Techlapia: A Data-Driven Aquaculture Management System for Nile Tilapia

A Thesis

Presented to

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Bachelor of Science in Computer Engineering

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INTRODUCTION

Tilapia ranks as the second most important aquaculture species, with a production of 281,111 metric tons in 2021 [3]. With an annual per capita fish consumption of 34.28 kg [1], domestic fishery production fails to meet local demand even after reaching 4.40 million metric tons of production in 2020 [2]. The Philippine Tilapia industry faces low survival rates, poor production, slow growth, rising costs, and climate change, leading to a 10.62% production decline in 2022 [3][4]. Limited technological advancements and reliance on traditional farming hinder efficiency and scalability [5]. Improper stocking density remains a persistent issue, as overcrowded conditions contribute significantly to stress, reduced growth performance, and increased vulnerability to disease [25]. Recurring fish kills [6][7][8][9][10][11] caused by deteriorating water quality, high ammonia, extreme temperatures, feeding problems, among other factors, exacerbate industry losses. These issues highlight the need for sustainable aquaculture practices through regulating stocking density, automating a data-driven feeding system, and climate-smart technologies [12][13][14].

Multiple studies [18][23][24] highlight three key factors influencing the growth of Nile Tilapia: stocking density, feeding challenges, and environmental conditions. Estimating weight and population in Tilapia farming is an important factor in regulating stocking density. Several studies [15][16][17][18] have introduced ways to estimate Tilapia weight and population by utilizing various computer vision and machine learning algorithms. However, YOLOv8 for fish recognition for length to weight ratio [18] outperforms other models with an accuracy of 94% in Tilapia fish counting and key point detection making it superior solution for aquaculture productivity and real-time monitoring compared to alternatives. The system [18] utilized realtime water quality monitoring and vision-based fish weight estimation to determine optimal feeding amounts through its automated feeder mechanism equipped with load cells. However, while it reduces feed waste, it lacks intervention mechanisms for maintaining water quality. To reduce pellet leaching and maintain water quality, a fully automatic fish feeder utilizing a microcontroller-based system was designed [21] to provide precise feeding schedules and dosage control, ensuring fish are fed even when the owner is away. Maria et al. [19] developed an IoT-based on-demand fish feeding system that dispenses floating pellets when triggered by a fish, incorporating

2real-time monitoring via an overhead camera to enable automated feeding evaluation, feed consumption analysis, and efficiency assessment for Nile Tilapia farming. Furthermore, to address the limitations of traditional and image-based fish feeding systems in turbid outdoor aquaculture ponds, Hu et al. [15] proposed an automatic fish feeding system that utilizes deep learning-based computer vision to analyze water wave patterns caused by fish feeding, along with water quality sensors to optimize feeding decisions, achieving 93.2% accuracy. Maintaining an ideal environment for Nile Tilapia is one of the three factors influencing its growth. Sunardi et al. [20] introduced an IoT-based smart aquaculture system powered by solar energy to enable real-time monitoring and automated aeration control in Tilapia fishponds, addressing oxygen deficiency through light sensors, cameras, and an Androidcontrolled aerator system to enhance fish health and growth. Environmental conditions like weather can significantly impact water quality parameters like the pH, temperature, and turbidity [23]. Amrita et al. [22] developed an IoT-based water quality monitoring and control system, integrating pH, temperature, turbidity, and salinity sensors to detect real-time water conditions, allowing farmers to remotely monitor pond status, make informed decisions, and maintain stable water quality, thereby reducing crop failure and improving harvest consistency.

While these existing systems have addressed specific challenges in Tilapia aquaculture, they lack an integrated and multifunctional approach that simultaneously tackles multiple aspects of fish farming. Furthermore, previous studies have largely overlooked the relationship between feeding ratios and stocking density, as well as the automation of aeration and water circulation, both of which are essential for achieving sustainable aquaculture production.

To address these gaps, the research aims to develop Techlapia, a data-driven system for managing Nile tilapia culture. Specifically, this study aims to: (1) develop a system with fish counting and weight estimation features using a computer vision algorithm; (2) develop a datadriven automated feeding management system; and (3) develop a water-quality intervention system equipped with feedback mechanisms for real-time water-quality monitoring.

The development of Techlapia brings significant benefits to urban and small-scale fish farmers in the Philippines by enhancing and modernizing various aspects of aquaculture through computer vision and data-driven technology. By integrating automated fish counting, weight estimation, and water quality monitoring, the system enables farmers to make informed, data-driven decisions, reducing manual labor and improving resource allocation. The automated feeding management system ensures precise feed distribution, minimizing waste and lowering operational costs in the long run. Additionally, real-time water quality monitoring system continuously records environmental data, while the automated intervention system helps mitigate risks, such as fish kills due to deteriorating water conditions, through aeration and water circulation.

This study focuses on designing a data-driven aquaculture system for Nile Tilapia, utilizing a computer vision algorithm, specifically the YOLOv8 model, for fish counting and weight estimation. The Techlapia system will be integrated with water quality monitoring to collect environmental data, mainly pH level, temperature, turbidity, and water level and provide intervention through automated aeration and water circulation mechanisms. Additionally, the system will incorporate a data-driven automated feeding management system. A 1.5m × 1.5m × 0.75m fish tank will be designed, and a low stocking density approach will be implemented, supporting a minimum of 15 tilapia fish throughout the period of the study.

