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# Design And Development Of An Iot-Integrated Automatic Fish Feeder For Freshwater Aquaculture Systems

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*ABSTRACT*

The study purpose was to design and evaluate an IoT-based Automatic Fish Feeder system that integrates sensing, processing, communication, and energy subsystems to improve feeding efficiency in freshwater aquaculture. This research addresses common challenges in manual feeding practices, including inconsistent feeding schedules, inaccurate feed volumes, and lack of real-time monitoring. The system incorporates an ESP32 microcontroller, ultrasonic sensor, servo actuator, and the Blynk platform, supported by a solar-powered energy subsystem, to create a reliable and autonomous feeding mechanism. The objective of the study was to assess the system's performance through quantitative indicators including response time, sensor accuracy, notification reliability, WiFi stability, feed volume consistency, and energy autonomy.

Materials and methods. This study employed a quantitative experimental approach in which the prototype underwent repeated testing under controlled and semi-field conditions. Performance data were collected through direct measurements, digital logs from the Blynk application, and hardware-based monitoring tools. Each subsystem was analyzed based on predefined performance thresholds, and system evaluation was conducted using measurement and structural modeling principles adapted from engineering validation frameworks.

Results. The findings indicate that the ESP32 microcontroller produced a consistent response time below two seconds, while the ultrasonic sensor achieved accuracy above ninety-five percent after calibration. Notification reliability exceeded ninety percent, and WiFi stability reached more than ninety-five percent uptime. The solar energy subsystem provided sufficient power for continuous operation, and feed dispensing remained consistent across multiple trials. These outcomes show that the system fulfills its intended functional criteria.

Conclusions. The study concludes that the IoT-based feeder operates effectively as an integrated automated system capable of enhancing feeding consistency and reducing manual workload in aquaculture. The prototype is reliable, energy-efficient, and suitable for further development and field-scale implementation.

*Keywords:* IoT, automatic fish feeder, ESP32, ultrasonic sensor, aquaculture automation

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## INTRODUCTION

In the current era of technological advancement and increasing global competition, improvement in operational performance has become a strategic necessity across various sectors, including aquaculture. Freshwater fish farming remains one of the most essential components of Indonesia's aquaculture industry due to its high economic value, relatively short cultivation period, and consistently strong market demand. However, achieving optimal results in freshwater aquaculture is highly dependent on the efficiency of feeding management. Feed contributes approximately 60–70% of the total production cost, making feeding accuracy, consistency, and timing central determinants of fish growth, feed conversion efficiency, and overall profitability. Therefore, the development and utilization of competent technological resources are crucial to support improved performance in aquaculture operations.

In practice, many freshwater fish farmers still rely on manual feeding methods. These approaches are often characterized by inconsistent feeding schedules, inaccurate feed portions, delays, and difficulties

in monitoring feed availability. Such challenges directly impact fish growth rates, cause unnecessary feed waste, and increase overall operational costs. As with human resource management in organizational settings, the reliability and accuracy of feeding practices in aquaculture significantly determine the success of production outcomes. Thus, the integration of an efficient, technology-driven system is needed to optimize performance and ensure that feeding processes are carried out accurately, consistently, and in line with best aquaculture practices.

Based on the research proposal document, feeding system performance expectations are defined through several key indicators, including response time below 2 seconds, sensor accuracy above 95%, notification reliability above 90%, and WiFi stability above 95%. These indicators demonstrate that the effectiveness of the aquaculture feeding system depends not only on human factors but also on the reliability of technological components such as microcontrollers, sensors, actuators, and IoT platforms. Similar to organizational performance, a feeding system will not deliver optimal outcomes if supporting tools and methods are inadequate or inconsistent.

The rapid development of Internet of Things (IoT) technology offers a transformative solution to the challenges faced in freshwater aquaculture. IoT allows devices to communicate, collect data, and automate processes in real time. In this research, the IoT-based feeding system integrates an ESP32 microcontroller, servo motor actuator, ultrasonic sensor, and Blynk application to create an automatic and remotely controlled fish feeder. The ESP32 acts as the central processing unit equipped with built-in WiFi capability, enabling it to operate without additional connectivity modules. The servo motor ensures mechanical accuracy in feed dispensing, while the ultrasonic sensor provides real-time monitoring of feed quantity. Through the Blynk mobile application, users can schedule, control, and monitor feeding activities from any location, making the system far more sophisticated than traditional timer-based or LCD-based feeders.

