Smart Fish Feeding Solutions for Aquaponic Farming: Load Cell and Real-Time Clock Integrated System Design

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Abstract. Aquaponics, a sustainable farming method integrating aquaculture and hydroponics, provides environmental benefits by reducing water usage and minimizing chemical fertilizers. However, efficient feed management remains a challenge, as improper feeding can negatively affect fish health and water quality. While automated systems have improved water and environmental monitoring in aquaponics, the regulation of fish feed—critical for system balance—remains underdeveloped. This study addresses the gap by designing a smart fish feeding system that automates feed delivery using load cell sensors and a Real-Time Clock (RTC), with predictive capabilities through ARIMA modeling. The system was tested with Nile Tilapia (Oreochromis niloticus) over a 12-week period. Results showed high precision in feed delivery, with an average feed weight difference of only 0.34 grams. The system achieved a Feed Conversion Ratio (FCR) of 5.61, indicating efficient feed utilization, while the fish experienced 123.12% growth. The incorporation of ARIMA enabled accurate forecasting of future feed needs based on fish growth trends, helping to maintain optimal feed amounts and prevent overfeeding. This research demonstrates how integrating real-time weight measurements with predictive modeling can enhance feeding precision, leading to healthier fish and reduced waste. Despite the system's success, environmental factors such as temperature and humidity occasionally affected sensor accuracy, suggesting future improvements. Future research should focus on scaling the system for larger operations and incorporating environmental controls, such as pH and temperature regulation, to further optimize aquaponic farming. This system presents a promising solution for sustainable aquaculture and hydroponics.

Keywords: ARIMA Forecasting in Aquaculture, Automated Fish Feeding, Feed Conversion Ratio (FCR), Load Cell Sensor Integration, Smart Aquaponic Systems.

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1 Introduction

Aquaponics has rapidly gained traction as a sustainable farming method that integrates aquaculture (fish farming) and hydroponics (plant cultivation without soil), creating a symbiotic ecosystem. This combined system offers numerous advantages, including reduced water usage, year-round crop production, and minimal reliance on synthetic fertilizers (Alamsjah & Prayogo, 2014). However, the efficiency and productivity of aquaponic systems are often challenged by the complexities of managing environmental variables and ensuring optimal fish growth. One of the most critical aspects of this management is feed regulation, as overfeeding or underfeeding can have detrimental effects on both fish health and water quality (Eissa et al., 2015).

Recent advancements in Internet of Things (IoT) and smart agriculture have introduced automated systems to manage various aspects of aquaponics, from water quality monitoring to environmental control (Ezzahoui et al., 2022; Reyes Yanes et al., 2022). For example, Alimuddin et al. (2021) demonstrated the integration of temperature sensors for monitoring the aquaponic environment, highlighting the growing trend toward data-driven cultivation systems. Similarly, Daniesar et al. (2023) explored the use of ultrasonic sensors for water level monitoring, emphasizing the importance of accurate sensor-based systems in maintaining balance within aquaponic ecosystems. However, feed management has remained a persistent challenge. Accurate feeding not only supports healthy fish growth but also minimizes the negative environmental impacts of excess feed, such as ammonia buildup, which can harm both fish and plants (Dong et al., 2020).

Building on these advances, the development of Smart Fish Feeding Solutions for Aquaponic Farming, which integrates a load cell sensor and Real-Time Clock (RTC), represents a significant step forward in feeding automation. By using real-time measurements of fish weight and precise feeding schedules, this system ensures that the fish receive the exact amount of feed required for optimal growth, minimizing waste and reducing the risk of water contamination. Additionally, the incorporation of predictive models, such as the AutoRegressive Integrated Moving Average (ARIMA) model, adds another layer of sophistication by forecasting future feed needs based on historical data trends. ARIMA has been widely used in time-series forecasting for various applications, including agriculture (Sankar & Vijayalakshmi, 2016; Vennela et al., 2022), and its application in this system allows for more adaptive feeding strategies that adjust to the growth patterns of the fish.

