Low-Cost Solar Powered Automated Modular Aquaponic System

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***Abstract*—The expansion of urbanization has resulted in a reduction of available land for agricultural purposes. As a response, aquaponics has emerged as an environmentally friendly solution for local food production. By integrating aquaculture (fish farming) and hydroponics (soilless farming), aquaponics provides an opportunity for individuals without access to land to engage in farming and aquaculture activities. Traditional aquaponic systems typically require substantial space. However, these systems can be upgraded through adequate financial resources and offer enhanced flexibility. This study presents a compact aquaponics system that operates efficiently using solar panels as a sustainable power source. Unlike the traditional aquaponic system, which does not offer any automated monitoring features, this system incorporates automatic monitoring features facilitated by Arduino microcontrollers and sensors, achieving a remarkable accuracy rate of over 90% in maintaining optimal conditions. In conclusion, aquaponics is a viable solution for urban farming in the face of limited available land. The compact aquaponics system proposed in this study, powered by solar panels, and automated monitoring capabilities, exemplifies a scientifically rigorous and sustainable approach to agricultural practices.**

Keywords—Aquaponics, hydroponics, Sustainable Agriculture, Microprocessors, Automated Monitoring

I. INTRODUCTION

Agriculture is vital for development, but in the Philippines, it strains natural resources, particularly water and land, with over 80% of water use and 30% of land area dedicated to it. Urbanization worsens this by converting fertile land into urban areas. To combat these issues, aquaponics, a sustainable system combining aquaculture and hydroponics, has emerged. It minimizes resource usage, eliminates pesticides and fertilizers, and reduces environmental impact.

Traditional aquaponics has limitations like manual monitoring, power needs, inflexibility, and high costs. To address these, our proposed system automates monitoring and control, ensures proper fish feeding, uses solar panels for sustainable power, and offers an efficient, space-saving, modular design.

In summary, aquaponics offers a sustainable solution for resource-efficient agriculture. The proposed automated system addresses traditional aquaponics' limitations, enhancing productivity and sustainability in fish and plant production. [1] Inocencio et al. (2018); [2] Van Vliet et al. (2017); [3] Aquaponics integrates aquaculture and hydroponics; [4] Reduces land and water usage, eliminates need for chemicals; [5] Manual monitoring challenges; [6] Continuous power supply requirement.

II. REVIEW OF RELATED LITERATURE

Several researchers present the benefits of integrating an Aquaponic system in the community; in addition to that, many studies have been proposed to innovate or improve the traditional design and implementation of the system. This review focuses on how the system has been widely used and how it impacts the environment and the economy. Moreover, this review highlights the effectiveness and the need for integrating innovation into the different designs of an Aquaponic system. This review provides a fundamental entry point and understanding of how to implement innovations in the methodology and create the essential components and features for an Automatic Compact Modular Aquaponic System.

A. Aquaponics

In aquaponics, the nitrogen cycle is a crucial process facilitated by nitrifying bacteria, as explained by Duarte et al. (2015). This cycle converts fish waste into nutrients for plants, ensuring the water quality remains non-toxic for both fish and plants [7]. Maintaining a balanced environment is essential, including monitoring temperature, pH levels, and water levels. An ideal pH value of 7 is crucial for optimal system performance [8].

Additionally, regular feeding of fish and monitoring plants for pests is necessary. Chua & Chua (2016) highlighted the five key components in an aquaponic system: rearing tanks, solids removal tools, biofilters, hydroponics subsystems, and sump tanks [9]. These components work together to maintain system stability and facilitate the nitrification cycle. Various media types, such as rocks like Pea Gravel and Vermiculite, aid in water filtration as biofilters [10].

Maintaining the proper ratio between fish waste and nutrient consumption by plants is crucial, as emphasized by Chua & Chua (2016) [11]. Proper equipment like water pumps and pH measuring tools is essential for system operation [12]. Typical materials used in aquaponics systems include PVC plastic piping for connections and hard plastic containers for durability.

B. Monitoring System in Aquaponics

Water testing is crucial for maintaining good water quality in aquaponics systems, as emphasized by Masabni and Sink (2020) [13]. Monitoring parameters like pH level and nitrate during the initial two months and then regularly thereafter is essential for assessing the health of bacteria populations.

Bollinger et al. (2015) provide a method involving four test tubes to monitor pH level, ammonia, phosphate, and nitrite, highlighting the importance of tracking pH and ammonia levels [14].

