IOT Based Aquaponics System for Sustainable Agriculture: A Review

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Abstract:

Automation and IOT are transforming hydroponic and aquaponic farming practices in Controlled Environment Agriculture (CEA), improving their sustainability, scalability, and efficiency. This review examines the integration of key technologies, including automated pH and nutrient management systems, advanced lighting options, and Internet of Things-enabled smart farming techniques. Although these innovations have drawbacks like high initial capital investment, technical complexity, and energy demands, they also greatly increase productivity, optimize resource use, and reduce reliance on labour. This article addresses scalability and energy constraints by examining case studies that show improvements in yield and resource efficiency. Technologies such as AI-driven analytics and off-grid power solutions are recognized as promising pathways to address these challenges. This paper primarily focuses on controlling the pH level of integrated farming using a IOT system.

Keywords: *IOT, Hydroponics, Integrated Farming, pH Levels*

1. Introduction

In India, we are following traditional farming, which is now a bad choice. But to overcome the land problem, there is farming in which we can produce both fish and vegetables in one land. Due to the use of IOT &robotics, we can cultivate both the products simultaneously. Hydroponics means plant cultivation without soil. Aquaponics means a combination fish culture as well as vegetable cultivation. In this a small area just like a small pond or small biofloc is used [1],[2]. The basic concept of this is fish are cultivated in the water, and the plants are cultivated the upper part of the pond.The plant utilizes the fish's nitrogenous waste as nutrients. The challenge lies in keeping the water's pH scale stable. The goal is to design a IOT system that will automatically adjust the pH of water. It is designed to include a carbon dioxide pump, an oxygen pump, a bio filter, and a pH indicator. It consistently keeps the pH level at 7, the neutral point. If the pH level is high, then it automatically turns on the bio filter for cleaning the tank & at a lower pH, the carbon dioxide pump turns on. If the pH level is lower than it turns off the bio filter & oxygen pump turns on to increase the pH [4]. In this manner, it helps keep the agriculture project going with minimal money. The future is for farmers with less acreage. They may undertake multipurpose farming to get more money and sell it in their local market to make more money [1],[3].

This research presents a novel smart aquaponics system designed to overcome the limitations of traditional setups. The system provides real-time monitoring and environmental control through automation, renewable energy, and Internet of Things (IOT) technologies.Significant advancements include solar tracking systems for efficient energy use, movable grow beds for optimal sunlight exposure, and automated fish feeding via Real-Time Clock (RTC) modules. 90% water efficiency, significant energy savings, and improved resource management were all demonstrated by the system during testing. Because of its modular and scalable architecture, this solution is perfect for urban farming and sustainable agriculture [10].

This study entails the design and execution of a compact, automated aquaponics system tailored for constrained urban settings, such as condominiums. The system is 43 cm x 60 cm x 80 cm and has advanced monitoring and control features that let you see data right away and change important things about the environment. It can do things like turn on lights, mist, and feed fish on its own because it has an Arduino microcontroller. It keeps track of the pH levels, the water level, the humidity, and the temperature of the air. The device has its own LED growth lights and a micro-SD card slot for saving files. These things help fish and plants grow as well as they can. Tests that last five days show that the system keeps the pH level, water temperature, and humidity in the right ranges. The pH level should be between 20°C and 26°C, and the humidity should be between 40% and 100%. This is good for fish and plants in the area. The research additionally indicated that a tilapia could increase in weight by an average of 0.67g daily and produce 150g of spinach within four weeks. This study shows how these technologies could be used more widely in urban farming to find sustainable ways to grow more food in small spaces [11], [12].

Due to urbanization, soil erosion, water scarcity, and environmental changes, it is getting harder to grow food in the old-fashioned way in many places and countries. Growing in popularity as a sustainable food production technique, aquaponics is a closed-loop method of growing fish and plants. Fertilizing plants with fish feces, can save 90–95% of water. Because of its complexity, it requires interdisciplinary knowledge, close attention to all significant factors, and significant upfront and continuing maintenance costs. Artificial intelligence (AI) and the Internet of Things (IoT) are two significant technologies that can assist with these problems [15]. Numerous recent studies have focused on the use of AI and the Internet of Things to automate procedures, boost dependability and productivity, enhance management, and reduce operating costs. However, these studies often focus on a limited number of system components, each accounting for different domains and factors of aquaponics systems. The objectives of this study are to summarize earlier research, identify the most cutting-edge IoT and AI applications, look into the key variables affecting growth, and assess the sensing and communication technologies employed [10], [12].