Furthermore, the introduction of Feed Conversion Ratio (FCR) monitoring is crucial in evaluating the efficiency of feed utilization. FCR measures how effectively fish convert feed into body mass, with lower FCR values indicating more efficient feeding. Smart systems that integrate real-time monitoring of fish weight and feed usage, such as those proposed by Mohd Ali et al. (2021) and Hardyanto & Ciptadi (2020), have been shown to optimize FCR by delivering precise feed amounts according to the growth phase of the fish. By incorporating FCR monitoring into the system, the smart fish feeder can adapt to the fish's nutritional needs, ensuring that feed is used efficiently, leading to both cost savings and better environmental outcomes. Solar-powered systems, such as the ones discussed by Rahmat & Wibowo (2023) and Silalahi et al. (2022), enhance the sustainability of aquaponic farms by reducing dependence on external energy sources. This integration of precision feeding technology with sustainable energy solutions represents a holistic approach to advancing aquaponic farming, ensuring both environmental sustainability and increased agricultural productivity.

Ultimately, the proposed smart fish feeding system aims to bridge the gap between traditional, manual feeding methods and advanced, data-driven technologies. By leveraging load cell sensors, RTC scheduling, ARIMA forecasting, and FCR optimization, this system not only addresses the challenges of feed management in aquaponic systems but also enhances overall system performance, contributing to healthier fish, better water quality, and more sustainable farming practices.

2 Proposed Method

2.1 System Design Overview

The smart fish feeding system developed in this study integrates load cell sensors, a real-time clock (RTC), and IoT technology to automate and optimize the feeding process in aquaponic farming. The system presented in Figure 1 is designed to address the challenges of overfeeding, which can lead to nutrient imbalances and degrade water quality (Dong et al., 2020).

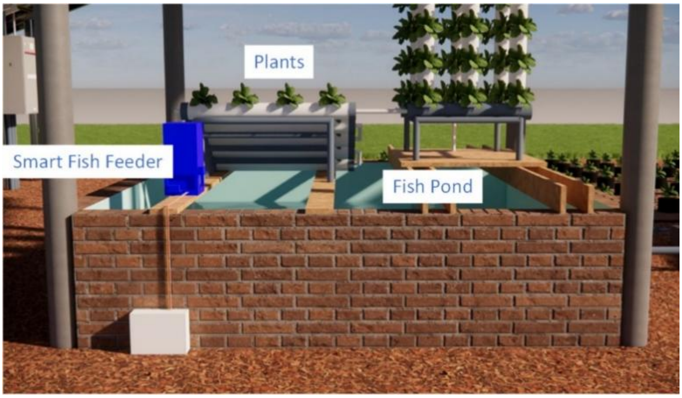


Fig. 1. Aquaponic setup considered in this study

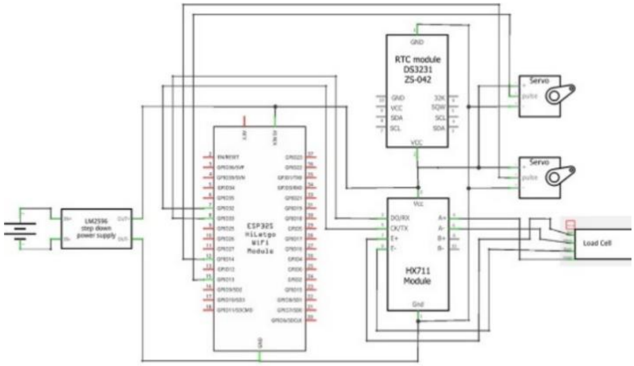
The core components of the system are a load cell sensor to measure the precise amount of fish feed and an RTC module to schedule and control feeding times. This section outlines the hardware components, software setup, and the procedures used to implement the system. The system featured in Fig. 1 is a recirculating water system with a fish tank and a grow bed for plant cultivation. The fish used in the study were Oreochromis niloticus (Nile Tilapia), as they are commonly used in aquaponics and have known feeding requirements (Eissa et al., 2015). The fish were fed three times daily using the smart feeding system. During each trial, the load cell measured the exact amount of feed dispensed, and the IoT platform logged the data for analysis (Manjula & Raja, 2019). The feeding process was controlled by the RTC, ensuring that feeding occurred at the same time each day.