METHODOLOGY

A. System Architecture

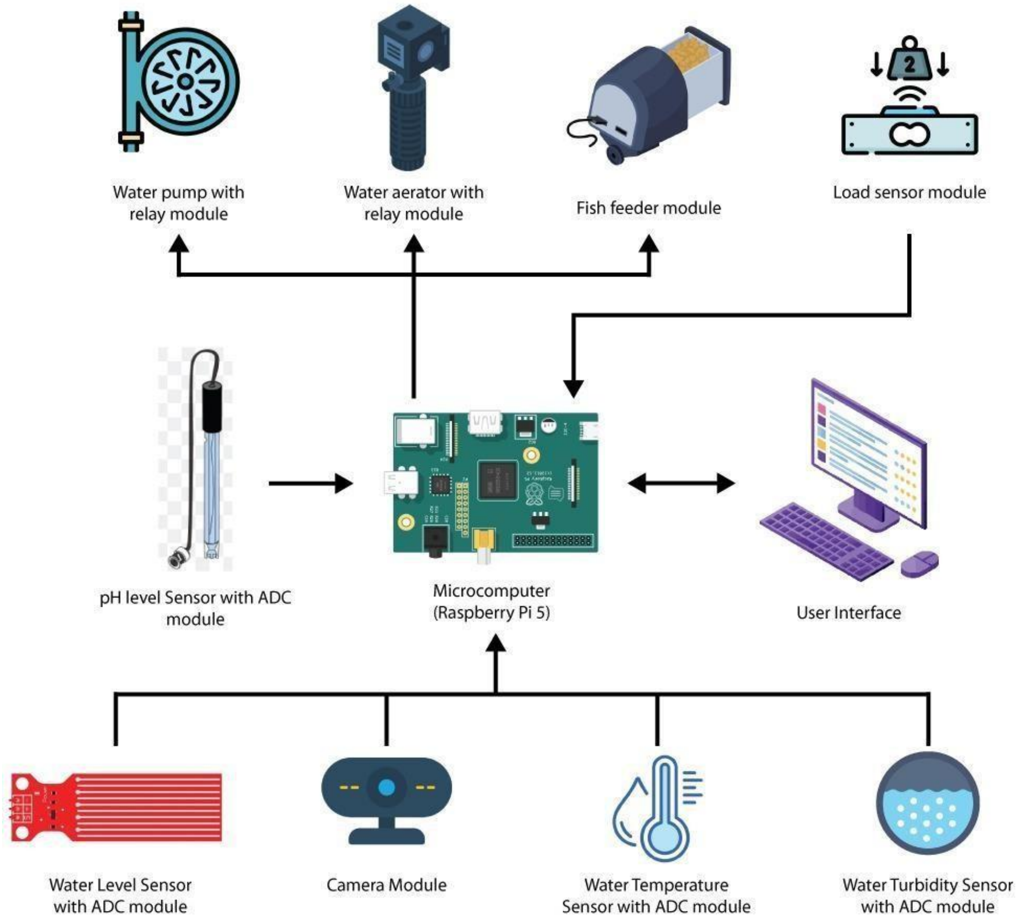


Figure 1. System Overview of Techlapia

The system operates through the integration of multiple sensing, processing, and control components that work together to automate key aquaculture functions. As shown in the system architecture, users interact with Techlapia through a dedicated user interface, which allows them to monitor real-time data, manage system actions, and activate manual overrides when necessary. Once the system is running, a set of water quality sensors—including pH, temperature, turbidity, and water level—continuously collects environmental readings. These analog signals are converted through ADC modules and transmitted to the Raspberry Pi 5, which serves as the central microcomputer responsible for processing all incoming data.

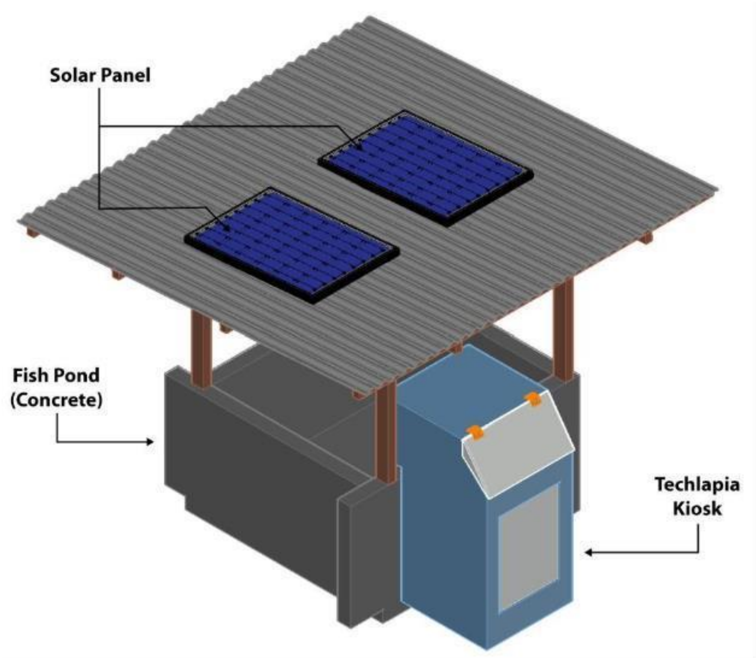
Simultaneously, the camera module captures images of the tilapia population at scheduled intervals. These images are forwarded to the Raspberry Pi, where an imageprocessing model extracts fish length and estimates their corresponding weight. Based on the computed results, the system determines the required feed amount and activates the feeder module. During dispensing, the load cell measures the actual feed released and communicates the values back to the Raspberry Pi so that the system can automatically stop the feeder once the target weight is reached.

The microcomputer also controls the aerator and water pump through relay modules, enabling automated responses based on predefined thresholds from sensor readings. All processed data—including fish growth estimates, water quality status, feeding activity, and device operations—is reflected in the user interface for continuous monitoring. In addition to automated processes, the user interface provides a manual override option, allowing users to directly operate the feeder, pump, and aerator whenever adjustments, maintenance, or immediate intervention are required. Through its coordinated sensing, computation, actuation, and user-directed control functions, the system maintains consistent monitoring and operational efficiency within the aquaculture environment.

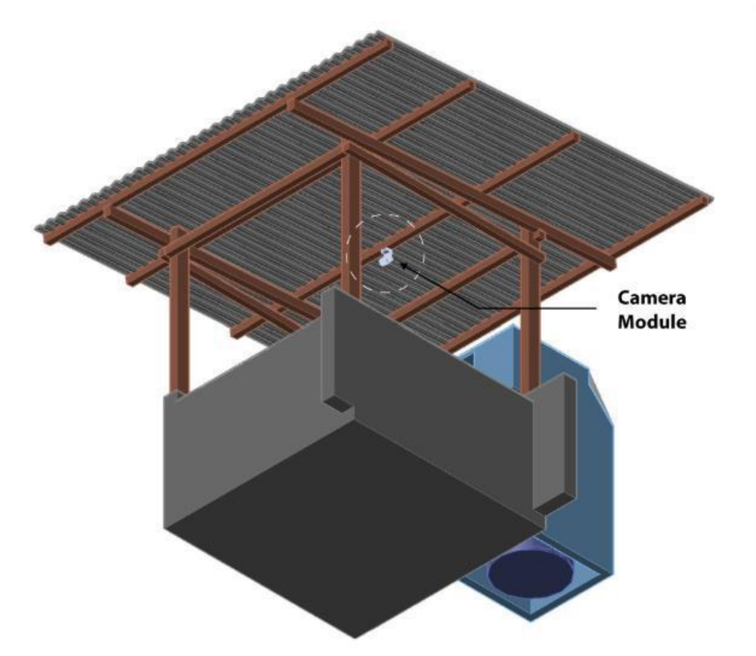
B. Hardware Design

B.1 Integrated Hardware Design

Figure 1(a) shows an overview of the Techlapia System that presents an integrated aquaculture setup designed to support automated and data-driven tilapia farming. The concrete fishpond, as shown in Figure 1, functions as the main culture area, providing a durable structure that supports controlled fish rearing conditions. Positioned beside the pond is the Techlapia system kiosk, which houses the microcomputer, control and sensor modules, and user interface used for monitoring system status, managing feeding operations, and enabling manual user interaction when needed. Figure 1(b) shows the camera module installed at the top of the structure, directly above the pond, enabling continuous visual monitoring of fish behavior and system conditions for data collection and analysis. Mounted above the structure, the solar panels supply renewable energy to power the system, allowing continuous operation while reducing reliance on conventional electrical sources. This configuration demonstrates a compact, sustainable, and functional design suitable for small-to-medium-scale aquaculture applications.



