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A Monitoring System for Aquaponics Based on Internet of Things

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ABSTRACT

Finding suitable water sources for fish and plant cultivation appears to be difficult. In addition, land scarcity is decreasing agricultural productivity, so it is crucial to combine land and water conservation technology with various vegetable varieties for optimal yields. Aquaponics is a sustainable farming method that combines aquaculture and hydroponics. This water system must regularly circulate through the growing medium to provide the plants with nutrient-rich, filtered water. This research develops a smart aquaponics system that uses a mobile application accessible via the internet to control and monitor acidity, water level, water temperature, and fish nutrition. In this system, sensors are installed to collect data, which is then sent to the Ubuntu IoT Cloud server, which can be accessed in real time over the internet. So as to preserve the purity and circulation of water. In this study, the waterlevel sensor has a 100% measurement success rate, the pH sensor has a 93 % measurement success rate, and the temperature sensor has a 96% measurement success rate. The temperature and pH range of the pond water are optimal for aquaponics at 25 to 35 degrees Celsius and 6,5 to 7,5, respectively, and the aquaponics monitoring system is functioning properly. A suggestion for future research is the development of an aquaponic system that can be modified based on the type of plant and its nutritional requirements.

Keywords: *Internet of Things, Aquaponics, monitoring system, fish and Plant Growth*

1. INTRODUCTION

According to agricultural statistics from 2016, agricultural land is converted from food production to non-food production every year. Due to the increasing number of settlements and industries, Indonesia's land area is decreasing as a result of its growing population. In Indonesia, agricultural land is converted to non-agricultural land at a rate of 100,000 hectares per year [1][2]. The demand for land for urban expansion exceeds the supply of land, resulting in the loss of agricultural land and a decrease in land area. Some parties involved in land clearing may be ignorant of the significance of agricultural land, such as rice fields. In addition to their economic use as a buffer for food needs, rice fields serve vital ecological functions, such as water management and carbon sequestration [3]. Hydroponic cultivation techniques combined with water recirculation from fish cultivation to plant cultivation is one of the most recent technological advancements in plant cultivation to combat the current phenomenon in land usage [3].

Aquaponics is a symbiotic system that permits aquatic organisms and plants to coexist in a closed loop. Plants use the nutrient-rich waste by product (Ammonia) produced by aquatic animals as fertilizer. Ammonia is converted to nitrite by nitrifying microorganisms (Nitrosamines) [4]. The nitrite is converted to nitrate by another nitrifying microorganism (Nitro-bacteria). The water becomes rich in nitrates, which are food for plants but are toxic to aquatic animals. In a grow medium containing a constant supply of this water, plants are grown. The plants gradually assimilate the nutrients, thereby decreasing or eliminating the water's toxicity, which was harmful to the aquatic animal [5]. The cycle continues as the now-clean water is returned to the aquatic animal environment [6]. Thus, this nutrient removal not only cleans or improves the water quality for aquatic organisms, but it also reduces the total amount of water consumed. External water is added to compensate for water lost through transpiration and absorption by plants. This system involves multiple mechanical and biological processes, including heating, pumping, filtering, etc. Data analytics and sensor technology enable the establishment of optimal conditions for both plant and fish units, thereby ensuring high productivity and optimizing resource utilization [7].

Through decades of research, the basic form of aquaponics has evolved into contemporary food production systems. In the 1980s, most early attempts to combine hydroponics and aquaculture were unsuccessful. Bio-filtration and the identification of the optimal fish-to-plant ratios led to the development of closed systems that permitted the recycling of water and nutrient accumulation for plant growth during the 1980s and 1990s. In its early aquaponics systems, researches demonstrated that only 5 percent of the water used in pond culture for plant growth was used in an integrated system [8]. This invention, along with other significant initiatives, demonstrated the compatibility of integrated aquaculture and hydroponic systems for the cultivation of vegetables and fish, particularly in arid and water-scarce regions. Although aquaponics has been used since the 1980s, it is still a relatively new method of food production, with a small number of researchers and practitioner hubs with limited aquaponics experience [8].