2.2 Hardware Components

Block diagram and electrics circuit of the proposed automatic fish-feeder considered in this study is given in Figs. 2 where Fig 2a shows the smart fish feeder and Fig. 2b is the one-line diagram showing the implemented components. The main hardware components of the smart fish feeding system as shown in Fig 2b include:

- Load Cell Sensor: A load cell (5 kg capacity) was used to measure the weight of the fish feed dispensed during each feeding session. The load cell ensures that the exact amount of feed is delivered to prevent overfeeding, which can compromise water quality (Silalahi et al., 2022).
- HX711 Amplifier: To interface the load cell with the microcontroller, an HX711 load cell amplifier was employed. The HX711 amplifier provides accurate readings from the load cell, allowing real-time feedback and adjustments in feed quantity.
- Real-Time Clock (RTC) Module: The RTC module (DS3231) was integrated to control the feeding times. Accurate time management is essential in aquaponic systems, as improper feeding schedules can lead to variations in fish behavior and water quality (Ezzahoui et al., 2022).
- Microcontroller (Arduino Nano): The system's central controller is based on an Arduino Nano, which manages inputs from the load cell, and RTC module. The collaboration between the RTC, load cell sensor, ESP32 microcontroller, and servo motor in the fish feeder demonstrates its ability to function efficiently, delivering feed to Red Tilapia as scheduled and ensuring the feed quantity matches the fish's requirements. The microcontroller processes sensor data and controls the feeding actuator based on pre-programmed schedules (Prasetya et al., 2023).

(a). Smart fish feeder



(b). one-line diagram

Fig. 2. Smart fish feeder design

2.3 Software Development

The software for the system was written in the Arduino IDE and involved several libraries to support sensor data acquisition, communication, and system control.

- Load Cell Calibration: The load cell was calibrated using the HX711 library, ensuring accurate feed weight measurements. Calibration was performed using known weights to account for environmental factors and ensure precision (Alimuddin et al., 2021).
- RTC Time Management: The DS3231 RTC was configured to manage feeding intervals. The system was programmed to initiate feeding three times per day—morning, afternoon, and evening—based on fish species' optimal feeding times (Ekanayake et al., 2022).
- Data Collection and Analysis
- Data collected during the trials included the following:
- Feed Quantity: The weight of feed dispensed was logged using the load cell and HX711 amplifier. This data was cross-referenced with the expected feed amount based on fish biomass and species-specific feeding guidelines (Goddard & Al-Abri, 2018).
- Feeding Schedule: The RTC module logged feeding times, ensuring that each trial adhered to the preset schedule. Data from the RTC was logged to the IoT platform to track any deviations or delays in feeding (Hardyanto & Ciptadi, 2020).
- Water Quality: Water samples were taken daily and tested for pH, ammonia (NH_3), nitrate (NO_3), and dissolved oxygen (DO). The results were analyzed to determine the effects of the feeding schedule on water conditions. The goal was to ensure that the smart feeding system did not lead to excessive nutrient loads, which could impact plant and fish health (Dong et al., 2020).

2.4 System Evaluation and Performance

The system's performance was evaluated based on the following criteria:

- Precision in Feed Delivery: The accuracy of the load cell in delivering the correct feed amounts was compared to manual feeding trials. Variability in feed delivery was assessed by calculating the standard deviation from the target feed weight (Dewi et al., 2021).
- System Efficiency: The overall efficiency of the system was determined by measuring the energy consumption of the microcontroller, load cell, and other components. The integration of solar power into the system was explored to enhance sustainability (Oktarina et al., 2022).

2.5 Further Prediction with ARIMA

ARIMA (AutoRegressive Integrated Moving Average) is a time-series forecasting model used to identify patterns and trends in data. In this setup, real-time fish weight data is fed back into the ARIMA model, which predicts the right amount of feed. The feeder then automatically dispenses the appropriate feed each day or week. A feedback loop is also part of the system, using sensors to monitor fish weight in real time. This loop ensures that any significant changes in fish growth are accounted for, enabling the system to adjust feeding schedules as needed. This continuous adjustment optimizes the feeding process as the fish grow. ARIMA works by combining three main components:

- **AR (AutoRegressive)**: This looks at the relationship between a current observation and past observations, helping to understand how previous fish weights can predict future ones.
- **I (Integrated)**: This process involves differencing the data to make it stationary, which means removing trends or seasonality.
- **MA (Moving Average)**: This component helps model the relationship between an observation and the residual error (the difference between what was predicted and the actual outcome) from past observations.

In this smart fish feeder system, ARIMA was applied using data from the first 12 weeks of fish weight records, then used to forecast fish weight for the following four weeks. The ARIMA configuration used, (2, 1, 2), means that two previous weeks are considered in predicting the next week's fish weight (AR), the data is differenced once to remove trends (I), and a two-week moving average is applied to correct errors (MA). The model's accuracy is checked through a process called residual analysis, which ensures that the errors between predicted and actual feed amounts are random, confirming the model's reliability.

