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Research Article

Automated Disease Detection and Control for Smart Aquaponics Systems

Mamatha K R[1*], Rashmi N[2], Thejaswini S[3], Ramesh Babu N[4], Dr. Girish H[5]

[1*]Dept. of ECE, B M S Institute of Technology and Management Bengaluru, Karnataka, India
[2]Dept. of ECE, B M S Institute of Technology and Management Bengaluru, Karnataka, India
[3]Dept. of ETE, B M S Institute of Technology and Management Bengaluru, Karnataka, India.
[4]Dept. of CS&BS, K S School of Engineering and Management, Bengaluru, Karnataka, India.
[5]Professor, Department of ECE, Cambridge Institute of Technology, Bangalore, Karnataka, India.

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ABSTRACT

Aquaponics is a highly efficient, symbiotic system that combines the principles of aquaculture (raising aquatic animals) and hydroponics (growing plants in nutrient-rich water) to create a sustainable agricultural environment. This innovative approach leverages the waste produced by aquatic animals to provide organic nutrients for plant growth, while plants, in turn, filter and purify the water, creating a self-sustaining cycle. The primary objective of this system is to drive advancements in the agricultural sector through the integration of emerging technologies, making sustainable farming more accessible and resource-efficient. A key feature of this system is its built-in disease detection and monitoring capabilities. Through the use of sensors, computer vision, and machine learning, the system actively monitors the health of plants, detecting subtle changes in leaf color, structure, and other visible symptoms that may indicate disease. When a potential disease is identified, the system automatically generates a detailed report outlining the affected areas, potential disease types, and recommended treatments. This report is then instantly sent to the owner via a mobile application, ensuring that they are alerted promptly to any health issues within the aquaponic ecosystem. By identifying diseases at an early stage, the system enables timely intervention, thereby preventing disease propagation and reducing the risk of widespread crop loss. This proactive approach to plant health management not only safeguards the productivity of the aquaponic system but also contributes to overall food security. With its emphasis on sustainability, smart monitoring, and efficient resource utilization, this aquaponics system represents a significant step forward in the modernization of agriculture, embodying a vision for a technology-driven, eco-friendly future in food production. This abstract covers the purpose, technology integration, disease detection, and benefits, creating a comprehensive overview. Let me know if you'd like adjustments.

Keywords—Smart aquaponics, Internet of Things, image processing, leaf identification, disease detection

I.INTRODUCTION

Agriculture increasingly relies on information and communication technology to improve productivity and sustainability. While it has long provided natural food sources to most of the global population, the intensive use of pesticides to accelerate crop growth has led to adverse effects on human health and soil quality in recent years. Aquaponics offers a sustainable alternative to traditional agriculture, addressing some of these food production challenges by continuously monitoring environmental parameters essential for the healthy growth of plants and fish. This multi-trophic system combines aquaculture with hydroponics, where nutrient-rich water from fish tanks is cycled through plant beds, facilitating efficient resource utilization.

In aquaponics, fish waste naturally fertilizes the water that circulates through the system, supporting plant growth without the need for chemical additives. This system requires specific conditions, including optimal water temperature, pH levels, and dissolved oxygen, to maximize plant and fish health. As such, smart aquaponics systems utilize sensors and actuators to automatically monitor and adjust these parameters, providing a balanced environment.

This paper presents the design and development of a home aquaponics system with integrated disease detection capabilities. The goal is to empower households to produce their own fish and plants, reducing national food demand and promoting sustainable living. A feature-rich Internet of Things (IoT) mobile application alerts users to any abnormal conditions within the system through early warning notifications, ensuring timely intervention and minimizing human oversight. Measurement results validate the proposed system's efficacy in growing healthy fish and plants with minimal operational costs and intervention.

This smart aquaponics system incorporates a disease detection module that uses artificial intelligence (AI) and image processing to identify, analyze, and classify plant diseases automatically. Early detection prevents losses in yield and product quality, with AI-based leaf analysis pinpointing diseases in affected plants. When an issue is detected, a report—complete with images of the affected areas—is sent to the user via the mobile application. The prototype application has been implemented successfully, demonstrating the potential of aquaponics as a sustainable solution for food production at the household level.
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II. SYSTEM ARCHITECTURE