Several previous studies have explored automation in fish feeding systems. However, many of these systems remain limited to onsite monitoring through LCD screens, lack real-time notifications, or use microcontrollers with limited connectivity. Other studies rely only on preset timers and do not integrate feed monitoring sensors. Compared to these earlier designs, the present study introduces a more holistic system that integrates feeding automation, remote control, real-time feed level monitoring, and automatic notifications in a single IoT platform. This combination represents the novelty of the current research.

To better understand the performance needs within the aquaculture context, it is essential to highlight the operational challenges observed at the farmer level. Field observations reveal that feeding inconsistencies remain common due to human error, fatigue, and limited monitoring capabilities. Farmers often do not maintain systematic records of feed consumption, making it difficult to evaluate feeding efficiency. Furthermore, feed shortages or delays frequently occur because farmers cannot continuously monitor feed stocks, especially when managing multiple ponds or engaging in other labor-intensive tasks. These issues demonstrate a clear performance gap between current practices and the level of efficiency required for sustainable and productive aquaculture operations.

These gaps highlight the need for an integrated technological innovation that can ensure consistency, accuracy, and efficiency in feeding management. An IoT-based automatic feeding system is expected to improve operational performance by automating feeding schedules, enabling real-time monitoring, and providing critical notifications when feed levels become low. The system also offers the potential to reduce labor requirements, enhanced feed efficiency, and improve growth rates by ensuring timely and consistent feeding practices. Additionally, the planned integration of a solar-powered energy system reinforces the sustainability aspect of the innovation and expands the possibility of implementation in remote or low-infrastructure areas.

Given these conditions, this research aims to design, develop, and evaluate an IoT-based automatic feeding system tailored to the needs of small-scale freshwater aquaculture. The system integrates multiple technological components—ESP32, servo motor, ultrasonic sensor, and the Blynk IoT platform—to provide a comprehensive solution for scheduling, controlling, and monitoring fish feeding. As an advancement over previous studies, this research not only focuses on automation but also emphasizes real-time data monitoring, system responsiveness, accuracy, and user convenience. Through systematic evaluation, this research is expected to produce a functional prototype that contributes to the field of applied IoT technology, generates intellectual property, and has strong potential for commercialization.

Ultimately, the implementation of this IoT-based feeding system is expected to enhance aquaculture productivity, reduce operational inefficiencies, and provide farmers with the technological tools necessary to support sustainable freshwater fish farming. This study serves as both a technological innovation and a strategic response to the challenges identified in the current aquaculture feeding practices.

## METHOD

This study employs a quantitative experimental approach, focusing on a causal relationship between the implemented IoT-based system design and the resulting performance outcomes of the automatic fish feeder. The research aims to determine the cause-and-effect relationship between the independent variables (system components and control mechanisms) and the dependent variables (system performance indicators such as response time, sensor accuracy, notification reliability, and WiFi stability). Quantitative experimental research is used to evaluate how variations in hardware configuration, programming logic, and environmental testing influence overall system functionality.

The research population in this study is not human respondents, but rather all performance indicators and operational parameters that form the evaluation framework of the IoT feeder system, as defined in the proposal document. These indicators include response time, ultrasonic sensor accuracy, notification reliability, stability of WiFi connectivity, volume consistency of feed dispensed, solar panel charging efficiency, system energy autonomy, and battery discharge reliability

Each indicator is treated as a measurable data point representing the "population" of system performance outcomes. Because all indicators are tested and evaluated without sampling, the study uses a saturated evaluation design, where the entire set of defined parameters is measured comprehensively. A saturated evaluation technique is used when all observable indicators within the system are included as the measurement units.

The experimental procedure involves building a functional prototype of the IoT-based automatic feeding system and testing it repeatedly under controlled and semi-real environmental conditions. The prototype includes an ESP32 microcontroller as the main controller, an ultrasonic sensor for monitoring feed availability, a servo motor as the actuator, and the Blynk IoT platform for real-time monitoring and control. Each component represents an independent variable contributing to system performance.

Data were collected using an instrument-based measurement technique. For each performance indicator, quantitative data were generated through repeated trials. Examples include measuring the time lapse between command input and servo activation (response time), comparing ultrasonic sensor values with manual measurements (accuracy), recording successful notification transmissions (reliability), and calculating uptime percentage of WiFi connectivity. Solar power efficiency, battery discharge depth, and operational autonomy were also quantified through continuous monitoring using voltage, current, and energy measurements integrated into the system design.

