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Disease Detection and monitoring of aquatic lives in smart aqua culture

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Abstract—

The increasing demand for seafood has made aquaculture a vital industry, but challenges such as disease outbreaks, water quality fluctuations, and inefficient feeding remain significant concerns. This paper introduces an advanced monitoring and disease detection system for aquatic life using Internet of Things (IoT) technology and machine learning. The system integrates IoT-based sensors to continuously track essential water parameters, including temperature, pH, turbidity, and dissolved oxygen, ensuring a stable aquatic environment. A machine learning model, specifically utilizing Convolutional Neural Networks (CNNs), is implemented for early disease identification, allowing timely interventions to prevent widespread infections. Additionally, an automated feeding mechanism optimizes food distribution, reducing waste and enhancing fish health. Real-time data analysis and remote access capabilities further improve decision-making and operational efficiency. This approach enhances aquaculture sustainability by minimizing environmental impact, improving productivity, and supporting economic growth.

I. INTRODUCTION

Ring Aquaculture, the practice of cultivating aquatic organisms such as fish, crustaceans, and mollusc's, has emerged as a key contributor to global food production. As the demand for seafood continues to rise, sustainable aquaculture practices are essential to ensure food security while minimizing environmental impact. However, the success of aquaculture depends on effectively managing various challenges, including disease outbreaks, water quality fluctuations, and feeding efficiency. Unchecked diseases can spread rapidly, leading to significant economic losses and environmental concerns.

With advancements in technology, modern aquaculture systems are integrating Internet of Things (IoT) devices, artificial intelligence (AI), and machine learning to enhance monitoring and control. IoT sensors provide real-time data on essential water parameters such as temperature, pH levels, dissolved oxygen, and turbidity. Machine learning algorithms further improve disease detection by analysing patterns and predicting outbreaks, allowing for timely intervention. Automated feeding systems optimize nutrition while reducing waste, contributing to better fish health and overall efficiency.

Disease detection is one of the primary concerns in aquaculture. Traditional methods rely on manual inspection and laboratory testing, which are time-consuming and often fail to identify early-stage infections. AI-powered image recognition and sensor-based monitoring has revolutionized disease detection, enabling quick and accurate identification of illnesses before they spread. These technological innovations contribute to a more sustainable and profitable aquaculture industry by improving fish health, reducing mortality rates, and ensuring optimal resource utilization.

This research explores the role of IoT and machine learning in smart aquaculture systems, focusing on disease detection, water quality monitoring, and automated feeding solutions. By leveraging these technologies, aquaculture operations can enhance efficiency, minimize losses, and promote sustainable seafood production for the future.

II. LITERATURE SURVEY

Fish Disease Detection

Fish disease detection has been a focal point of research due to its critical role in maintaining aquaculture sustainability. Several studies have explored machine learning and deep learning models for detecting fish diseases with high accuracy. One study utilized a Convolutional Neural Network (CNN) model to classify fish into three categories: **white spot, red spot, and healthy fish**, achieving an accuracy of **94.44%**. Another research employed the **Random Forest** algorithm for disease classification, distinguishing between **EUS, fin and tail rot, and healthy fish**, with an accuracy of **88.87%**.

Further advancements include the application of **Support Vector Machines (SVM)** in fish disease classification. Researchers compiled a dataset of **266 images**, which was later expanded through data augmentation, leading to **1,105 training images** and **221 test images**. The SVM model demonstrated an accuracy of **91.42% without augmentation** and **94.12% with augmentation**, showcasing the effectiveness of machine learning in improving disease detection.

Smart Pet Care System Using IoT

A study on smart pet care systems aligned closely with the objectives of smart aquaculture. This research introduced an **automated feeding system** that dispensed food based on preset schedules. However, the system had a drawback—it used a **single large storage unit** for food, which, in case of failure, could lead to overfeeding. To address this issue, an improved design was proposed with **smaller storage units and real-time monitoring features**. The upgraded system allowed pet owners to control feeding schedules remotely via **IoT- enabled devices**, ensuring better food management and animal health.

Development of Automatic Fish Feeder

The automation of fish feeding has been extensively studied to optimize food consumption while maintaining water quality. An early design featured a **single-container food storage unit**, which dispensed food at preset intervals of **12-hour or 24-hour formats**. However, this rigid schedule posed challenges such as overfeeding or underfeeding, impacting fish health and increasing waste accumulation.

