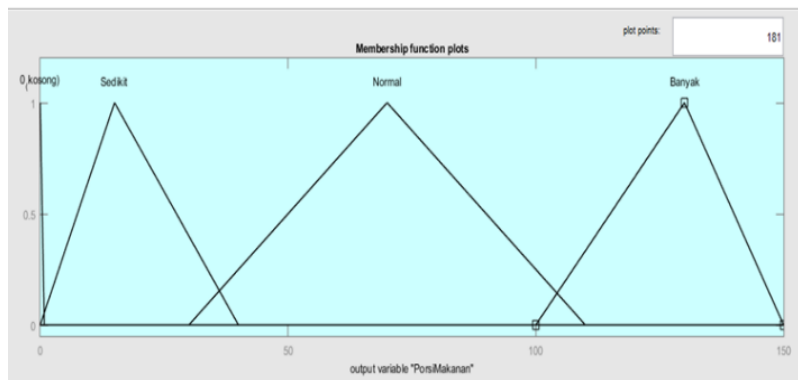
**Figure 8.** Remaining Food Membership Function Graph

The Dry Food Portion variable is the output of the fuzzy logic system, representing the amount of dry food dispensed per day. It is determined through fuzzification, inference, and defuzzification based on cat age, cat weight, and

remaining food. It is classified into three linguistic categories: *Low*, *Normal*, and *High*, each represented by a triangular membership function.

**Table 4.** Output Cat Food Portion

Category	Range (grams/day)	MF
Empty	0	[0, 0, 0]
Low	0 – 40	[0, 15, 40]
Normal	30 – 110	[30, 70, 110]



**Figure 9.** Cat Food Portion Membership Function Graph

### 5. Inference Process

The inference process applies a Mamdani fuzzy rule base to determine the output based on combinations of multiple input variables [19-22]. The fuzzy logic system in this device uses a rule base constructed from three input variables: cat age, body weight, and the amount of food remaining in the container. Each combination of these inputs produces an output category indicating the food portion: Less, Normal, or More. The rules are designed to emulate human decision-making in a logical yet flexible manner. For example, if the cat is in the Kitten stage, has a Light body weight, and the remaining food is Low, the system will provide a More portion with an estimated range of 100–150 grams per day. This is because kittens are in a growth phase and require higher nutritional intake. Conversely, for a Senior cat with a Heavy body weight and a High remaining food level, the system will assign a smaller portion, as energy requirements decrease with age and appetite tends to decline. Through this approach, the fuzzy logic system can automatically and intelligently adjust the food portion based on the cat's actual condition, ensuring a more efficient, accurate, and appropriate daily feeding process.

**Table 5.** Fuzzy Rule Base

Age Group	Body Weight	Remaining Food	Food Portion
Kitten	Light	Empty	High
Kitten	Light	Low	Normal
Kitten	Light	High	Low

Kitten	Medium	Empty	High
Kitten	Medium	Low	Normal
Kitten	Medium	High	Low
Kitten	Heavy	Empty	Normal
Kitten	Heavy	Low	Low
Kitten	Heavy	High	Zero
Adult	Light	Empty	High
Adult	Light	Low	Normal
Adult	Light	High	Low
Adult	Medium	Empty	Normal
Adult	Medium	Low	Low
Adult	Medium	High	Zero
Adult	Heavy	Empty	Low
Adult	Heavy	Low	Zero
Adult	Heavy	High	Zero
Senior	Light	Empty	Normal
Senior	Light	Low	Low
Senior	Light	High	Zero
Senior	Medium	Empty	Normal
Senior	Medium	Low	Low
Senior	Medium	High	Zero
Senior	Heavy	Empty	Low
Senior	Heavy	Low	Zero
Senior	Heavy	High	Zero

## 6. Defuzzification Process

Defuzzification is the final stage of the fuzzy logic system, which converts the results of fuzzy inference into a single crisp value that serves as the basis for determining the amount of dry food to be dispensed to the cat. In this system, the Mamdani defuzzification method with the Centre of Gravity (COG) approach is applied to obtain a precise and representative output value [15]. The fuzzy output sets generated by the inference process are clipped according to their respective rule activation levels, then combined into a single aggregated fuzzy output using the maximum (MAX) operator. The COG method is subsequently employed to compute the crisp value by determining the centroid of the aggregated fuzzy membership function across the output domain. The resulting crisp value represents the food portion in grams and is adaptively influenced by the cat's age, body weight, and the amount of food remaining in the container. The control system then utilises this value to regulate the servo motor opening duration, with higher defuzzification values resulting in longer servo activation times and a greater quantity of dispensed food. In comparison, lower or zero values reduce or completely stop the feeding process.

