Fish Species Selection and Growth Monitoring for Sustainable Aquaculture

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Abstract

Project "Water Quality Driven Fish Type Selection and Growth Monitoring for Sustainable Aquaculture" aim to overcome the key challenges faced by aquaculture including poor fish growth, bad species selection and wasteful resource utilization. However, the productivity with traditional fish farming relies on poor productivity as a result of no real time monitoring and no data driven decision making. Through this project, I suggest an advanced aquaculture system that makes use of IoT and ML in monitoring the critical water quality parameters, pH, temperature and turbidity that have direct bearing on the type of fish species chosen and expected growth rates. For the system, it consists of the individualized modules that support real time sensor data on fish species classification, growth tracking and behavior tracking. An easily usable interface offers actionable insights and timely alerts and thus aid fish farmers with making informed management decisions. Firstly, initial findings indicate that accurate fish species recommendation and improve growth rates may contribute to the sustainable, efficient and productive aquaculture practices. This solution provides an alternative to help fish farming systems cope with increased resource use demands and mitigating the environmental impacts from fish farming, improving the resilience of the fish farming systems, and strengthening the global aquaculture industry.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The objective of this research work investigates how technology through IoT and machine learning can solve the problems faced by conventional aquaculture systems. The study examines present fish farming practices since their deficiencies block the industry from productive growth and sustainable operations.

The necessity of developing this problem stems from aquaculture becoming a crucial sustainable protein source to fulfill increasing seafood consumer demand. The current practices of fish farming experience multiple problems including slow fish development together with improper species choice and inadequate resource management. Former studies have drawn attention to these obstacles in fish farming whereas new solutions must be developed to advance fish farming methods.

A smart aquaculture system based on IoT and machine learning technology demonstrates the capability to accomplish real-time water quality monitoring while also tracking fish activities which leads to enhanced fish growth performance. The implemented methodology includes continuous information monitoring together with analytical operations for aquaculture decision support to boost fish production quantities and reduce environmental consequences.

Selection criteria for assessing this investigation's outcomes focus on fish wellness and development combined with enhanced resource management and operational profitability.

Summary of Key Points:

- The research examines how technology improves aquaculture practices as its primary goal.
- Traditional fish farming methods experience both poor performance and weak system security which constitutes the core problem under investigation.
- Background research demonstrates the increasing seafood market demand together with traditional aquaculture obstacles which led previous studies to advocate innovative solutions.
- A smart aquaculture system achieves higher fish farming outcomes by using technological solutions according to the thesis analysis.
- Successful results will lead to better fish health with streamlined resources as well as enhanced productivity rates.

Its main focus is the research into how technology improves the aquaculture practice. The core problem to be studied is that traditional fish farming methods suffer poor performance and very weak fishing system security. Thus, previous studies suggested innovative solutions arising out of background research on the increasing seafood market demand and traditional aquaculture challenges. According to the analysis in the thesis, a smart aquaculture system has better fish farming outcomes through technological solutions. Better fish health with better productivity rates, fewer resources and point sources is expected from successful results. Essential water quality parameters, such as the pH, temperature and turbidity are controlled by the smart aquaculture system based on ongoing measurements of these parameters. These vital parameters are critical to fish health as well as to growth requirements, which depend on them. The system can acquire current data by the help of the IoT sensors that indicates the real conditions of the aquaculture environment. The information helps farmers do what is necessary to protect water quality standards and also promote fish health improvement strategies.

Fish feeding actions and social activities and total health condition are taken into the system's behavior monitoring feature that gathers data from the system. By thus enabling a farmer to know if a cow is distressed, conditions that will otherwise go on to be unhealthy can be prevented. Machine learning algorithms are used to study the data collections trying to find those correlations that would generate relevant species recommendations as well as suitable operational management strategies. The fish growth rate can be monitored by the size capabilities in the system, thus the system helps farmers to adjust their fish feeding schedules according to their changes. For better business profit potential, fish growth to their optimum size in the right time period directly contributes to operational productivity. The smart aquaculture system enables the farmers to seamlessly monitor all correct time data and relevant information, such as automatically sending alerts and recommendation that assists the farmers to make sensible enhancement within the fish's truly nice health and productivity. A meaningful break has been introduced to the aquaculture field by modern technology. This smart aquaculture system addresses issues of standard fish farming which results in increased sustainable and operational fish cultivation system. Such approaches increase fish health outcomes as well as yield production while maintaining low environmental impacts. It is crucial to have smart technology in the aquaculture industry because they are providing a platform to develop seafood production in line with growing demand, while maintaining fish farming at a high level. The findings presented in this research can be used to help discussions about sustainable aquaculture to recognize what both the challenges of the industry and the ways to innovate. It investigates how technology acts as a pivotal factor in the revolutionization of the present day aquaculture operations. The smart aquaculture system addresses all challenges of traditional fish farming to develop food security and environmentally friendly seafood production using IoT and machine learning.

Chapter 2

Review of Literature

Table 2.1: Literature Review

Sr. No	**Year**	**Paper**	**Methods**	**Limitations**
1	2019	Automatic Recognition of Fish Diseases in Fish Farms[5]	Introduced a system for detecting fish diseases using IoT and machine vision to improve aquaculture health management.	Validation limited to specific disease scenarios; requires more robust datasets for broader applicability.
2	2019	Using Machine Vision to Estimate Fish Length[4]	Developed a machine vision method to estimate fish lengths using regional convolutional neural networks, achieving high accuracy in controlled conditions.	Accuracy decreases with extreme image rotations; dependent on controlled imaging environments.
3	2019	Analyzing the Quality of Water and Predicting Suitability[6]	IoT-based prediction of water quality and its impact on fish farming, integrating real-time monitoring and effective prediction techniques.	High dependency on IoT infrastructure and limited adaptability to diverse aquaculture environments.

Table 2.2: Literature Review (Part 2).

Sr. No	Year	Paper	Methods	Limitations
4	2024	Charting the Aquaculture IoT Impact[1]	Highlights the role of IoT in water quality monitoring, feeding optimization, and fish health management in aquaculture.	Requires substantial infrastructure investment; sensor durability issues persist in aquatic environments
5	2022	Tracking Fish Behavior Using Computer Vision[2]	Used YOLO and neural networks to detect and analyze fish behaviors in different scenarios, achieving high accuracy.	Limited dataset diversity; computationally intensive.
6	2024	Smart Pond Water Quality Monitoring (Aquabot System)[3]	IoT-based system for real-time monitoring of water quality and fish farming recommendations, achieving high accuracy.	Setup costs, sensor corrosion, and dependency on consistent data transmission.

2.1 Review of Literature

This study consists of a conducted literature review of seven selected research papers about the application of IoT, machine vision and deep learning in aquaculture and fishery management. Published between 2000 and 2024, these studies present new methodologies for monitoring, analyzing and operationally enhancing the aquaculture system and the evaluation of fish behavior.

Using the techniques of a critical review, the current state of knowledge is summarized, main findings are pointed out and awareness of missing areas is expressed in the context of broader scope of smart aquaculture management.

As early as 2019, Paper 1 utilized an IoT approach to its fish disease recognition problem in aquaculture systems. Integrating machine vision techniques into aquaculture monitoring of health was also demonstrated in the study.

Similar to 2019, the estimates of fish length of Paper 2 were obtained using a machine vision system based on convolutional neural networks (CNNs). Under controlled conditions the method was found to be accurate, and the method is valuable for ecological research and fisheries management. However, the performance of the system declined when the images were analysed under rotation or in an uncontrolled environment, thereby preventing its practical deployment.

Paper 3 (2019) looked at the application of IoT systems to monitor the water quality and to predict if the water was suitable for fish farming. The real time monitoring was then effectively implemented, while the potential of IoT based solution in aquaculture was also shown. However, these presented challenges for broader application: a reliance on robust IoT infrastructure and a lack of flexibility to deal with lack of environmental conditions.

