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A SMART MONITORING AND OBSERVATION FRAMEWORK FOR AQUAPONICS ECOSYSTEM

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ABSTRACT

Aquaponics is a sustainable and efficient agricultural system that integrates aquaculture with agriculture. This system integrates Internet of Things (IoT) technology in aquaponics systems with the potential to change sustainable agriculture by combining farming of fish (aquaculture) and soilless cultivation of plants (hydroponics) into a single, efficient ecosystem. This paper explores the design and development of a smart aquaponics system that allows aquaponic farming at commercial scale feasible, leveraging IoT to continuously gather data through various sensors, monitor environmental conditions, and automate control processes. The proposed system architecture is based on a three-tier model, ensuring scalability and maintainability. The proposed system consists of a three-layer architecture: the Perception Layer for measuring different environmental factors and controlling them, the Network Layer for data transmission, and the Application Layer for data storage, manipulation, and user interaction. The key components include sensors for monitoring pH, humidity, temperature, sunlight, oxygen levels, and water proximity; devices such as lights, water pumps, fans, and oxygen pumps for environmental control; and an ESP8266 microcontroller for system management. The system's software is developed using C# DOT NET CORE 8.0, React, MySQL, C, and Arduino. The system allows users the ability to maintain optimal conditions for fish and plant growth, notify users of irregularities, and allow remote control through a web application, proving it to be an intelligent, flexible, low-cost, and stable solution for large-scale aquaponics.

Keywords: aquaponics, IoT, smart farming, hydroponics, aquaculture.

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1. INTRODUCTION

Aquaponics is a system that supports the dual combination of raising fish (aquaculture) and growing plants without soil using nutrient-based solutions (hydroponics). The waste of the fish containing ammonia is treated with nitrogen converting it into nitrites and then to nitrates, which can be used as nutrients for the plants. When compared to traditional farming methods, aquaponics is favorable in places with no or less fertile soil, water scarcity, or even the unavailability of free land or soil [1-4].

In today's fast-paced world, the swift advancement of nations has significant implications for agriculture, particularly through the conversion of farmland into urban areas for construction and housing developments. To address these challenges, vertical hydroponics emerges as a viable alternative for gardeners confronted with constrained horizontal space or those aiming to optimize their output. This method is particularly advantageous for shorter plant varieties and can be ingeniously applied to surfaces such as walls, fences, patios, and compact gardens, fostering denser vegetation. Furthermore, the adoption of aquaponic systems offers a safer approach to pest management by significantly reducing reliance on harmful chemical pesticides [5-6]. The potential benefits of this innovative farming technique extend beyond individual gardens, potentially revolutionizing large-scale crop cultivation. By harnessing the precise control over environmental factors inherent in aquaponics, the necessity for chemical interventions is substantially diminished.

This is an alternative approach to traditional agriculture but there are a lot of factors that can cause challenges for large-scale adoption of such systems. A lot of research and development is required to efficiently control and utilize this system in a large-scale environment so; they can be deployed in commercial sectors. Extensive research has already been done on aquaponics systems and the most promising methodology for using such systems is to use technology to efficiently monitor and control all the factors that are at play. Research shows if efficient systems are developed, the food production landscape will be changed drastically providing a more efficient and environmentally friendly approach [7] [8].

According to the characteristics of aquaponics systems and urban agriculture scenarios, this paper attempts to design and develop a smart aquaponics system that can integrate fish and plant farming by continuous data gathering through various sensors, monitoring the sensor information, and controlling the system accordingly. In addition, the proposed system will notify the user in case of any irregularities and take appropriate actions automatically. Users can control their ecosystem through a web application.

2. LITERATURE REVIEW

Historically vegetable farming and fish farming have been integrated in countries like China and Thailand.

Fish were fed farm waste and cultivated in rice paddies filled with water. [9]

In fish farming only (25 to 30) % of nutritional elements consumed by fish are utilized for weight gain. The remaining surplus nutrients are discharged in solid and liquid forms. Vegetable hydroponics can be integrated into this water to recover the nutrients that would otherwise be released into the environment. [10]

Aquaponics combines two farming techniques: hydroponics which incorporates soilless plants and vegetable production and aquaculture which incorporates breeding fish and other aquatic organisms in an enclosed water body such as a water tank. Fish produce much waste that needs to be cleaned regularly keeping water clean and livable by fish. In the same way, hydroponics requires nutrition for growing plants. So waste-filled water from fish is circulated through plant roots which absorb these nutrients and clean water for fish. [11]

IoT technology can be employed to regulate and continuously monitor the process of an aquaponic ecosystem. A smart IoT-based aquaponics system utilizes digital sensors for data monitoring and maintaining a closed ecosystem, providing a low-cost and self-sustainable solution for digital farming. [12]

The design and creation of an aquaponics system requires domain knowledge from multiple fields, such as environmental, mechanical, and civil engineering design concepts, and also aquatic and plant biology, biochemistry, and biotechnology.