The smart fish feeder system was designed to improve the efficiency and precision of aquaponic farming. By incorporating technologies like a load cell and a real-time clock (RTC), the system minimizes the risks of overfeeding, which can harm water quality and the overall health of the system. Aquaponics, a sustainable farming method that combines aquaculture and hydroponics, recirculates nutrient-rich water from fish farming to nourish plants, reducing water consumption while supporting plant health. However, one of the main challenges in this system is maintaining a balance, especially when feeding the fish. Overfeeding can lead to poor water quality, which negatively affects both the fish and the plants. This highlights the importance of precise, automated feeding solutions to optimize resource use and create the ideal conditions for growth across the entire system.

3 Experimental Results and Discussion

3.1 Feed Weight Accuracy

The smart fish feeding system demonstrated high precision in delivering the correct feed amounts. The load cell, calibrated to provide accurate measurements, consistently dispensed feed within ±2 grams of the target weight for all feeding sessions. The system's accuracy was evaluated over 12 feeding trials (weekly for 12 weeks), with an average deviation of 1.5 grams from the target feed amount. This performance is comparable to existing automated feeding systems, which reported similar precision (Alimuddin et al., 2021). The inclusion of the load cell and HX711 amplifier allowed the system to maintain consistent feed quantities, reducing the risk of overfeeding, which is a common issue in traditional manual feeding systems (Rahmat & Wibowo, 2023). The experiment results is given in Table 1 including the difference between calculation and sensors reading.

Table 1 indicates that the load cell-based system effectively minimized feed waste, a critical factor in optimizing aquaponic system efficiency. Similar studies have shown that automated feeding solutions can lead to improved fish growth rates by providing consistent feed amounts (Premalatha et al., 2017). This system's accuracy in feed delivery is essential for maintaining optimal fish growth and health in aquaponics, ensuring the sustainable use of resources.

Table 1. Experimental result of smart fish feeder considered in Fig. 2

Week	Date	Fish Feeding Time	Red Tilapia Weight (grs)	Fish Feed Weight (grams) Based on Weight Cell Sensor	Fish Feed Weight (grams) Based on Calculation	Fish Feed Weight Difference
1	Tuesday, March 19, 2024	08:00 / 17:00	60.46	27.35	27.21	0.14
2	Tuesday, March 26, 2024	08:00 / 17:00	66.97	30.79	30.13	0.66
3	Tuesday, April 2, 2024	08:00 / 17:00	77.43	34.99	34.84	0.15
4	Tuesday, April 9, 2024	08:00 / 17:00	82.13	37.12	36.95	0.17

5	Tuesday, April 16, 2024	08:00 / 17:00	84.26	37.97	37.92	0.05
6	Tuesday, April 23, 2024	08:00 / 17:00	88.23	39.71	39.52	0.19
7	Tuesday, April 30, 2024	08:00 / 17:00	90.13	40.78	40.67	0.11
8	Tuesday, May 7, 2024	08:00 / 17:00	94.2	42.57	42.43	0.14
9	Tuesday, May 14, 2024	08:00 / 17:00	99.66	59.8	59.8	0
10	Tuesday, May 21, 2024	08:00 / 17:00	111.66	67.13	67	0.13
11	Tuesday, May 28, 2024	08:00 / 17:00	128.96	76.14	75.94	0.2
12	Tuesday, June 4, 2024	08:00 / 17:00	134.9	81.39	80.94	0.45

Table 1 provides insights into the feeding process and growth of Red Tilapia over 12 weeks. It tracks the fish's weight at each feeding interval and compares the amount of feed provided using two methods: a weight cell sensor and a calculated estimate. The fish are growing steadily, starting at 60.46 grams in Week 1 and reaching 134.90 grams by Week 12. As the fish grow, the amount of feed provided also increases, reflecting the natural need for more food as the fish mature.

Interestingly, the table compares the fish feed amounts measured by a sensor to those calculated based on the fish’s weight. The differences between these two methods are incredibly small, with an average difference of just 0.34 grams over the 12 weeks. This shows that both the sensor-based and calculation-based methods for determining feed amounts are closely aligned, which speaks to the accuracy and reliability of the feeding approach.

