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Design and Implementation of an IoT-Based Soilless Aqua-Beans Farm Monitoring System Using Thinker.io

Aminu Murtala Yukur[1], D. M. Nazif[2], Nasiru Abdullahi[3], S. B. Nghalmi[4]
[1]Modibbo Adama University, Yola, Nigeria; [2,3,4]Federal Polytechnic Bauchi, Bauchi State, Nigeria
mohamed.o.hussen@uoanbar.edu.iq

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Abstract

The increasing global population, coupled with limitations in conventional agriculture—such as land scarcity and water shortages—demands innovative approaches to sustainable food production. Aquaponics, which integrates aquaculture and hydroponics in a closed-loop system, offers a viable solution by recycling water and nutrients. Despite its advantages, traditional aquaponic systems often struggle to maintain optimal environmental conditions and rely heavily on manual oversight. This study presents the design and implementation of a smart, IoT-enabled soilless aqua-beans farm monitoring system, leveraging the Thinker.io platform to address these challenges. The system comprises an ESP32 microcontroller connected to a suite of environmental sensors (temperature, humidity, pH, water level, and light intensity), with data transmitted via MQTT to the Thinker.io cloud for real-time visualization and analysis. An automated feedback mechanism, incorporating water pumps and LED lights, ensures environmental parameters remain within ideal thresholds. A two-day monitoring phase demonstrated the system's effectiveness in stabilizing conditions necessary for the cultivation of beans and fish. The findings underscore the potential of IoT integration to enhance precision, remote accessibility, and resource efficiency in urban farming. Moreover, the project supports scalability through the provision of documentation and farmer training, aiming to facilitate broader adoption in resource-constrained regions such as Nigeria.

Keywords: IoT-Based Aquaponics; Smart Farming; Soilless Agriculture; Environmental Monitoring; Urban Agriculture

INTRODUCTION

Aquaponics is a sustainable agricultural practice that integrates two systems—aquaculture (the cultivation of aquatic organisms like fish) and hydroponics (the cultivation of plants in water rather than soil). This system creates a symbiotic environment where waste produced by aquatic organisms, primarily fish, serves as a natural fertilizer for plants, while plants help purify the water for the fish. In this process, beneficial bacteria play a crucial role by converting fish waste, particularly ammonia, into nitrates essential for plant growth. The closed-loop design of aquaponics ensures that water is continually recycled and reused, making it a highly resource-efficient and environmentally friendly method of farming (Nguyen et al., 2020).

The integration of aquaculture and hydroponics offers several benefits, especially in terms of resource efficiency. Aquaponics uses significantly less water than traditional soil-based farming and eliminates the need for synthetic fertilizers and pesticides. This method supports the growth of a diverse range of crops alongside fish, such as leafy greens, herbs, and fruits. Moreover, aquaponics reflects the growing trend toward sustainable agricultural practices by minimizing environmental impact while maximizing crop yield. As a result, it aligns with global efforts to promote eco-friendly food production systems (Khaoula et al., 2021).

Nguyen et al. (2020) describe an efficient aquaponics system combining IoT technology with biological processes, enabling smart farming through real-time monitoring and automated control, which enhances sustainability and reduces human intervention. Sugeru et al. (2020) emphasize aquaponics' versatility in supporting various crops and fish, minimizing reliance on external inputs such as water and chemicals. The integration of IoT platforms, like Thinker.io, allows for optimized conditions for plant and fish growth, improving productivity and reducing costs by monitoring factors such as water temperature and nutrient levels (Alselek et al., 2022).

Aquaculture, recognized as one of the fastest-growing food production systems globally, has adapted various production models to improve efficiency and environmental sustainability (FAO, 2019). Among these, aquaponics has emerged as one of the most sustainable practices of the 21st century, primarily due to its ability to recycle water and nutrients within a closed-loop system (Budihartono & Rakhman, 2024; Dawa et al., 2022).

By minimizing waste and maximizing the utility of inputs, aquaponics provides a practical solution to food production in urban and resource-limited environments.

Aquaponics promotes biodiversity and cultural diversity by combining traditional farming with modern technology, especially in arid areas. It supports food security and environmental sustainability, making it a viable future food production model, particularly in water-scarce regions. Integrating IoT technologies can optimize aquaponics systems, enhancing their contribution to sustainable agriculture. This project focuses on designing a smart aquaponics system to yield beans efficiently while conserving resources, providing a scalable future food model.