According to a United Nations Food and Agriculture report, the aquaponics system has a number of flaws. The system is knowledge-intensive, and researchers around the world are attempting to make it more sustainable and efficient. Additionally, the system is costly to establish, energy- and resource-intensive, requires daily maintenance, and offers fewer management options than agriculture and aquaculture [9]. Typically, these systems can be replaced and managed by automating the system. This automated system consists of three sections: production process at the bottom, which includes sensors, actuators, hardware, etc.; enterprise resource planning systems for managing data, including Data-Acquisition system and Mobile-based Application; and production process at the top, which includes sensors, actuators, hardware, etc. The final section is a Photovoltaic System that uses renewable energy to make the system sustainable. These sections describe the informational characteristics of the automated system, including real-time, transmission, data-acquisition, and other requirements [10].

The objective of this research is to develop a smart aquaponics system based on IoT that will make farming simpler and more productive. This system is created by combining a real-time mobile application with an internet network, allowing the aquaponics system to be automatically controlled without the need for frequent direct observations.

2. LITERATURE REVIEW

The greatest obstacles in commercial aquaponics are multidisciplinary, necessitating additional knowledge in economics, finance, and marketing. These factors explain why this system is not utilized by large corporations and has not replaced conventional agriculture. Using appropriate eco-designs can reduce system performance and environmental loads while increasing economic benefits. Approaches LCC (Life Cycle Costing) and LCA (Life Cycle Assessment) can be used to collect environmental design information for a process. This analytical method permits computing the system's strengths and weaknesses prior to its actual construction [11].
In addition to aquaponics, there are several other farming methods, such as hydroponics and aeroponics. The primary components of a hydroponic system are the grow bed and the reservoir. The reservoir contains a nutrient solution, or water mixed with a variety of nutrients that are essential for plant growth in media beds. In contrast, grow beds contain the media and "cups" that hold the plants in place. Hydroponics necessitates a constant water supply change because nutrient solutions build up salts and chemicals in the water that can kill plants [12].
Aeroponics is a variation of hydroponics in which the plants are suspended, with their roots facing a sprinkler system connected to the main nutrient reservoir, rather than being grown in media-filled beds. A high-pressure pump, sprinkler, and timer constitute the aeroponic system. If any of these are damaged, the plant is susceptible to damage or death [13].
Aquaponics systems are superior to hydroponics and aeroponics systems. Aquaponics is a combination of hydroponics and aquaculture. Aquaculture refers to the cultivation of fish in a controlled environment, as opposed to fishing for wild fish or farming in the ocean. Hydroponics is soilless agriculture. Instead, plant roots are grown in a nutrient-rich solution that meets their water and mineral requirements. This plant can grow in the absence of a substrate, clinging to water pipes, or in an inert substrate such as gravel. Aquaponics combines this by using the nutrient-rich solution produced by the fish to water the plants, which then filter the water and return it to the fish.
Several numerical trade-offs are recommended for maximizing efficiency and productivity, as described below.

2.1 pH . Stabilization

In a cyclical system, pH is crucial for all living organisms, including fish, plants, and bacteria. The optimal pH for each individual organism varies. The majority of plants require a pH between 6 and 6.5. The optimal range for fish growth was between pH 7.0 and pH 9.0. Nitrifying bacteria have a pH greater than 7; Nitrobacter is 7.5 and Nitrosomonas is 7.0 to 7.5. The pH imbalance causes ammonia to accumulate in the system. Consistently maintaining the highest pH value possible will prevent ammonia accumulation. The optimal pH range for the system is 6.8 to 7.0 [14].

2.2 Nutrions Balance

Fish feed consists of assimilated feed, uneaten feed, soluble fish manure, and solid fish manure. Until they are converted to nitrites and nitrates by nitrifying bacteria, soluble impurities, especially ammonia and minerals, are most readily available [15]. Unconsumed feed and solid feces are broken down into ionic mineral forms that can be assimilated by plants. Minerals have varying levels of solubility and do not accumulate uniformly, which affects their concentration in water. The effluent is filtered externally and can be fed back into the hydroponic layer after being mineralized [15].