To develop a smart system, this expertise must be complemented with in-depth knowledge of software development. Furthermore, ensuring commercial viability necessitates proficiency in economics, finance, and marketing. One of the main challenges faced is the different adaptability of species to the aquaponic environment, which makes monitoring and regulating growth conditions for fish and plants crucial for optimizing production. Therefore, the successful implementation of aquaponics hinges on the integration of specialized knowledge and skills across these diverse domains. [13] [14]

Knowing which plants and fish are suitable for an aquaponic environment is a crucial challenge [15]. Balancing the plant-fish ratio for effective production and matching fish and plant nutrition is extremely important in aquaponics, the main source of nutrition for fish and plants as well [16] [17]. "Figure-1", shows the working sequence of an aquaponics ecosystem, highlighting the relationship between fish and plants in the system.

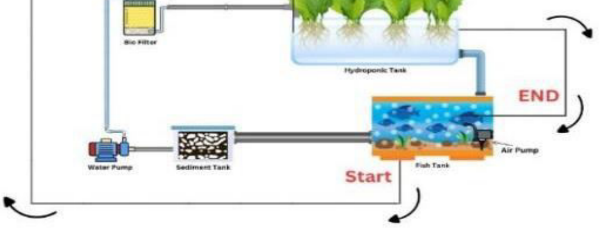

Figure-1. The working sequence of an Aquaponics Ecosystem.

Various studies have focused on developing monitoring and control systems based on IoT technology for aquaponics. These systems enable real-time monitoring of environmental parameters, remote control of actuators, and improved growth conditions for plants and fish. The integration of IoT technology enhances the efficiency and sustainability of aquaponics systems [18].

3. PROPOSED SYSTEM ARCHITECTURE

The proposed system architecture has three layers: Perception Layer (sensing and control unit), Network Layer (data transmission), and Application Layer (data storage and manipulation).

A. Perception Layer

The physical layer consists of sensors, devices, and a control unit to control those devices. Data is collected through the sensors and the devices are controlled through an ESP that is used to send control signals to relays.

A) Sensors: collect and acquire data (PH, humidity, temperature, sunlight, oxygen level, proximity) from the environment and water to evaluate the environmental conditions of both fishes and plants.

a) PH Sensor: The PH of the solution within the tank is measured using this sensor.

b) Light detection sensor: The amount and intensity of light can affect plant growth as it is directly related to photosynthesis; a light detection sensor is used to measure the intensity of light provided.

c) Proximity sensor: Water level needs to be measured and maintained for both fish and plants. The proximity sensor tells us about the amount of water present in the tank.

d) Temperature sensor: Temperature needs to be maintained for the survival of both fish and plants and also breaks down nutrients and waste and it is monitored using this sensor.

e) Humidity sensor: Too little or too much humidity can be troublesome as it can cause infestations and other problems so, to measure and maintain humidity, a humidity sensor is used.

f) Oxygen level sensor: Oxygen is vital for the survival of fish and oxygen levels are tracked using an oxygen sensor.

B) Devices: The sensors are used to measure different environmental factors in an aquaporin system and then these factors are maintained using different devices to maintain a healthy amount and sustain growth within an aquaponic system. Some of these devices are the following:

a) LED Light: a 200-watt LED light that activates when sunlight starts to dim.

b) Water pump: A water pump is used to circulate water throughout the system. The power of the water pump depends on the size of the system. It pumps

ARPN Journal of Engineering and Applied Sciences

water from the tank to the plant bed providing nutrition to plants.

c) Fan: reduces humidity and temperature of the ecosystem.

d) Oxygen pump: oxygen pump to inject oxygen to the fish tank if oxygen level falls.

C) Control unit: Consists of an ESP 8266 that is used to control these devices and also send data to the application.

B. Network Layer

The second layer of the proposed system is the network layer. The main purpose of this layer is to connect the whole system and transfer data collected from all different sensors to the server which helps the user monitor all the information in a digestible manner. This communication is done over HTTPS protocol.

The data is transferred wirelessly to the remote cloud server and ESP8266, a low-cost Wi-Fi microcontroller is used for this purpose. After transfer the data is stored in the cloud and accumulated over time which can later be used to assess the performance of the system over time.