In response to the global need for sustainable food production due to rising populations, there is a demand for innovative agricultural systems. Traditional methods face challenges such as land availability and environmental degradation. Aquaponics, which combines aquaculture and hydroponics, offers a potential solution, though it currently requires significant labor and faces challenges in optimizing conditions for fish and plants. This project focuses on developing a smart aquaponics system using modern technologies for automation, resource optimization, and sustainability. It aims to enhance productivity, reduce environmental impact, and support global food security, along with providing training materials and test plans for Nigerian farmers to improve their value chain.

METHODOLOGY

This system consists of sub-units, such as a power supply unit circuit and a liquid crystal display, each made of components with specific datasheet specifications, including current, voltage, and power ratings. This necessitates careful design calculations and implementation for each sub-unit to ensure the overall system functions as intended.

System Layout

Block Diagram

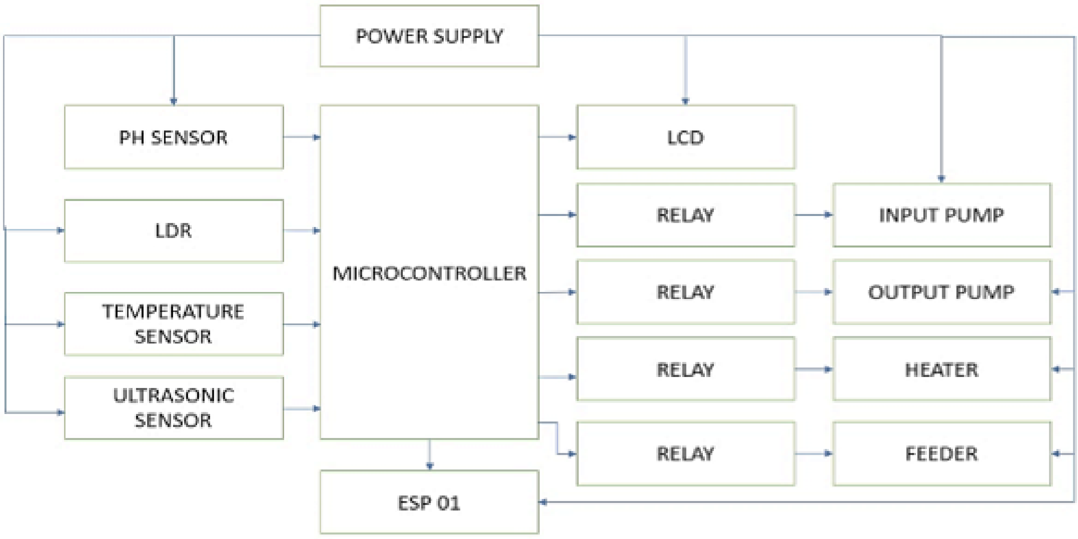

Figure 1: Block Diagram

Flowchart Diagram

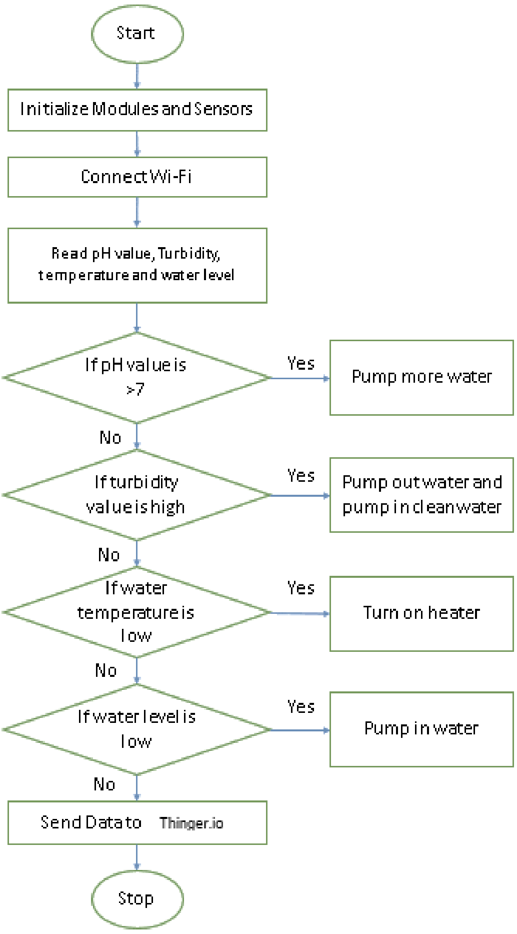

Figure 2: Flowchart Diagram

Circuit Diagram

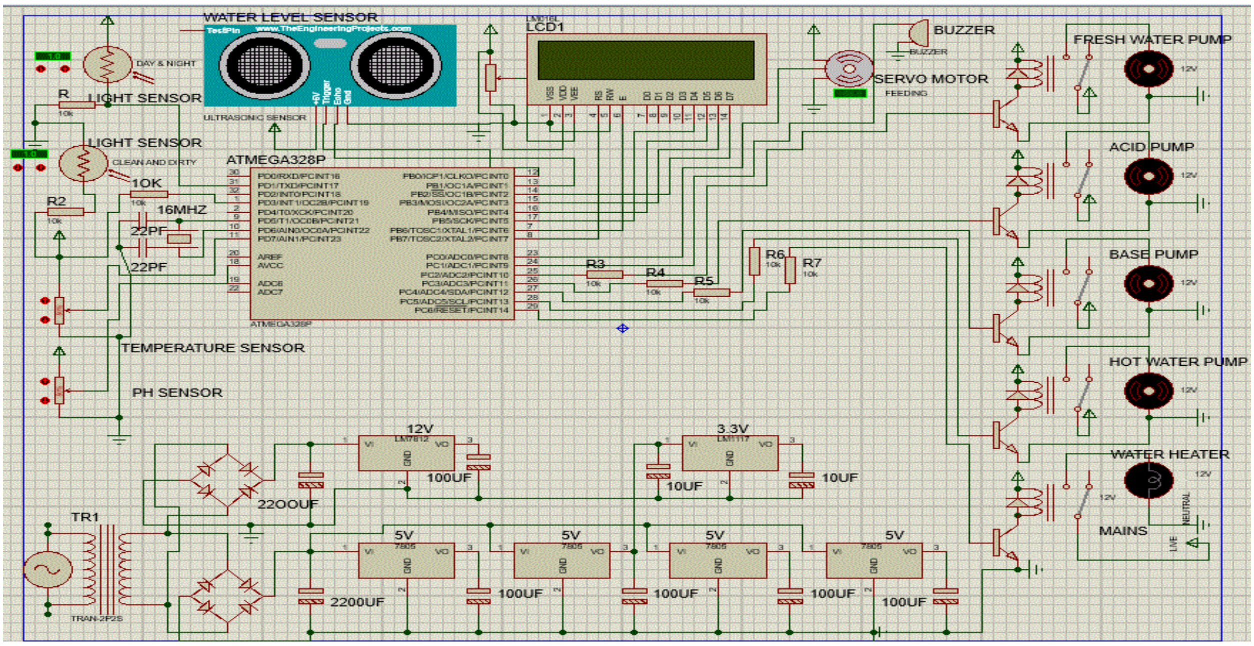

Figure 3: Circuit Diagram

System Implementation

The system employs Thinker.io as the platform for data collection and remote monitoring, with an IoT architecture that integrates multiple sensors to track environmental and water quality variables such as temperature, humidity, pH, nutrient levels, and light intensity in a soilless aqua-beans farm. At the core of the design is a microcontroller, such as an ESP32 or Raspberry Pi, which connects to the sensors and Thinker.io for real-time data logging and analysis.