Paper 4, published in 2022, employs YOLO and neural networks to analyze fish behavior under various scenarios. The study achieves high precision in detecting fish behaviors like feeding and stress responses. However, the limited dataset diversity and high computational requirements restrict its scalability.

Paper 5, published in 2024, investigates the transformative impact of IoT in aquaculture. It highlights applications in water quality monitoring, feeding optimization, and fish health management. While the study underscores the potential for global aquaculture improvements, it also identifies significant challenges, including infrastructure costs and sensor durability.

Paper 6, also from 2024, introduces an IoT-based Aquabot system for smart pond water quality monitoring and fish farming recommendations. This system demonstrates high accuracy (94%) in real-time monitoring and predictive analytics. However, the initial setup cost, sensor corrosion, and dependency on consistent data transmission are notable limitations.

In conclusion, the synthesis of these papers underscores the transformative potential of IoT, machine vision, and deep learning in aquaculture and fisheries management. The studies demonstrate advancements in monitoring, analysis, and automation, but also highlight critical challenges, such as infrastructure requirements, cost-effectiveness, and scalability. This review contributes to a deeper understanding of the current landscape and offers insights for future research and development in smart aquaculture systems.

Chapter 3

Project Vision

The project vision based on this introduction is to develop an innovative and sustainable aquaculture system that ensures optimal growth, efficient resource utilization, and high productivity. By prioritizing water quality, species recommendation, and disease detection, the project aims to support global food security while promoting environmental sustainability and reducing dependency on wild fish stocks. This vision seeks to leverage technology and data-driven solutions for sustainable and efficient aquaculture practices.

3.1 Problem Statement

Aquaculture faces challenges such as suboptimal fish growth due to traditional methods, difficulties in choosing the right fish species, and resource wastage from poor water management. Inadequate disease detection tools increase the risk of outbreaks, which impacts fish health and overall productivity.

3.2 Business Opportunity

This Project has high business opportunities such as:

1. **Aquaculture Technology Solutions**: Develop IoT based monitoring system, auto-

mated feed tools and movement monitoring.

2. **Sustainable Practices**: Provide consulting for eco friendly aquaculture, species indicate that these recommendations can also be used as breeding stock and to enhance recommendation services.

3. **Market Expansion**: Market Expansion by supplying sustainably farmed seafood to global markets, as is well as partnering with retail and B2B channels..

4. **Education and Training**:Avenues to offer such workshops certifications of digital courses for aquaculture professionals.

5. **Carbon Credits & ESG**: If businesses reduce their carbon footprints, lower their carbon footprints, and contribute to Environmental Social and Governance (ESG), they will be able to showcase and appeal to environmentally conscious investors.

Particularly, these opportunities serve the increasing seafood demand, help sustainable practices, and smart farming technologies to achieve both profitability and environmental impact. The demand for seafood, environmental impact, and environmentally sound practices have opened up these opportunities, ensuring that the ventures are profitable and sustainable.

3.3 Objectives

This will be a project to develop an advanced aquaculture system that incorporates a provide fish type classification model, size and growth monitoring, behavior tracking. It can be used to improve fish farming practices through detection. These modules are to be integrated with existing systems and sensors to develop an effective solution that helps guarantee survival and productivity of fish. Real-time alerts and a user-we will develop a friendly web/app interface for user monitoring of fish conditions, and to notifications, and take timely actions.

3.4 Project Scope

The goal of the project is to revolutionize aquaculture by bringing together the best of new technologies, green and sustainable, efficient and scalable. The scope of the project includes:

3.4.1 Water Quality Monitoring:

IoT based sensors for real time monitoring of water parameter like pH and temperature, turbidity, and dissolved oxygen.
Predictive analytics to find and deal with issues with potential water quality.

3.4.2 Species Recommendation

Recommend fish species for sale that take advantage of water conditions and customers' demands.
Enable farmers to optimize production by species with high growth rates.

3.4.3 Growth Optimization

Ensure automation of feeding systems to get the most out of feed usage, minimize waste, and encourage for healthy fish growth.
Monitor fish growth and use AI to adapt fish farming practice.

3.4.4 Size Measurement

Machine vision and image processing technique can be used to precisely measure fish size in real time.

3.4.5 Sustainability

In support of sustainable,A means to increase productivity using less and damaging environment. Diminish resource wastage and promote eco friendly aquaculture.
A means to increase productivity using less and damaging environment.

3.4.6 Efficient Resource Utilization

Provide solar powered systems for the IoT devices in order to integrate energy efficient solutions.
Use data based decision making to fully utilize resource and maximization of profitability.

3.4.7 Scalability and Accessibility

Make design systems applicable to varying farm sizes and area.
This includes ensuring that small to large scale fish farmers can afford and find them easy to use.

Consequently, the project seeks to improve productivity, profitability, and create a sustainable aquaculture model in order to meet the increasing demands in the global market for seafood.

3.5 Constraints

3.5.1 Technological Limitations

High setup costs and sensor durability issues in aquatic environments.
Connectivity challenges in remote areas affecting real-time data transmission.

3.5.2 Environmental Factors

Water quality variability due to pollution and climate change.

Potential ecological impacts of intensive aquaculture.

3.5.3 Scalability

Adapting technology for small-scale farms and diverse geographic locations. Operational Costs

Recurring expenses for maintenance and dependence on skilled labor.

3.5.4 Data Accuracy

Risk of sensor errors and challenges in ensuring reliable real-time analytics.

3.5.5 Regulations

Compliance with environmental laws and ethical considerations in farming.

3.6 Stakeholders Description

3.6.1 Stakeholders Summary

The primary stakeholders for this aquaculture project include:

- **Fish Farmers**: Individuals and organizations managing aquaculture operations, seeking improved productivity and reduced costs.
- **Technology Providers**: Companies offering IoT devices, sensors, and software solutions to enhance aquaculture efficiency.
- **Regulatory Bodies**: Government and environmental agencies ensuring compliance with regulations and promoting sustainability.

- **Investors**: Individuals or institutions funding aquaculture technology development and deployment.
- **End Consumers**: Customers demanding sustainably sourced, high-quality seafood.

3.6.2 3.6.2 Key High-Level Goals and Problems of Stakeholders

- **Fish Farmers**
  - **Goals**: Maximize yield, reduce costs, and ensure fish health.
  - **Problems**: High setup costs, lack of technical expertise, and risks of disease or poor water quality.
- **Technology Providers**
  - **Goals**: Deliver innovative, scalable, and affordable solutions.
  - **Problems**: Sensor durability, connectivity issues, and limited adoption by small-scale farmers.
- **Regulatory Bodies**
  - **Goals**: Ensure environmental sustainability and compliance with farming standards.
  - **Problems**: Limited monitoring resources and enforcement capabilities.
- **Investors**
  - **Goals**: Achieve returns on investments through scalable solutions.
  - **Problems**: High initial costs and market adoption risks.
- **End Consumers**
  - **Goals**: Access high-quality, sustainably sourced seafood.
  - **Problems**: Lack of transparency about sourcing and sustainability practices.

Chapter 4

Software Requirements Specifications

This chapter will have the functional and non functional requirements of the project.

4.1 List of Features

- Real-time water quality monitoring.
- Automated species recommendation.
- Growth tracking and size measurement.
- Resource optimization through IoT-based solutions.
- User-friendly dashboards for data visualization.

4.2 Functional Requirements

- The system must monitor water parameters like pH, temperature, and turbidity in real time.
- Provide automated fish species recommendations based on water quality.
- Measure and track fish growth using machine vision techniques.

- Generate actionable alerts for suboptimal conditions.
- Offer an intuitive web and mobile interface for users.