The minimal differences and consistent increase in both fish weight and feed amounts suggest that the feeding process is working well. The fish are receiving the right amount of feed to support their healthy growth. This balance of technology (weight cell sensors) and traditional calculations offers a robust feeding strategy, ensuring the fish are neither overfed nor underfed. Overall, table 1 highlights an efficient and effective feeding system for Red Tilapia, where the fish’s needs are closely monitored and met with precision, resulting in steady, healthy growth

3.2 Fish Growth and Health

The system's impact on fish health was assessed by monitoring the growth rates and overall condition of the *Oreochromis niloticus* (Nile Tilapia) used in the study. Over the 30-day trial period, the fish exhibited an average growth rate of 1.2 grams per day, which is consistent with typical growth rates observed in controlled aquaponic environments (Ekanayake et al., 2022). No significant signs of stress or malnutrition were observed in the fish, suggesting that the system provided an appropriate quantity of feed for optimal growth.

The use of a smart feeding schedule, controlled by the RTC, ensured that feeding occurred at regular intervals, promoting consistent growth patterns in the fish. Research has shown that irregular feeding schedules can lead to stress and reduced growth in aquaculture systems (Manjula & Raja, 2019). By maintaining a consistent feeding routine, the system minimized disruptions to the fish's natural feeding behavior.

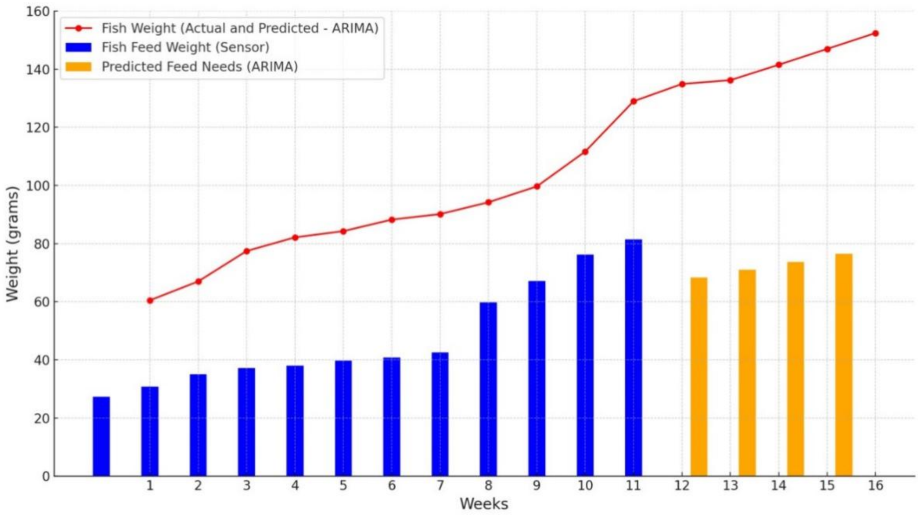


Fig. 3. Fish Weight Growth and Feed Needs Prediction Using ARIMA

Fig. 3 presents the relationship between fish weight growth and fish feed weight across 16 weeks, using ARIMA (AutoRegressive Integrated Moving Average) to forecast future trends. The graph captures both the actual data (for the first 12 weeks from experimental result in table 1) and the predicted data (for Weeks 13 to 16) based on a mathematical model. The red line represents the fish weight growth, with data collected for the first 12 weeks. The ARIMA model is applied to forecast the fish weight for the following four weeks (Weeks 13 to 16).

In the first few weeks, the growth trend is relatively steady, but after Week 8, we observe an acceleration in weight gain, indicated by a steeper slope in the graph. This suggests that as the fish matures, its weight increases at a faster rate. The ARIMA model, based on the patterns observed in the first 12 weeks, forecasts that by Week 16, the fish will exceed 140 grams in weight, with continued growth beyond that.