The sensor module includes TDS and pH sensors to monitor nutrient concentration and acidity, DHT11 sensors to measure temperature and humidity, and a light sensor for tracking light intensity. These sensors interface with the microcontroller, which processes the data and transmits it wirelessly to Thinker.io. The microcontroller unit (MCU) not only collects data but also runs basic edge-computing algorithms for noise filtering and local decision-making, such as activating water pumps when nutrient levels fall below a threshold.

For communication, the system adopts the MQTT protocol, which is lightweight and ideal for IoT applications in low-bandwidth environments. Actuators are integrated to automate farm operations based on sensor readings. These include water pumps for irrigation, ventilation systems for climate control, and LED grow lights to supplement natural light when needed.

The cloud-based monitoring component is facilitated through Thinker.io, which provides dashboards for real-time visualization and analysis of parameters like pH, TDS, and temperature. It also supports threshold-based alerts via mobile or email, enabling proactive management. Over time, the analytics features of Thinker.io help optimize farm conditions by identifying operational trends and patterns.

To ensure reliability, the system can be powered by solar panels with battery backup, offering a sustainable energy source suitable for remote areas with unstable electricity supply. This integration enhances resilience and supports the continuous operation of the IoT-enabled soilless farming system.

RESULTS AND DISCUSSION

The following table presents the collected data from the IoT-based soilless aqua-beans farm monitoring system, recorded at 2-hour intervals from 6:00 AM to 6:00 PM for two days. The components monitored include temperature, pH levels, water level, light intensity, and humidity, as measured by the system's sensors.