(a)



(b)

Figure 2. (a) Overall View of the Techlapia System, (b) Location of Camera Module

B.2 Fishpond Design

The Techlapia concrete fishpond is designed to provide a stable and durable enclosure for tilapia culture, as shown in Figure 3. It has overall dimensions of 191 cm × 172 cm × 94 cm providing adequate space to accommodate tilapia fingerlings and support their growth under controlled rearing conditions.

Wooden braces are incorporated to reinforce the structure and enhance its stability, while a metal roof is installed above the pond to provide protection from direct sunlight and rainfall.

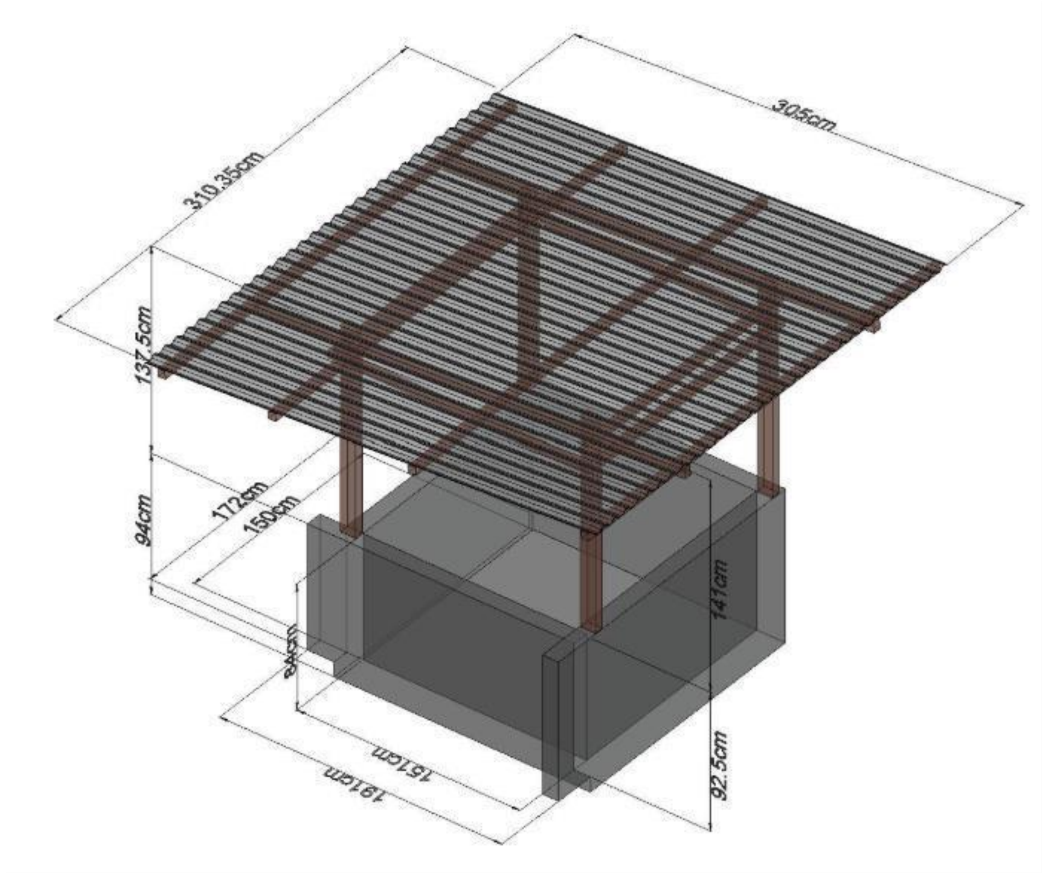
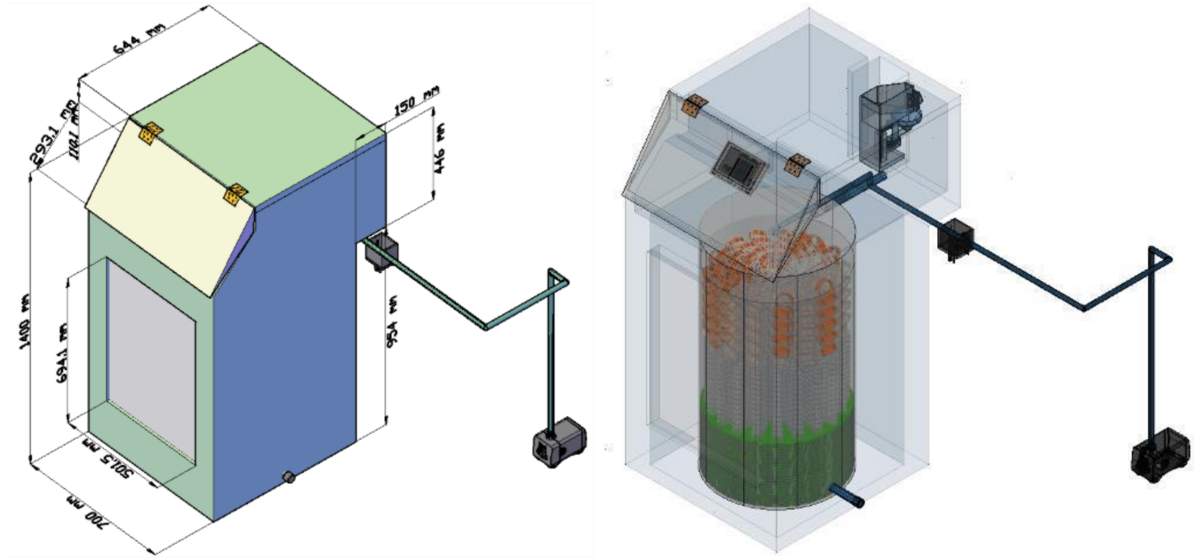


Figure 3. Fishpond Design of Techlapia

B.3 Techlapia Kiosk Design

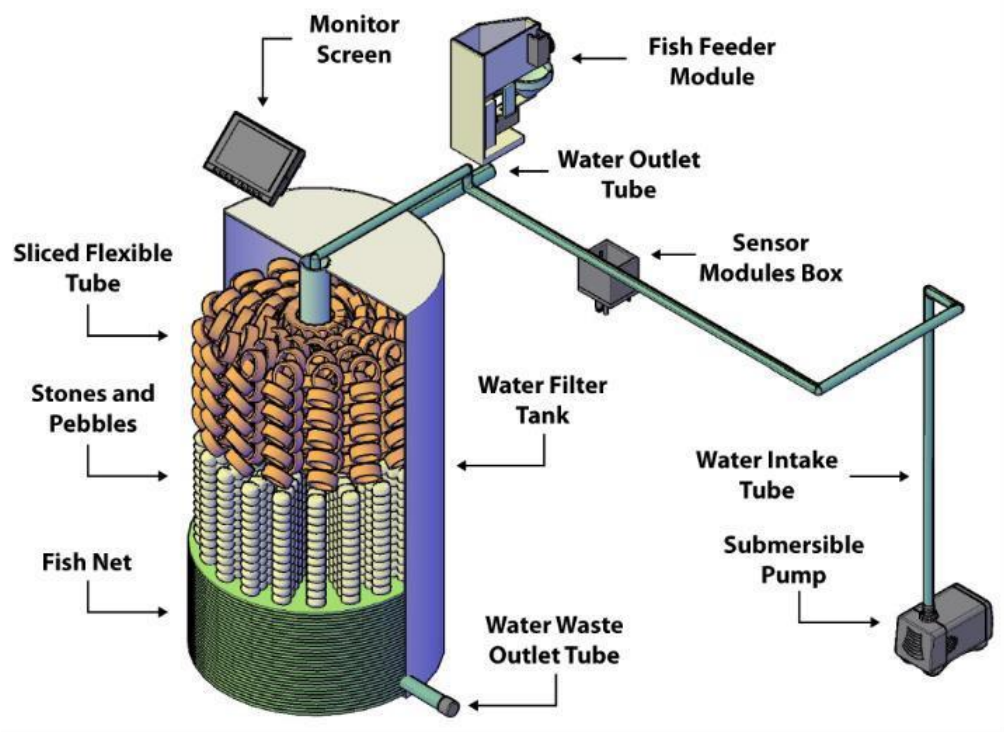
Figure 4 illustrates the physical design of the Techlapia kiosk, showing the external structure in Figure 4(a) and the internal components in Figure 4(b).