4.3 Quality Attributes

- **Reliability**: Ensure continuous operation with minimal downtime.
- **Scalability**: Support farms of various sizes.
- **Accuracy**: Deliver precise measurements and recommendations.
- **Usability**: Maintain a user-friendly interface for non-technical users.
- **Efficiency**: Optimize resource usage, minimizing waste and energy consumption.

4.4 Non-Functional Requirements

- The system must operate on low power consumption.
- Ensure compatibility with common IoT devices and sensors.
- Provide data security through encryption.
- Maintain response time within 2 seconds for real-time alerts.
- Support at least 500 concurrent users.

4.5 Use Cases/ Use Case Diagram

1. **View Information**
    - **Actors**: User
    - **Description**: Allows users to access fish health, water parameters, and movement data.

- **Extensions**: Includes ‘Check Fish Disease‘.

2. **Check Fish Disease**

    - **Actors**: User
    - **Description**: Checks for fish diseases using captured data from ‘Disease Detection‘.

3. **Capture Images**

    - **Actors**: Camera
    - **Description**: Captures images for ‘Fish Size Monitor‘ and ‘Disease Detection‘.

4. **Fish Size Monitor**

    - **Actors**: Camera
    - **Description**: Measures fish size using image data to monitor growth.

5. **Capture Videos**

    - **Actors**: Camera
    - **Description**: Captures videos for ‘Fish Movement Monitoring‘ and ‘Capture Parameters‘.

6. **Fish Movement Monitoring**

    - **Actors**: Camera, User
    - **Description**: Tracks fish movement and behavior using video data.

7. **Capture Parameters**

    - **Actors**: Sensors
    - **Description**: Collects water data (pH, temperature, turbidity) for analysis.

8. **Fish Species Recommendation**

    - **Actors**: Sensors, User

- **Description**: Recommends fish species based on water quality parameters.

9. **Water Monitoring**

- **Actors**: Sensors
- **Description**: Monitors water quality and raises alerts for deviations.