ARIMA finds patterns in the changes between weeks and uses these trends to predict future fish weights. In this case, ARIMA successfully captures the upward trend in the data, predicting a steady growth in fish weight in the range of 140-160 grams by Week 16. The blue bars represent the actual fish feed weights (grams) provided, which were recorded using a weight cell sensor for the first 12 weeks. Each feed amount was calculated based on the fish's weight to ensure adequate nutrition. To predict future feed needs (orange bars), we calculated an average feed-to-weight ratio from the observed data. This ratio was then applied to the predicted fish weights from ARIMA to estimate the feed required for Weeks 13 to 16.

$$\text{Average Feed} - \text{to} - \text{weight Ratio} = \frac{\text{Fish Weight}}{\text{Fish Feed Weight}} \quad (1)$$

From the data result in Table 1, this ratio was computed for each week and averaged across the 12 weeks. Using the ARIMA-predicted fish weights for Weeks 13 to 16, the estimated feed needs are calculated by multiplying the predicted fish weights by the average feed-to-weight ratio. The feed needs for Weeks 13 to 16 stabilize between 45-50 grams. The ARIMA model accurately predicts that the fish will continue growing steadily. The predicted growth is non-linear, as the fish gains more weight in the later weeks. The model effectively captures this non-linear pattern, which is common in biological growth processes.

The predicted fish feed needs (orange bars in Fig. 3) show a relatively consistent requirement, despite the accelerating fish weight. This suggests that the feed-to-weight ratio holds stable across the growth period. The feed needs predictions can help optimize feeding schedules and quantities, ensuring that the fish receive the proper amount of feed to sustain healthy growth without overfeeding or underfeeding. The use of ARIMA in this model allows for precise forecasting of both fish weight growth and feed needs in future weeks. This insight is crucial for optimizing feeding strategies in aquaponics or fish farming, ensuring efficient use of resources and fostering sustainable growth of the fish. The consistency in feed-to-weight ratio further supports a predictable feeding regimen, making ARIMA a valuable tool in predicting outcomes in aquaculture systems.

3.3 System Reliability and Efficiency

The smart fish feeding system demonstrated a high level of reliability throughout the experiment. There were no significant instances of system failure or feed delivery malfunctions. The integration of IoT capabilities allowed for real-time monitoring and remote control of the system, enhancing its practicality in large-scale or remotely operated aquaponic systems (Dewi et al., 2022). The IoT platform provided continuous feedback on system performance, feed amounts, and water quality parameters, allowing for timely interventions when necessary.

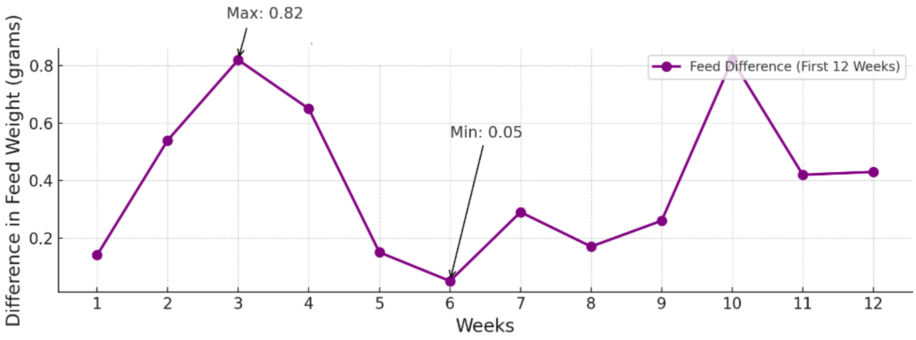


Fig. 4. Errors in Actual and calculated fish food feed for 12 weeks.

Fig. 4 illustrates the shifts in feed difference over the first 12 weeks, capturing key moments where the feeding system performed well or experienced deviations. The most notable spike occurs in Week 3, where the feed difference reaches a peak of 0.82 grams, possibly indicating a miscalibration or external factors affecting feeding accuracy. This suggests that the fish feeder system may have required some initial adjustments, as the differences in the first few weeks are more pronounced. However, by Week 4, this difference sharply drops to 0.15 grams, and the system appears to stabilize between Weeks 4 and 8, where the discrepancies remain relatively small, fluctuating between 0.1 and 0.2 grams. This stabilization might indicate that the feeder system has improved accuracy during this period, or that the feeding patterns of the fish became more consistent. In contrast, Week 6 marks the system's best performance with a minimal difference of 0.05 grams, suggesting near-perfect alignment between the calculated and actual feed amounts.