Table 1: Data for IoT-based soilless aqua-beans farm monitoring system

Date	Time	Temperature (°C)	pH Level	Water Level (cm)	Light Intensity (LUX)	Humidity (%)
14th Sept, 2024	06:00	23.8	6.9	34.7	320	66
	08:00	24.2	7.0	34.6	450	68
	10:00	25.1	7.1	34.4	650	70
	12:00	25.8	7.2	34.2	800	72
	14:00	26.3	7.2	34.0	760	74
	16:00	25.7	7.1	34.1	600	71
	18:00	24.9	7.0	34.5	400	68
15th Sept, 2024	06:00	23.9	6.8	34.7	310	67
	08:00	24.3	6.9	34.6	460	69
	10:00	25.3	7.0	34.3	640	71
	12:00	26.0	7.1	34.1	805	73

	14:00	26.4	7.2	33.9	770	75
	16:00	25.8	7.1	34.0	620	72
	18:00	25.0	7.0	34.4	410	69

The temperature increased steadily throughout the day, peaking around 26.4°C in the early afternoon and cooling by evening. The pH level fluctuated slightly, staying within the range of 6.8 to 7.2. The water level saw minimal variation, remaining between 33.9 cm and 34.7 cm. Light intensity increased significantly from the morning and peaked around noon, with lower readings in the evening. Humidity levels increased from morning to afternoon, peaking at 75% before decreasing in the evening.

The results show that the system maintains consistent environmental control, which is essential for optimizing the growth of the aqua-beans farm.