To overcome these limitations, a **smart feeding algorithm** was introduced. Unlike conventional systems that relied solely on timers, this system utilized **real-time data from IoT sensors** to adjust feeding schedules dynamically. The algorithm determined optimal feeding times based on **fish activity, hunger levels, and environmental conditions**, significantly **reducing waste and improving fish growth rates**.

Water Quality Monitoring and Prediction

Maintaining optimal water quality is crucial for aquaculture. Studies have demonstrated that **machine learning and big data analytics** can be applied to predict water quality parameters such as **pH, dissolved oxygen, temperature, and turbidity**. One research project employed **Random Forest and XGBoost models** to analyse real-time sensor data, achieving **high prediction accuracy** for water contamination levels.

Similarly, a **Web-Based Water Pollution Classification System** was developed using **decision tree algorithms** to categorize water quality into different classes based on **World Health Organization (WHO) standards**. This system provided real-time alerts and recommendations for corrective measures, demonstrating the feasibility of **AI-driven water quality monitoring** in aquaculture.

Another notable study implemented **Fog Computing** for water quality assessment. This approach involved deploying multiple sensors across different locations, which collected and processed water quality data in a decentralized manner. The system enhanced data efficiency and **enabled real-time decision-making** by reducing cloud computing latency.

Real-Time IoT-Based Monitoring in Aquaculture

The integration of **IoT and AI** in aquaculture has led to the development of real-time monitoring systems for disease detection and water management. Researchers have implemented **sensor-based networks** to track key parameters such as **temperature, pH, dissolved oxygen, and ammonia levels**. The collected data was analysed using **deep learning models** to predict disease outbreaks before they occurred.

An IoT-based fish monitoring system utilized **Wi-Fi-enabled ESP8266 modules** for remote data transmission, enabling fish farmers to monitor tank conditions from any location. **Predictive analytics** were incorporated to detect potential threats, such as disease onset or deteriorating water conditions, allowing for **proactive intervention**.

Conclusion of Literature Survey

The reviewed literature highlights significant advancements in **fish disease detection, water quality monitoring, and automated feeding systems** using **IoT and AI technologies**. Machine learning algorithms such as **CNN, SVM, and Random Forest** have proven effective in identifying fish diseases with high accuracy. Automated feeding systems have evolved from **preset timers to intelligent, sensor-driven mechanisms**, reducing waste and optimizing nutrition. Additionally, **IoT-based water quality monitoring** has revolutionized aquaculture by enabling **real-time data analysis and predictive maintenance**.

These studies collectively indicate that **smart aquaculture** holds great potential for improving efficiency, sustainability, and fish health. Future research should focus on enhancing **model accuracy, minimizing power consumption in IoT systems, and integrating blockchain technology** for data security and transparency in aquaculture management.

III. METAHDOLOGY

The proposed system for **disease detection and monitoring in smart aquaculture** integrates **IoT, machine learning, and real-time sensor networks** to improve aquatic health management. The methodology consists of several key components, including **sensor-based water quality monitoring, automated feeding systems, disease detection models, and cloud-based data analysis**.

1. System Architecture

The system architecture comprises three main components:

1. **Data Collection Layer:** This layer consists of sensors that monitor essential water quality parameters, including **temperature, pH, dissolved oxygen, turbidity, and ammonia levels**.
2. **Processing and Analysis Layer:** A microcontroller unit, such as **Arduino or Raspberry Pi**, collects and processes data from sensors. The information is then transmitted to a cloud server via **Wi-Fi-enabled ESP8266 modules**.
3. **Decision-Making Layer:** Machine learning models analyze the collected data to detect disease symptoms in fish and predict water quality fluctuations. Alerts are sent to fish farm operators for timely intervention.

2. Water Quality Monitoring

Maintaining optimal water conditions is crucial for fish health and disease prevention. The proposed system employs **IoT- based sensors** to continuously monitor key parameters. The steps involved are:

1. **Real-Time Data Collection:** Sensors measure **temperature, pH, turbidity, and dissolved oxygen levels** at regular intervals.
2. **Data Transmission:** The collected data is sent to a **cloud- based platform** using **wireless communication protocols**.
3. **Threshold Comparison:** Predefined thresholds are set for each parameter. If the values exceed or fall below the ideal range, an **alert is triggered**, notifying farm operators.
4. **Predictive Analysis:** A **machine learning model** processes historical data to forecast potential **water quality deterioration**, enabling preventive actions.

