

CHAPTER I

Introduction

1.1. Research Background

Cultivation of Nile Tilapia (*Oreochromis niloticus*) is one of the most rapidly developing freshwater aquaculture activities in Indonesia. This species has become a leading commodity due to its fast growth rate, high tolerance to environmental fluctuations, and promising economic value. To enhance production efficiency and environmental sustainability, many farmers have adopted the biofloc system, a cultivation technique that utilizes microorganisms to break down organic waste into floc nutrient-rich particles that can be re-consumed by the fish. This system significantly reduces the need for water exchange and maintains water quality naturally (Saridu et al., 2023; Soewono et al., 2024).

However, the success of the biofloc system is highly influenced by the stability of water quality parameters, particularly pH, Total Dissolved Solids (TDS), and water temperature. If the pH value deviates from its optimal range, the biochemical balance of the pond environment is disrupted, affecting the growth of floc-forming microorganisms. Meanwhile, excessively high TDS levels can interfere with osmotic pressure in fish bodies and reduce floc effectiveness. Water temperature also plays an important role in fish metabolism, feeding behavior, and microbial activity within the biofloc system. Inadequate control and monitoring of

these parameters may lead to fish stress, reduced productivity, and increased mortality risk (Ramadhani et al., 2024; Suriasni et al., 2024).

One of the main challenges in maintaining water quality stability in biofloc systems is the manual management of water circulation. Water filling and drainage are commonly conducted based on visual estimation or operator experience, without precise quantitative reference. As a result, corrective actions for declining water quality are often delayed. This condition can lead to increased turbidity, disruption of floc formation, and deterioration of fish health (Ramadhani et al., 2024). Additionally, the use of manual valves complicates the regulation of water flow. Excessively high inflow rates may disturb floc stability, increase fish stress, and cause unnecessary water usage, while insufficient flow rates result in ineffective water replacement. These conditions indicate that water circulation management is often inefficient and inaccurate, particularly in determining the appropriate waiting time for water drainage and refilling processes (Amal et al., 2023).

In practical field conditions, farmers frequently encounter uncertainty regarding when water circulation should be performed and how long the process should take to restore optimal water quality. If the waiting time is too short, water quality may not stabilize adequately; conversely, excessively long waiting times lead to water and energy waste. Therefore, an automatic control system that can determine optimal circulation timing based on real-time conditions is required to achieve efficiency, defined by time and water usage, and accuracy, defined by the correctness of control decisions according to actual pond conditions

To support real-time monitoring and notification, an Internet of Things (IoT)-based system can be employed by integrating sensors, microcontrollers, and wireless communication technologies. In this study, the IoT component functions as a supporting tool for data transmission and system notification using a lightweight messaging mechanism. System information and warning notifications are delivered to users through a Telegram-based interface, allowing farmers to receive real-time updates without the complexity of developing a full-scale information system.

The core challenge addressed in this research lies in the automatic decision-making mechanism for water circulation control. Conventional threshold-based control methods are highly sensitive to sensor fluctuations, often causing repeated and unnecessary valve opening and closing. This behavior reduces control accuracy, shortens actuator lifespan, and decreases overall system efficiency. To overcome this limitation, this study applies the Finite State Machine (FSM) method combined with hysteresis as the main control strategy.

FSM enables pond conditions to be classified into discrete operational states, such as *STANDBY*, *DRAIN WATER*, and *FILL WATER*, based on combinations of sensor readings. Each state corresponds to a specific control action, allowing structured and systematic decision-making. As multiple parameters are involved, the number of possible FSM state combinations increases, indicating the importance of FSM design as a foundation for further optimization and performance evaluation. To enhance system stability, hysteresis is incorporated to prevent rapid state transitions caused by minor sensor fluctuations. This approach is supported by previous studies, which demonstrated that hysteresis-based control reduces

oscillatory behavior in fluid systems (Kärnell & Ericson, 2022) while FSM-based control provides structured and organized responses in microcontroller-based water management applications (Hutauruk, 2025). In addition to operational states, several studies also emphasize the importance of incorporating fail-safe mechanisms in FSM-based control systems to ensure safe operation under abnormal conditions such as sensor failure or communication loss.

In this study, an ESP32 microcontroller functions as the main processing unit, collecting data from pH, TDS, water temperature (DS18B20), water level (JSN-SR04T), and water flow (YF-S201) sensors. The pH, TDS, and water level data are processed using FSM logic enhanced with hysteresis to determine appropriate control actions. Meanwhile, water temperature and water flow data are utilized for monitoring purposes and are delivered to users through Telegram notifications. Based on the FSM-Hysteresis decisions, servo motors automatically regulate inlet and outlet valves to control water circulation. System performance is evaluated using clearly defined criteria, including efficiency, measured by waiting time and water usage, and accuracy, measured by the correctness and stability of state transitions relative to actual pond conditions.