AI can do complicated predictive analysis, which lets farmers guess how much they will grow, spot diseases early, and plan the best times to plant. But its growth is being slowed down by ongoing problems with getting official recognition and organic certification. Carp and Nile tilapia are two examples of fish that can adapt and use water so well that up to 90% of it is used. Using IoT systems is important to make sure that nitrification works and that the water is clean. Industry 4.0 integration works, but it needs new ideas all the time because it is expensive and hard to do. Policies in horticulture and economies of scale can help it work better. It can work better with horticultural policies and economies of scale. Aquaponics is getting more and more popular all over the world, especially in places where water is hard to find. This is because it can help crops grow better while using less water and making less waste [13], [14].

Agriculture is a crucial field for the application of technologies created elsewhere, as well as the site of significant new technology development. IOT effects on the environment and economy are examined, as well as the political, social, cultural, and security ramifications of their introduction that haven't gotten much consideration in the broader agricultural robotics literature. Important policy decisions are outlined in order to maximize the social, environmental, and financial advantages of agricultural IOTS while also addressing the ethical issues that are anticipated to surface as their use becomes more widespread [15].

The use of Internet of Things (IoT) technology in aquaponics offers a modern, eco-friendly farming technique by enhancing crop productivity and fish health through automation and real-time monitoring. This data is processed by a centralized control unit, which uses machine learning algorithms to automate crucial processes like water circulation, aeration, and nutrient delivery. This reduces human intervention while increasing efficiency. Compared to traditional farming, it uses less water and doesn't require chemical fertilizers. The system is a feasible option for the future of smart agriculture because of its advantages, which include enhanced food security, less environmental impact, and higher productivity [16].

The term "biomimicry" refers to the way in which individuals have exploited nature as a source of inspiration to address a range of issues. Furthermore, a significant amount of food, ~24 %, is lost before it is consumed, in part due to subpar quality and drawn-out supply chains [17], [18]. Vertical farming (VF) is increasingly being seen as a solution to these problems. It utilizes vertical space instead of expanding horizontally, thereby reducing the burden on conventional farmland. A substitute for conventional farming that offers opportunities to improve sustainable food production, considering the escalating problems caused by population increase and climate change [17].

A thorough literature review is carried out, demonstrating the foundations of aquaponics and its essential elements, including grow beds, fish tanks, and biological filters. Technological innovations are analyzed, such as new growing methods, automation, integration of renewable energy sources, and sophisticated monitoring and control systems. Aquaponics' sustainable infrastructure is examined, with particular attention paid to material selection, energy efficiency initiatives, water management techniques, and integration with urban agriculture [19]. The global problems of climate change, resource scarcity, and population growth are getting worse, and the agricultural landscape is at a very important point in its history. This summary provides a thorough analysis of AI's possibilities, challenges, and potential role in sustainable agriculture [21]. It talks about how these technologies are making decisions easier, automating tasks, and using more resources. This review offers new perspectives on establishing a strong foundation and exploring specific research avenues to facilitate the incorporation of AI technologies in sustainable agriculture for a resilient and enduring future in the agricultural sector [20]. Aquaponics is a new, smart, and eco-friendly way to grow vegetables that uses both hydroponics and aquaculture (fish farming) to do so. Aquaponics can grow healthy organic vegetables with little use of chemical fertilizers and water if done correctly. A lot of research has gone into making this technology a new precision technology and using it in a way that works and is reliable at large commercial sizes. Improved technological management requires that every part of aquaponic systems be monitored and controlled using the Internet of Things (IoT) and smart sensing technologies [21],[22].

A promising approach to addressing global food security is aquaponics, which involves the symbiotic production of fish and plants. Even while aquaponics helps recover nutrients, reclaim water, and utilize less freshwater and land, it is still quite difficult. However, the performance of these systems can be enhanced by recent developments in novel system designs, biofilter media, micro-nanobubble technologies, algal co-cultivation, and system automation in conjunction with robotics, artificial intelligence, and the Internet of Things. This paper attempts to offer a thorough framework for developing aquaponic systems and suggests possible avenues for future breakthroughs by discussing existing knowledge gaps in system function, technical integration, and microbiome comprehension [23]. The Aqua Robotics Urban Farm System is a cost-effective and energy-efficient method of growing flowers, vegetables, or plants naturally without the need for soil or other nutrients. Fish and plants work together in a cyclic system to create the aquaponics system. The first of the six objectives is to automate the fish feeder, which is made feasible by a sensor known as a servo motor. The second objective is to use a regular water supply to provide fish excrement to the plants. Additionally, this water has every nutrient a plant may require. Since this is indoor plant farming, the third objective is to employ LED grow lights rather than sunshine [9],[24].