## C. Result and Discussion

This section presents the results of system testing, including the evaluation of the automatic cat feeder hardware using fuzzy logic and testing of the web-based monitoring and control interface. The testing aims to verify that the system

functions correctly, including determining the appropriate food portion and providing accurate real-time information through the web interface.

### Fuzzy Algorithm Testing

This test evaluates the performance of the fuzzy logic system in determining cat food portions based on three input variables: cat weight, age, and the amount of remaining food detected by the load cell sensor. The Mamdani fuzzy inference method is applied to generate a daily food target, which is then gradually distributed via partial feeding to prevent overfeeding. When the daily target is reached, the system automatically blocks further feeding, regardless of infrared sensor detection triggers or scheduled feeding times. The results demonstrate that the fuzzy logic system dynamically adapts feeding portions and effectively enforces daily intake limits.

**Table 6.** Fuzzy Logic Testing Result

Time	Cat	Remaining food (g)	Daily Target (g)	Dispensed Portion (g)	Remaining Quota (g)	Rule Base	Method
07:20	Mossi	0.0	91.0	41.5	49.5	Medium-Adult-Empty → Normal	IR Sensor
09:00	Mossi	23.7	91.0	25.5	24.0	Medium-Adult-Low → Normal	Schedule
12:00	Mossi	58.1	91.0	11.4	12.6	Medium-Adult-High → Less	Manual
15:00	Mossi	39.6	91.0	12.6	0.0	Medium-Adult-Low → Normal	Schedule
19:00	Mossi	28.4	91.0	0.0	0.0	Daily target achieved (feeding blocked)	IR Sensor
21:00	Mossi	10.0	91.0	0.0	0.0	Feeding blocked	Schedule

### Hardware Implementation Results

Figure 10 shows the realised automatic cat feeder system after hardware assembly and integration. All system components, including the ESP32 microcontroller, sensors, servo motor, and food container, are installed inside the casing according to the designed prototype.



**Figure 10.** Realisation of the automatic cat feeder system

The hardware implementation results show that the system operates reliably during testing. The servo motor responds accurately to the defuzzification output by adjusting its opening duration based on the calculated food portion. The ESP32 successfully processes sensor readings from the infrared sensor and load cell to support feeding decisions. These results confirm that the hardware implementation is integrated correctly with the fuzzy logic decision-making process.

### **Web Interface Testing Results**

The web interface testing was conducted to verify its functionality as a monitoring and control platform for the Smart Fuzzy Cat Feeder. The results show that all data transmitted from the device to the server are successfully displayed in real time and remain consistent with the system execution. The web interface correctly presents essential information, including active cat profiles, feeding records, food weight data, fuzzy logic results, and feeding schedules synchronised with the RTC module. Configuration changes made through the web interface are properly applied by the device, confirming reliable two-way synchronisation. In addition, feeding history and food consumption graphs provide a clear visualisation of feeding events and daily feeding limits, allowing users to monitor feeding patterns and evaluate system performance. Figures 11-15 illustrate the main interface views used during testing.