2.3 Pest and Disease Control

Conventional pesticides utilized in hydroponics cannot be utilized in aquaponics due to the risk of fish toxicity and the need for biofilm [16]. Maintaining nitrifying biofilms and other nutrient-dissolving microorganisms prevents the use of antibiotics and fungicides in aquatic environments for the control and removal of fish pathogens. In addition, antibiotics are not permitted for plant applications, so their use against fish pathogens in aquaponics systems should be avoided [17]. This constraint necessitates the development of innovative pest and disease management strategies for fish and crops that minimize negative effects on fish and desirable microorganisms.

2.4 Socio-environmental Challenges

Aquaponics addresses a number of ecological and social challenges, highlighting the significance of focusing on efficient and sustainable agricultural production methods [16].

3. METHODOLOGY

3.1 Smart Aquaponics System

Smart aquaponics system is the concept of integrating bio-integrated farming systems with internet-based electronic technology to create bio-integrated farming systems. This method is designed to utilize water from ponds or cultivation containers with additional feed nutrients as a source of nutrients or hydroponic growing media. This permits the evaluation of the efficacy and efficiency of plant nutrients and feed [9]. In this study, water spinach (Lactuca sativa L.) and CatFish were utilized. In this experiment, aquariums and modified pipes were used for agriculture.

3.2 Networked Things

There are numerous layered Internet of Things architectures (IoT). The first layer, perception, is responsible for reading and collecting data from the physical environment. The data will subsequently be utilized at the application layer. The perception layer is responsible for converting data into signals that are then transmitted across the network and interpreted by the application layer, such as when a convenience store uses barcodes. The barcode [10] contains information such as names, prices, and inventory.

3.3 Standard of Service (QoS)

Quality of Service (QoS) is a method for measuring the performance of a network to determine the characteristics and quality of service. QoS includes a variety of metrics, such as throughput, packet loss, and latency [11].

3.4 System Design

Figure 1 depicts the system architecture, which includes a microcontroller, sensors, Android and web interfaces, local display, backup water, pump, fish feeder, notification, and emergency source.

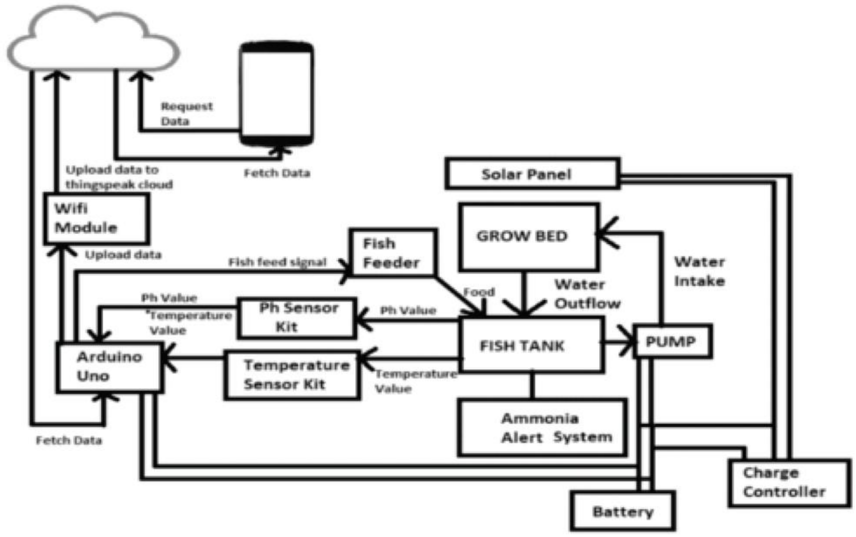

Figure 1. Aquaponics Monitoring System Design

4. RESULTS AND ANALYSIS

4.1 Water Level Sensor Testing

The purpose of this test is to compare the results of the waterlevel sensor's measurements with those of a ruler's manual measurements. This test also attempts to identify the error value derived from reading the waterlevel sensor in response to changes in the aquarium's water level. However, the results of waterlevel sensor testing are always working with no error.

