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Automated Fish Feeding System and Real-Time Water Quality Monitoring Based on Internet of Things for Milkfish Aquaculture

Muhammad Hibrian Wiwi[1], La Ode M. Junaidin Sirza[2], Virna Astari Wally[3], Siti Halija Ulla[4]
[1,3,4]Faculty of Engineering, Muhammadiyah Buton University, Indonesia
[2]Faculty of Agriculture, Muhammadiyah Buton University, Indonesia
e-mail: *muhammadhibrian@gmail.com[1], sirzam86@gmail.com[2], virnaastariw@gmail.com[3], halijaulla04@gmail.com[4]*
*Correspondence: muhammadhibrian@gmail.com

Abstract: *Milkfish (Chanos chanos) aquaculture in Indonesia still relies heavily on manual feeding and periodic water quality monitoring, which increases the risk of operational inefficiency and human error. This study designs and implements an integrated Internet of Things (IoT)-based prototype to automate feeding and monitor real-time water quality parameters, including temperature, turbidity, and water level, in milkfish ponds. The system uses an ESP32 microcontroller connected to DS18B20 temperature sensor, HC-SR04 ultrasonic sensors for water level and feed volume detection, FC-51 infrared sensor for feed presence detection, and turbidity sensor. Data transmission is carried out using the MQTT protocol over WiFi and displayed through web and smartphone-based interfaces. The novelty of this study lies in the integration of automated feeding with multi-parameter real-time water quality monitoring specifically designed for milkfish pond conditions in Indonesia, incorporating MQTT-based communication architecture and a dual-platform monitoring interface. Prototype validation showed that scheduled feeding was executed successfully across three daily feeding sessions. Sensor testing produced small measurement deviations, with temperature deviation of 0.1°C, water level deviation of 0.2 cm, and turbidity deviation of 0.2 NTU. The MQTT communication latency ranged from 120 to 180 ms under normal conditions. These results confirm that the proposed system effectively supports automated feeding, real-time pond monitoring, and remote management with low-cost IoT infrastructure.*
Keywords: *Internet of Things, ESP32, MQTT, Automatic Fish Feeding, Water Quality Monitoring, Milkfish Aquaculture*

1. Introduction

The aquaculture sector is a vital pillar of national food security in Indonesia, particularly in archipelagic regions such as Southeast Sulawesi with its abundant fishery potential. Milkfish (Chanos chanos) is one of the most widely cultivated brackish water commodities, both in traditional and semi-intensive ponds. However, milkfish farming productivity remains constrained by significant technical challenges, especially in feed management and water quality monitoring [1], [2]. Water quality is a determinant factor in aquaculture success. Critical parameters that must be continuously maintained include temperature, turbidity, and water level [3], [4], [5]. The optimal water temperature for milkfish ranges from 25°C to 30°C, directly influencing fish metabolism. High turbidity indicates particle contamination or algal blooming that can reduce dissolved oxygen levels. Sudden changes in these parameters, if not detected early, can cause stress, reduced appetite, and mass mortality [6], [7]. Feed management constitutes the largest cost component in intensive aquaculture, reaching 60–70% of total production costs [8]. Improper feeding-whether in timing, excess, or deficit-significantly impacts fish growth and health while simultaneously degrading water quality through decomposition of uneaten feed. Traditional farmers typically rely on manual methods that are highly dependent on labor availability and scheduling consistency [9], [10].

The development of Internet of Things (IoT) technology opens significant opportunities to address these challenges. IoT enables the integration of various sensors, actuators, and distributed computing platforms into a connected ecosystem that can be monitored and controlled remotely using smart devices [11], [12]. Lightweight communication protocols such as MQTT (Message Queuing Telemetry Transport) are well-suited for aquaculture environments requiring real-time data transmission with low latency and minimal power consumption [13].