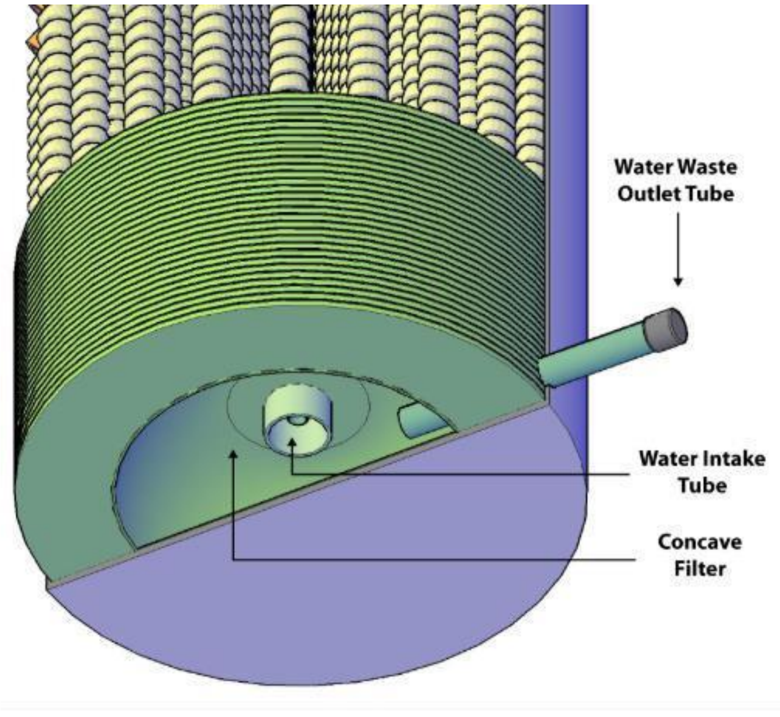
(a) (b)

Figure 4(c) shows the operation of the Techlapia kiosk with user interaction through the monitor screen, which serves as the primary interface for viewing real-time system status, water quality readings, and operational alerts. As the system runs, environmental data are continuously collected by the camera and sensor modules and transmitted to the microcomputer for processing. These data guide automated system responses, including the activation of the fish feeder module, which dispenses feed based on preset schedules while still allowing the user to intervene manually when needed.

Simultaneously, water circulation is maintained by the submersible pump, which draws water from the pond through the water intake tube and drives it into the filtration tank. Figure 4(c) shows the four-layer filtration system composed of sliced flexible tubing for coarse debris trapping, a layer of stones and pebbles for sediment removal, a fish net layer for finer particle filtration, and a concave filter that captures remaining impurities before discharge. Accumulated waste and settled residues are directed through a dedicated water waste outlet tube located at the bottom of the tank, as shown in Figure 4(d). After filtration, the treated water is returned to the pond through the water outlet tube. This continuous cycle of monitoring, automated feeding, multi-layer water filtration, and recirculation enables reliable system operation while supporting stable conditions for tilapia rearing.



(c)



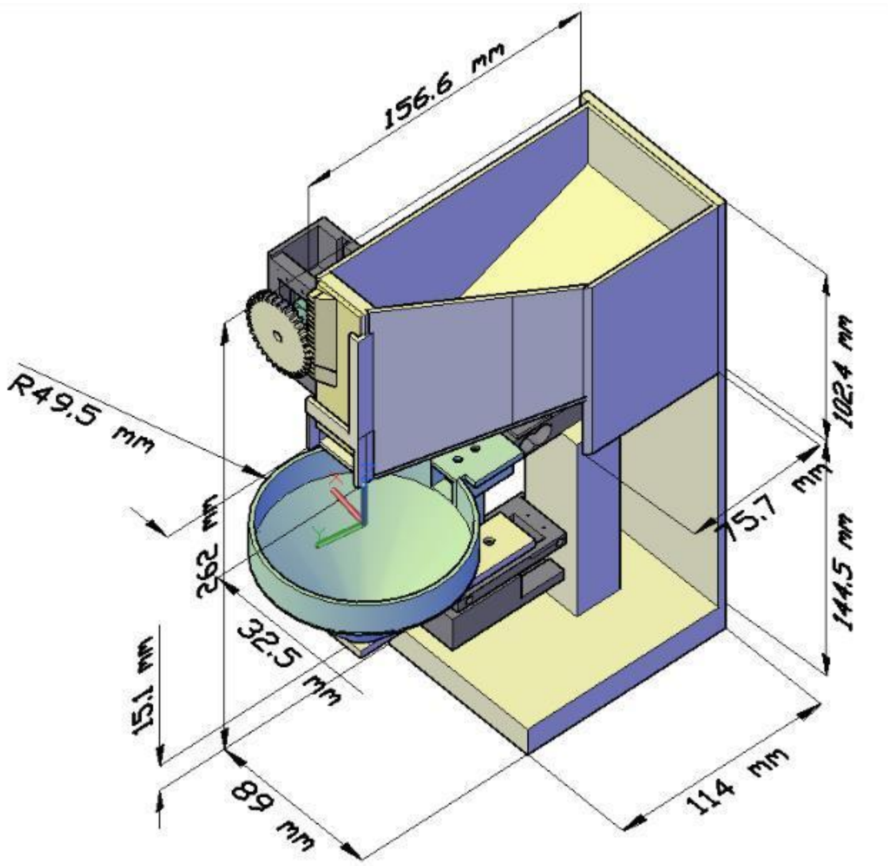
(d)

Figure 4. Kiosk Design of the Techlapia: (a) Outer View, (b) Skeletal View, (c) Inner View, (d) Bottom View of Water Filter Tank