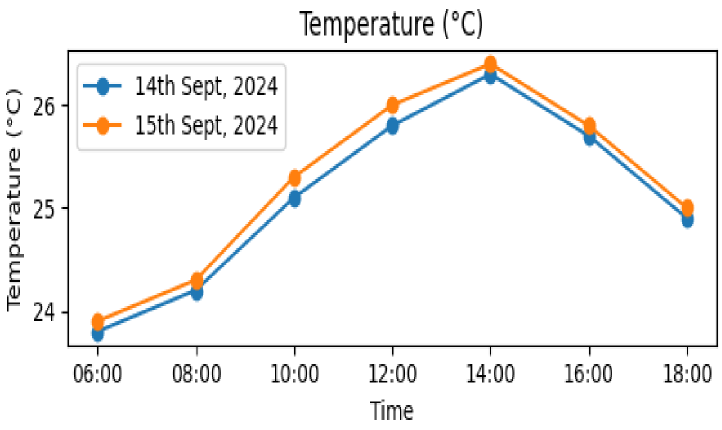

Figure 4: Graph of Temperature (°C) against Time

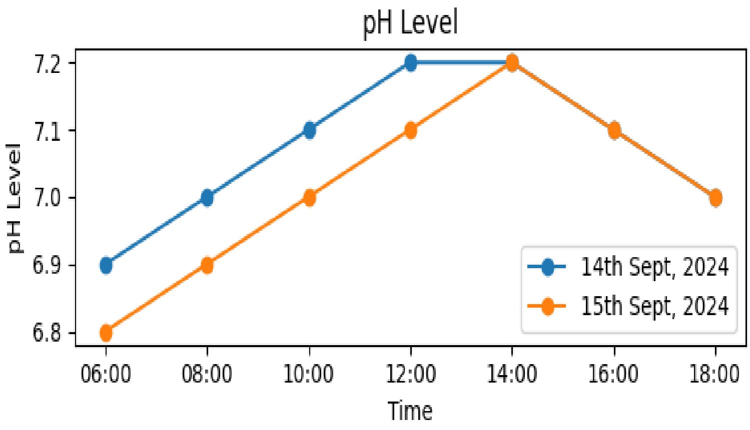

Figure 5: Graph of pH Level against Time

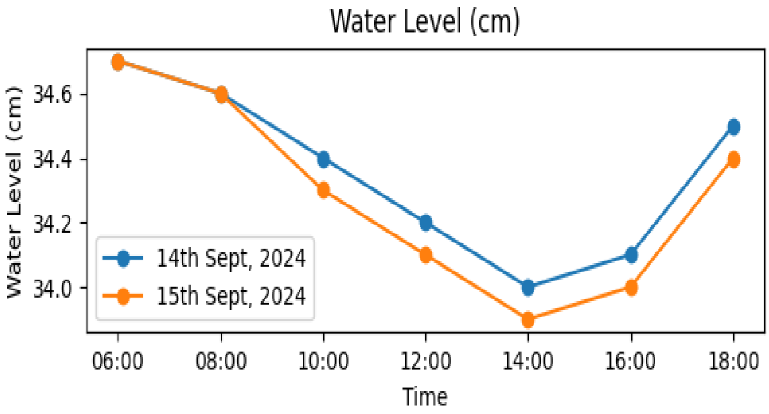

Figure 6: Graph of Water Level(cm) against Time

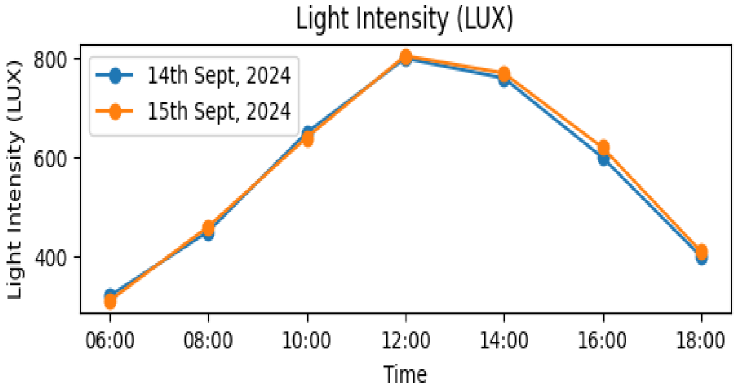

Figure 7: Graph of Light Intensity (LUX) against Time

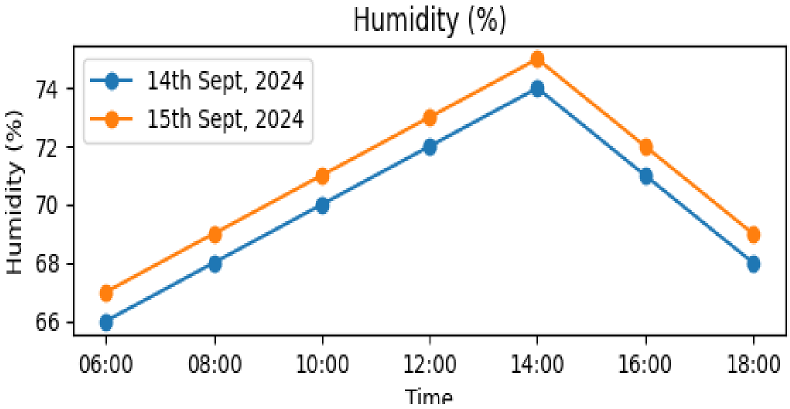

Figure 8: Graph of Humidity against Time

The integration of IoT in soilless farming offers numerous advantages, including precise control of environmental factors and real-time data-driven decision-making. By employing IoT-based automation, farmers can enhance crop yield, conserve water, and minimize labor costs. The successful deployment of Thinker.io enabled a seamless connection between hardware (sensors and actuators) and the cloud platform, creating an efficient and scalable system. The monitoring system's real-time feedback loop plays a critical role in maintaining a stable environment for both beans and fish, ensuring that growth conditions are consistently optimized. Furthermore, the system's ability to remotely control various aspects of the farm reduces the need for manual intervention, thus saving time and labor. This project demonstrates the viability of integrating IoT with soilless farming techniques, particularly for crops like beans that require precise water and nutrient management. The implementation of IoT not only improves productivity but also promotes sustainable farming practices by minimizing resource consumption.

CONCLUSION

This study presents the successful design and implementation of an IoT-based monitoring system for a soilless aqua-beans farm, demonstrating its capacity to automate environmental control within aquaponic systems. Utilizing an ESP32 microcontroller integrated with sensors for temperature, pH, water level, humidity, and light intensity, the system employed the Thinker.io platform for real-time data visualization and analysis. An automated feedback mechanism regulated environmental conditions through actuators such as water pumps and LED lights. Over a two-day monitoring period, the system maintained stable parameters conducive to the simultaneous cultivation of beans and fish, validating its operational viability within the project scope.

The study contributes to the growing field of precision agriculture by (1) advancing the integration of IoT technologies in closed-loop, soilless farming systems; (2) demonstrating the feasibility of remote environmental monitoring and control in resource-constrained settings; and (3) promoting sustainable urban agriculture through automation, reduced manual intervention, and improved resource management. These contributions are particularly relevant in the context of global challenges such as land scarcity and water limitations, where efficient and scalable food production models are essential.

Future research should extend the system's deployment over longer durations and varied climatic conditions to evaluate performance stability and scalability. To mitigate current limitations, further development is recommended to enable offline functionality and incorporate energy-efficient power solutions. Additionally, expanding the sensor network to include parameters such as dissolved oxygen or nutrient concentration could enhance the system's diagnostic precision and support the cultivation of a wider range of aquaponic crops.

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