IoT-Based Smart Aquaponics System with Remote Monitoring and Actuator Control

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***Abstract*—This innovative aquaponics system integrates automation to streamline the cultivation of plants and fish in a sustainable, symbiotic environment. We focus on developing an application for the automation and real-time water quality monitoring. The system incorporates an automatic water transfer system and feeding mechanism that optimizes nutrition delivery to the fish, ensuring their health and growth. Simultaneously, real-time water quality parameter monitoring guarantees a stable and conducive aquatic environment. This automation not only reduces the labor-intensive aspects of aquaponics but also improves the overall efficiency and productivity of the system, making it a promising solution for sustainable food production.**

Keywords—Aquaponics, Aquaculture, Hydroponics, Ammonia, pH, Agriculture, IoT, Arduino Uno, ESP32, ThingSpeak, Flutter, Dart, Node.js.

I. INTRODUCTION

Aquaponics combines aquaculture and hydroponics to cultivate plants and aquatic organisms in a symbiotic environment, resulting in fresh, organic produce that does not require harmful pesticides or fertilizers. Fish waste is converted into plant nutrients, making the system water-efficient and environmentally friendly, as well as providing two food sources. Aquaponics is emerging as a promising solution to the dgrowing global demand for sustainable agriculture. However, there has been a lack of comprehensive reviews of aquaponics automation techniques and communication platforms in recent literature. This paper fills a gap by examining recent research in smart aquaponics systems, with a focus on technological advancements. Successful aquaponics systems necessitate precise design and management, which can be expensive to achieve, especially on a commercial scale. The goal of integrating smart automation and IoT technologies is to reduce manual labor and improve process control, and facilitate proactive decision-making.

The paper's structure encompasses subsections covering previous smart systems and IoT use cases in aquaponics, followed by methodology detailing sensor-based water quality parameter sensing and IoT actuator system integration. It evaluates practical implementation and discusses current limitations and main challenges facing aquaponics system automation. This review contributes to understanding recent advancements in computer-integrated aquaponics systems supported by sensors, smart tools, and IoT capabilities, aiming to enhance system efficiency and productivity.

II. Literature Review

Aquaponics systems have recently garnered significant attention due to their potential in addressing agricultural, water management, and food security challenges. This section offers an overview of recent advancements in incorporating smart systems and Internet of Things (IoT) technology into aquaponics, highlighting key studies in the field. Dutta et al. [1] developed a system integrating databases and a monitoring division to supervise pH levels, temperature, humidity, and water levels of aquaponics systems. The gathered data were transmitted to a web server, accessible to users in both JavaScript object notation and graphical formats. Daniela et al. [2] presented an automated aquaponics system featuring continuous water withdrawal adjustment and monitoring of water and air temperatures, as well as pH levels. Their greenhouse operates on solar power to address environmental concerns. Adrian K. Pasha et al. [3] created a system that allows visualization of various hydroponic parameters, including water temperature, pH levels, and water levels, along with operational details for pumps, lamps, fans, and bells. This information is displayed in tabular format on a web page, accessible from various browsers and devices. Huang et al. [4] proposed an integrated aquaponics system, combining aquaculture and hydroponics to address water pollution and food scarcity concerns. Their research demonstrated the efficacy of a combined aquaponic and recirculating system for improving water quality and promoting sustainable agriculture. Abbasi et al. [5] developed a cloud-based data acquisition and monitoring system for aquaponics facilities, using IoT technology to collect real-time data on water quality parameters. This study paved the way for future autonomous aquaponic applications and decision support systems. Miller et al. [6] investigated the potential of IoT devices and platforms in continuous water quality monitoring, focusing on pH, temperature, and oxygen levels. Despite challenges with data management and security, IoT applications demonstrated the potential to provide valuable insights for water quality assessment. Maulini et al. [7] developed an Arduino-based monitoring system for aquaponic water quality, focusing on parameters like pH, temperature, and ammonia levels. This demonstrated the feasibility of using IoT technology for remote oversight and management of aquaponics systems. Rao et al. [8] designed and implemented an automated aquaponics system with IoT technology to monitor key metrics like pH, water level, and temperature. Their system, which combined sensors and cloud-based dashboards, aimed to improve plant growth while reducing human intervention in farming practices. Taha et al. [9] reviewed smart systems and IoT integration in aquaponics automation, highlighting IoT technology's potential to address challenges such as water quality management, nutrient control, and predictive modeling in aquaponics systems. Alselek et al. [10] proposed an automated health monitoring system for aquaponics, incorporating sensors to transmit real-time data to remote monitors, reducing the challenges of manual monitoring.

This paper aims to develop an automated aquaponics system utilizing IoT for real-time and remote monitoring of water quality parameters and control of actuators such as motors and feeding systems. The goal is to create a system that reduces the need for constant user monitoring, saving time and enabling remote supervision and control.