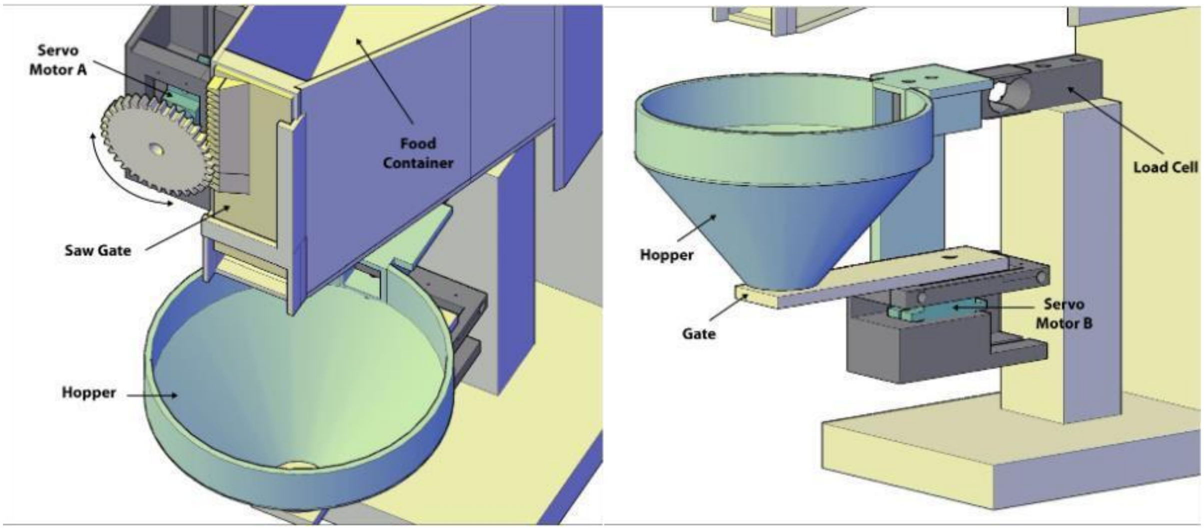
B.4 Fish Feeder Module Design

Figure 5(a) shows the overall design and dimension of the fish feeder module. The fish feeder module works by following a set of mechanical and electronic steps to feed the fish.

First, the feed is stored in the food container located above the hopper, as shown in Figure 5(b). When feeding begins, servo motor A drives its attached gear, which engages the saw gate positioned below the food container. This saw gate regulates the amount of feed allowed to drop into the hopper, where a load cell, as shown in Figure 5(c), continuously measures the weight of the feed. Once the desired amount of feed is detected by the load cell, servo motor A begins to close the saw gate, stopping additional feed from entering the hopper. Immediately after, servo motor B activates to open the gate at the bottom of the hopper, releasing the measured feed into the fish tank.



(a)Overall Fish Feeder Module Design



(a) (c)

Figure 5. (a) Overall Fish Feeder Module Design, (b) Dispensing Mechanism, (c) Load Measurement Mechanism

C. Software Architecture

Figure 6 shows the proposed software architecture of Techlapia is organized into four main layers: the User Interface Layer, Data Layer, Processing Layer, and Control Layer. Each layer has a specific function to enable real-time monitoring, automated feeding, and environmental management for efficient tilapia aquaculture.

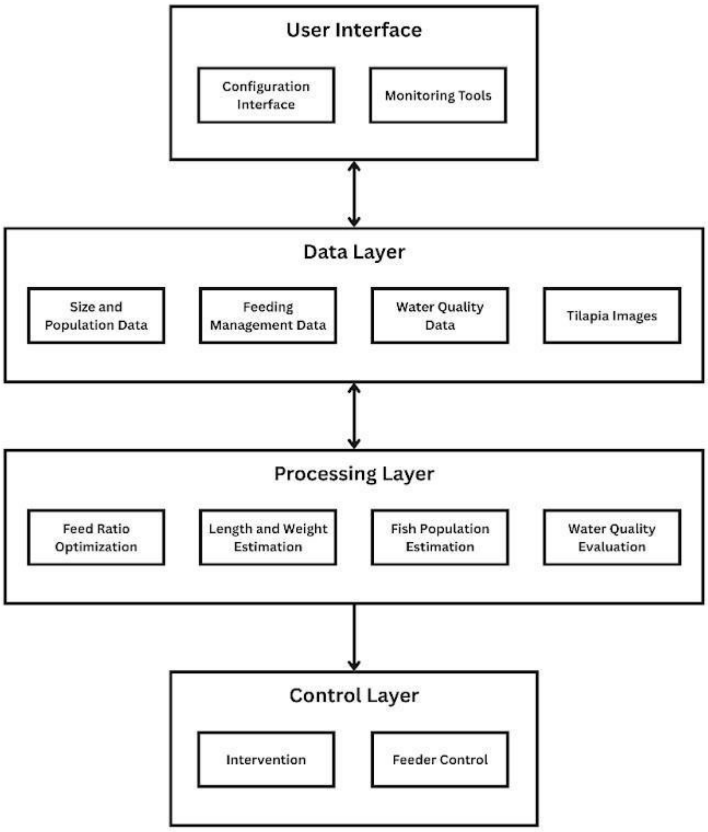


Figure 6. Software Architecture of the Techlapia System

The User Interface Layer allows users to interact with the system through the Configuration Interface and Monitoring Tools. In the configuration interface, users input the target fish weight and tank dimensions, which the system uses to calculate the recommended stocking density and initial fish population. The monitoring tools provide real-time visualization of fish population, weight trends, and water quality, as well as alerts when parameters exceed safe thresholds. The User Interface layer continuously exchanges information with the Data Layer, retrieving records and feeding information for display and confirmation. The Data Layer manages all collected and processed information, storing gathered data in one central location on the Raspberry Pi. It maintains fish size and population records, feeding management data, water quality readings (pH, temperature, turbidity, and water level), and tilapia images captured by the camera module. By organizing all these data, the layer supports both realtime decision-making and historical tracking for trend analysis and optimization.

The Processing Layer performs computational analysis using machine learning and optimization techniques. The YOLOv8 algorithm is employed for Fish Population Estimation and Length and Weight Estimation, while a feed optimization algorithm computes the Feed Ratio based on fish weight and stocking density. The resulting data including the estimated fish population, individual weights, total biomass, and optimized feed ratio are then used to generate precise feeding schedules and environmental control strategies that guide the actuators. The Control Layer executes actions derived from the processing results. It includes Feeder Control for dispensing feed in the correct amounts and schedules, Intervention for handling abnormal conditions such as high pH, temperature fluctuations, or turbidity. These responses include activating aeration, enabling water circulation, adjusting cooling mechanisms, or temporarily suspending feeding. Through this structure, the Control Layer directly manages system actuators using validated system data and user-defined parameters to ensure stable and efficient aquaculture operation.

C.1 Software Algorithm

Figure 7 illustrates the overall system flow of the Techlapia aquaculture management system.