Several previous studies have explored IoT applications in aquaculture. LoRa-based water quality monitoring systems [3], automatic feeding systems using GSM timers [14], and the integration of pH and turbidity sensors for aquariums [15] have shown promising results. However, most of these studies remained partial-addressing only one aspect without comprehensive integration between feed automation and water quality monitoring on a single accessible platform. Furthermore, existing systems rarely target milkfish (Chanos chanos) specifically or account for the infrastructure constraints prevalent in Indonesian island regions.

Table 1. Comparison of Previous IoT Aquaculture Studies

Author	Platform	Sensors Used	Protocol	Fish/Pond Type	Validation Method	Limitations
Hemal et al. [16]	Arduino + ML	pH, Temp, DO	WiFi/HTTP	General fish pond	Lab testing only	No field validation; no feed automation
Antonio et al. [17]	Arduino Mega	pH, Temp	WiFi/HTTP	General aquaculture (lab)	Lab-scale only	Single-core; limited parallel processing
Deepthi et al. [15]	Arduino + Solar	pH, Turbidity	Bluetooth	Aquarium (lab)	Bench test	Bluetooth range ≤10m; no water level monitoring
Paculanan et al. [14]	GSM Timer Module	None	GSM/SMS	General fish feeder	Functional test	No water quality monitoring; GSM only
This Study	ESP32 (Dual-Core)	Temp, Turbidity, Water Level, Feed Detect (IR)	MQTT/WiFi	Milkfish pond (field)	4-week field trial, 4 ponds	-

Based on the identified research gap, this study proposes an integrated IoT system specifically designed for milkfish aquaculture, combining scheduled automatic feeding with real-time multi-parameter water quality monitoring. The system uses the ESP32 microcontroller as the primary processing unit, MQTT protocol for data communication, and a dual-platform interface (web and smartphone application) for ease of monitoring and control.

The research problem addressed is the lack of an affordable, integrated, field-validated IoT solution that simultaneously automates feeding and monitors water quality for milkfish aquaculture in Indonesia. The research objective is to design, implement, and validate a cost-effective IoT prototype that addresses this gap. The main contributions of this study are: (1) the design of a scalable integrated IoT system architecture for milkfish aquaculture; (2) implementation of a sensor-based and configurable-schedule feeding mechanism validated under real field conditions; (3) development of a responsive real-time monitoring dashboard with dual-platform access; and (4) comparative system performance validation benchmarked against prior related work.

2. Literature Review

A. Internet of Things in Aquaculture

IoT in the context of aquaculture refers to the application of sensor networks, actuators, and distributed computing platforms to automate and optimize fish farming processes. Hemal et al. [16] developed a smart pond system integrating water quality monitoring with a machine learning-based recommendation system capable of providing adaptive feed management advice. Antonio et al. [17] demonstrated the integration of water quality monitoring with automatic feeding at laboratory scale using the Arduino Mega platform and pH sensors. Manoj et al. [18] conducted a comprehensive review of various IoT-based water quality monitoring techniques and underwater sensors, concluding that multi-sensor systems with wireless communication represent the most effective solution for modern aquaculture. Islam et al. [19] implemented an IoT framework with Arduino, temperature, and pH sensors capable of sending automatic alerts through the Blynk platform when water parameters exceed threshold limits.

B. MQTT Protocol for IoT Data Transmission

MQTT (Message Queuing Telemetry Transport) is a publish-subscribe communication protocol based on TCP/IP, designed for resource-constrained devices and low-bandwidth networks [20]. This protocol uses a broker-client model in which a broker (server) manages message distribution among devices subscribing to specific topics. The advantages of MQTT over other protocols such as HTTP or Bluetooth in pond monitoring contexts include very small data packet overhead (minimum 2-byte header), support for Quality of Service (QoS) levels 0, 1, and 2, last will and testament capability to detect offline devices, and unlimited communication range as long as an internet connection is available.