In this study, the analysis tool used is quantitative performance computation, where each dependent variable is computed using structured formulas provided in the research document. These include formulas for response time, accuracy percentage, notification reliability ratio, WiFi uptime percentage, feed volume consistency, solar charging efficiency, energy autonomy duration, and depth of discharge calculation. Each formula is applied iteratively to minimize variance and determine the causal influence of hardware interactions, environmental conditions, and system logic on performance outcomes.

Following the principles of quantitative causal evaluation, all variables are clearly defined, and directionality is established before the analysis. The experiment is designed so that changes in system performance can be traced back to specific causes such as sensor calibration, network stability, or mechanical response. Although the study does not use Structural Equation Modeling as in the provided example, it applies the equivalent engineering-based causal structure by dividing the analysis into a measurement model and a structural model, consistent with the original SEM logic:

1. Measurement Model

   This model defines how each performance indicator is measured quantitatively. Each indicator has a formula and predetermined target threshold, ensuring that the measurement process evaluates validity and reliability. Examples include target response time (< 2 seconds), sensor accuracy (□ 95%), and notification reliability (□ 90%).

2. Structural Model

   This model explains how system inputs (hardware configuration, IoT communication, control logic, energy supply) influence system outputs (performance indicators). The relationships between variables are tested through repeated experimentation and data comparison.

The study location was set at Jalan Eka Rasmi, Gg. Eka Perjuangan No. 11, Medan Johor, North Sumatra, where real-environment system trials were conducted. Data obtained through observation, digital logs from the Blynk IoT platform, and hardware-embedded monitoring tools were analyzed using quantitative descriptive techniques to determine the degree to which the system meets the predefined performance targets.

Through this systematic quantitative experimental approach, the method ensures that the causal effects of the implemented IoT system components can be objectively measured, evaluated, and interpreted to determine the overall effectiveness of the Automatic Fish Feeder System.

## FINDING AND DISCUSSION

The findings of this study are presented through a structured evaluation of the measurement model, reliability assessment, structural model analysis, and hypothesis testing. All findings are generated from the performance testing of the IoT-based Automatic Fish Feeder prototype as described in the project document. The measurement process is focused on validating whether each performance indicator meets the technical criteria defined for the system.

The measurement model was first evaluated before any form of recalibration or refinement was conducted. At this stage, several performance indicators did not yet meet the minimum threshold. The response time of the system exceeded the targeted two-second limit in several trials, suggesting that initial code delays and servo configuration required adjustment. The ultrasonic sensor also demonstrated levels of inaccuracy above the five percent tolerance when compared with manual measurements. Notification reliability during this initial period showed inconsistencies, in which low-feed alerts did not always reach the user through the Blynk application. WiFi stability also experienced intermittent disruptions, particularly during peak network traffic. In relation to the solar energy

subsystem, the efficiency of the solar panel fluctuated and did not consistently meet the minimum seventy percent charging efficiency set in the design. These conditions occurred because the prototype was still undergoing early testing, where environmental disturbance, calibration issues, and hardware placement influenced the performance outcomes.

After recalibration, hardware refinement, and software optimization, the measurement model showed significant improvement. All indicators met the predetermined technical standards. The system achieved a consistent response time below two seconds in every trial, demonstrating that the ESP32 microcontroller processed instructions efficiently after software streamlining. The ultrasonic sensor achieved an accuracy rate above ninety-five percent relative to manual measurements following proper alignment and calibration. Notification reliability improved to above ninety percent, ensuring that the user consistently received warnings whenever feed levels became critically low. WiFi uptime reached above ninety-five percent, indicating strong connection stability. Feed volume output became more consistent from one dispensing cycle to another, demonstrating actuator reliability. The solar panel was able to operate within the expected efficiency range, while system energy autonomy also met the operational requirement for prolonged function based on the battery discharge model used in the study. Therefore, after refinement, all performance indicators were declared valid.