4.2 Testing pH and Temperature Sensors

In this testing procedure, the probe of the pH meter sensor is immersed in water with varying acidity (pH) levels. The reading was noted for every week. Table 1 shows the test result.

Table 1. pH and Temperature

Week	pH	Temp (^{0}C)
1	7,5	25
2	7.1	30
3	6.8	35
4	6.5	32

Another test is intended to calibrate the pH sensor and determine the acidity of the aquarium or container's water. The sensor readings are compared using a digital pH meter. The water temperature sensor is attached to the pH sensor and used concurrently in the test. From the maximum error value for the pH sensor for the acidity (pH) meter was 12.37 percent and the minimum error value was zero percent, while the average error was 7.67 percent and the average success rate was 100 percent.

4.3 Smart Aquaponics Monitoring System

In this study, the IoT platform server Ubidots was utilized. The data transfer procedure to the Ubidots server is conducted over a WiFi network using a token-based account id. In this study, only one device with four variables was used. Then, all data received from NodeMCU is saved in a single variable. On the backend of the aquaponic IoT program is an ESP32 with multiple sensors, and on the frontend is a react application that will manage, control, and display data from the backend. On the client side utilizing the programming language JavaScript. On the client side utilizing the React Framework and serves as a controller of the microcontroller that transmits and receives sensor data signals.