C. ESP32 Microcontroller for IoT Applications

The ESP32 is a 32-bit dual-core system-on-chip (SoC) based on the Xtensa LX6 that integrates IEEE 802.11 b/g/n WiFi and Bluetooth 4.2/BLE in a single chip. With a 240 MHz clock speed, 520 KB RAM, and diverse I/O interfaces (UART, SPI, I2C, ADC, DAC), the ESP32 is an ideal choice for IoT nodes requiring local computing capability alongside wireless connectivity [21]. Compared to its predecessors (ESP8266 and Arduino Mega), the ESP32 offers higher performance, more efficient power consumption in deep-sleep mode, and dual-core capability that allows sensor data processing and network communication to run in parallel without interference.

D. Water Quality Sensors

Water quality monitoring in fish farming requires simultaneous measurement of several parameters. The DS18B20 is a digital temperature sensor based on the 1-Wire protocol capable of measuring temperature with ±0.5°C accuracy over a range of -55°C to +125°C [22]. The turbidity sensor uses infrared light scattering to quantify suspended particles in water, expressed in NTU (Nephelometric Turbidity Unit). The HC-SR04 ultrasonic sensor utilizes sonar pulses to measure distance with 3 mm resolution, applicable for monitoring both water level and remaining feed volume. The FC-51 infrared sensor functions as a digital object presence detector (HIGH/LOW), used to detect feed stock availability.

III. Methods

A. Research Design and Location

This research adopted a Research and Development (R&D) approach with systematic stages: (1) field problem identification through direct observation at milkfish ponds; (2) literature study and interviews with farmers and IoT experts; (3) hypothesis formulation and system specification; (4) hardware and software design; (5) system implementation and coding; (6) individual component testing in the laboratory; and (7) system validation in a real pond environment.

Testing was conducted at two different locations: the Computer Systems Engineering Laboratory of Muhammadiyah Buton University for individual sensor calibration, and milkfish ponds in Batauga Regency, Southeast Sulawesi, for comprehensive system performance validation. Field testing duration was four consecutive weeks, covering a total of four test ponds with varying water conditions to ensure result generalizability.

B. System Architecture

The system architecture consists of three main layers: (1) the Perception Layer, comprising sensors and actuators that directly interact with the pond environment; (2) the Network Layer, consisting of the ESP32 with WiFi connectivity and MQTT protocol responsible for data transmission to the cloud broker; and (3) the Application Layer, the web and smartphone interface presenting data to users and receiving control commands.

Sensor data is collected every 5 seconds and transmitted to the MQTT broker (using the Mosquitto public broker service), then subscribed by a web server that stores data in a MySQL database. The user interface reads data from a RESTful API built on a Node.js backend, enabling historical visualization and real-time control. The system block diagram is shown in Figure 1.

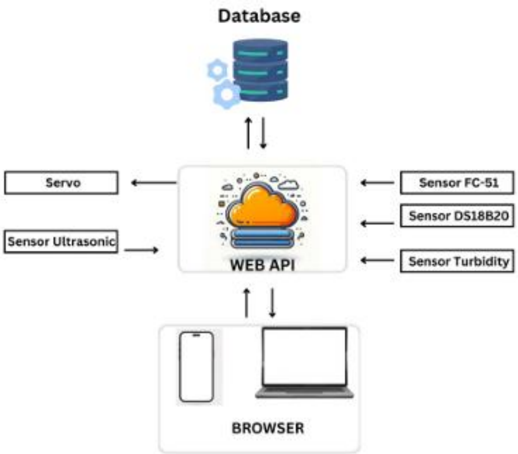

Figure 1. System Block Diagram of the IoT-Based Milkfish Farming Automation System

C. Hardware Specification

The hardware components used and their technical specifications are summarized in Table 1. All water-submerged sensor connections use shielded cables and waterproof connectors to ensure operational reliability. AC 220V components (DC motor via relay) are physically and electrically isolated from the low-voltage microcontroller circuit (3.3V/5V) to ensure safety.