4.5.1 Use Case Diagram

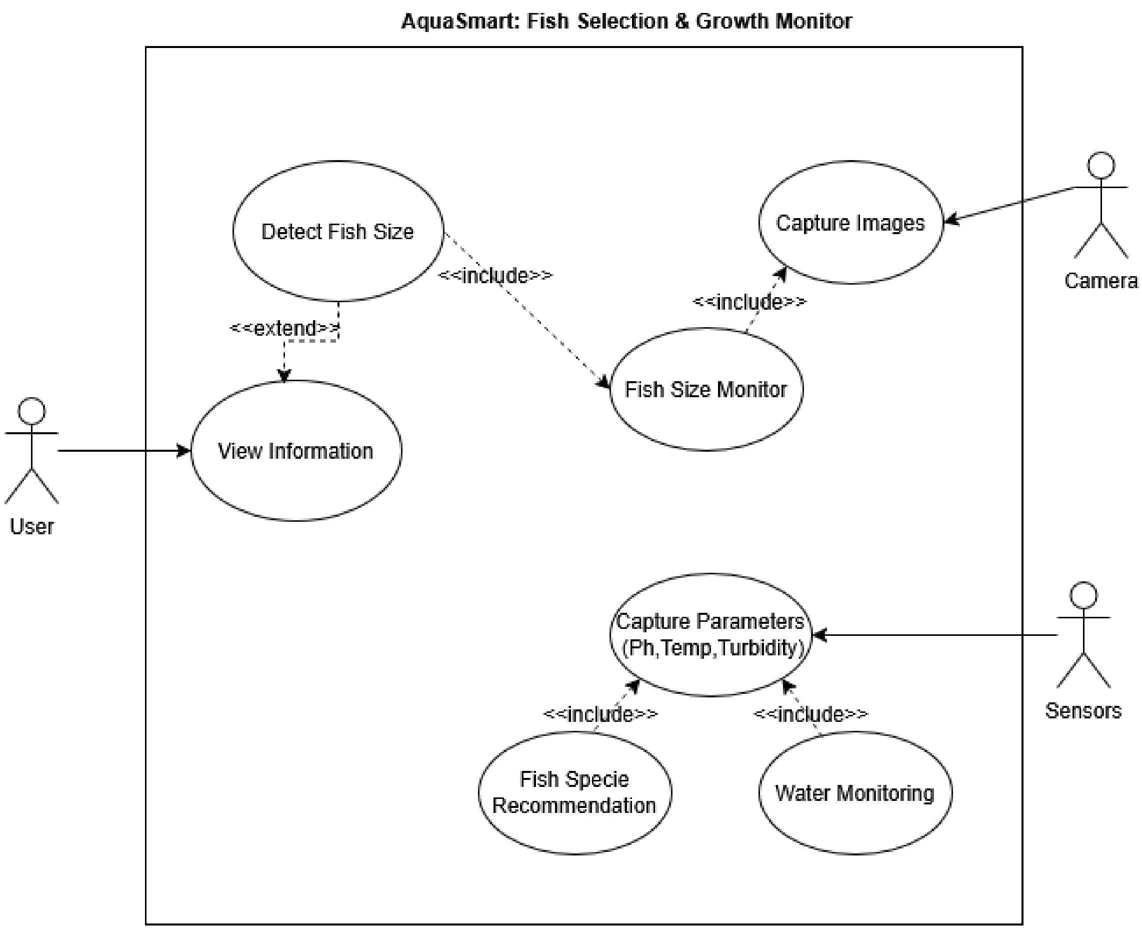


Figure 4.1: Architecture Diagram

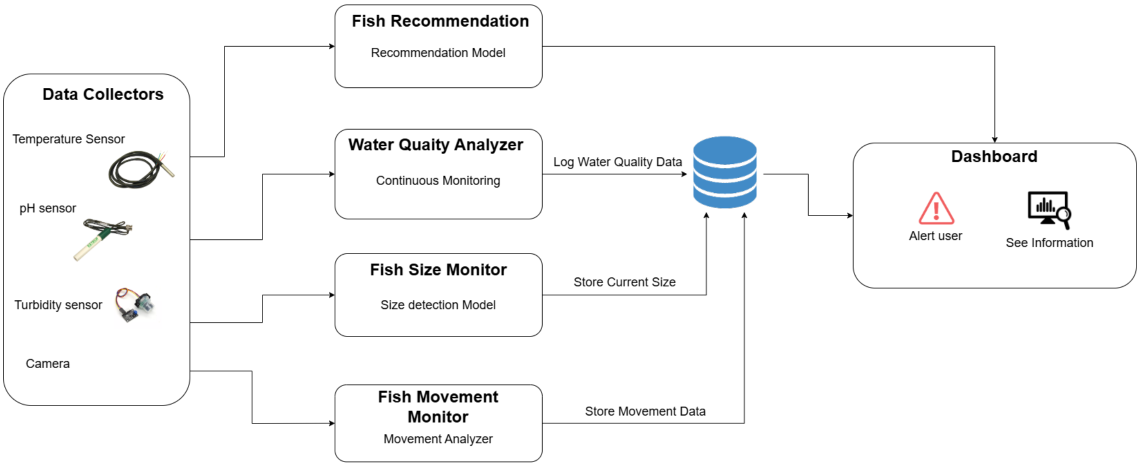


Figure 4.2: Architecture Diagram

4.6 Architecture Diagram

4.7 UI Screens

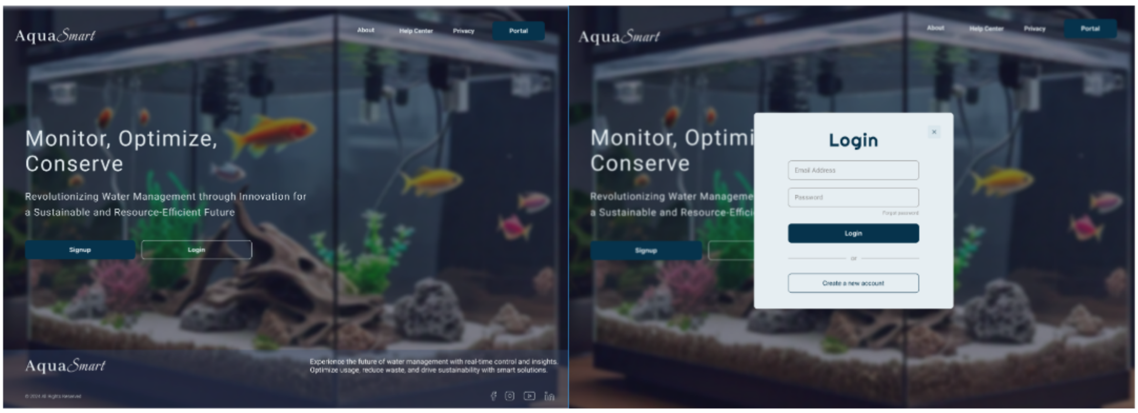


Figure 4.3: Login Page

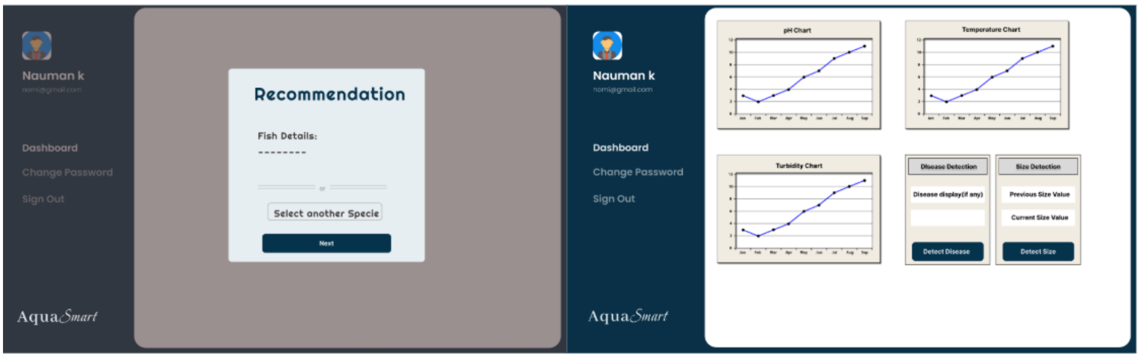


Figure 4.4: Dashboard

Chapter 5

Iteration Plan

5.1 Planning Strategy

Planning Strategy for our project will be as:

5.1.1 FYP 1 Mid:

- Literature review related to fish monitoring systems and recommendation techniques
- Initial dataset collection and pre-processing
- Designed use-case, system diagram

5.1.2 FYP 1 Final:

- Dataset creation and annotation for fish detection
- Trained YOLO-based model for fish detection
- Integrated fish size measurement module
- Initial design and development of website for data visualization

- Delivered demo for detection and measurement system

5.1.3 FYP 2 Mid:

- Integration of recommendation with detection system
- Continued website development for displaying results and analytics
- Started development of IoT device for real-time monitoring
- Testing of detection and recommendation pipeline

5.1.4 FYP 2 Final:

- Complete IoT device integration
- Movement monitoring module implementation
- Final website integration and polishing
- Final testing and debugging
- Final system demonstration

Chapter 6

Iteration 1(FYP 1 MIDS)

Our Final Year Project started with the laying of a good foundation for a smart and sustainable aquaculture system. In this phase our goal was primarily to understand the theoretical and technical aspects of fish farming automation. It is consisted of extensive literature reviews on fish monitoring technologies, intelligent recommendation systems and water quality analysis methods.

In addition to this, we began collecting and pre-processing relevant datasets in order to support the fish detection model, as well as by designing the system architecture and related use case diagrams.

6.1 Literature Review

In this thesis, I had reviewed literature on the existing smart aquaculture system, fish detection with computer vision, and recommendation system for aquaculture management. Key topics explored include:
Sensor-based monitoring of pH,temperature, and turbidity.
Object detection in aquaculture using the YOLO (You Only Look Once) models.
Water-quality-based fish type selection methods.
AI based fish growth optimization and the optimal, sustainable aquaculture practices.

This review guided how we undertook current challenges and technologies, and how our project design.