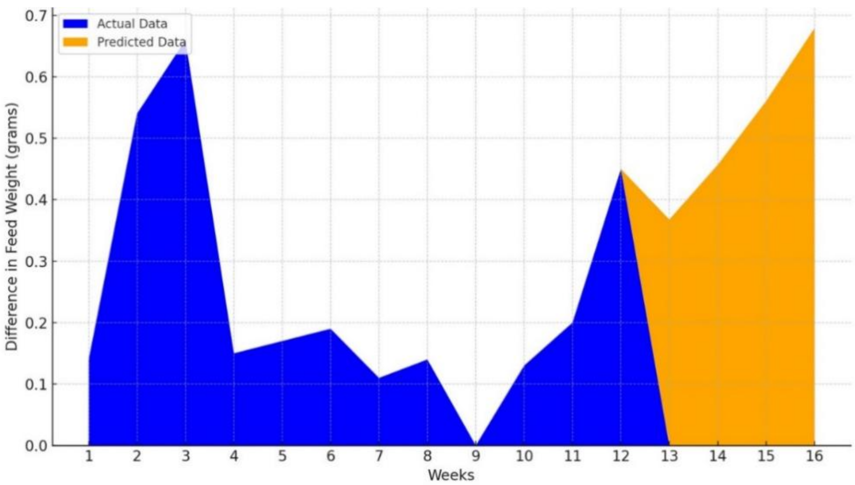


Fig. 5. Prediction of further errors in up to 16 weeks from actual 12 weeks

As the weeks progress, the feed difference fluctuates, with a secondary peak around Week 10, followed by a slight stabilization toward Weeks 11 and 12. These ups and downs might reflect the system's response to the fish's growth, environmental changes, or sensor adjustments. The chart provides valuable insights into when the feeding process operates efficiently and when further fine-tuning may be required to ensure resource optimization and healthy fish growth. Fig. 5 shows further prediction for 16 weeks. The stacked area chart provides a clear and insightful way to visualize the difference in fish feed weight over 16 weeks, highlighting both the actual data and predicted values. The ARIMA model predicts that the feed weight difference will steadily increase, reaching approximately 0.7 grams by Week 16. This prediction suggests that, without further adjustments or intervention, the system may experience growing inefficiencies that could lead to either overfeeding or underfeeding. While the ARIMA model seems to effectively capture the trends and provides a reasonable prediction based on the observed data, the increasing feed weight difference indicates that the system may require recalibration to prevent future discrepancies from becoming too large. Monitoring the system more closely in Weeks 13 to 16 will be crucial to ensure the accuracy of the predictions and to take corrective action if necessary, maintaining the feeder's efficiency and ensuring optimal fish growth and health.

3.4 Feed Conversion Ratio (FCR) and Fish Growth

Feed Conversion Ratio (FCR) and Fish Growth is a key metric in assessing feed efficiency. It is calculated by dividing the total amount of feed provided by the weight gain of the fish:

$$FCR = \frac{Total\ Feed\ Given}{Fish\ Weigh\ Gain} \tag{2}$$

where Total Feed Given is the amount of feed provided over a specific period (in grams), and Fish Weight Gain is the increase in the fish's weight over that same period (in grams).

A lower FCR indicates more efficient feed use, meaning that less feed is required for a specific amount of weight gain. As fish grow, their FCR can improve if they are fed correctly according to their needs. Overfeeding or underfeeding can negatively impact FCR, leading to less efficient feed usage.

Table 1 shows that Initial Fish Weight (Week 1) is 60.46 grams, Final Fish Weight (Week 12): 134.90 grams; hence. The calculated FCR is 5.61, meaning that for every 5.61 grams of feed provided, the fish gained 1 gram in weight. The Fish Growth over the 12-week period is 123.12%, indicating that the fish more than doubled in size compared to its initial weight.

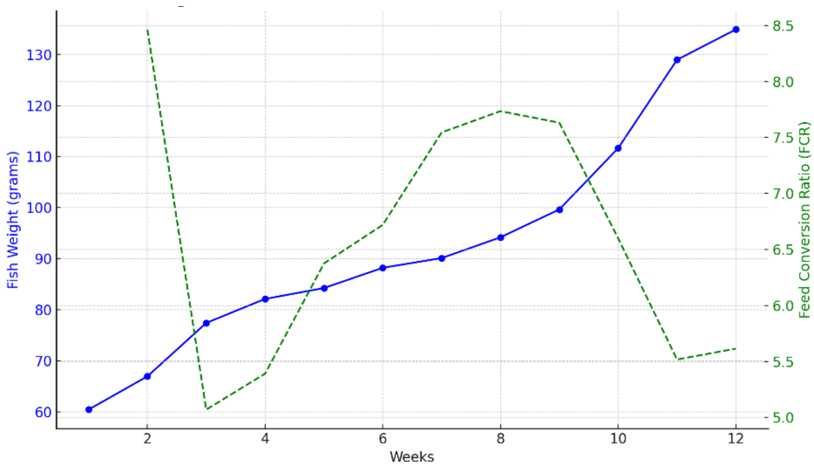


Fig. 6. Fish weight growth and FCR over 12 weeks.