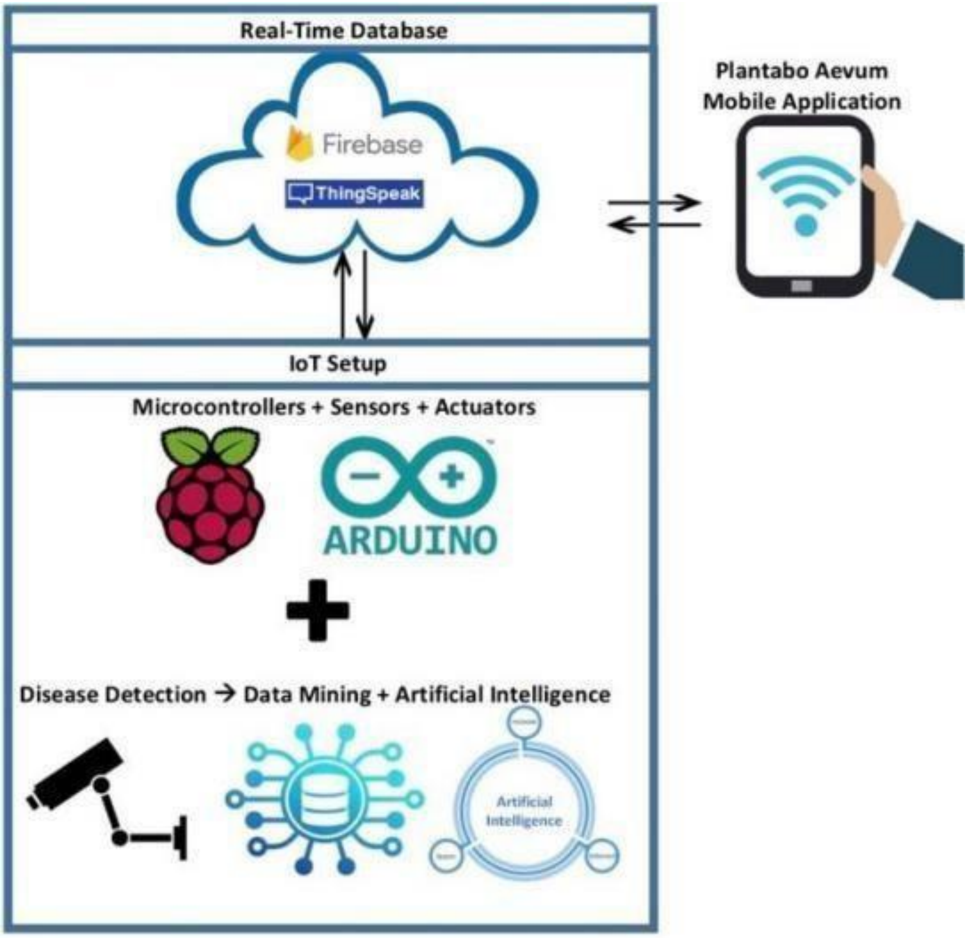


Fig. 1. Architecture of Plantabo Aevum

The system is composed of the following core components:
Aquaponics Setup: This includes essential components to cultivate plants and fish. Fish reside in the lower section, where their waste fertilizes the water. This nutrient-rich water is then pumped to the plant section, supporting plant growth.

IoT Setup: Positioned above the aquaponics setup, the IoT framework consists of two Raspberry Pi (RPi) 3 units and an Arduino Uno. The Arduino efficiently processes analog data, while the first RPi gathers sensor data and updates a real-time database with this information. It also reads user commands from the database and activates actuators as needed. The IoT setup integrates various sensors—monitoring air and soil temperature and humidity, pH, light, and visuals through Pi cameras. The second RPi is dedicated to the disease detection system, enabling advanced video processing and adaptability across multiple stations.

Leaf and Disease Detection: Using a Raspberry Pi with enhanced RAM to run OpenCV, this component captures leaf images to identify plant species and detect possible diseases via a machine learning classifier.

Real-Time Database: A Firebase real-time database stores data collected from sensors and actuators. ThingSpeak visualizes this data with graphs and widgets, creating a user-friendly interface for monitoring. This database acts as a link between the IoT setup and the mobile application.

Mobile Application: The mobile app accesses sensor data via ThingSpeak and Firebase, allowing the user to view live status updates of the aquaponics system and its IoT components. Users can remotely adjust actuator settings and receive email alerts with attached photos if any disease symptoms are detected.

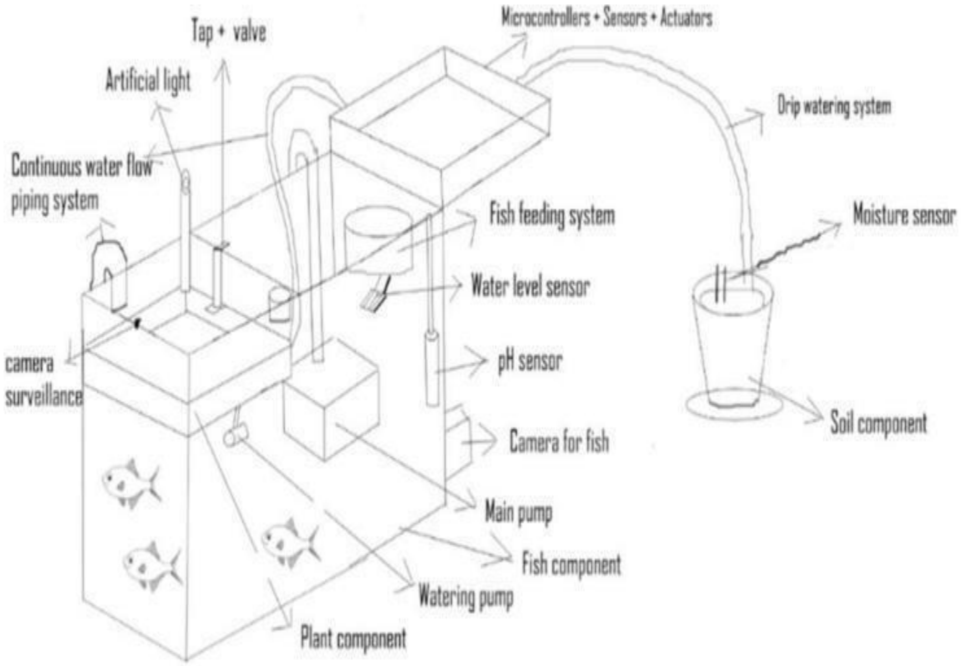
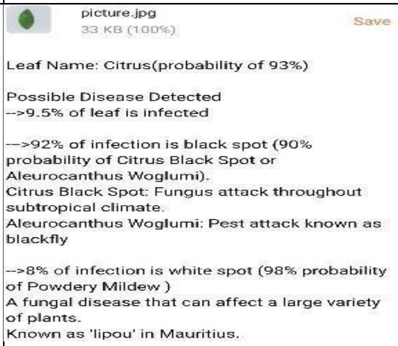
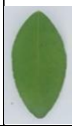
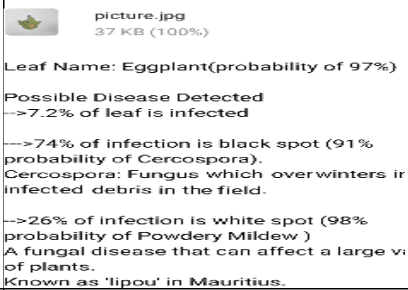