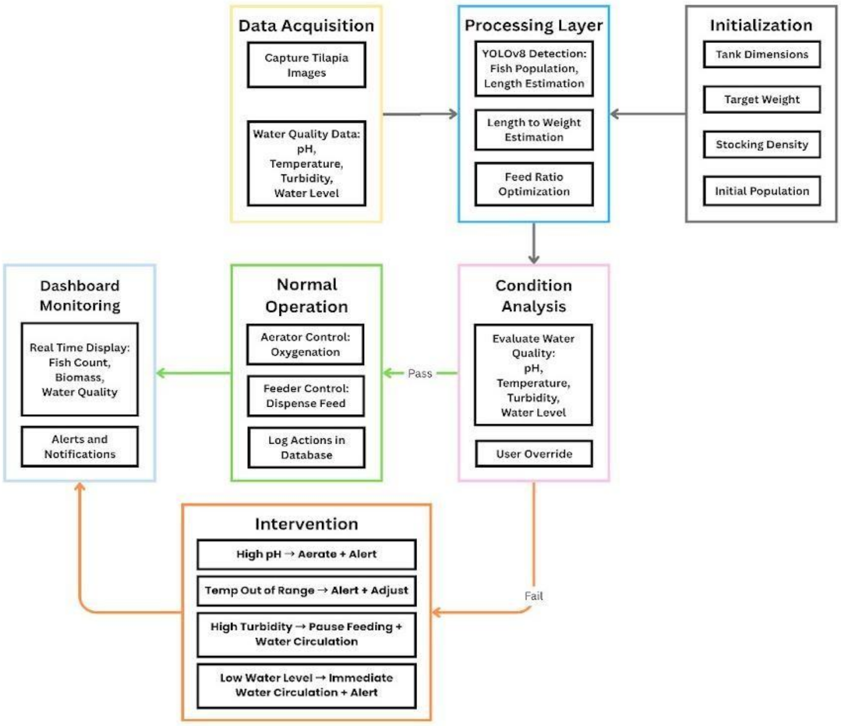


Figure 7. Software Algorithm for the Techlapia System

The process begins with the Initialization stage, where the user inputs tank dimensions, target weight, and stocking density through the configuration interface. The Data Acquisition stage collects real-time data from two primary sources, the image data from the camera module and environmental readings from the sensor suite, which monitors parameters such as pH, temperature, turbidity, and water level. The parameters are then processed in the Processing

Layer, where the YOLOv8 model performs fish population detection and length estimation. Using the detected lengths, the system computes weight estimates through a length-to-weight formula, and a feed ratio optimization algorithm determines the optimal daily feeding schedule based on the biomass. The Condition Analysis stage evaluates the current water quality against predefined limits. If all parameters are within acceptable limits, the system proceeds to the Normal Operation stage, where automatic control mechanisms activate the aerator to maintain oxygenation and the feeder to dispense food according to the optimized schedule.

The system provides a user override option, allowing direct manual control of the aerator, water circulation pump, and feeder at any time. Each control event is logged into the database for tracking and analysis. If environmental conditions fall outside the acceptable range, the system transitions to the Intervention stage. This module automatically initiates corrective actions, such as activating aeration and sending alerts for high pH levels, adjusting aerator operations for temperature fluctuations, pausing feeding and recommending water changes for high turbidity, or initiating immediate water circulation for low water levels. All interventions are recorded and communicated to the user. The Dashboard Monitoring stage provides realtime visualization of fish count, biomass, and water quality, along with alerts and notifications for system anomalies. Users can review system performance, monitor environmental stability, and intervene manually if necessary. The Techlapia software algorithm operates continuously ensuring efficient aquaculture management, optimized feeding, and stable environmental conditions for tilapia growth.

C.2 Computer Vision Algorithm

Figure 8 illustrates the YOLOv8-based custom architecture for Techlapia.

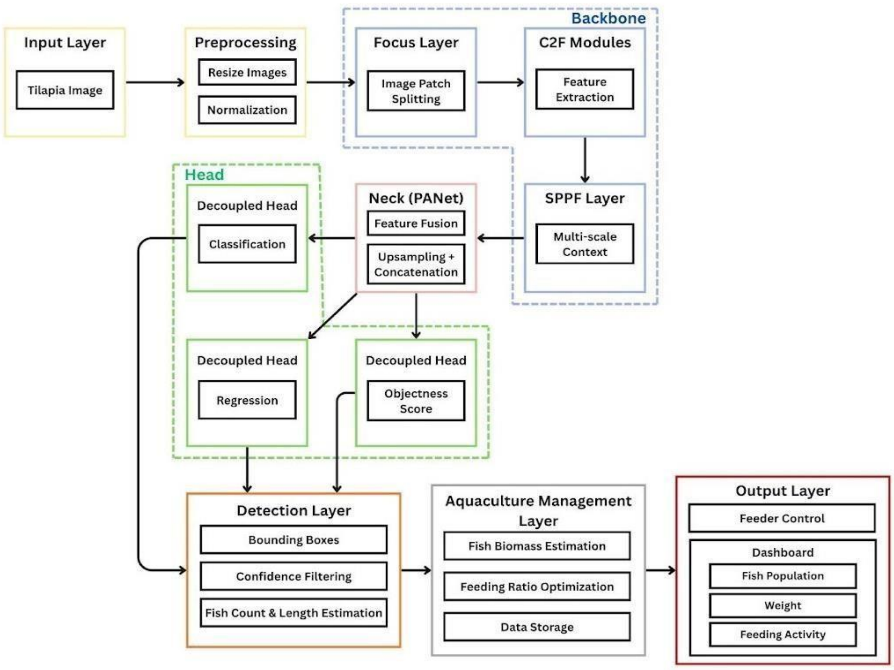


Figure 8. Computer Vision Algorithm for the Techlapia System

The process begins with tilapia image input captured from the tank's camera module. These images are first handled by the Preprocessing Layer, which resizes the raw inputs to a fixed 640×640 resolution and normalizes pixel values to ensure consistent illumination and scale. The backbone network functions as the primary feature extractor of the architecture and is composed of three main components. The Focus layer slices and rearranges spatial information to reduce computational overhead while preserving essential visual features. The C2f modules perform deep convolutional feature extraction to detect structural characteristics such as shape, texture, and edges of tilapia. The Spatial Pyramid Pooling–Fast (SPPF) module aggregates multi-scale contextual information, allowing the system to detect tilapia reliably across varying tilapia sizes and orientations. The features extracted by the backbone are then passed to the neck, which utilizes a Path Aggregation Network (PANet) with upsampling and concatenation to improve multi-scale feature fusion. This ensures that relevant visual information is retained and refined across different spatial resolutions, enhancing object localization and recognition performance. The head of the architecture employs a decoupled prediction strategy in which classification, regression, and objectness scores are computed independently. This approach enables accurate detection of tilapia. The Detection Layer generates bounding boxes, confidence scores, and corresponding fish population and length measurements.

The Aquaculture Management Layer consists of key components including Fish Biomass Estimation, which calculates weight from the detected lengths, Feeding Ratio Optimization, which uses this biomass data to compute automatically adjusted feeding schedules, and Data Storage, which records fish population, feeding activity, and biomass trends for historical analysis. The Output Layer connects the analytical results with the physical and user-interactive components of the Techlapia system. It includes the Feeder Control, which automates feed dispensing according to the optimized feeding schedule, and the Dashboard, which compiles and visualizes real-time fish population, weight trends, and feeding activity. This integration allows for both automated system execution and continuous user monitoring, enabling precision-based, data-driven aquaculture management.