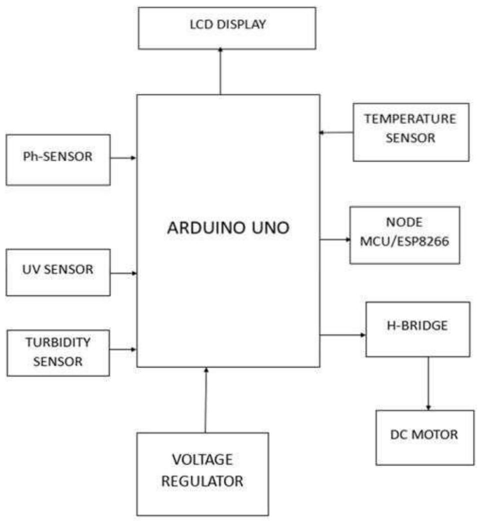


fig 3. 1 Block Diagram for Disease detection of aquatic life

3. Disease Detection Model

Fish diseases are identified using **deep learning techniques**, particularly **Convolutional Neural Networks (CNNs)**. The disease detection process consists of:

1. **Data Acquisition:** Images of fish are collected using underwater cameras and preprocessed to enhance clarity.
2. **Feature Extraction:** The CNN model extracts key features such as **color variations, lesion patterns, and body deformations** associated with different diseases.
3. **Model Training and Classification:** The dataset is split into **training and testing sets** (80% for training, 20% for validation). The model learns to classify fish into categories such as **healthy, white spot disease, red spot disease, or black spot disease**.
4. **Prediction and Alerts:** When a fish is detected with symptoms, the system generates an **automated alert** and provides recommendations for treatment.

4. Automated Feeding System

Feeding efficiency is optimized through **IoT-enabled automated feeders**, which operate based on real-time fish activity and water quality conditions. The feeding process follows these steps:

1. **Activity Monitoring:** Sensors detect fish movement patterns to determine hunger levels.
2. **Portion Control:** The feeding system dispenses precise amounts of food based on the **species, age, and size** of the fish.
3. **Remote Control & Scheduling:** Farm operators can manually adjust feeding times and quantities through a **mobile application**.
4. **Waste Reduction:** Excess food detection mechanisms prevent overfeeding, reducing waste and improving water quality.

5. Cloud-Based Data Management

All collected data is securely stored in a **cloud database** for real-time monitoring and historical analysis. Key features include:

1. **Data Logging:** Continuous recording of **sensor readings, feeding schedules, and disease reports**.
2. **Remote Access:** Fish farmers can monitor and control the system via a **web dashboard or mobile app**.
3. **Automated Reports:** The system generates **weekly/monthly reports** on fish health, feeding efficiency, and water conditions.

Hardware Requirements

1. **Microcontroller Unit**: The system relies on a **microcontroller** such as the **Arduino Uno or Raspberry Pi**, which acts as the central processing unit. This microcontroller collects data from various sensors, processes it, and controls connected IoT devices. It facilitates communication between different components, executes automation commands for water quality control and feeding, and transmits data to cloud storage for remote monitoring. The Raspberry Pi is particularly useful for handling complex computations, while Arduino is more efficient for simpler, real-time control tasks.
2. **Water Quality Sensors**: Maintaining optimal water quality is essential for aquatic life. Several sensors are integrated into the system to continuously monitor key parameters:
   - **pH Sensor**: Measures the acidity or alkalinity of the water, ensuring that it remains within the safe range for fish health. Any deviation from the ideal range triggers alerts for corrective action.
   - **Temperature Sensor (LM35 or DS18B20)**: Continuously monitors water temperature, which is crucial for the growth and survival of fish. It prevents temperature fluctuations that may lead to stress or diseases.
   - **Dissolved Oxygen (DO) Sensor**: Detects oxygen levels in the water, ensuring that there is sufficient oxygen for fish respiration. Low oxygen levels can lead to suffocation and mass fish mortality.
   - **Turbidity Sensor**: Measures water clarity by detecting suspended particles, algae, or waste materials. High turbidity levels indicate poor water quality, requiring filtration or water changes.
   - **Ammonia Sensor**: Identifies toxic ammonia buildup, which can be harmful to aquatic organisms. Early detection allows for timely water treatment to prevent fish poisoning.