6.2 Design Diagram

Use case diagram

Architecture Diagram

Activity Diagram

6.3 Use case Diagram

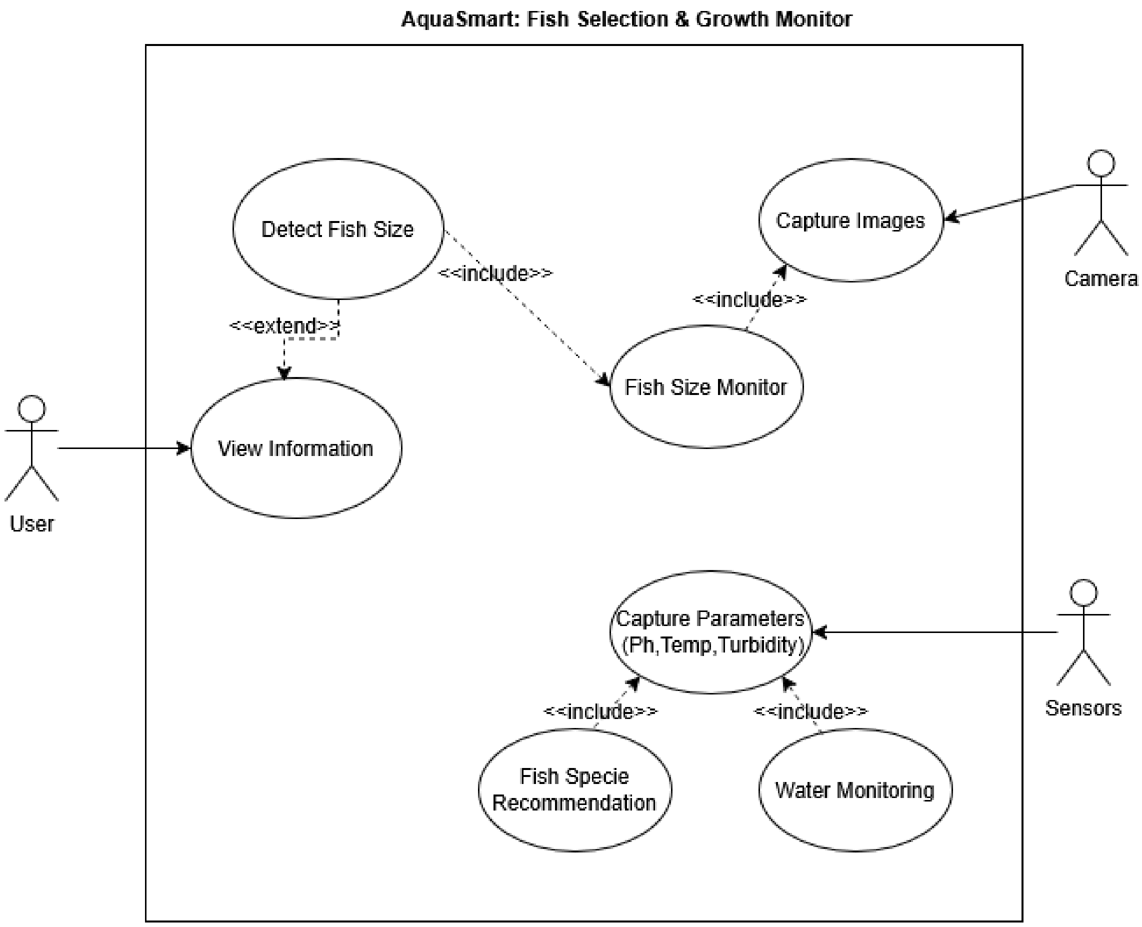


Figure 6.1: Architecture Diagram

6.4 Architecture Diagram

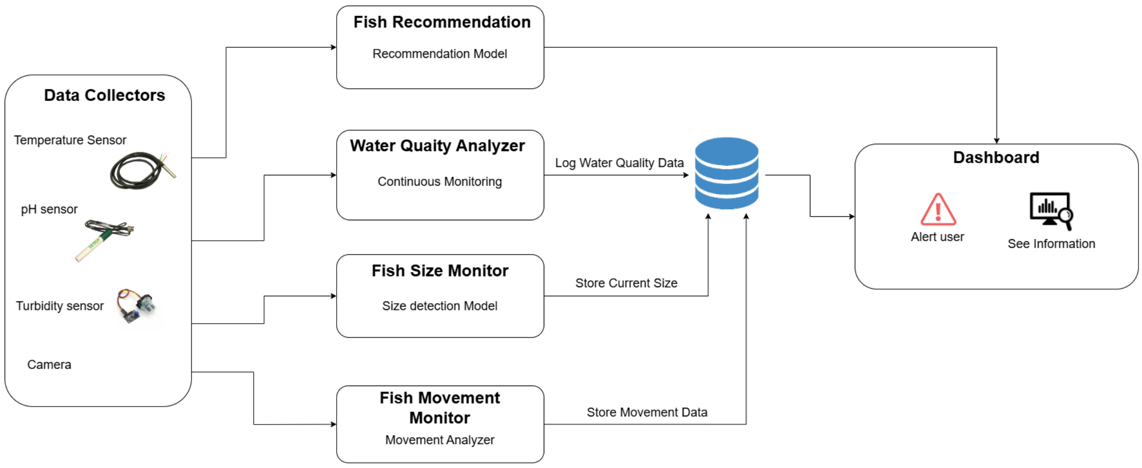


Figure 6.2: Architecture Diagram

Chapter 7

Iteration 2(FYP 1 Final)

Our First Iteration in our Final Year Project was aiming on building the foundation for building a smart and sustainable fish farming system. The purpose of this phase was to learn and build the core parts to be eventually incorporated into a solution for real time aquaculture monitoring and recommendation. It was divided into 3 main modules in this iteration.

The creation of Fish Dataset Of Object Detection.

Recommendation System Planning

Collection and Initial Testing of IoT Devices

One module focused at a particular core function of the project while making a huge design and development pathway towards the final system.

7.1 The creation of Fish Dataset Of Object Detection.

An important aspect of going through this process was compiling a robust dataset for training the YOLOv12n fish detection model. The steps done in this phase are:

Data was collected from public datasets as well as from youtube videos and aquarium.

I labelled fish objects through Data Annotation with LabelImg that included training bounding boxes in XML format.

Image Augmention (rotation, flipping, brightness adjustment), resized to YOLO compatibility.

Divide dataset into training(70%), validation(20%), and test(10%) folders for the sake of the model pipeline.

In the next iteration, the fish detection will be built and evaluated on this dataset.

7.2 Recommendation System Planing

We designed the recommendation system to recommend the best fish species according to the present water condition. During this iteration:

Water Quality Parameters Selected: pH level, temperature, and turbidity.

Ideal environmental ranges of fish like Tilapia, Catla, Rohu and Pangasius are compiled to define fish species criteria.

Described how the system will communicate with the sensor data and show recommendations to the web interface.

Intelligent decision making is introduced to the aquaculture setup which is adaptive and environment aware.

7.3 Collection and Initial Testing of IoT Devices

For the purpose of real time water quality monitoring, we identified and procured the needed hardware components. In this phase:

Devices Collected:

7.3.1 PH sensors

By measuring acidity/alkalinity of water, pH Sensor is for it.

Figure 7.1: Ph sensor

7.3.2 Temperature Sensor (DS18B20)

To measure the water temperature.

Figure 7.2: Temperature Sensor (DS18B20)

7.3.3 ESP-32-CAM

The ESP32-CAM is used for capturing images of the fish as input to the detection model. Initial Testing: This was to test the data accuracy individually and confirm the data connectivity using Arduino UNO for devices,

Data Flow Planning: Began the process of designing the process by which sensor data

Figure 7.3: ESP-32-CAM

will be collected, transmitted and stored in the database.

The next iteration will incorporate these sensors and modules to form a complete monitoring system based on IoT.

7.4 Turbidity Sensor

Turbidity sensors measure the clarity of water by detecting the amount of suspended particles. Higher turbidity levels may indicate poor water quality, excessive waste, or overfeeding all of which can negatively impact fish health.

Figure 7.4: Turbidity sensors

Chapter 8

Iteration 3

The third iteration of the project was the development and partial integration of the major components in the system. The implementation of the fish size measuring module was done, development of the recommendation model done, creation of the website done and integration of sensor data with the website for real time monitoring. It acts as a shift from theory design to real functional development.

8.1 Fish Size Measuring Module

We then implemented an image processing technique which calculate an Approximate Size of detected fish from the images captured by the ESP32-CAM.

Steps Performed: The fish is detected by YOLOv11 and it returns bounding box coordinates of fish.

We measure the length of the fish in centimeters through setting a reference scale (e.g. a known object in the tank or a fixed pixel-to-cm ratio).

The data is stored in the database and a measured size for Fish ID along with timestamp.

This module tells us how fast the fish grows in time and is shown on the dashboard.

8.1.1 Code

```
import cv2
import numpy as np
from ultralytics import YOLO

def load_model(model_path):
    """ Load the trained YOLO model using the latest Ultralytics YOLO class """
    model = YOLO(model_path)
    return model

def get_image_size(image_path):
    """ Get the dimensions (width, height) of an image """
    img = cv2.imread(image_path)
    h, w, _ = img.shape
    return w, h

def detect_fish(model, image_path):
    """ Detect fish using YOLO model and return bounding boxes """
    results = model(image_path)  # Run YOLO detection
    detections = []
    for result in results:
        for box in result.boxes.xyxy:
            x, y, x2, y2 = map(int, box[:4])
            w, h = x2 - x, y2 - y
            detections.append((x, y, w, h))
    return detections

def extract_and_stack_fish(image_path, detections):
    """
    Extracts detected fish from the image and places all at (0,0).
    """
    img = cv2.imread(image_path)
    stacked_img = np.zeros_like(img)  # Create a blank image

    for (x, y, w, h) in detections:
        fish_crop = img[y:y+h, x:x+w]  # Crop the detected fish
        stacked_img[0:h, 0:w] = fish_crop  # Place fish at (0,0)

    return stacked_img
```

Figure 8.1: Size measuring code

```
def find_first_non_zero_pixel_y(image_path):
    """Finds the first row (y-axis) where any pixel value is non-zero."""
    img = cv2.imread(image_path, cv2.IMREAD_GRAYSCALE)  # Convert to grayscale
    h, w = img.shape

    for y in range(h):
        if np.any(img[y, :] > 0):  # Check if any pixel in the row is non-zero
            return y  # Return the y-coordinate of the first non-zero pixel
    return None

def calculate_fish_size_esp32cam(image_width, image_height, first_non_zero_y):
    """Calculate the fish size in real-world units based on ESP32-CAM parameters."""
    FOCAL_LENGTH = 3.6  # mm (ESP32-CAM OV2640 lens)
    SENSOR_WIDTH = 3.6  # mm (ESP32-CAM OV2640 sensor width)
    OBJECT_DISTANCE = 304.8  # mm (1 foot distance)

    pixel_size = SENSOR_WIDTH / image_width  # Approximate pixel size in mm
    fish_pixel_height = image_height - first_non_zero_y  # Fish height in pixels
    fish_real_height = (fish_pixel_height * pixel_size * OBJECT_DISTANCE) / FOCAL_LENGTH
    return fish_real_height  # Fish size in mm


model_path = "fish_detector12nadd300.pt"  # Path to your trained YOLO model
image_path = "f.jpg"
model = load_model(model_path)
image_width, image_height = 640, 480 # Assuming image is 1600x1200
detections = detect_fish(model, image_path)
stacked_image = extract_and_stack_fish(image_path, detections)
stacked_image_path = "stacked_fish.jpg"
cv2.imwrite(stacked_image_path, stacked_image)

first_non_zero_y = find_first_non_zero_pixel_y(stacked_image_path)
print("First non-zero pixel row at Y-axis:", first_non_zero_y)

if first_non_zero_y is not None:
    fish_size_mm = calculate_fish_size_esp32cam(image_width, image_height, first_non_zero_y)
    print("Estimated Fish Size (mm) using ESP32-CAM:", fish_size_mm)
```

Figure 8.2: Size measuring code

8.1.2 Expected Results

First of all , detect the fish with help of frames captured by esp-32 cam.