D. User Interface (UI)

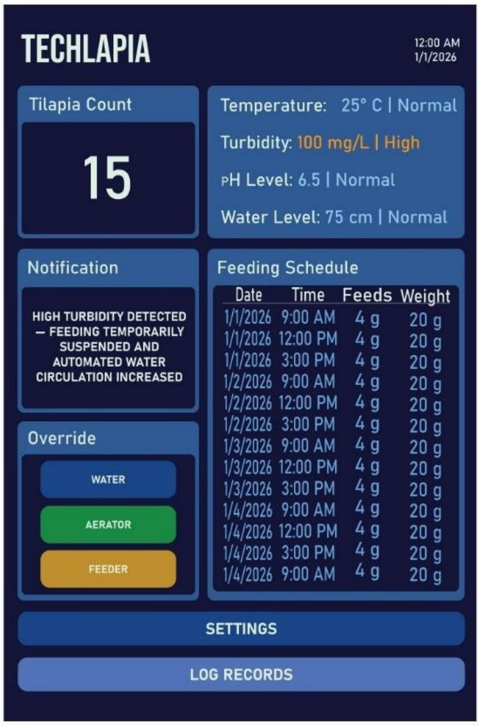
The Techlapia user interface is designed as a centralized monitoring and control dashboard with a clear, panel-based layout. The main page, as shown in Figure 9, displays a live feed from the camera module, allowing real-time visual observation of the pond. On the right side, information cards present key system data such as tilapia count, current water quality parameters including temperature, turbidity, pH level, and water level, each paired with a status indicator. A notification panel summarizes system conditions, while the feeding schedule table provides planned feeding times and quantities. Manual override buttons enable direct control of critical components such as the water system, aerator, and feeder. Settings and Log Records buttons at the bottom allow access to the settings screen and view log history, ensuring straightforward operation and quick user response to system conditions.

Figure 9. Main UI Page Design

Figure 10 presents the different system notifications and status conditions generated by Techlapia, illustrating alerts for low temperature, low water level, low pH level, high turbidity, high pH level, and high temperature. These visual indicators demonstrate how the system identifies and communicates abnormal environmental conditions that require user attention or corrective action.


TECHLAPIA
12:00 AM
1/1/2026
Tilapia Count
15
Temperature: 25° C | Normal
Turbidity: 50 mg/L | Normal
pH Level: 6.5 | Normal
Water Level: <60 cm | Low
Notification
WATER LEVEL BELOW MINIMUM THRESHOLD — AUTOMATED REFILLING ACTIVATED. PLEASE INSPECT FOR POSSIBLE LEAKS
Feeding Schedule
Date Time Feeds Weight
1/1/2026 9:00 AM 4 g 20 g
1/1/2026 12:00 PM 4 g 20 g
1/1/2026 3:00 PM 4 g 20 g
1/2/2026 9:00 AM 4 g 20 g
1/2/2026 12:00 PM 4 g 20 g
1/2/2026 3:00 PM 4 g 20 g
1/3/2026 9:00 AM 4 g 20 g
1/3/2026 12:00 PM 4 g 20 g
1/3/2026 3:00 PM 4 g 20 g
1/4/2026 9:00 AM 4 g 20 g
1/4/2026 12:00 PM 4 g 20 g
1/4/2026 3:00 PM 4 g 20 g
1/4/2026 9:00 AM 4 g 20 g
Override
WATER
AERATOR
FEEDER
SETTINGS
LOG RECORDS

(a)


TECHLAPIA
12:00 AM
1/1/2026
Tilapia Count
15
Temperature: 25° C | Normal
Turbidity: 100 mg/L | High
pH Level: 6.5 | Normal
Water Level: 75 cm | Normal
Notification
HIGH TURBIDITY DETECTED — FEEDING TEMPORARILY SUSPENDED AND AUTOMATED WATER CIRCULATION INCREASED
Feeding Schedule
Date Time Feeds Weight
1/1/2026 9:00 AM 4 g 20 g
1/1/2026 12:00 PM 4 g 20 g
1/1/2026 3:00 PM 4 g 20 g
1/2/2026 9:00 AM 4 g 20 g
1/2/2026 12:00 PM 4 g 20 g
1/2/2026 3:00 PM 4 g 20 g
1/3/2026 9:00 AM 4 g 20 g
1/3/2026 12:00 PM 4 g 20 g
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1/4/2026 9:00 AM 4 g 20 g
1/4/2026 12:00 PM 4 g 20 g
1/4/2026 3:00 PM 4 g 20 g
1/4/2026 9:00 AM 4 g 20 g
Override
WATER
AERATOR
FEEDER
SETTINGS
LOG RECORDS

(b)


TECHLAPIA
12:00 AM
1/1/2026
Tilapia Count
15
Temperature: 10° C | Low
Turbidity: 50 mg/L | Normal
pH Level: 6.5 | Normal
Water Level: 75 cm | Normal
Notification
WATER TEMPERATURE OUT OF OPTIMAL RANGE — AUTOMATED WATER CIRCULATION STOPPED
Feeding Schedule
Date Time Feeds Weight
1/1/2026 9:00 AM 4 g 20 g
1/1/2026 12:00 PM 4 g 20 g
1/1/2026 3:00 PM 4 g 20 g
1/2/2026 9:00 AM 4 g 20 g
1/2/2026 12:00 PM 4 g 20 g
1/2/2026 3:00 PM 4 g 20 g
1/3/2026 9:00 AM 4 g 20 g
1/3/2026 12:00 PM 4 g 20 g
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1/4/2026 9:00 AM 4 g 20 g
1/4/2026 12:00 PM 4 g 20 g
1/4/2026 3:00 PM 4 g 20 g
1/4/2026 9:00 AM 4 g 20 g
Override
WATER
AERATOR
FEEDER
SETTINGS
LOG RECORDS

(c)


TECHLAPIA
12:00 AM
1/1/2026
Tilapia Count
15
Temperature: 35° C | High
Turbidity: 50 mg/L | Normal
pH Level: 6.5 | Normal
Water Level: 75 cm | Normal
Notification
WATER TEMPERATURE OUT OF OPTIMAL RANGE — AUTOMATED WATER CIRCULATION STOPPED
Feeding Schedule
Date Time Feeds Weight
1/1/2026 9:00 AM 4 g 20 g
1/1/2026 12:00 PM 4 g 20 g
1/1/2026 3:00 PM 4 g 20 g
1/2/2026 9:00 AM 4 g 20 g
1/2/2026 12:00 PM 4 g 20 g
1/2/2026 3:00 PM 4 g 20 g
1/3/2026 9:00 AM 4 g 20 g
1/3/2026 12:00 PM 4 g 20 g
1/3/2026 3:00 PM 4 g 20 g
1/4/2026 9:00 AM 4 g 20 g
1/4/2026 12:00 PM 4 g 20 g
1/4/2026 3:00 PM 4 g 20 g
1/4/2026 9:00 AM 4 g 20 g
Override
WATER
AERATOR
FEEDER
SETTINGS
LOG RECORDS

(d)

(e)

(f)

Figure 10. (a) Low Water Level, (b) High Turbidity, (c) Low Temperature, (d) High Temperature, (e) Low pH Level, (f) High pH Level

Figure 11 illustrates the Settings UI page layout of the Techlapia system, which allows users to configure key production parameters while viewing a live feed from the camera module. The interface enables input of the initial fish population, tank dimensions (length, width, and depth), and target fish weight, with the system automatically recalculating the stocking density in real time whenever any variable is modified. This dynamic calculation supports accurate stocking management without manual computation. Settings and Log Records buttons at the bottom of the interface to allow quick navigation back to the primary UI page or view log history.