3. **IoT Communication Module**: A **Wi-Fi module (ESP8266)** is used for real-time data transmission. This module allows sensor readings to be sent to a **cloud-based storage system**, enabling fish farmers to monitor the status of their aquaculture system remotely. The ESP8266 ensures seamless communication between the microcontroller and an online dashboard, where users can access historical data, set alerts, and receive notifications in case of abnormal water conditions.

4. **Automated Feeding System**: To improve feeding efficiency and prevent overfeeding or underfeeding, the system includes an **automated fish feeder**. This system comprises:
   - **Servo Motor or Stepper Motor**: Controls the release of fish food at scheduled intervals or based on fish activity detected by sensors.
   - **Food Dispenser Unit**: Stores and dispenses the required amount of food per feeding cycle, ensuring fish receive adequate nutrition while minimizing waste.
   - **Load Cell (Weight Sensor)**: Measures the quantity of food dispensed to maintain accuracy and avoid overfeeding, which can degrade water quality due to excess organic matter accumulation.

5. **Power Supply**: A **5V or 12V power adapter or battery pack** is used to power the microcontroller and sensors, ensuring stable operation. Additionally, a **solar panel** can be integrated into the system, particularly for remote aquaculture farms where electricity supply may be limited. Solar power enhances sustainability by reducing dependence on non-renewable energy sources and ensuring uninterrupted system functionality.

6. **Camera Module for Disease Detection**: An **underwater camera** with **high resolution and night vision capabilities** is used for real-time fish monitoring. The camera captures images and videos of fish, which are then processed by an **AI-based disease detection model**. The system analyzes physical symptoms such as **color changes, lesions, abnormal swimming patterns, and infections**, helping farmers identify diseases early and take preventive measures before they spread.

7. **Cloud Storage & Edge Computing**: All collected data, including water quality readings, feeding logs, and disease detection reports, is stored securely in **cloud storage**. This allows for historical analysis, predictive modeling, and remote access through a **web dashboard or mobile app**. In addition, **edge computing devices** such as external SD cards or USB storage are used for local data backup, ensuring the system remains operational even if cloud connectivity is temporarily lost.

The integration of these **hardware components** creates an efficient, **automated aquaculture management system** that optimizes water quality, enhances fish health monitoring, and streamlines feeding operations. By leveraging **IoT technology, real-time data analysis, and automation**, the system ensures **higher productivity, reduced fish mortality rates, and improved sustainability in aquaculture practices**.

Software Requirements

1. **Operating System**

- **Raspberry Pi OS (if using Raspberry Pi)**: Provides a stable environment for running scripts, handling sensor data, and executing automation commands.
- **Windows / Linux / macOS**: Used for system development, coding, and deployment.

2. **Programming Languages**

- **Python**: Primary language used for **machine learning, data processing, and IoT control**. It is essential for writing algorithms to analyse sensor data, detect fish diseases, and automate feeding schedules.
- **C / C++**:Used for **microcontroller programming**, particularly for **Arduino-based components**. It allows real-time control of sensors, motors, and communication modules.
- **SQL / NoSQL (MongoDB, Firebase, or MySQL)**: Used for **storing and managing collected data** such as sensor readings, disease detection results, and feeding schedules.

3. **Integrated Development Environments (IDEs)**

- **Arduino IDE**: Required for writing, compiling, and uploading **C/C++ code** to the **Arduino microcontroller**, enabling communication between sensors and actuators.
- **Python IDEs (PyCharm, VS Code, Jupiter Notebook)**: Used for **data analysis, machine learning model development, and cloud connectivity**.
- **Raspberry Pi Configuration Tools**: Used for setting up **Wi-Fi, GPIO control, and cloud-based automation** on Raspberry Pi systems.