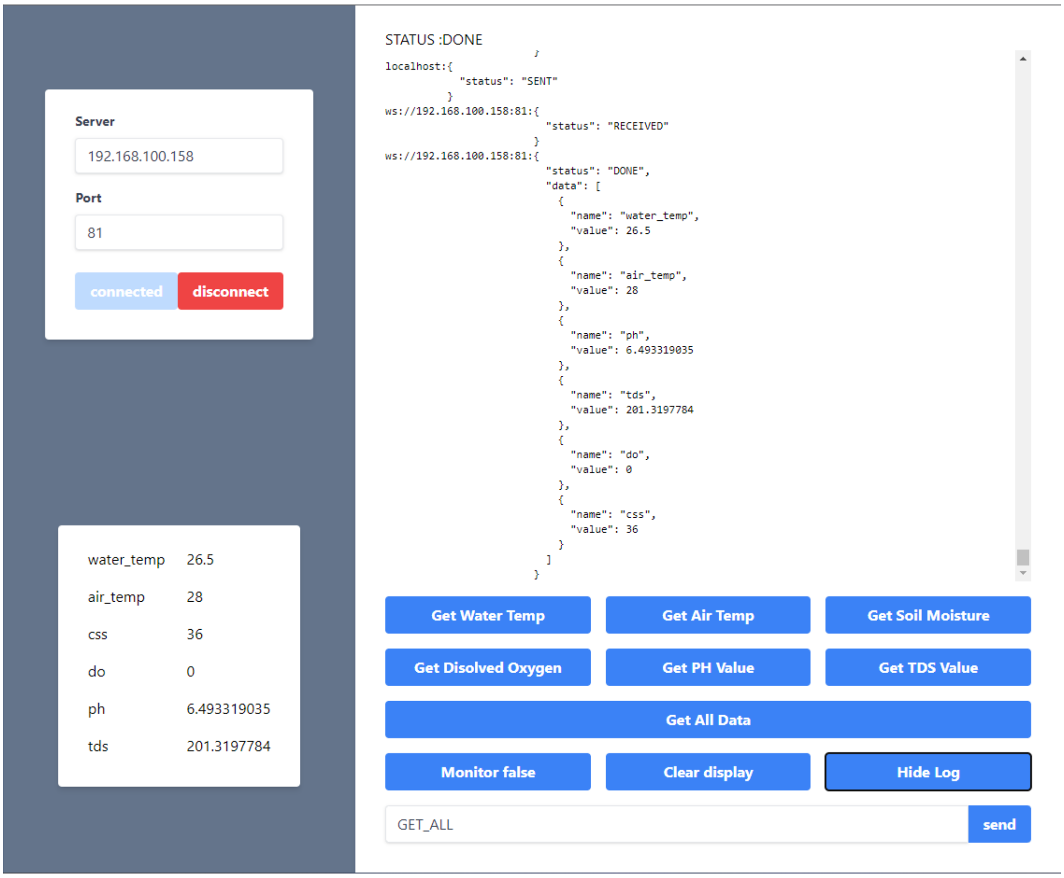

Figure 1. The Frontend of the Aquaponics Monitoring Application

4.4 Testing of Service Quality

Service Excellence In this study, throughput, latency, and packet loss are highlighted as important parameters. Each piece of sensor data transmitted to the server over a WiFi network will be evaluated based on these three attributes. The data is transmitted using a serial monitor, received by the server, and then manually analyzed for calculations. To determine whether a monitoring system is effective or ineffective, the calculation results are compared to the categories of each of the examined metrics.

4.5 Plant and Fish Growth

Table 2 demonstrates that the avarage of the water spinach growth was moderately sluggish, as evidenced by the emergence of a few leaves, and the plant height increased from 4 to 5 cm per week, reaching only 25 cm at 1 month. Due to the high temperature on Aceh, the growth of water spinach is stunted, and many water spinach plants perish from evaporation. According to Karsono et al., if the air temperature is high and evapotranspiration continues, plant growth will be inhibited (2003).

Table 2. Water Spinach and Catfish Growth

Week	Plant Growth (cm)	Fish Weight (gram)
1	5,1	4
2	12,2	12.2
3	18,3	22.2
4	25.4	35,5

Other than temperature, factors that can affect the production of fish manure include a water pH that is not optimal and that does not meet the needs of plants. During the four weeks, the number of leaves and plant height increased despite the increase in only one strand (see Figure 10). Figures 5 through 8 depict the growth of water spinach.

Figure 2. Aquaponics Fish and Plan

There were 50 CatFish placed in aquaponics, all of which were approximately one week old. There were three feedings a day (morning, afternoon, and evening). Table 2 depicts the growth of CatFish, with data indicating that the average growth of fish is healthy and continues to increase each week, with fish weight increasing by approximately 12 gram each week since the first week of rearing. In addition, with the exception of weight due to equipment limitations, fish body size always increases.

4.6 Discussion

Based on testing and research, it is clear that the sensor used has a high level of accuracy, with an average success rate of 100 % for waterlevel sensors 100% for pH sensors, and 97% for temperature sensors. Using a WiFi connection, sending and receiving sensor data to a server based on the Internet of Things is straightforward. The temperature of the plants and fish in the intelligent aquaponics system is between 25 and 35 degrees Celsius, the pH of the pond water is between 6.5 and 7.5, and the fish are fed three times daily. The network monitoring system of the smart aquaponic system has poor characteristics, with a throughput index of 1, a packet loss index of 4, and a delay index of 1. A suggestion for future research is the development of an aquaponic system that can be modified based on the type of plant and its nutritional requirements.

5. CONCLUSION

In this research project, a smart aquaponics system was designed and developed by integrating a data acquisition unit, an alarm unit, a system rectification unit, a central processing unit, a web application, a mobile application, and a cloud server. The proposed system can continuously monitor and control water quality, light intensity, and fish feed; automatically send early warnings via email, SMS, and push notification; and automatically correct system abnormalities, which make the aquaponics system intelligent and reduce human involvement in the system's maintenance.

Future work consists of:

1. Adding a dissolved oxygen sensor and a nitrate sensor to detect oxygen level and nitrate concentration level in the water,
2. Incorporating solar panels to harness solar energy to power the actuators, and
3. Providing live video streaming of the aquaponics system via the mobile application. Implemented on a large scale.

6. ACKNOWLEDGMENT

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