III. Experimental Details

A.Experimental set-up

The setup consists of two plastic containers, of which one is used to grow the fish and the other for the plants. The hydroponics system is filled with gravel or pebbles which is used the growth bed for the plant growth. The two containers are connected by a bell siphon which facilitates the circulation of the water after the nitrogen cycle from the hydroponic system to the fish tank. Unclean water from the fish tank is pumped into the hydroponic system using an electric water pump which can be controlled by the operator. The sensors required for monitoring the water parameters are dipped in the fish tank and the data collected from the environment is relayed to the mobile application.

B.Hardware Components

This section discusses the devices used and their implications for the proposed system.

1. **Arduino Uno**: The Arduino Uno is a microcontroller board designed by Arduino.cc that uses the ATmega328P MCU. It has 14 digital and 6 analog I/O pins for connecting to various shields and circuits. Programming is made possible by using the Arduino IDE and a type B USB cable.
2. **ESP32**: The ESP32 is a highly integrated Wi-Fi and Bluetooth chip manufactured by TSMC. It combines Wi-Fi and Bluetooth capabilities with few external components, including an antenna switch, RF balun, and power management modules. It is made from ultra-low power 40 nm technology. It is designed to provide optimal power and RF performance and is suitable for a wide range of applications.
3. **DS18B20**: The DS18B20 is a 1-wire programmable temperature sensor which can be used to monitor air and liquid temperatures. Its range is from -55°C to +125°C. Each sensor has a unique address and only needs one MCU pin for data transfer, making it ideal for multi-point temperature monitoring.
4. **pH sensor**: The pH sensor is used to determine the pH of liquids by measuring hydrogen-ion activity in water-based solutions. It works with both 9V systems and integrates seamlessly with Arduino. It can work in a high temperature range and eliminates basic alkali errors, and it is linear in the pH range of 0 to 14. The reference system includes an Ag/AgCl gel electrolyte salt bridge.

5. **Actuators**: Actuators such as remotely controlled water pumps and automatic feeding systems are critical for maintaining the nitrogen cycle and feeding fish in aquaponics systems, ensuring continuous, self-sustaining operation.

IV. METHODOLOGY

A. The System Mechanism

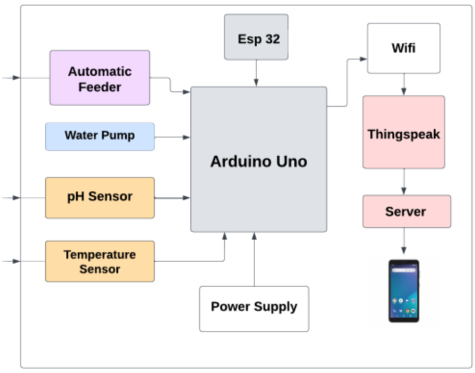

Fig 1. Architecture of Proposed Model

The proposed system is intended to provide optimal conditions for the plants and fish in the aquaponic system. The described system uses a feedback loop mechanism to maintain optimal conditions for both plants and fish in an aquaponics system. The system enables real-time monitoring and remote control of water quality parameters and actuators through a mobile application. Users can now access and manage the system from anywhere with an internet connection.

Upon initialization, the system parameters are set to ensure ideal conditions for plant and fish growth. Sensors then continuously monitor key parameters such as pH, temperature, dissolved oxygen, and sunlight. Sensor data is processed according to predefined conditions for plant and fish growth. If the data falls within expected ranges, no action is taken. However, if there's any inconsistency or deviation from the optimal range, the system triggers appropriate actions using actuators. The pH sensor monitors the water pH, crucial for both plant and fish health. If pH deviates from the safe range (6–7), actions are taken such as adjusting fish feeding and controlling temperature to stabilize pH levels. The temperature sensor monitors water temperature within the range of 18–32 °C. If it falls below or exceeds this range, the system activates the heater or water pump respectively to regulate temperature. In case of any parameter inconsistency or critical condition, the system generates warning messages on the web server, alerting users to take necessary actions. Overall, the system operates by continuously monitoring key parameters, processing sensor data, and triggering appropriate actions through actuators to maintain optimal conditions for both plants and fish in the aquaponics system.

B. Design of the System

This system design outlines the implementation of sensors, actuators, IoT devices, cloud integration, mobile application development, and maintenance procedures necessary for the successful deployment of the system.