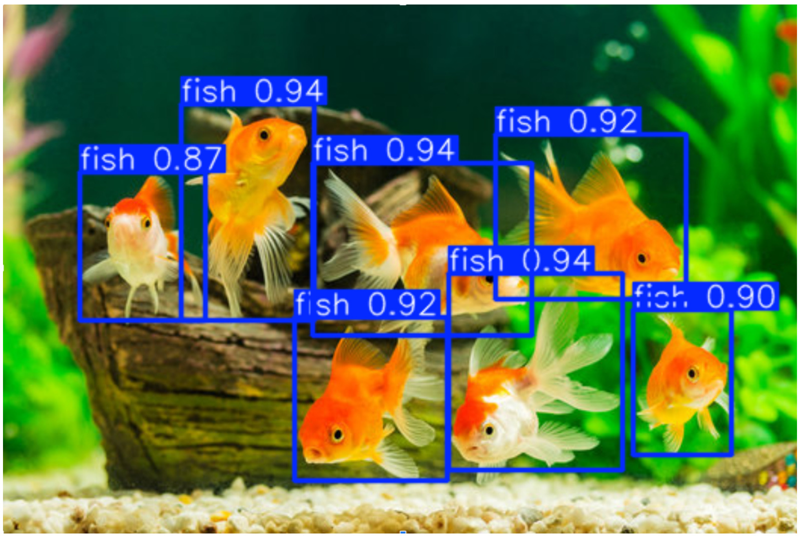


Figure 8.3: Fish Detection

. Second, we detect the largest fish in that image.

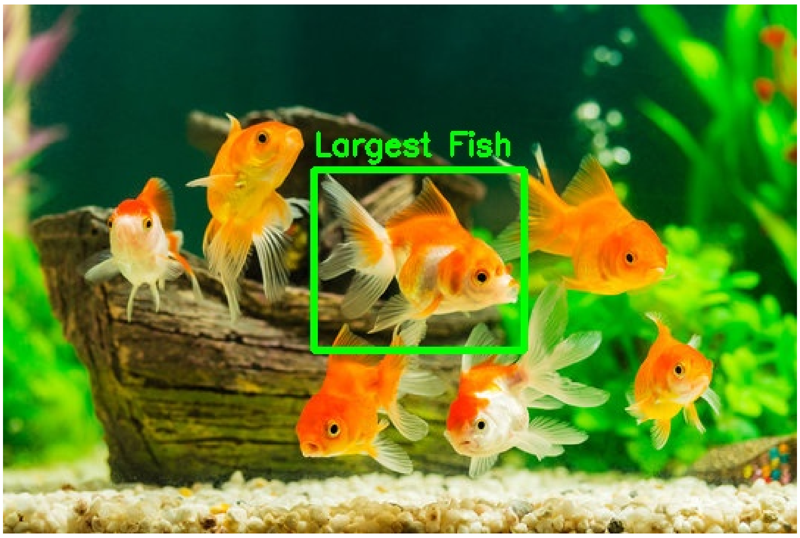


Figure 8.4: Largest Fish Detection

. Then, the image was stacked and place it to the top corner of the blank image.

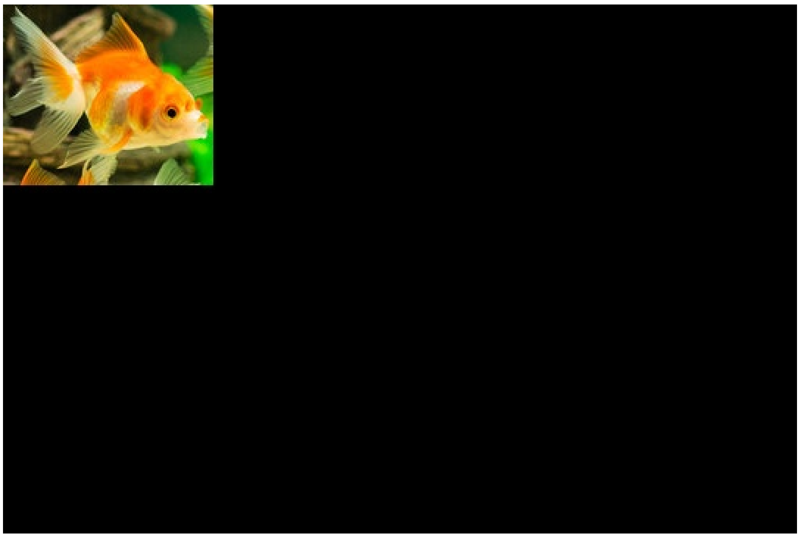


Figure 8.5: Stack image

8.2 Recommendation Model Implementation

Three main parameters were considered for the building of the recommendation engine and it was built on top of a rule based logic system.

pH level

Temperature

Turbidity

How It Works: Real-time sensor data is fetched.

It is compared with ideal environmental conditions for particular fish species.

The system outputs the most suitable fish type(s) for the current environment.

This model is Python based script running in the backend and updating recommendation section of the website dashboard in real time.

8.3 Website Development

For Backend services i.e. how it will communicate with the database, we used Firebase and build that using HTML, CSS and JavaScript.

Features Implemented: Real-time display of pH, temperature, and turbidity data.

Dashboard for fish detection results.

Use historical fish size data to generate growth tracking chart.

Recommendation display of the most suitable fish to create in accordance with the current conditions.