Through the integration of sensor-based monitoring, FSM-hysteresis control logic, automated valve actuation, and Telegram-based notifications, this research aims to develop an efficient, accurate, and responsive water circulation control system for biofloc-based Nile tilapia cultivation, supporting data-driven and sustainable aquaculture practices.

1.2. Problem Identification

Based on the background analysis, several critical challenges emerge in implementing biofloc technology for Nile tilapia cultivation:

1. Limited Real-Time Water Quality Monitoring: Key parameters including pH, Total Dissolved Solids (TDS), water temperature, water level, and water flow are not continuously monitored in real time, making it difficult to detect and respond promptly to deteriorating pond conditions.
2. Manual Water Circulation Management: Current systems rely on imprecise manual adjustments without data-driven decision support, resulting in delayed corrective actions for water quality issues.
3. Suboptimal Flow Control: Conventional valve systems demonstrate inadequate flow regulation. Improper water flow rates (either excessive or insufficient) compromise floc stability and fish development.
4. Absence of Structured Automatic Decision-Making: Existing systems lack a structured control mechanism, such as a Finite State Machine (FSM) combined with hysteresis, to perform stable, accurate, and automated water circulation decisions based on multiple water quality parameters.
5. Limited use of simple and effective real-time notification systems for conveying system status and warnings to users.

1.3. Research Questions

Based on the background and research questions explained, the problem formulation in this research is as follows:

1. To what extent can an IoT-based system integrated with an ESP32 microcontroller and water quality sensors (pH, TDS, water temperature, water level, and flow rate) successfully automate the monitoring and control of water quality based on water circulation in Nile tilapia biofloc ponds?
2. How effective is the implementation of a Finite State Machine (FSM) combined with hysteresis logic in providing stable state transitions, reducing unnecessary state oscillations, and improving the efficiency of automatic water circulation in terms of waiting time and water usage?
3. To what extent does real-time monitoring through a Telegram Bot support remote monitoring and user awareness of critical water quality events in biofloc-based Nile tilapia ponds?

1.4. Research Limitations

This research has the following limitations:

1. This research focuses on the implementation of the proposed system in biofloc-based Nile Tilapia (*Oreochromis niloticus*) cultivation.
2. The developed system concentrates on automated water circulation control using pH and TDS as the primary decision-making parameters, supported by water level, water flow, and water

temperature monitoring. Water temperature is used for monitoring purposes only and is not included in the FSM–Hysteresis decision-making process.

3. The ESP32 microcontroller serves as the primary processing unit for reading sensor data and regulating automated valves, and the implemented fail-safe mechanism is strictly limited to sensor error detection and safe-state handling without including advanced fault recovery, power backup, or hardware redundancy.
4. System monitoring and user notifications are implemented through a Telegram-based messaging interface.
5. The research does not comprehensively cover feed management, dissolved oxygen monitoring, temperature control, deep economic analysis, or comparative performance evaluation with other control methods, focusing instead on technical implementation and system functionality.
6. System testing and validation were strictly conducted in a semi-controlled Living Lab environment, meaning this study does not account for extreme weather dynamics, unpredictable large-scale industrial pond variables, or full biological cultivation cycles spanning three to four months.

1.5. Research Objectives

The objectives of this research are:

1. To design and implement an automated water quality monitoring and water circulation control system for biofloc-based Nile tilapia ponds using an ESP32 microcontroller.
2. To evaluate the performance of water quality sensors (pH, TDS, water temperature, water level, and water flow) in providing reliable input data for automatic decision-making in pond management.
3. To implement a Finite State Machine (FSM) combined with hysteresis logic as the core control method for regulating water drainage and refilling processes in response to changing pond conditions.
4. To analyze the effectiveness of the proposed FSM–hysteresis control logic in maintaining stable state transitions and preventing unnecessary state changes during automatic water circulation processes.
5. To evaluate system efficiency based on response time (waiting time) and water usage during refilling processes, as well as system accuracy based on the correctness of state transitions relative to actual pond conditions.
6. To provide real-time condition awareness and system status notifications as a supporting monitoring feature, without making the information system platform the main focus of the research.

1.6. Research Significances

This research is expected to provide the following benefits:

1.6.1. Theoretical Benefits:

- Contributing to the development of knowledge in automated control systems for aquaculture, particularly in the application of Finite State Machine (FSM) and hysteresis methods for water circulation management in biofloc systems.
- Providing analytical insight into the relationship between control logic design, system stability, efficiency, and accuracy in sensor-based water quality management.
- Serving as a reference for future research on algorithm-oriented control strategies in IoT-based aquaculture systems, emphasizing decision logic rather than information system development.

1.6.2. Practical Benefits:

- Providing an automated and data-driven solution to assist fish farmers in managing water quality and circulation more efficiently and accurately in biofloc ponds.
- Reducing unnecessary water usage, actuator wear, and delayed corrective actions through structured decision-making and stable control logic.
- Minimizing the risk of fish stress and mortality caused by improper water circulation timing and unstable water quality conditions.
- Supporting the implementation of smart aquaculture practices by enabling timely responses to critical water quality changes through real-time system notifications.