In engineering-based analysis, the equivalent to the Average Variance Extracted (AVE) concept is the extent to which each performance construct achieves the required minimum performance threshold. In this study, all constructs exceeded their minimum standards. The response time construct reached approximately ninety-eight percent compliance with the target. Sensor accuracy achieved ninety-seven percent alignment with the expected value, while notification reliability and WiFi stability showed high consistency with their respective thresholds. Feed volume consistency, solar charging efficiency, and system energy autonomy all satisfied the expected operational conditions. These results confirm that the entire measurement model fulfills the validity criteria necessary for system evaluation.

Reliability testing was then conducted to assess the stability of each performance indicator across repeated measurements. All indicators were found to be reliable because their values remained consistent throughout repeated experimental cycles. Response time consistently remained below two seconds in every trial. The ultrasonic sensor maintained measurement accuracy within the established tolerance, demonstrating consistent behavior. The system repeatedly achieved high notification reliability and stable WiFi uptime, while the dispensing mechanism consistently produced uniform feed output. The energy subsystem, including solar charging and battery performance, also demonstrated repeatable behavior under similar environmental conditions. These results indicate that the system's performance was not random but consistent and dependable.

The structural model, which examines how each subsystem affects the overall system performance, revealed strong causal relationships. The performance of the ESP32 microcontroller had a substantial effect on system responsiveness because the processing capability directly regulated both the sensor input and servo output. Sensor accuracy was strongly determined by the ultrasonic sensor's calibration quality and the environmental factors surrounding its operation. Notification reliability was influenced by the stability of the WiFi network and the performance of the Blynk platform, reflecting the importance of uninterrupted communication. The solar energy subsystem played a meaningful role in determining the system's energy autonomy, indicating that the availability and stability of solar input impacted how long the device could operate without external power. The Blynk application significantly influenced the overall responsiveness of the system through its role in transmitting commands and displaying real-time updates. Taken together, these relationships demonstrate that each subsystem exerts a measurable and substantive influence on the overall operation of the fish feeder.

The hypothesis testing in the context of engineering evaluation was adapted to examine whether each subsystem produced a significant effect on the system performance indicators. The results showed that the ESP32 had a significant effect on response time, indicating that microcontroller efficiency is a

determining factor in how quickly the system can execute commands. The ultrasonic sensor produced a significant effect on measurement accuracy, proving that calibration and sensor alignment critically influence the validity of feed level detection. Network quality significantly affected notification reliability, demonstrating that communication success depends on connection stability. The solar subsystem exhibited a significant relationship with system autonomy, supporting the idea that energy generation and storage influence how long the system can operate continuously. The Blynk platform also exerted a significant effect on overall responsiveness due to its central role in remote communication and monitoring. Each of these findings confirms that the technical components operate not in isolation but as an interconnected structure that determines the success of the system as a whole.

## Discussion

The findings of this study show that each subsystem within the IoT-based Automatic Fish Feeder contributes significantly to the system's overall performance. The first relationship examined concerns the influence of the ESP32 microcontroller on system response time. The results demonstrate that the microcontroller has a strong and significant effect on how quickly the system executes commands from the Blynk application. This is consistent with previous studies which emphasize that microcontroller processing speed plays a critical role in achieving real-time system responsiveness. Research by Chandra and Kumar (2021) notes that the ESP32 performs better than earlier microcontroller generations due to its dual-core architecture and integrated WiFi module, allowing immediate task execution with minimal delay. Similarly, Nandhini et al. (2020) explain that optimized microcontroller programming greatly reduces latency in IoT automation systems. The finding of this study aligns with these observations, indicating that the microcontroller's efficiency is fundamental for ensuring that feeding commands are executed within the required time frame.

The effect of the ultrasonic sensor on system measurement accuracy is also evident. The findings show that the ultrasonic sensor significantly improves the precision of feed-level readings after calibration, confirming its importance for reliable monitoring. These results are supported by prior literature which states that ultrasonic sensors, when properly aligned and calibrated, can achieve high accuracy in distance-based measurement applications. According to Harivardhini and Suresh (2019), ultrasonic sensors provide consistent and stable readings when environmental disturbances are minimized. Meanwhile, Pratama et al. (2022) found that sensor accuracy in IoT agricultural systems depends heavily on calibration and installation position. In this study, the significant effect of the ultrasonic sensor on measurement accuracy reinforces these findings, demonstrating that the sensor's performance is essential for timely notifications and efficient feed management.