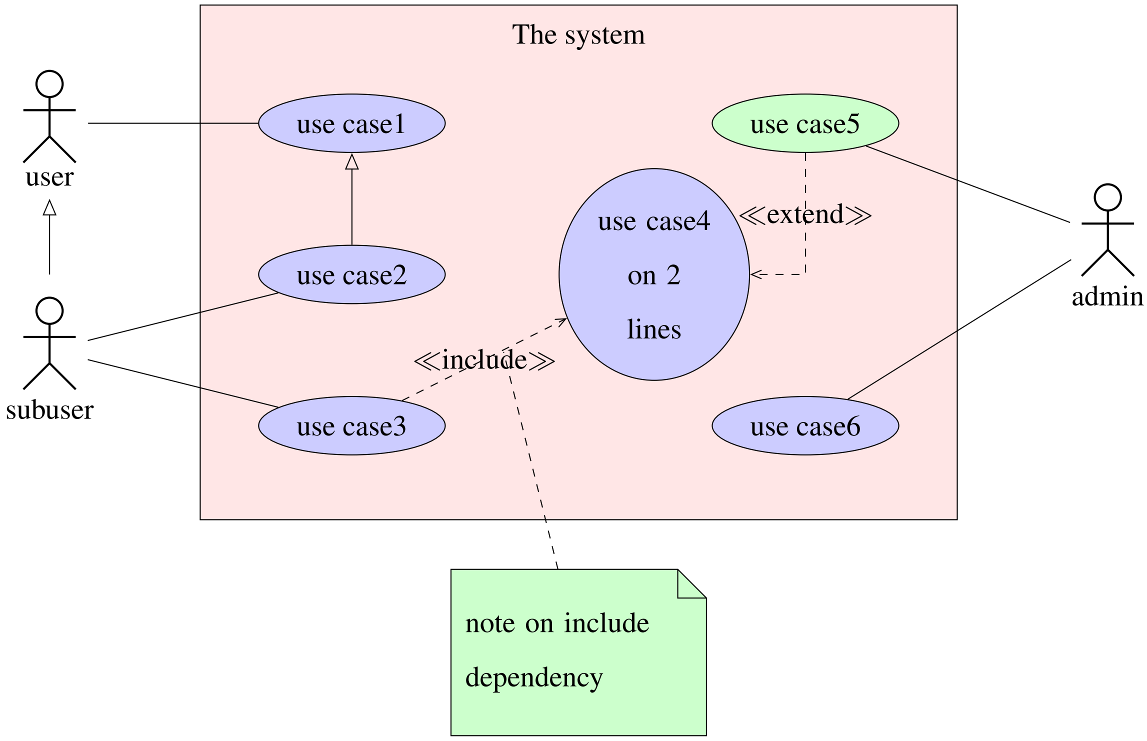
8.4 Sensor Integration with Website

The hardware module (the sensors) was integrated with the website successfully enough to allow live monitoring.
Firebase Realtime Database receives upload from uploaded sensor data in NodeMCU/ESP32.
JavaScript reads this data from the website and auto updates the dashboard.
There is a Threshold values where the notification triggers.
With this integration, the physical tank was linked with the user interface seamlessly.

Chapter 9

Iteration 4

The first iteration is expected to be completed by the final of the FYP-2. This chapter will have some of the artifacts based on system design. The requirements analysis section is same for all the systems while the design may vary. There may have two types of designs the structural design or . First section is for the structural design.



Chapter 10

Implementation Details

10.1 Introduction

The implementation of the individual modules, namely sensors for water quality monitoring, fish detection using computer vision and web based interface in the implementation phase of our final year project formed a complete smart aquaculture system. The objective was to provide real-time monitoring capabilities for fish and fish environmental parameters to support intelligent recommendations on fish type selection as well as growth optimization. This chapter tells how the system was connected and deployed, all hardware and software components, and how it tested to be functional.

10.2 Sensor Integration and Real-Time Data Collection

The following sensors were integrated with Arduino UNO and NodeMCU microcontroller.

pH Sensor: Captures real-time pH levels of the water.

Temperature Sensor (DS18B20): Monitors the water temperature with waterproof accuracy.

Turbidity Sensor: Measures water clarity, an indicator of water quality and cleanliness.

In order to access the sensor data, the data was read at regular intervals and each sensor was connected to the Arduino. Wi-Fi connectivity was made possible using the NodeMCU (ESP32 cam) and data was transmitted to a Firebase Realtime Database in real time.

10.3 ESP32-CAM Integration for Fish Detection

A configuration was created on the ESP32-CAM module to periodically capture fish images. Then these images would be stored locally or sent to a server to be processed. YOLOv11 model was used for the detection purposes, it was trained using a custom fish dataset which was made and annotated earlier.
Steps involved:
Capturing image using ESP32-CAM.
Invoking a Python-based Flask API for inference by sending image.
The fish is detected and classified by YOLOv12n in the image.
The outputs are the fish type and estimated size. The recommendation logic had the same detection output stored in the same database which was synchronized with the water quality data.

10.4 Recommendation System Integration

In this work, we implemented a rule based recommendation system in Python. It will fetch real time sensor data and make recommendation of fish of type which is best suited for the given water conditions.

10.5 Website and Dashboard Development

In this project, we have built a responsive web dashboard using HTML, CSS, JavaScript and Firebase to visualize the real time data. Key features include:

Live Sensor Readings (pH, temperature, turbidity)

Bounding boxes and species name on which the fish detection has been performed.

Based on the water parameters the Recommended Fish Type is.

They provide for growth tracking via fish size estimation history.

To enable seamless flow of data between IoT devices, detection modules and front-end, Firebase was used both for authentication and as backend database.

10.6 Complete Workflow

The data and images are sent onto a backend system.

YOLOv12n detects fish and estimates size.

Based on the data processed, the machine puts forward the best possible fish types.

Live results are displayed in web dashboard to be viewed by the end users.

10.7 Fish Movement Monitoring Module

In addition to water quality monitoring and fish detection, a fish movement module was developed to analyze fish activity and detect abnormal behavior. Water quality monitoring and fish detection as well as a fish movement module was developed to determine fish activity and detect un natural behavior.

Working Mechanism: The ESP32-CAM captures video frames periodically.

Consecutive frames are compared in consecutive frames using OpenCV in Python through frame differencing.

The system is set to record if fish are active or if they are inactive, and the later information is then used an indirect indicator of fish health and stress.

Output: A movement score (e.g., percentage of active pixels).

Desks it to alert if fish movement falls beneath a normal threshold.

It allows farmers to dispatch fish health when it is abnormal, but not during passive monitoring of fish health.

10.8 Final Testing and Deployment

Then, full integration was performed and the system was deployed in a small-scale fish tank environment. Tests included:

Accuracy of sensor readings.

YOLOv12n fish detection performance.

Recommendation consistency with environmental changes.

Real-time responsiveness of website UI.

The system was demonstrated live on the FYP final presentation when all components were successfully validated.

Chapter 11

User Manual

The chapter presents a usable approach for users to engage with the smart aquaculture system. The chapter details how users who mostly include fish farmers together with system operators can access the system while providing monitoring features and utilization methods.

11.1 Accessing the Dashboard

Open the system's dashboard URL within your web browser.
Follow the authentication process using your registered email combined with your password through the Firebase system.
When login is successful you will reach the main dashboard page.

11.2 Monitoring Water Quality Parameters

One will find live sensor data presented on the dashboard homepage through real-time updates.
pH level
Water Temperature
Turbidity (clarity level)

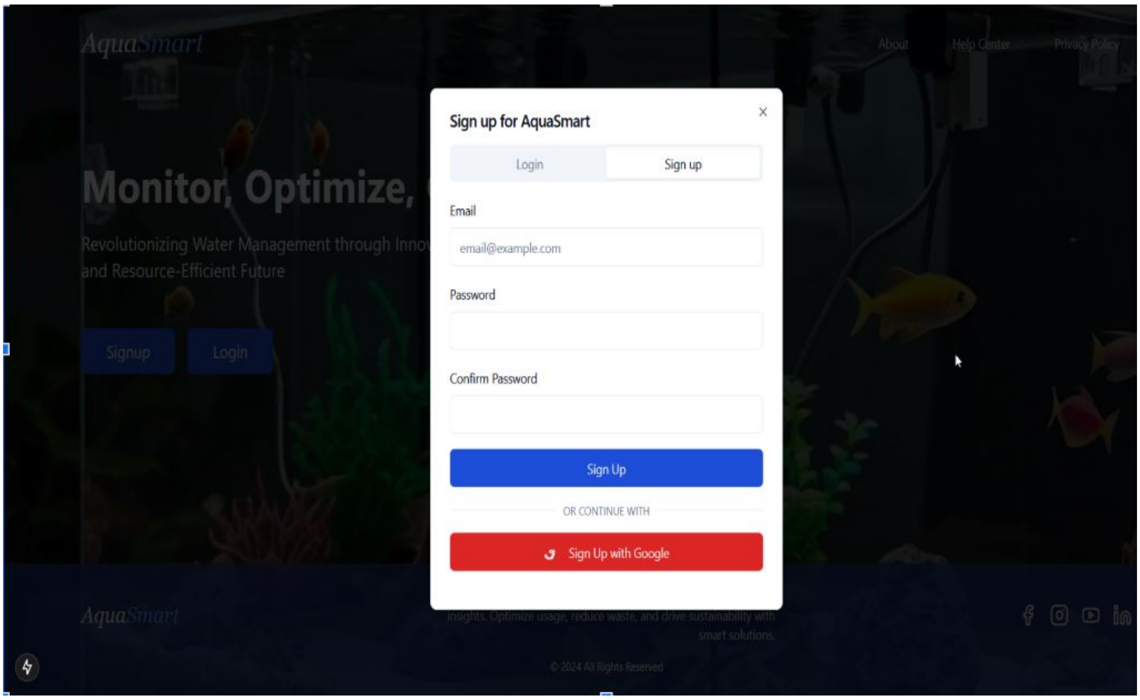


Figure 11.1: Login page

The connected sensors refresh the displayed values at regular intervals of few seconds.