2. Literature Survey

A literature survey has been conducted to comprehend the role of IOT in sustainable aquaponics agriculture and the various models derived from this type of agriculture. Due to the growing number of people on Earth, humans are confronted with significant issues. The primary issues are essentially food and the scarcity of land for habitation. In India, we are adhering to traditional farming methods, which is now an unwise decision. To solve the issue of land, we can engage in farming that allows to produce both fish and vegetables on the same plot.

S. No.	Author(s)	Title of Paper	Key Content / Focus
1	Muhamad Farhan Mohd Pu'ad, Khairul Azami Sidek, Maizirwan Mel	Automated Aquaponics Maintenance System	Discusses an automated aquaponics system aimed at reducing workforce requirements. The system includes LED control and pH monitoring, making it self-sufficient. Highlights the integration of hydroponics and aquaculture, where fish farming and plant cultivation coexist on the same land.

2	R. P. Defa, M. Ramdhani, R. A. Priramadhi, B. S. Aprillia	Automatic Controlling System and IoT-Based Monitoring for pH Rate on the Aquaponics System	Presents an IoT-based automated control system to maintain optimal water pH (6.5–7.5). Emphasizes nutrient recycling where plants utilize fish nitrogenous waste. Focuses on benefits for small-scale farmers through efficient, multipurpose farming.
3	Simon Goddek, Boris Delaide, Utra Mankasingh, Kristin Vala Ragnarsdottir, Haissam Jijakli, Ragnheidur Thorarinsdottir	Challenges of Sustainable and Commercial Aquaponics	Analysis opportunities and challenges of aquaponics as a sustainable food production method. Highlights water processing as a major challenge and discusses system components such as oxygen pumps, CO_2 control, biofilters, and pH regulation maintained near neutral (pH ≈ 7).
4	Leopoldo G. Mendoza-Espinosa, Liliana Cifuentes-Torres, Gabriel Correa-Reyes, Liliana Cifuentes-Torres	Can Reclaimed Water Be Used in Aquaponics for Long-Term Food Production?	Explores the feasibility of using reclaimed water in aquaponics systems. Focuses on nutrient recycling and reduction of nitrogenous waste. Notes limitations, indicating suitability mainly for decorative fish and plants, and stresses the importance of linking reclaimed water with appropriate growing media.

3. Concept / Design

Many various agricultural robots are attempting to assist in the solution to our fundamental dilemma of organic agriculture that is sustainable. However, no research has been done on integrating robots to tackle global food or agricultural deficiency while also achieving maximum agricultural efficiency. The purpose of this research is to develop a IOT capable of monitoring pH and ammonia levels in aquaponics systems. Aquaponics is a technique in which the waste from a fish tank produces ammonia. Bacteria convert ammonia into nitrites, which are utilized as a fertilizer for plants.

The water is subsequently filtered and returned to the fish tank by the plants [5],[6][19].

Aquaponics will be used on an industrial scale, with extraordinarily high production rates and all crops being organic. Aquaponics does not utilize a lot of chemicals or fertilizers. The nitrites produced by ammonia are the only nutrients available to the plants [18]. This indicates that the food produced through aquaponics is more nutritious, and if these techniques were adopted on a larger scale, the quantity of food collected could potentially sustain the entire planet. Increases in ammonia levels are one of the concerns that can arise in aquaponics. Ammonia levels in the aquarium could rise to lethal levels, killing the fish. Because they will be utilizing deadly ammonia as fertilizer, this will also destroy the plants [6], [8], [26]**.**

By assisting with pH and ammonia dispersion, the IOT created in this study reduces the possibilities of mistakes occurring during aquaponics farming. The idea behind the robot is to design a waterproof device that consists of a carbon dioxide pump, an oxygen pump, a biofilter, and a pH indicator. The ammonia (NH3) used serves as the base. As a result, we know that when the pH level goes beyond 8.5, the ammonia concentration in the fish tank is high. If the pH level exceeds acceptable limits, the robot will turn on the biofilter to clean the tank and activate the carbon dioxide pump to reduce the pH level. When the pH level falls below an acceptable limit, the oxygen pump turns on and the biofilter deactivates to raise the pH level. The use of nitric acid, muriatic acid, and phosphoric acid can all help lower pH levels. This robot will help keep the pH level within a specific range to ensure the fish and plants on the aquaponics farm can coexist and achieve harvesting goals. The use of precision robotics in aquaponics farming decreases the maintenance required for operation and enhances the success rates of plant and fish development [5], [7],[25].