C. Application Layer

The purpose of this layer is to provide a user-friendly user interface (UI) where users can interact and monitor the system. It allows controlling all the functionality such as bundling different devices and sensors (Setup Area) so they can be handled collectively, fetching sensor data from the database for both real-time monitoring and reports, setting up rule chains for managing the ecosystem without needing human monitoring, and using notification centers.

Data at the farm is collected and sent to the application layer through ESP. “Figure-2”, shows the three-layer architecture.

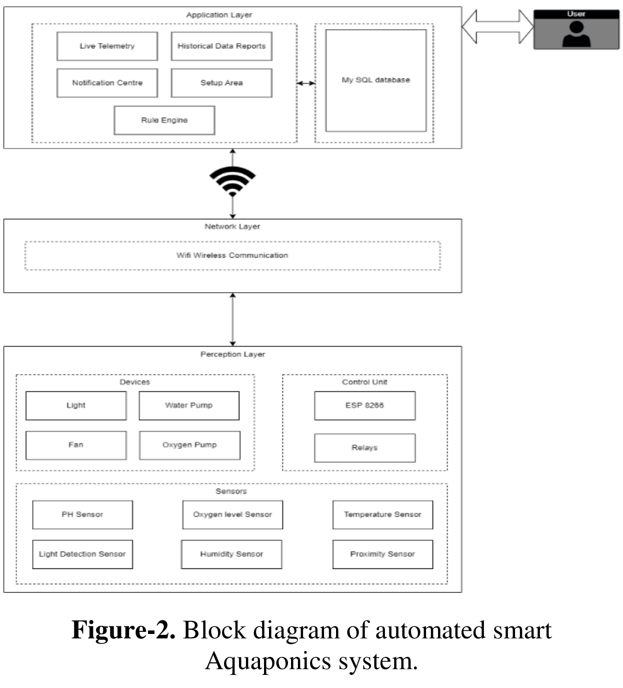

Figure-2. Block diagram of automated smart Aquaponics system.

A) Web Application Design: The web application of the proposed system named AEMOS (Aquaphonic ecosystem monitoring and observation system) is based on 3 tier architecture mainly Presentation, Application, and Data, each running on separate servers for improved scalability and maintainability.

a) Presentation tier: The presentation tier manages user interactions and displays information. Built using React, a JavaScript library for creating dynamic user interfaces, it consists of multiple React components, each responsible for different UI elements. This tier operates on a dedicated server, ensuring that the user interface is isolated from backend processes, which enhances performance and security.

b) Application tier: The application tier processes business logic and handles data operations. Implemented using ASP. NET Core 8 and C#, it includes several key components:

- **Entity layer:** Manages business entities and domain models.
- **API layer:** Exposes functionalities through ASP .NET Core Web API, facilitating communication with the presentation tier.
- **Business logic layer:** Contains core business rules and logic.
- **Data access layer:** Facilitates data interactions and CRUD operations. This tier is hosted across separate servers to ensure efficient processing and modularity, allowing for scalable and maintainable business logic.

c) Data tier: The data tier is responsible for data storage and management, utilizing MS SQL Server. Its key components include:

- **Tables:** Store data.
- **Views:** Provide specific data representations.
- **Stored procedures:** Execute predefined SQL operations. Running on a separate server, this tier maintains data integrity and security. This architecture facilitates a clear separation between the user interface, business logic, and data management layers, enabling independent development, deployment, and scaling of each tier

Each layer has its purpose and there is also interaction between different layers. “Figure-3”, shows the three-tier architecture. Components of different tiers and hierarchy of interaction between them.

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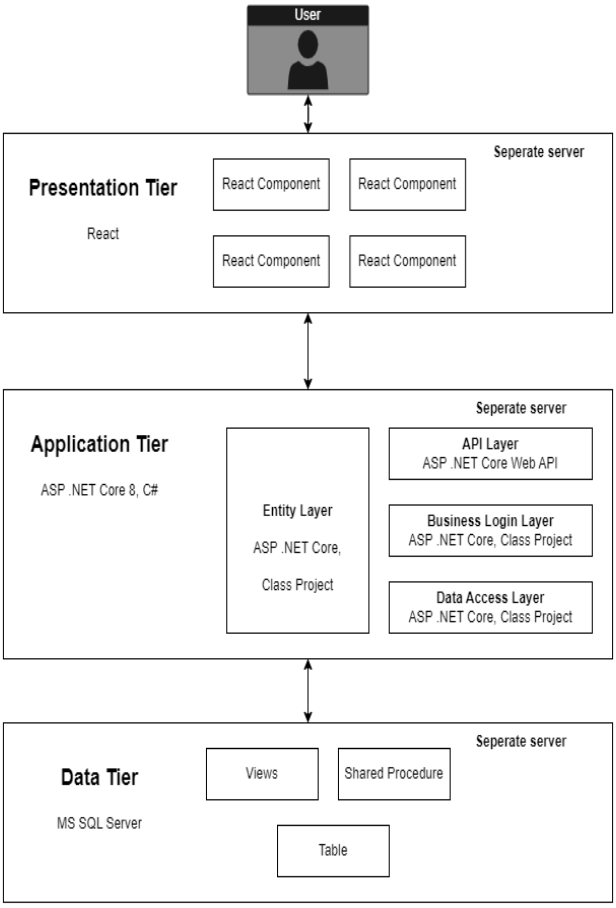