While automated monitoring systems have advantages, they pose engineering challenges, as Oommen et al. (2019) explain, particularly when deploying sensor nodes in remote locations and ensuring long-term robustness and autonomy [15].

Murad Z. et al. (2017) offer a design using Arduino microcontrollers for aquaponics water monitoring, suitable for small-scale systems powered by batteries [16].

C. Automatic Fish Feeders

According to the study of Kishore et al. (2017), an automated fish feeding for aquaponics was developed in which the farmer would manage the boat using an RF transmitter which included a fish feeder capable of providing both solid and liquid feed as well as medication [17]. In a study by Akhilesh K et al. (2017), a Smart Fish Feeder, a GSM module, and a microprocessor were utilized to automatically feed the fish in specific periods [18]. A microcontroller was used to manage the to and from the motion of the motor in the research proposed by Dada et al. (2019), Arduino UNO Automatic Fish Feeder, so feeding was done only for that period [19].

D. Tilapia in Aquaponic System

Tilapia is one of the most common fish species cultivated in aquaponic systems, as mentioned in Advising's article (2022) [20]. They are known for their adaptability to various aquatic environments and are considered ideal starter fish for aquaponics due to their low maintenance requirements. However, successful Tilapia cultivation requires attention to certain factors. Tilapia can tolerate a wide temperature range, from 13°C to 35°C, but they become vulnerable if the temperature drops below 11°C. The optimal temperature for their growth falls between 3°C and 30°C. They exhibit resilience to pathogens and parasites and can handle stress well.

Regarding Tilapia enclosures, it's recommended to provide 3 gallons of water per pound of Tilapia, with fully grown Tilapia typically weighing around 1 pound or 0.45 kg (Eunice, n.d.).

E. Growing Lettuce in an Aquaponic System

In aquaponic systems, nearly all plants can be grown, but their success depends on various factors, as discussed in Vergeer's article (2022) [21]. The choice of plants is influenced by factors like location, system type, nutrient requirements, climate, and available space.

For beginners and small-scale systems, small leafy vegetables like Lettuce are recommended, as they require lower nutrient concentrations and are easier to cultivate, as highlighted by Gallagher (2022) [22].

Lettuce thrives when the water temperature is maintained between 70 and 74°F (21-23°C), which is also suitable for many fish species commonly used in aquaponics. The ideal pH level for growing Lettuce is between 5.8 and 6.2, but it can tolerate some pH variation.

METHODOLOGY

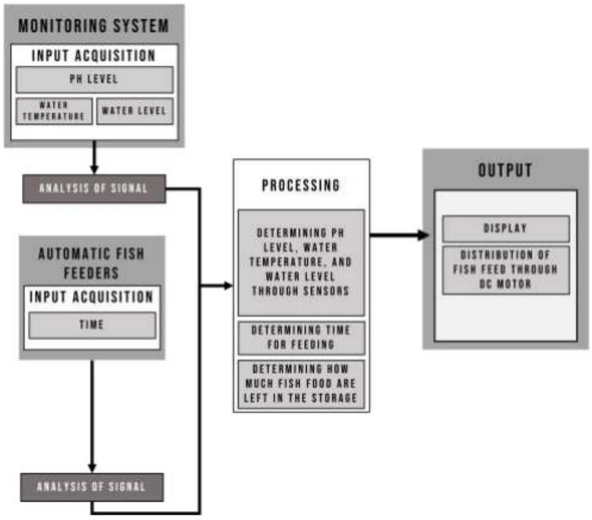

Figure 3.1. Conceptual Framework

A. Input Acquisition

Monitoring water quality in the aquaponics system involves factors like pH level, water level, and temperature. Meanwhile, the automatic fish feeders' operation depends on the feeding session duration and frequency, affecting the remaining fish feed in storage.

B. Processing

The microprocessor acts as the CPU, handling instructions and calculations. It's vital for receiving, interpreting, and generating output from sensor data during data processing.

C. Output

Processed data will be converted into user-friendly statistics using an LCD interface. These statistics will offer insights into water quality and notify when the fish feed container needs refilling.

III. TECHNICAL STUDY

Total Cost of the Design

The computation of total cost includes the cost of labor when hiring someone to assemble the system. Making the system yourself will save you approximately Php 1,000 based on the current labor rate.