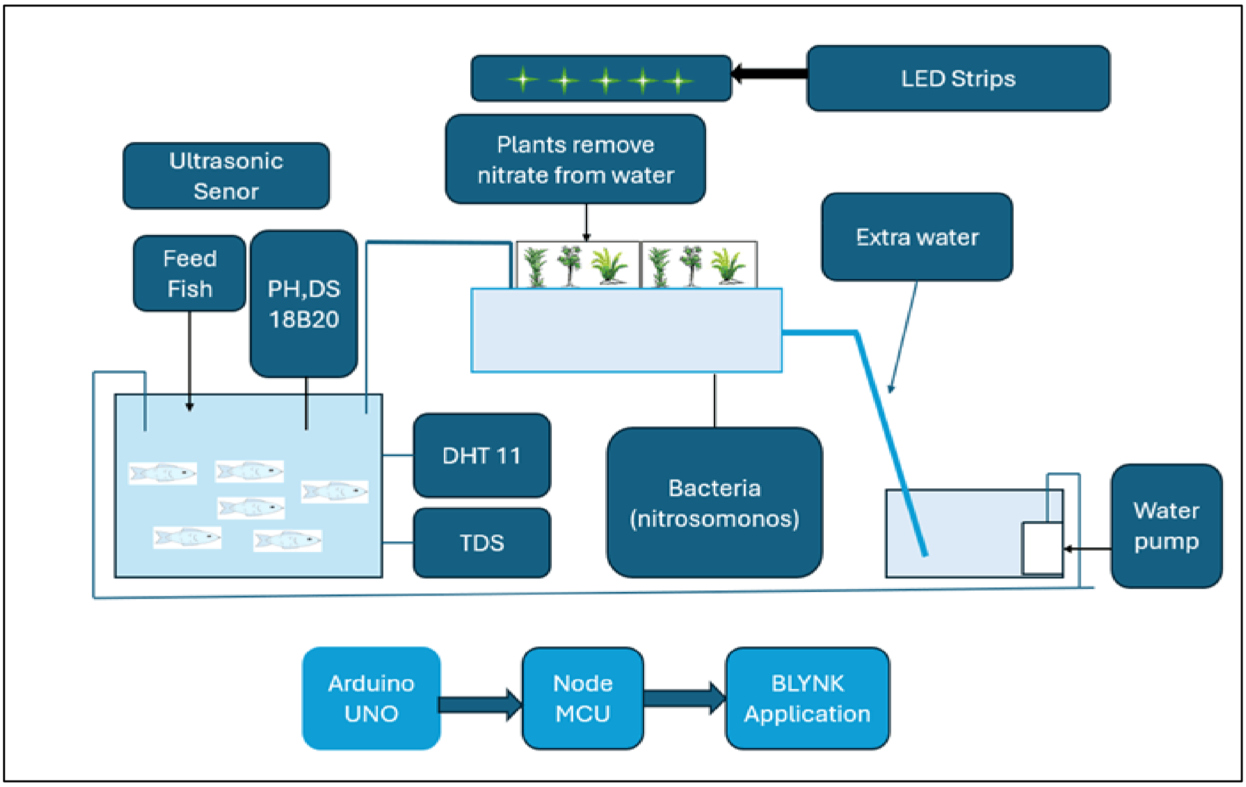

Fig. 1. Hydroponic System Integrated [30].