1. **Sensor Integration and Data Transmission**: Water quality parameters are monitored using sensors such as the DS18B20 temperature sensor and pH analog sensor. These sensors are connected to an Arduino Uno, which interfaces with them serially. The Arduino Uno is then linked to an ESP32 module via UART communication to provide WiFi connectivity. The ESP32 module sends the collected sensor data to the ThingSpeak IoT cloud platform through HTTP requests. ThingSpeak serves as a RESTful API, enabling access to sensor data through HTTP requests from external applications.
2. **Actuator Control**: Actuators, such as the water pump and feeder, are connected to the Arduino Uno. Users can control these actuators manually through the mobile application interface. Additionally, the actuators can be automatically activated based on specific conditions determined by the sensor readings. At a set interval of time, the values are checked and the actuators are initiated based on the requirements.
3. **Backend Server**: The Node.js backend server is responsible for receiving sensor data from the ESP32 module. It hosts a RESTful API to handle communication between the IoT devices and the mobile application. The server processes incoming sensor data, performs necessary calculations, stores the data in a database for future retrieval, and sends activation signals to the actuators based on the parameters. It also manages the notification system by setting thresholds for water parameter values and triggers alerts when sensor readings surpass predefined thresholds, notifying users through the mobile application.
4. **Mobile Application**: A Flutter-based mobile application is developed to provide remote monitoring and actuator control functionalities to users. The mobile application retrieves sensor data from the ThingSpeak server via HTTP requests and options are provided for manual or automatic control of the actuators through the mobile application.
5. **Data Analytics and Visualization**: Charts and graphs are generated from the data stored in the ThingSpeak cloud platform.These visualizations provide analytics of the system's performance and insights for the aquaponics farmer. The charts are displayed within the mobile application, allowing users to monitor system trends and make informed decisions.

V. RESULTS

A. Aquaponics System

The aquaponics system is the foundation for the IoT-based smart aquaponics system, which provides a symbiotic environment for plant and fish cultivation. Traditional aquaponics combines aquaculture and hydroponics, in which fish waste provides nutrients for plants while plants help purify fish water. In this case, the IoT system optimizes the symbiosis by continuously monitoring critical parameters like water quality and temperature and controlling these parameters using automatically controlled actuators. The system ensures efficient nutrient cycling and maximizes growth potential by keeping both plants and fish in optimal conditions. Additionally, the IoT system provides benefits in terms of scalability, resource conservation, and remote management.

Fig 2. Aquaponics System

B. Hardware Components

The hardware components of the IoT-based smart aquaponics system consist of sensors, actuators, microcontrollers, and communication modules. Sensors such as the DS18B20 temperature sensor, pH sensor, analog DO sensor, and TDS sensor are strategically placed within the aquaponics system to monitor water quality parameters in real-time. These sensors are interfaced with an Arduino Uno microcontroller, which collects and processes sensor data. The Arduino Uno communicates with an ESP32 module using UART communication protocol to provide WiFi connectivity. Actuators, including water pumps and feeders, are connected to the Arduino Uno for automated control based on sensor readings.

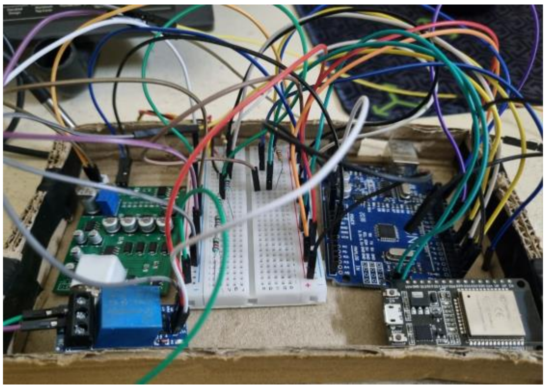

Fig 3. Hardware Implementation

C. Software Implementation

The software implementation of the IoT-based smart aquaponics system encompasses the development of a Node.js backend server and a Flutter-based mobile application. The Node.js server serves as the central hub for processing sensor data, managing communication between IoT devices and the mobile application, and facilitating data transmission to the ThingSpeak IoT cloud platform. It hosts a RESTful API for interaction with external applications and databases. The Flutter-based mobile application provides users with remote monitoring and control capabilities, allowing them to access real-time sensor readings, adjust actuator settings, and receive notifications/alerts. The application also features data visualization tools for analyzing system performance and trends. Together, the software components form an integrated ecosystem that empowers users to optimize aquaponics operations while promoting sustainability and efficiency in agriculture.

Fig 4. Software Implementation

VI. CONCLUSION

In conclusion, the IoT-based smart aquaponics system presented in this paper represents a significant step forward in addressing the challenges of modern agriculture while aligning with the principles of sustainability and efficiency. By leveraging the power of the Internet of Things, this system offers a comprehensive solution to monitor and manage aquaponics operations with precision and intelligence. The integration of IoT technology not only ensures process integrity but also unlocks a myriad of advantages, including scalability, enhanced productivity, and resource optimization. Through cloud storage and database implementation, the system enables informed management decisions, leading to optimized growth inputs and conservation of vital resources such as water and nutrients. Moreover, the socioeconomic implications of IoT-based smart aquaponics systems are profound. By democratizing food production and making fresh produce accessible in diverse settings, these systems contribute to food security and economic development. As we reflect on the insights gained from this project and our discussion, it becomes evident that IoT-based aquaponics systems represent a sustainable, scalable solution to pressing socioeconomic challenges. By harnessing technology to optimize resource usage and promote agricultural efficiency, we pave the way for a more resilient and equitable food system, while simultaneously mitigating environmental impacts and reducing human costs.

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