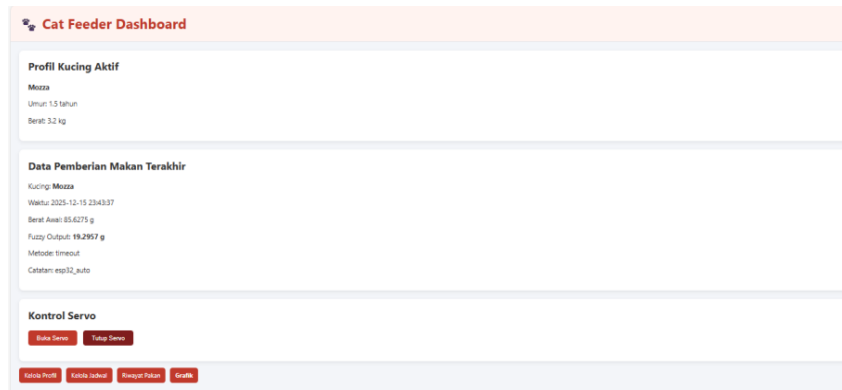


Figure 11. Dashboard Web Interface

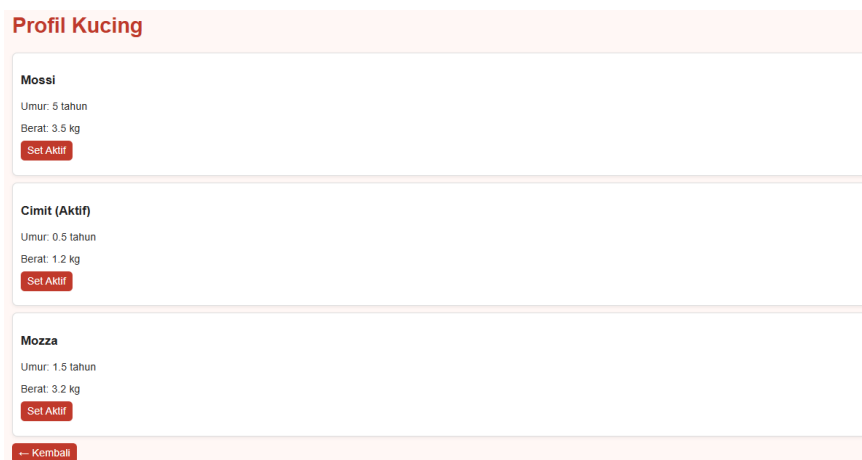


Figure 12. Cat Profile Menu



Figure 13. Feeding Schedule Menu

Kucing	Sisa (g)	Target Harian (g)	Porsi Keluar (g)	Sisa Kuota (g)	Rule Base	Metode
Mossi	39.6	91.0	12.7	-0.1	Sedang-Dewasa-Sedikit → <b>Normal</b>	SCHEDULE_FEED
Mossi	58.1	91.0	11.4	12.6	Sedang-Dewasa-Banyak → <b>Sedikit</b>	MANUAL_BUTTON
Mossi	23.7	91.0	25.5	24.0	Sedang-Dewasa-Sedikit → <b>Normal</b>	SCHEDULE_FEED
Mossi	0.0	91.0	41.5	49.5	Sedang-Dewasa-Kosong → <b>Normal</b>	IR_FEED

Figure 14. History Feeding Record

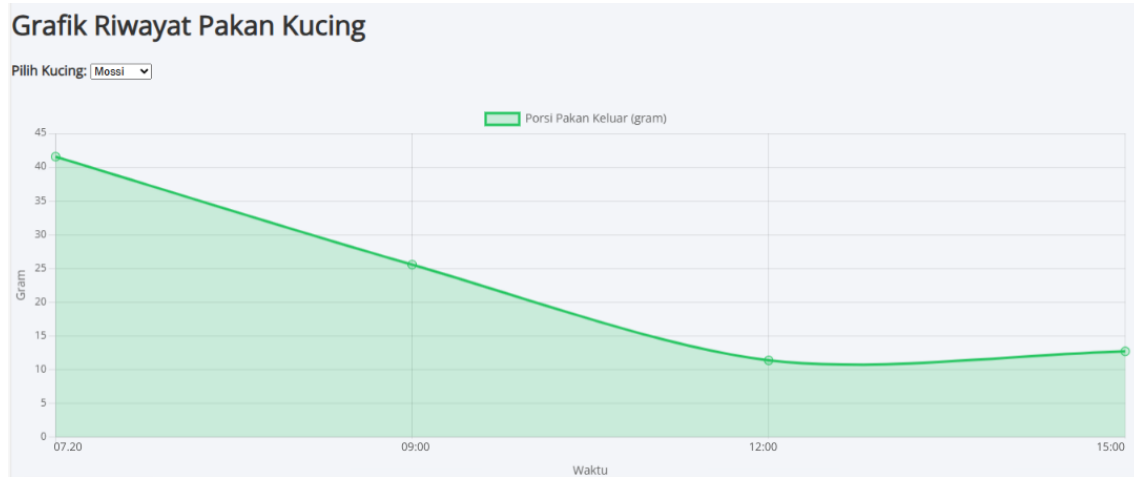


Figure 15. Food consumption graphs

#### D. Conclusion

This study has successfully designed and implemented a smart, automatic cat feeder based on the ESP32 microcontroller, with fuzzy logic and a web-based interface. The fuzzy logic method is used to determine adaptive food portions based on the cat's age, body weight, and the amount of food remaining in the container. Experimental results show that the system accurately dispenses food in accordance with daily feeding targets and prevents overfeeding by blocking dispensing once the target is reached. The hardware implementation operates reliably, with sensors, a servo motor, and control mechanisms functioning as expected. In addition, the web interface supports real-time monitoring, visualisation of feeding history, and synchronised configuration of the feeding schedule with the RTC module. Overall, the proposed system demonstrates an efficient, accurate, and flexible solution for automatic cat feeding and has the potential to improve pet care management through intelligent decision-making and remote monitoring.

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