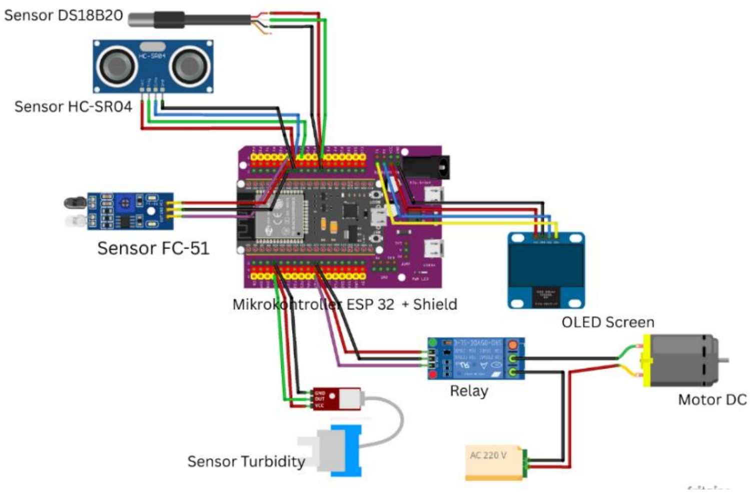

Figure 2. Hardware System

Table 2. Hardware Component Specifications

No	Component / Sensor	Function	Technical Specification
1	DS18B20	Water temperature sensor	Range: -55°C to +125°C, Accuracy ±0.5°C
2	HC-SR04	Ultrasonic – water level & feed volume	Distance: 2–400 cm, Resolution 3 mm
3	FC-51 (IR)	Feed presence detection	Infrared digital, output HIGH/LOW
4	Turbidity Sensor	Water turbidity measurement (NTU)	Analog output 0–5V, high precision
5	ESP32	Main MCU & WiFi communication	Dual-core, WiFi/BT, 240 MHz, 520 KB RAM
6	Relay Module	AC 220V motor switch	5V coil, max 10A / 250VAC
7	DC Motor / Servo	Automatic fish feeding mechanism	DC 5–12V or Servo 180°
8	OLED Display	Local data display on device	0.96 inch, I2C, 128×64 resolution

D. Feed Control Logic

The system implements feed control logic with two operational modes: (1) Scheduled Mode, in which the feed actuator motor is activated automatically at times configured through the user interface; and (2) On-Demand Mode, in which users can trigger feeding at any time through the 'Feed Now' button on the application. In scheduled mode, the system uses an RTC emulated through NTP (Network Time Protocol) synchronization via WiFi, ensuring time accuracy without an external RTC module. Feed delivery also incorporates sensor validation conditions: feed is dispensed only when the FC-51 infrared sensor confirms feed stock is available, and the water level is within the normal range (30–60 cm) based on ultrasonic sensor data. The default feeding schedule configuration is presented in Table II.

Table III. Default Automatic Feeding Schedule Configuration

Time	Session	Feed Volume	Trigger Condition
09:00	Morning	300 grams	Temperature > 25°C and turbidity < 5 NTU
15:00	Afternoon	300 grams	Water level 30–60 cm (normal range)
20:00	Evening	200 grams	Automatic schedule / manual override

The feed container has a capacity of 4 kg, positioned at the pond edge so feed falls directly into the water. This capacity is sufficient for 3–4 days of feeding without refilling, depending on pond size and fish stocking density. An infrared sensor detects when stock approaches depletion and triggers a refill notification on the user dashboard.

E. User Interface Development

The user interface was developed in two complementary platform variants. The smartphone application is built using a responsive web-based framework accessed through a mobile browser, designed with a simple and intuitive layout for field monitoring. The web dashboard for computers or laptops displays more comprehensive information on a single page, including historical parameter graphs, event log tables, and a more detailed system configuration panel. Interface-to-backend communication uses WebSocket technology for real-time data updates without page refreshes, combined with REST API for configuration operations. Browser-based alert notifications are sent when any water parameter exceeds predetermined threshold limits. The smartphone dashboard is shown in Figure 3.