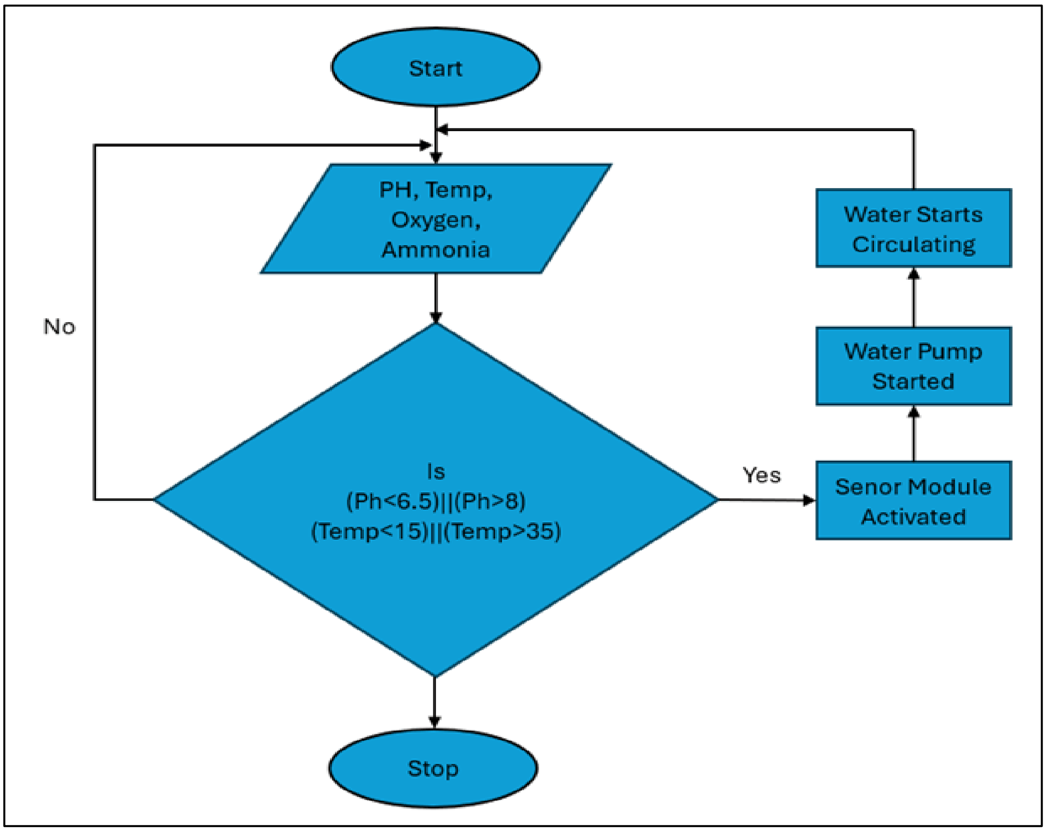

Fig.2.Flowchart of working principle

According to the flowchart, setting up the system is the first step. This is when sensors start to pick up on vital things like pH, temperature, dissolved oxygen, and ammonia levels. The data that was collected is transferred to a data server for storage and shown on the monitoring interface right away. The system then compares the sensor readings to values that have already been specified. The sensor module turns on when the pH level drops below 6.5 or rises above 8.0, or when the temperature drops below 15 °C or rises above 35 °C. This means turning on the water pump to keep an eye on the system. The method maintains an eye on things on its own if all the parameters stay within the allowed range. This automated feedback system keeps the water quality and the environment at their best all the time, which is good for the plants and fish in the aquaponic system.

4. Hardware And Software

4.1 Arduino IDF:

The Arduino Integrated Development Environment (IDE) is a free and open-source platform that many people use to write code and send it to microcontroller-based systems. It works with the C and C++ programming languages and comes with built-in libraries, debugging tools, and a Serial Monitor for seeing data in real time. The Arduino IDE makes it easy to connect various sensors and actuators in aquaponic systems, allowing for monitoring of key factors such as water temperature, pH, dissolved oxygen, and nutrient levels. It works with modules like the ESP32 and ESP8266, which lets you send data wirelessly and operate things from a distance. This makes it a great tool for building automated and IoT-enabled aquaponic systems [29],[30].

4.2Ultrasonic sensors:

Ultrasonic sensors work by sending out high-frequency sound waves and detecting how long it takes for the echoes to return after hitting an object. This lets them calculate distance very accurately, just like sonar. These sensors usually run on 5V DC and work at frequencies higher than 20 kHz. They can be readily connected to microcontrollers like Arduino. They are often used in aquaponic systems to keep an eye on water levels and make sure that tanks are circulating properly. Ultrasonic sensors are a good choice for automated aquaponic systems since they can measure without touching anything, are reliable, and are resistant to dust and moisture [29].