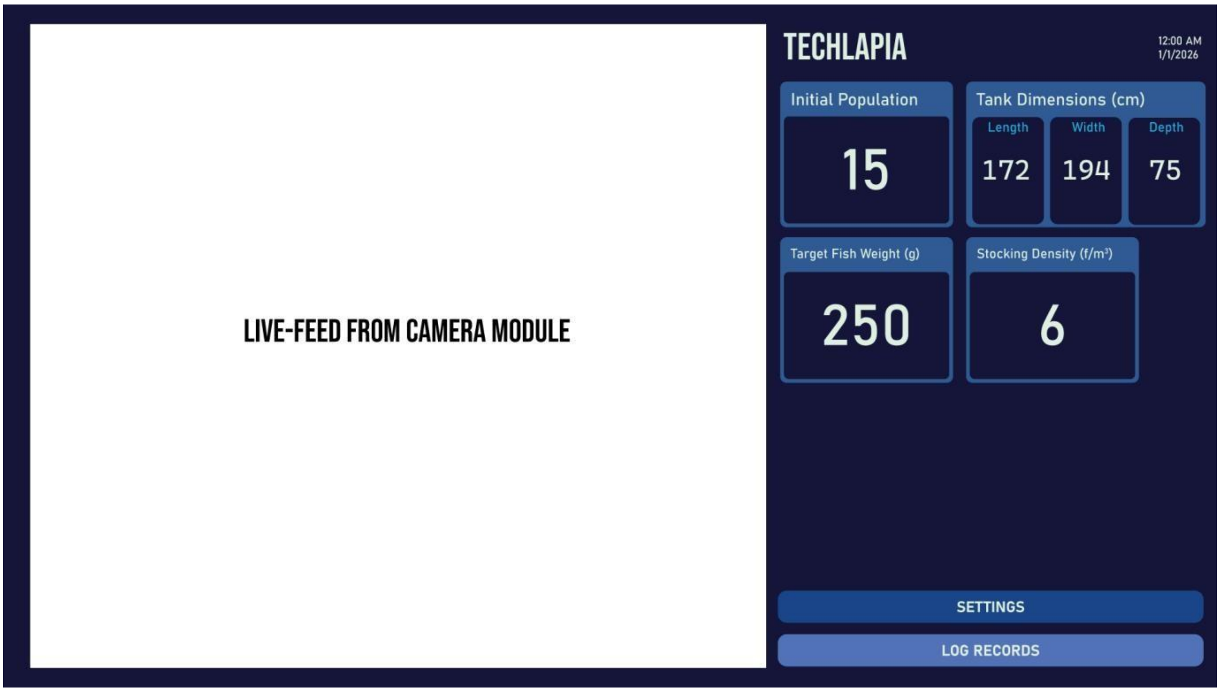
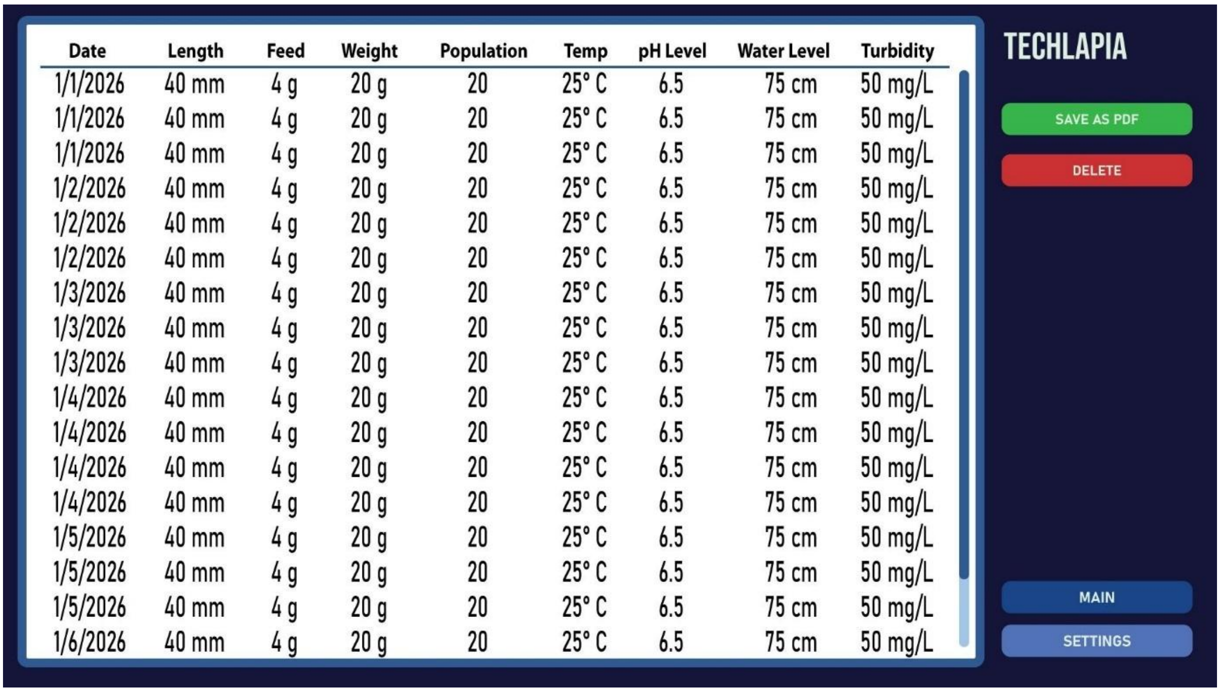


Figure 11. Settings UI Page Design

Figure 12 illustrates the Log Records UI page of the Techlapia system, which presents a structured tabular view of historical aquaculture data collected during system operation. The interface displays recorded parameters such as date, fish length, feed amount, average weight, population count, water temperature, pH level, water level, and turbidity. These records support continuous monitoring and retrospective analysis of both fish growth and water quality conditions. The interface also provides data management functions, including options to save the records as a PDF file and to delete entries, as well as navigation controls for returning to the main and settings pages, thereby supporting organized documentation and system operation.



Date	Length	Feed	Weight	Population	Temp	pH Level	Water Level	Turbidity
1/1/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/1/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/1/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/2/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/2/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/2/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/3/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/3/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/3/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/4/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
1/4/2026	40 mm	4 g	20 g	20	25° C	6.5	75 cm	50 mg/L
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Figure 12. Log Records UI Page Design

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