Figure-3. Block diagram of software's application layer architecture.

4. KEY FUNCTIONALITIES OF WEB APPLICATION

The application consists of the following features: user login, Real-time monitoring, historical data reports, remote control of devices, and rule engine. Figure-4 represents the framework of the application.

A. Create Organization

Let a potential user sign up and set up an organization for managing aquaponic farms.

An organization can have one too many farms controlled through the application of the proposed system.

B. Setup User (Role-Based Access Control)

Let an organization administrator create further sub-users for his organization such as supervisors, operators, etc. each of whom is assigned an organization admin-defined set of customized responsibilities.

C. Create Area

Creating an area lets an admin bundle his devices and sensors installed at the farm together so that it can be managed collectively, on a single dashboard by a user assigned by an administrator.

D. Setup Devices

This functionality allows connecting devices to the AEMOS dashboard.

E. Setup Sensors

This functionality allows connecting sensors to the AEMOS dashboard.

F. Configure Notifications

The system sends real-time alerts and notifications to users in case of any critical parameter deviation or system malfunction. This ensures timely responses to potential issues, improving the chances of maintaining a healthy aquaponics ecosystem.

G. Generate Reports

Generate reports based on historical data of aquaponic farms such as temperature changes for the day.

H. Rule Engine

The Rule Engine allows the defining of complex workflows, automates data processing, and triggers actions based on specific conditions or events.

I. Real-Time Monitoring

Tracks critical environmental parameters including light, oxygen level, pH level, humidity, proximity, and temperature in real-time. These parameters are viewed in the form of easy-to-understand widgets.

J. Historical Data

Historical data for farms can also be accessed which could potentially be used for data analysis.

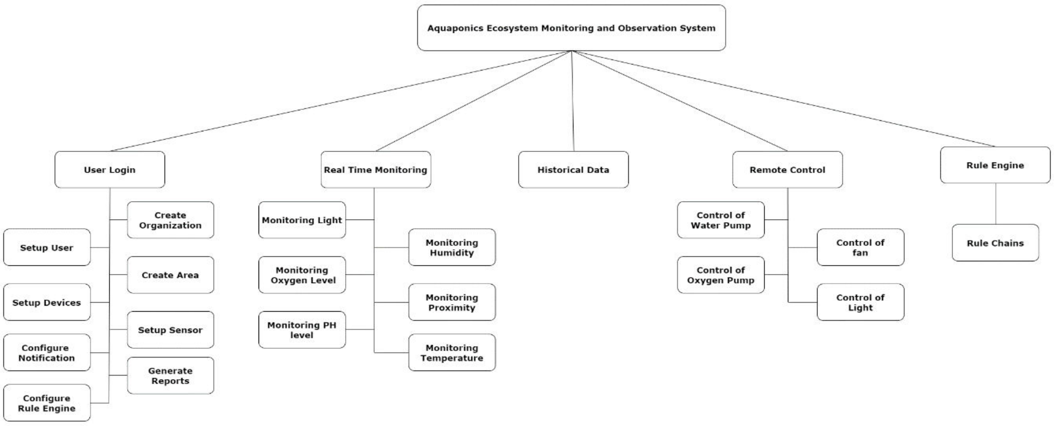

Figure-4. Diagram of functionalities offered by software system.

5. CONCLUSIONS

The smart aquaponics ecosystem monitoring and observation system (AEMOS) effectively integrates IoT technology to optimize the management of aquaponics farming. By utilizing continuous data gathering through sensors and providing real-time monitoring and control, the proposed system enhances the efficiency and sustainability of the aquaponic environment. The three-tier architecture ensures scalability, maintainability, and clear separation of concerns. The system's functionalities, including automated notifications, historical data analysis, and a robust rule engine, provide users with comprehensive tools to maintain optimal conditions for both fish and plants. This research highlights the importance of interdisciplinary expertise in developing advanced agricultural technologies and underscores the potential of IoT in revolutionizing modern farming practices.

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