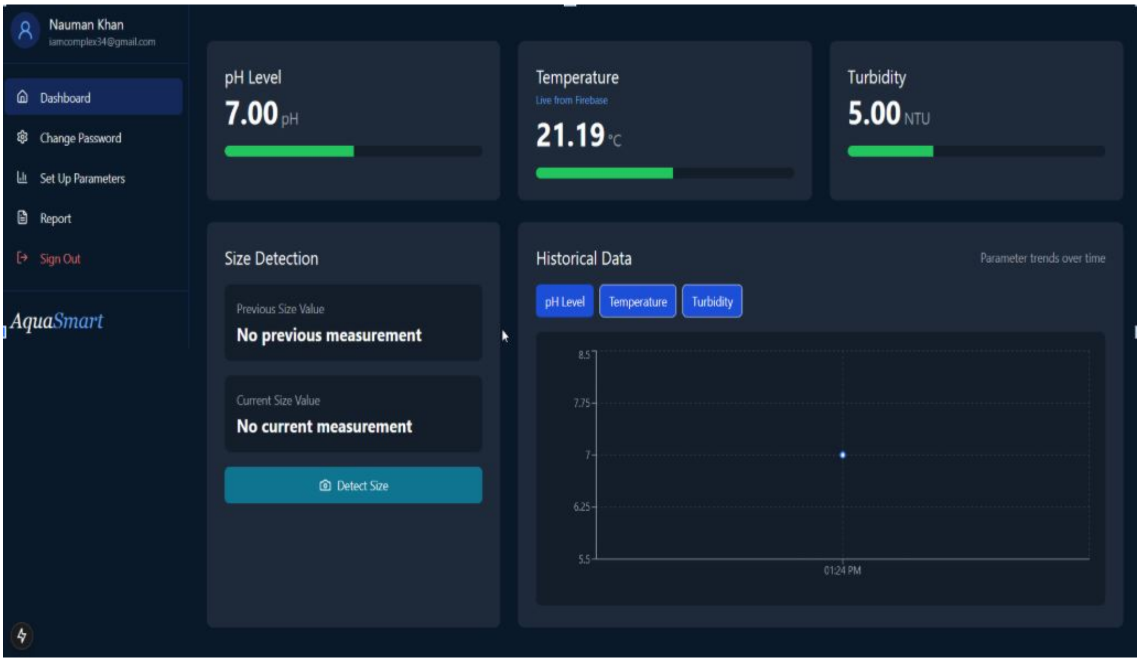


Figure 11.2: Water quality Viewer

11.3 Viewing Fish Detection and Size

Fish Monitoring tab presents the size of largest fish from newest image recording from the ESP32-CAM camera.

The bird boxes enclose detected fish while the labels display:

Estimated size (in cm)

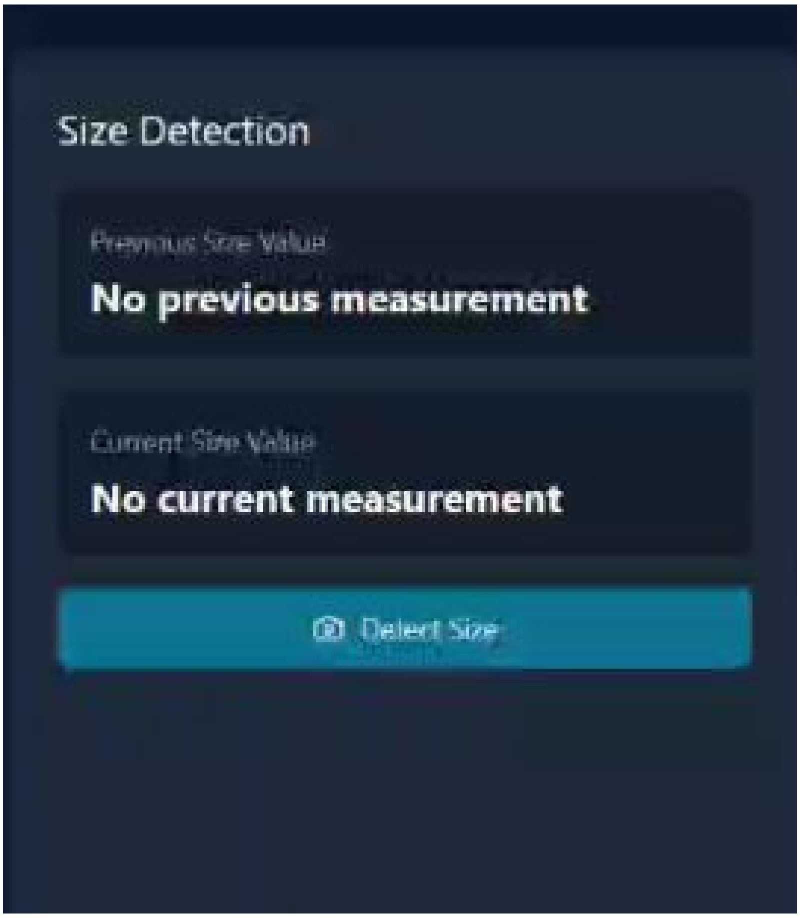


Figure 11.3: Size

11.4 Checking Fish Type Recommendations

Live water quality data determines which fish species appear in the Recommendation tab for selection.

The system creates this labeling through a rule-based method which uses sensor readings to compare against optimal ranges for various fish species.

A record of previously made recommendations can be viewed through the system.

11.5 Fish Movement Monitoring

Open the Movement Monitoring tab to view:

A list of all detected Fish IDs.

Total Movement Time (in minutes) for each fish throughout the day.

A real-time graph showing activity levels over time.

Inactivity Alerts will appear if a fish's total movement drops below a safe threshold.

11.6 Additional Features

This module displays visual representations of live fish size measurements throughout time periods.

The user interface includes a manual entry system that allows the logging of observations.

The system will send alerts for cases where pH or temperature exceeds safe parameters.

11.7 Notifications and Alerts

Alerts pop up if:

pH, temperature, or turbidity exceed safe ranges.

A fish is inactive for an unusual amount of time.

Chapter 12

Conclusions and Future Work

12.1 Conclusions

Aside from sensor-based water monitoring, YOLO based detection and fish type recommendation, the project also involved fish movement tracking using image processing. This module helps to enrich the analysis of fish health and signals of environmental stress or health issues early on by tracking behavioral patterns.
The system is the smart aquaculture solution consisting of the four modules:
Water Quality Monitoring
Fish Detection & Size Estimation
Fish Type Recommendation
Fish Movement Monitoring

12.2 Future Work

Additional improvements can include:
Movement Classification Based on trained ML model to classify (normal, stressed, aggressive) fish behavior.
Movement and visual cue: Combine movement and visual cues to detect possible first symptoms of disease.

Low Activity: Be notified automatically, and optionally, take environment action (e.g. aeration).

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