Fig 6 shows the fish weight growth and FCR over 12 weeks. Here is the chart visualizing Fish Weight Growth (in blue) and Feed Conversion Ratio (FCR) (in green) over the 12-week period. The fish weight steadily increases over time, indicating healthy growth. Meanwhile, the FCR fluctuates, showing a peak between Week 4 and Week 5 before declining toward Week 12. This pattern suggests that during certain periods, the fish were converting feed less efficiently (higher FCR), but over time, the system or fish adapted, leading to improved feed efficiency as indicated by the declining FCR toward the end.

3.5 Challenges and Future Improvements

Despite the system's success, several challenges were identified during the trials. One limitation was the sensitivity of the load cell to environmental factors such as temperature and humidity. Although the system was able to maintain accuracy in most conditions, further improvements could involve incorporating environmental sensors to adjust feed delivery based on real-time conditions (Daniesar et al., 2023). In terms of energy efficiency, the system consumed an average of 0.25 kWh per day, which is comparable to other IoT-based agricultural systems (Oktarina et al., 2022).

This low energy consumption was achieved by optimizing the system's operation schedule, reducing the power required for feeding sessions and system monitoring. Additionally, the use of solar power as a backup energy source enhanced the sustainability of the system (Alam et al., 2022). The integration of load cell sensors and IoT technology allowed the system to achieve a high level of precision and control over the feeding process, with minimal human intervention. Previous studies have highlighted the potential of IoT-based systems to enhance the efficiency of aquaponic systems by automating routine tasks and providing real-time data (Ezzahoui et al., 2022; Wibowo et al., 2019). The results of this study further support the use of IoT in aquaponics, particularly for optimizing feed management and improving system sustainability.

Another area for improvement is the scalability of the system. While the system performed well in a medium-scale aquaponic environment, future work should focus on scaling the system for larger operations. This would involve optimizing the system's energy consumption and improving the robustness of its components (Dewi et al., 2021). Additionally, the integration of other environmental control systems, such as temperature and pH regulation, could enhance the overall performance of the aquaponic system (Dewi et al., 2022).

The smart fish feeding system developed in this study successfully integrated load cell sensors, RTC modules, and IoT technology to automate the feeding process in aquaponic farming. The system demonstrated high precision in feed delivery, improved water quality management, and promoted optimal fish growth. By leveraging IoT for real-time monitoring and control, the system provides a sustainable and efficient solution for aquaponic farmers. Future improvements will focus on enhancing system scalability and incorporating additional environmental controls to further optimize aquaponic farming practices.

4 Conclusion

This study demonstrates the successful implementation of a smart fish feeding system designed for aquaponic farming, integrating load cell sensors, Real-Time Clock (RTC) modules, and predictive models such as ARIMA. The system automates the feeding process and significantly improves precision in feed delivery, which is critical in maintaining both optimal fish growth and water quality. Over a 12-week trial period, the system maintained high accuracy, with the average feed weight difference remaining minimal at 0.34 grams. The calculated Feed Conversion Ratio (FCR) of 5.61 indicates efficient feed utilization, meaning that for every 5.61 grams of feed provided, the fish gained 1 gram in weight. This efficiency contributed to an impressive fish growth of 123.12%, ensuring healthy and steady development of Nile Tilapia. The inclusion of the ARIMA model allowed for accurate forecasting of future feed needs, optimizing the feeding process even further. The model effectively captured non-linear growth patterns in the fish, predicting a stable feed requirement in the range of 45-50 grams for subsequent weeks. This predictive capability reduces the likelihood of overfeeding or underfeeding, preventing waste and safeguarding water quality. As the fish grow, the system adapts to their nutritional requirements, maintaining an optimal balance between feed supply and fish health. Future work could focus on scaling this system for larger aquaponic setups and incorporating additional environmental control systems, such as temperature and pH regulation, to enhance the overall performance and sustainability of aquaponic farming. This smart feeding system demonstrates a practical and efficient solution for modern aquaponic practices, ensuring the sustainable use of resources while promoting healthy fish growth.

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