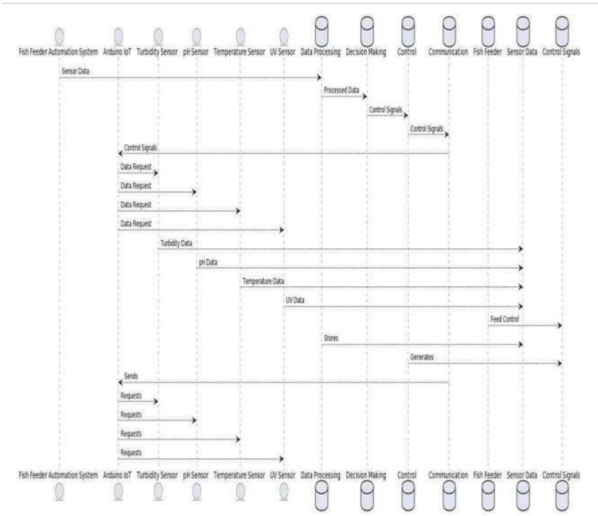


fig 3. 3 Data flow diagram level 1

4. **IoT & Communication Frameworks**

- **MQTT (Message Queuing Telemetry Transport)**: A lightweight messaging protocol used for **real-time data transmission** between sensors, cloud storage, and monitoring devices.
- **HTTP & REST APIs**: Used for connecting **IoT devices to cloud platforms** and enabling remote monitoring via mobile or web applications.
- **Firebase Realtime Database / Google Cloud IoT**: For **storing real-time data from sensors**, enabling farmers to track environmental conditions remotely.

5. **Machine Learning & AI Frameworks**

- **TensorFlow / Keras / PyTorch**: Used for developing **deep learning models** that analyze fish images and detect diseases based on visual patterns.

- **OpenCV**: A computer vision library for **image processing and enhancement**, used in **AI-powered disease detection**.
- **Scikit-Learn**: Supports **machine learning-based predictive analysis**, such as forecasting water quality fluctuations.

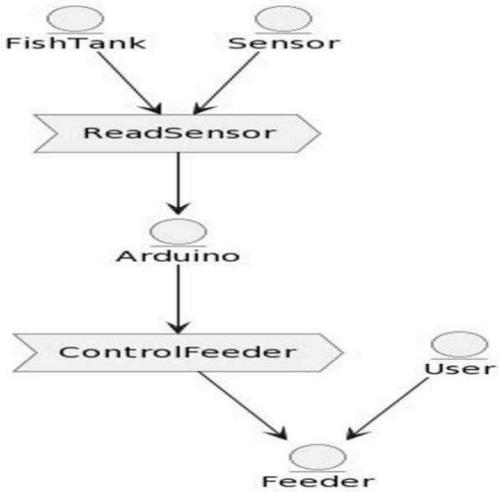


fig 3. 2 flow chart of Data flow diagram level1

6. **Web & Mobile Application Development**

- **Flask / Django (Python-based Web Frameworks)**: Used to build a **web-based dashboard** where users can monitor fish health, water quality, and feeding schedules.
- **React Native / Flutter**: For **developing mobile applications that allow fish farm operators to control the system remotely.**
- **HTML, CSS, JavaScript**: Used for designing **user-friendly web interfaces** for real-time monitoring and alert notifications.

7. **Cloud Services & Data Storage**

- **Google Cloud / AWS / Azure IoT**: Used for **real-time data processing, remote access, and cloud-based predictive analytics**.
- **Firebase / MySQL / PostgreSQL**: Manages **historical data storage** for analysis and reporting.
- **Google Drive / OneDrive / Dropbox (Optional)**: For **backing up sensor data, reports, and AI model outputs**.

8. **Data Visualization & Reporting**

- **Matplotlib / Seaborn / Plotly**: Used for **graphical representation of sensor data**, helping users analyze trends in **water quality, feeding patterns, and disease outbreaks**.
- **Power BI / Tableau**: (Optional) For **advanced data visualization and reporting**, useful in large-scale aquaculture farms.

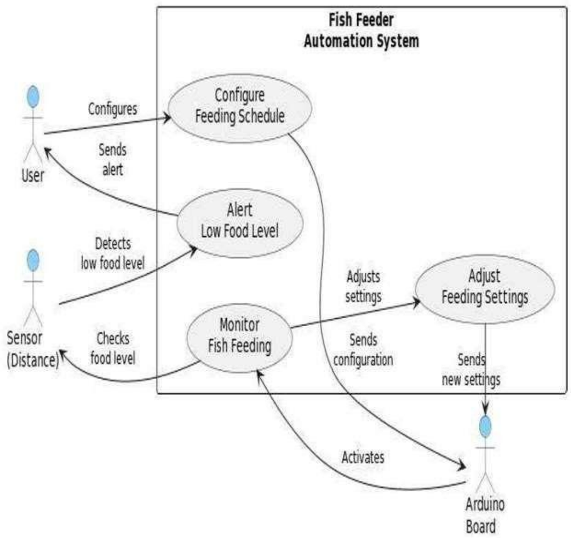


fig 3. 4 Use case diagram

RESULTS:

Hardware part:

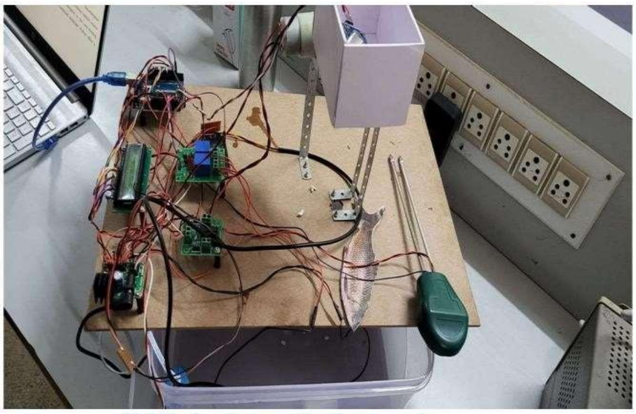


Fig 5.1 hardware implementation of smart aquaculture

The implementation of a smart aquaculture system integrating a pH detector, temperature detector, turbidity detector, and automated fish feeder powered by IoT technologies has demonstrated significant improvements in efficiency, sustainability, and fish health management.

pH Detection and Control

By incorporating a pH detector, the system enabled real-time monitoring of the water's acidity. Any deviations from the optimal pH range (6.5–8.5, suitable for most aquaculture species) were instantly detected, allowing for rapid corrective action.

Outcome: Enhanced water quality management reduced fish stress and mortality rates. Automated pH adjustment systems, such as the addition of buffering agents, ensure a stable aquatic environment.

Temperature Monitoring

The temperature sensor provided accurate and continuous monitoring of water temperature, a crucial parameter for maintaining species-specific growth and survival rates.

Outcome: The system effectively managed optimal water temperatures through IoT-controlled heaters or coolers, resulting in improved fish growth rates and a lower incidence of diseases related to temperature fluctuations.

1. **Automated Fish Feeder**

The IoT-enabled fish feeder dispensed food at programmed intervals, adjusting the quantity based on the fish population and their growth stages.

Outcome: This feature minimized feed wastage and overfeeding, reducing operational costs and water pollution. The controlled feeding schedule also contributed to more consistent fish growth and healthier populations.

2. **IoT Integration and Data Analytics**

The seamless integration of IoT provided centralized control and data logging, accessible via mobile or web applications. Real-time data visualization and alerts improved operational decision-making.

Outcome: Predictive analytics allowed for proactive measures such as preemptive water changes or feed adjustments, further enhancing the efficiency and sustainability of the aquaculture system.

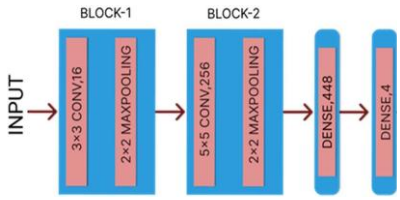
Software part:

1. Image Pre-processing

Image pre-processing enhances image quality for accurate analysis. Key steps include:

- **Resizing**: Adjusting image dimensions (e.g., 224×224 pixels) using OpenCV to maintain aspect ratio.
- **Sharpening**: Applying the filter2D() method in Python to enhance clarity.
- **Colour Space Conversion**: Transforming BGR to HSV using cv.cvtColor() for better feature extraction.
- **Dataset Splitting**: Dividing images into **80% training** and **20% testing** sets for improved classification accuracy.

2. **Disease Detection Using CNN**



A **Convolutional Neural Network (CNN)** classifies fish as healthy, white spot, red spot, or black spot.

- **Pooling Layer**: Reduces spatial dimensions and computational load while preserving key features.
- **Fully Connected Layer**: Analyses extracted features and assigns probabilities to disease categories.
- **Activation Function**: Uses **SoftMax** for multi-class classification and **Sigmoid** for binary classification.

3. **Optimization and Model Tuning**

- **Adam Optimizer**: Adjusts learning rates dynamically for faster convergence.
- **Batch Size & Epochs**: Optimized to balance memory usage and training efficiency.
- **Overfitting Prevention**: Techniques like **Dropout, L1/L2 Regularization, and Early Stopping** enhance model generalization.