Fig. 2. Aquaponics and IoT Setup

Figure 2 illustrates the integrated aquaponics and IoT setup, featuring the primary components essential to system functionality. The primary habitat for aquatic animals, where fish produce waste that enriches the water with essential nutrients. This nutrient-laden water is then pumped to support hydroponic plant growth, while plants help purify and recycle the water. The area dedicated to cultivating plants, which receive nutrient-enriched water from the fish habitat, promoting healthy growth without soil. An additional site for plant growth, using the nutrient-rich water as part of a regulated watering system. Equipped with various sensors to gather vital data on environmental conditions, these components transmit the data to the microcontrollers for analysis and control. These components maintain optimal climatic conditions by executing adjustments based on sensor data, supporting ideal growth environments for both fish and plants. Microcontroller acting as the system's control center, these components process data from the sensors and issue commands to the actuators, ensuring the system operates efficiently and responds dynamically to environmental changes.

III. VALUATION

TABLE I. LEAF AND ANOMALY DETECTION

Original Leaf	**Leaf & Anomaly Detection**	**Notification on Mobile App**
		 picture.jpg 33 KB (100%) Save Leaf Name: Citrus(probability of 93%) Possible Disease Detected -->9.5% of leaf is infected -->92% of infection is black spot (90% probability of Citrus Black Spot or Aleurocanthus Woglumi). Citrus Black Spot: Fungus attack throughout subtropical climate. Aleurocanthus Woglumi: Pest attack known as blackfly -->8% of infection is white spot (98% probability of Powdery Mildew) A fungal disease that can affect a large variety of plants. Known as 'lipou' in Mauritius.
		Leaf Healthy - No notification received.
		 picture.jpg 37 KB (100%) Leaf Name: Eggplant(probability of 97%) Possible Disease Detected -->7.2% of leaf is infected -->74% of infection is black spot (91% probability of Cercospora). Cercospora: Fungus which overwinters ir infected debris in the field. -->26% of infection is white spot (98% probability of Powdery Mildew) A fungal disease that can affect a large vi of plants. Known as 'lipou' in Mauritius.
		Leaf Healthy - No notification received.

We evaluated our system, Plantabo Aevum, against other similar smart aquaponics and deduce that in terms of sensors and actuators, Plantabo Aevum performs comparatively with respect to other systems whereby similar devices were used. The main feature that demarcates Plantabo Aevum with other smart aquaponics system is its ability to detect the presence or absence of diseases on the leaves of a plant.

Though in our prototype, we made use of a low- resolution camera to capture only the infected leaf, we believe that with a powerful camera, this limitation would have been easily overcome and a picture of the whole plant could have been taken with the different leaves being extracted. As the leaf identification and disease detection system is based on a constructed dataset, the accuracy of the system can easily be increased since it depends on the number of leaves' features collected and the number of records in the dataset. 3D scattered graph obtained from our dataset which shows that the training data used was reliable. The values were well grouped and quite distinct. Another important aspect worth noting is that since our system uses different ratios, the system performed correctly irrespective of the distance between the camera and the leaf and also irrespective of the side of the leaf.

IV. CONCLUSION

A smart aquaponics system is introduced that integrates traditional aquaculture with hydroponics, enhanced by the Internet of Things (IoT) for continuous environmental monitoring and control. This system includes a mobile application that allows users to view real-time status updates and remotely control various actuators within the setup based on sensor data. Additionally, the app provides a live camera feed, enabling the owner to observe the plants and fish remotely. The system also incorporates a disease detection module that first identifies the leaf and then analyzes it for any signs of disease. Potential enhancements include training the system to recognize a wider range of plant species, particularly those common in the local environment and frequently affected by disease.

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