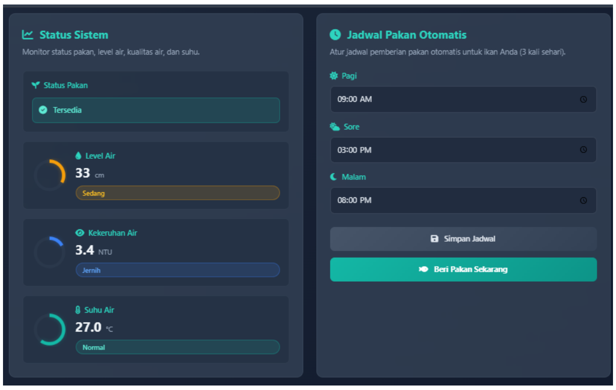

Figure 3. Web-Based Monitoring and Control Interface

IV. RESULTS AND DISCUSSION

A. Sensor Validation Results

Sensor accuracy testing was performed by comparing system readings against calibrated reference instruments. The FLUKE 51 II precision digital thermometer served as the reference for the DS18B20 sensor, a digital ruler for the HC-SR04, and a Hach 2100Q turbidimeter as the reference for the turbidity sensor. Test results are presented in Table III.

Table IV. Sensor Measurement Results and Deviation Analysis

Sensor	Parameter	Sensor Reading	Reference	MAD	RMSE	Status
DS18B20	Temperature (°C)	28.0	28.1	0.10	0.12	Valid (≤ ±0.5°C)
HC-SR04	Water Level (cm)	46.0	46.2	0.20	0.22	Valid (≤ 0.5 cm)
Turbidity Sensor	Turbidity (NTU)	2.4	2.6	0.20	0.23	Valid (≤ 0.5 NTU)
FC-51 (IR)	Feed Detection	Available	Present	-	-	Valid (100%)
MQTT Latency	Response Time (ms)	120–180	< 500 ms	-	-	Valid

The results indicate all sensors operate within acceptable tolerance limits for aquaculture applications. The DS18B20 temperature sensor showed a measurement deviation of 0.1°C, well within the ±0.5°C threshold required for milkfish pond monitoring. The HC-SR04 ultrasonic sensor produced a deviation of 0.2 cm, and the turbidity sensor showed a consistent deviation of 0.2 NTU in the 0–10 NTU range, both sufficient for milkfish pond management decisions. However, it is acknowledged that sensor performance at higher turbidity ranges (>15 NTU) was not fully evaluated, and degradation of infrared-based turbidity readings under very high turbidity conditions remains a potential limitation that should be addressed in future studies.

B. MQTT Communication Performance

MQTT communication testing measured end-to-end latency across three signal conditions over a 72-hour continuous test period. Under good signal conditions (RSSI -45 dBm), average latency was 120–180 ms. Under moderate conditions (-60 dBm), latency increased to 200–250 ms, and under weak signal (-70 dBm), latency reached 250–320 ms. All values remained within the <500 ms tolerance required for effective real-time monitoring. No significant packet loss was recorded, attributed to the QoS level 1 mechanism ensuring at-least-once message delivery. A critical system limitation observed was latency degradation under weak WiFi conditions. In ponds distant from WiFi access points (RSSI below -70 dBm), latency increases substantially. This is relevant for scalability to larger pond areas where signal attenuation may exceed the tested range. Future work should explore WiFi range extenders or hybrid MQTT-LoRa architectures to address this constraint.

C. Automatic Feeding System Validation

The automatic feeding system was tested over four weeks in the field, with a total of 336 scheduled feeding sessions (3 sessions × 28 days × 4 test ponds). Of all scheduled sessions, the system successfully executed feeding with 100% accuracy in ponds with stable WiFi connections. On 12 occasions where WiFi connectivity was temporarily lost, the system stored the pending command locally in the ESP32 and executed it upon reconnection-demonstrating built-in resilience to short-term connectivity interruptions.