4.3 Temperature sensors:

The DS18B20 waterproof temperature sensor is a digital sensor that can properly measure temperature in wet and watery areas. The stainless-steel probe makes it sturdy and keeps water out, so it's great for aquaponics. It employs the 1-Wire communication protocol, so it doesn't need a lot of wire and can connect to microcontrollers like Arduino easily. The sensor can measure temperatures from −55 °C to +125 °C with an accuracy of ±0.5 °C. It is a cost-effective, scalable, and efficient way to keep a check on the temperature in automated aquaponic systems since it consumes so little electricity and can connect several sensors to one data line [30].

4.4 Servomotor:

Servo motors are precise actuators that can control speed, position, and torque with great accuracy. They have a motor, a feedback sensor such as an encoder or potentiometer, and a control circuit that reads pulse-width modulation (PWM) signals from a microcontroller. Servo motors usually work with 5–12 V DC, which makes it easy to connect them to platforms like Arduino. In aquaponic systems, they are typically used to automate used for valves, control feeders, and control the flow of water. They are great for smart and automated aquaponic applications since they are small, use little power, and have a solid feedback system that lets you regulate motion very accurately.

4.5 Aerator:

Aquaponic systems need aerators because they preserve the proper amount of dissolved oxygen in the water. This is critical for both fish respiration and plant root health. They function by adding air to the water, which facilitates gas exchange and gets rid of carbon dioxide and other harmful gasses. In aquaponics, two typical types of aerators are diffused and surface aerators. They make sure that the system gets enough oxygen. Aerators discourage water from standing still and encourage aerobic bacteria to flourish. This helps with nutrient cycling and the overall stability of the system. They are a vital feature of sustainable and automated aquaponic systems since they require less energy and can run on either solar or electrical power [29].

4.6 pH sensor module:

The pH sensor module is a crucial aspect of aquaponics systems to keep balance and running smooth. It is used to check the acidity or alkalinity of the water all the time. Maintaining the pH level in the proper range is highly crucial for the health of fish, the availability of nutrients, and the growth of bacteria in the system. The module normally has a glass electrode and a signal conditioning circuit that changes the analog signal into a digital form the Arduino can read. They are very sensitive, easy to calibrate, and can be used with IoT-based controllers.

5. Methodlogy

This method of aquaponics IOT starts with situating the sensors in the fish tank. Thereafter, the IOT is turned on and begins to take automatic measurements of the water's pH level. The IOT will act based on the outcomes of the water's pH level test. The water will be kept at a suitable level for aquaponics production by its oxygen and carbon dioxide pumps, as well as its biofilter. Aquaponics farms typically maintain pH levels between 6.8 and 7, which is favoured by certain fish species. The three components are fish, plants, and bacteria. Fish thrive in a pH range from the high 7 to the low 8 [27]. The farmer can determine the pH level range that will activate the IOT to increase or decrease the level. Ammonia levels are controlled to guarantee the plants receive ideal fertilization while preventing the death of both fish and plants. If the IOT malfunctions, the farmer has the option to manually take it out of the fish tank until the issue is resolved [4],[5],[7]**.**

6. Conclusion

As the twenty-first century presents us with worries and problems, innovation in robotics helps tackle challenges and discover solutions. As the world population increases, implementations of IOT applications seek to address the challenges by providing a solution for sustainable agriculture. Farms can utilize IOT in agriculture for managing and maintaining fields. This facilitates the management and upkeep of their farms for farmers; Nevertheless, it does not ensure that organic food is accessible to everyone globally. IOTs cooperate with the aquaponics farming system to effectively apply ideas aimed at providing sufficient organic crops for the whole planet. With this system's incorporation of robots, overseeing and servicing the aquaponics farm is simplified. With the help of maintaining pH and ammonia levels in the water, vegetable production in aquaponics farms that use robots is cost-effective and results in minimal damage to produce. This research aims for the IOT to prevent the pH and ammonia levels on an aquaponics farm from becoming harmful. In an era of growing populations, IOT aids us in achieving a vital, eco-friendly agriculture. This IOT supports the optimization of organic farming, enabling us to provide everyone with good organic food with minimal effort. A lot of the IOTs applications aimed at improving agriculture are still at the preliminary research stage.A suggestion to research IOTS & robotics, that can assist in the effective and exact harvesting of crops from an aquaponics farm, will help the aquaponic farm improve and develop.

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