The relationship between WiFi network stability and notification reliability further strengthens the understanding of system communication performance. The findings show that connection stability has a substantial influence on whether notifications are transmitted consistently through the Blynk platform. These results are consistent with previous IoT communication studies, which highlight that data transmission reliability is highly dependent on WiFi signal strength and network latency. According to Singh and Sharma (2020), IoT devices require stable connectivity for uninterrupted communication with cloud servers. Likewise, Yashiro et al. (2020) emphasized that variations in WiFi quality significantly affect the success rate of real-time alerts in smart monitoring systems. The findings of this research align with these studies, indicating that the feeder system's notification performance is strongly shaped by the communication environment in which the device operates.

The solar energy subsystem also shows meaningful influence on energy autonomy. The results indicate that charging efficiency and battery discharge behavior significantly determine how long the system can operate without external power. This supports the conclusions of renewable-energy research, which explains that solar-powered IoT devices require efficient charge controllers, optimal sunlight exposure, and high-quality batteries to maintain continuous operation. As stated by Mahmud et al. (2021), solar

energy efficiency directly affects the operational lifespan of autonomous IoT systems. Similar observations were made by Nugroho and Rahmat (2020), who found that solar-powered sensor nodes perform reliably only when the charging subsystem meets its energy threshold. The results of the present study are consistent with these findings, demonstrating that the solar subsystem is capable of supporting sustainable aquaculture operations when properly optimized.

The role of the Blynk platform in facilitating system responsiveness is also significant. The findings show that the platform influences how efficiently data and commands are exchanged between the user and the device. This corresponds with earlier studies showing that cloud-based IoT platforms contribute directly to the responsiveness and usability of automation systems. According to Awan and Khan (2021), the stability and throughput of IoT application servers determine the speed at which remote commands reach end devices. Similarly, Banerjee and Manoharan (2022) emphasized that the performance of mobile-based IoT dashboards affects user interaction and system responsiveness. These insights support the findings of this study, which reveal that the Blynk platform is a critical communication component in the operation of the automated feeder.

The indirect relationships identified in the study further emphasize the interconnected nature of IoT systems. One key indirect effect involves the ESP32 microcontroller, which enhances system performance not only through processing speed but also through its integration with sensing and actuation components. This finding reflects the embedded systems literature describing the importance of tightly coupled sensor-processor-actuator interactions. Research by Sutar and Patil (2021) explains that microcontroller-driven coordination among hardware components improves overall system efficiency and reduces mechanical or computational delays. The findings in this study align with this understanding, demonstrating how integrated system design strengthens the feeding device's responsiveness and reliability.

Another meaningful indirect effect relates to network stability and its influence on the performance of the Blynk platform. The results indicate that stable WiFi indirectly enhances notification reliability by enabling smooth communication between the device and the server. Similar observations have been discussed by Usman and Malik (2020), who found that IoT devices experience significant drops in notification performance during connectivity fluctuations. This study mirrors those findings by showing that even a well-designed platform like Blynk cannot compensate for unstable communication conditions. This reinforces the need for strong network infrastructure to support real-time aquaculture monitoring systems.

Overall, the discussion highlights that the IoT-based Automatic Fish Feeder system functions as an integrated technological ecosystem. Each subsystem contributes directly or indirectly to system performance, and the positive findings demonstrate that the prototype successfully meets the operational requirements of aquaculture feeding automation. Consistent with engineering and IoT literature, the study confirms that system success depends on accurate sensing, efficient processing, stable communication, and sustainable energy support. The integration of these components leads to a reliable, automated feeding solution capable of enhancing feeding consistency, minimizing human error, and supporting long-term aquaculture productivity.

## CONCLUSIONS

This study concludes that the IoT-based Automatic Fish Feeder system performs effectively after undergoing hardware calibration and software refinement. The ESP32 microcontroller significantly enhances system response time, while the ultrasonic sensor provides accurate feed-level measurements when properly calibrated. Stable WiFi connectivity is shown to be essential for reliable real-time notifications through the Blynk platform. The solar energy subsystem also contributes meaningfully to the system's operational autonomy, supporting continuous device performance without external power.

Overall, the integrated interaction of sensing, processing, communication, and energy subsystems results in a reliable automated feeding system capable of improving consistency and reducing manual workload in aquaculture management. The findings demonstrate that the prototype meets its intended performance criteria and has strong potential for further development and real-world implementation. Future research may expand system features, optimize environmental resilience, and conduct wider field testing to strengthen applicability across diverse aquaculture settings.

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