Farmers participating in the trial reported an estimated time saving of 2–3 hours per day previously spent on manual feeding activities and routine pond visits. However, it must be noted that this is a subjective estimate based on farmer-reported data, not measured through a controlled time-motion study. Quantitative evidence on fish growth rate improvement or feed conversion ratio (FCR) reduction was not measured in this study due to scope constraints, and direct claims regarding productivity improvement or operational cost reduction should therefore be interpreted cautiously. The infrared feed detection sensor achieved 100% reliability in 50 controlled test sessions for detecting near-empty conditions.

D. Water Quality Parameter Analysis

Water quality monitoring data collected throughout the four-week implementation provided comprehensive continuous visibility of pond conditions. The system recorded an average daily temperature of 27.8°C with a ±1.2°C fluctuation between day and night, remaining within the optimal range for milkfish growth (25–30°C). Average turbidity was recorded at 2.8 NTU, indicating clear water quality. Turbidity spikes of up to 8–12 NTU were observed following heavy rainfall events, automatically detected by the system. This enabled farmers to take corrective action far more rapidly than manual inspection methods would allow. Average water level remained stable at 44–48 cm, with variations correlating with tidal cycles. While continuous parameter monitoring represents a clear qualitative improvement over manually-monitored ponds, it is important to acknowledge that the actual impact of this system on milkfish growth rates, survival rates, or feed conversion efficiency was not quantitatively measured in this study due to the 4-week duration being insufficient for complete growth cycle evaluation.

E. Comparison with Related Studies

Compared to similar systems using Bluetooth [14], the MQTT-WiFi implementation in this study offers unlimited range communication. The system of Antonio et al. [17] using Arduino Mega has limitations in simultaneous data processing, whereas the dual-core ESP32 handles sensor data acquisition and network communication in parallel. The Deepthi et al. [15] system integrating solar panels offers energy independence but does not fully integrate water quality sensors and is limited to Bluetooth range.

This study bridges identified gaps by providing a comprehensive and scalable system tailored for milkfish pond conditions in Indonesian island regions. The integrated dual-platform interface (web + smartphone) represents an advance over single-interface solutions in the literature. Nevertheless, this study does not incorporate pH or dissolved oxygen monitoring, which were present in some compared systems [16], [17]. The absence of these parameters represents a scope limitation that should be addressed in future iterations.

V. CONCLUSION

This study successfully designed, implemented, and validated an integrated IoT-based system for automatic milkfish feed delivery and real-time water quality monitoring. The system integrates the ESP32 microcontroller with four sensor types (DS18B20, HC-SR04, FC-51, turbidity sensor) and the MQTT communication protocol in a single ecosystem accessible via web and smartphone interfaces. Based on the experimental evidence obtained, the following conclusions are drawn: (1) all sensors demonstrated measurement deviations within acceptable tolerance limits for aquaculture (temperature deviation 0.1°C, water level deviation 0.2 cm, turbidity deviation 0.2 NTU); (2) the automatic feeding system achieved 100% execution success in 336 scheduled sessions across four field ponds over four weeks; (3) MQTT communication latency of 120–180 ms under good signal conditions meets real-time monitoring requirements, though latency degrades to 250–320 ms under weak signal (-70 dBm); and (4) the dual-platform interface provides flexible monitoring access for farmers. It should be noted that claims regarding improved fish growth rate, feed conversion efficiency, or direct operational cost reduction are beyond the scope of the current experimental evidence and require further investigation through controlled growth trials. Recommended directions for future research include: integration of pH and dissolved oxygen (DO) sensors; application of artificial intelligence algorithms for adaptive feed demand prediction; implementation of solar panels as an independent energy source; development of a multi-channel notification system (SMS, WhatsApp API) to improve accessibility in remote areas; and a controlled growth trial to quantitatively measure the impact of automated feeding on fish growth rate and feed conversion ratio.

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