4. **Pretrained Model (VGG-16)**

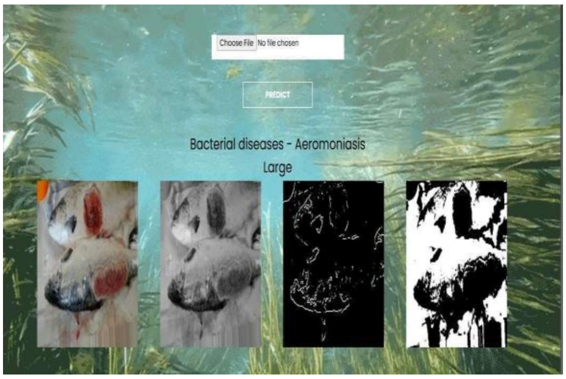
- Utilizes pre-trained **VGG-16** on **ImageNet**, fine-tuned for fish disease detection.
- Freezing early layers retains learned features while adjusting higher layers for specific tasks.

5. **Web-Based Deployment Using Flask**

- **Real-Time Disease Detection**: Users upload fish images for immediate classification.
- **User-Friendly Interface**: Flask-based web app allows seamless interaction for aquaculture operators.
- **Scalability & Automation**: Supports diverse fish species and minimizes manual inspection.

6. **Key Outcomes**

- **>90% Accuracy** in disease classification.
- **Early Detection** prevents widespread infections and reduces mortality.
- **Remote Monitoring** enables efficient farm management.
- **Optimized Feeding & Water Quality** enhances sustainability and cost-efficiency.



Advantages and Applications

Advantages:

1. **Improved Efficiency**: Smart aquaculture systems can automate essential tasks, such as feeding, monitoring water conditions, and maintenance, thereby improving operational efficiency and reducing labor costs.

2. **Increased Productivity**: These systems help optimize various factors like water quality, feeding schedules, and environmental parameters, all of which contribute to better fish growth rates, thus boosting productivity.
3. **Improved Water Quality**: Smart systems monitor and regulate parameters such as pH, temperature, and dissolved oxygen levels, ensuring that the water environment is conducive to healthy fish growth.
4. **Reduced Disease Risk**: By continuously monitoring the health of fish and the water conditions, smart systems can detect early signs of disease, allowing farmers to intervene promptly and reduce the likelihood of large-scale outbreaks.
5. **Increased Transparency**: Real-time data provided by smart aquaculture systems enhance transparency, fostering greater consumer trust and improving the overall reputation of the aquaculture industry.
6. **Improved Food Safety**: These systems help ensure food safety by keeping track of crucial parameters, including water quality, feed quality, and fish health, ultimately reducing the risk of contamination.

Applications for Smart Aquaculture Systems:

1. **Fish Farming**: In fish farming, smart systems regulate environmental factors like water quality and feeding schedules, which help increase fish growth rates and minimize disease.
2. **Aquatic Research**: Smart aquaculture systems are valuable for conducting research on aquatic ecosystems. By precisely controlling parameters like water quality and feeding, researchers can gain deeper insights into aquatic life.
3. **Water Quality Monitoring**: Smart systems are used to monitor key water parameters, such as pH levels, temperature, and dissolved oxygen. This ensures the well-being of fish and other aquatic organisms.
4. **Fish Health Monitoring**: These systems track indicators of fish health, including stress levels, disease, and the presence of parasites.

CONCLUSION AND FUTURESCOPE CONCLUSION

In today's fast-paced world, automation is increasingly implemented to reduce human effort. Previous systems, however, were inefficient and not cost-effective. Embedded systems, especially those based on microcontrollers, often had limited memory and peripheral interfaces, which led to performance lags. To overcome these limitations, we propose an automated aquarium system based on Arduino. This system integrates sensors to monitor and manage various aquarium conditions such as temperature, feeding schedules, turbidity levels, and lighting. By using the Arduino controller, it allows for efficient, automated management of these factors, ensuring smoother operation and improved control.

FUTURESCOPE

The future of smart aquaculture holds significant promise for continued innovation and development. Integrating advanced sensors, artificial intelligence (AI), and big data analytics will enable more accurate real-time and predictive decision-making, which is crucial for maintaining customer trust and ensuring high product quality. The adoption of renewable energy sources like solar-powered IoT devices will contribute to the sustainability of aquaculture operations. Additionally, research into robotics for underwater monitoring and maintenance could reduce the need for manual interventions. As the global demand for sustainable food production increases, smart aquaculture systems will become vital in addressing food security challenges while minimizing their environmental footprint.

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