Table 4.1. Total Cost of the Design

Item	Specific type	Price	Quantity	Total
Microcontroller	Arduino mega	₱549	1	₱549
pH sensor	SEN0161	₱2059.80	1	₱2059.80
Water temperature	W1209	₱73	1	₱73
Water level sensor	Water level sensors detection liquid surface	₱45	1	₱45
Solar panel	200 W	₱835.17	1	₱835.17
Battery	50 Ah lead-acid rechargeable battery	₱2,790	1	₱2,790
DC water pump	DC 800 L/H solar motor water pump	₱388	3	₱1,164
Aerator pump	Resun 18W Aerator pump	₱1,286	1	₱1,286
Displays	20x4 12C LCD module	₱244.76	2	₱489.52
Solar charger controller	NS-3301C	₱761	1	₱761
ATS	ATS 2P 63A 240V	₱818	1	₱818
Wall grid	Chicken wire	₱104	3	₱312
Wall planters	100 Pack Net Cups	₱302	100	₱302
Fish enclosure	30 gallons fish tank	₱1,200	2	₱2,400
Storing rack	3 layer storing rack	₱2,000	1	₱2,000
Inverter	Solar power inverter	₱999	1	₱999
PVC pipe	2 inch	₱612	5	₱3060
Neltex	Cement	₱120	3	₱360
PVC pipe	1/2 inch	₱160	1	₱160
Labor costs	Two days	₱1,000	1	₱1,000
Garden net	1 by 3 meters	₱289	1	₱289
PVC pipe elbows	2 inch pipe elbow	₱35	12	₱420
PVC pipe coupling	2 inch pipe coupling	₱35	7	₱245
PVC pipe cap	2 inch pipe cap	₱32	12	₱384
Lettuce seeds	Four season lettuce seeds	₱43.2	108	₱43.2
Total				₱22,844.69

Block Diagram

The control system for the Low-cost Solar-powered Hydroponics Water Quality Automation System involves input from various sensors like SEN0161/SEN0169, W1209, and a water level sensor. An Arduino Mega processes this data to make necessary system adjustments using servo motors. All data and adjustments are displayed on a 20x4 I2C LCD panel. Power comes from a 200W solar panel connected to an NS-3303C, which charges a 50 AH lead acid battery. The system can also switch to the electrical grid when solar power is insufficient using a Micro Circuit Breaker Dual Power Automatic Transfer Switch.

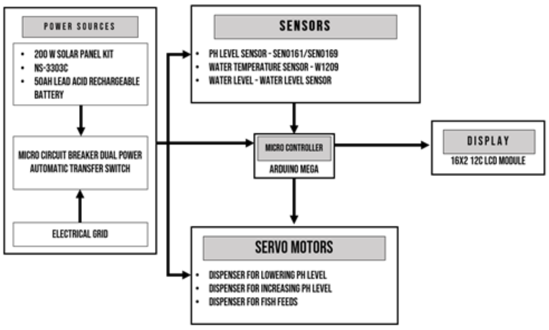

Figure 4.1. Block Diagram

Flow Chart

This section outlines the proposed system's functioning. After initialization, data is collected through sensors, and the system checks if adjustments are required for parameters (water level, temperature, and pH). It repeats this process until the parameters meet the desired levels. The data and adjustments are displayed on the LCD panel. This loop continues until the system is turned off.

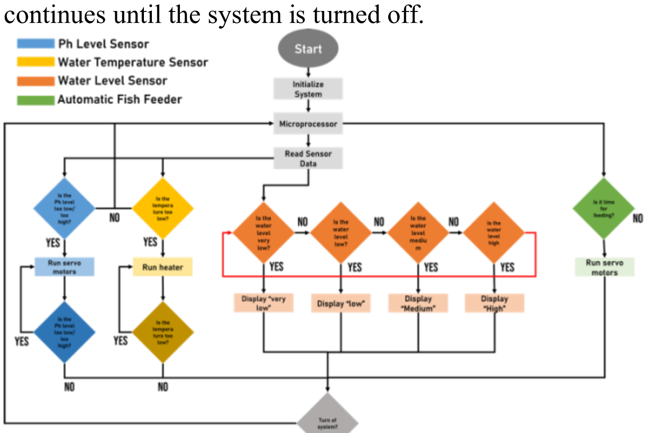

Figure 4.2. Flow Chart

Graphic User Interface

The project will use a 20x4 12C LCD module where all the information about the water quality condition is displayed.

Verification Plan

Sensor calibration was deemed necessary due to the possibility of slight discrepancies between the measured output of sensors in the system and the expected or actual output, particularly in the case of pH sensors. To enhance sensing performance and overall accuracy, calibration procedures were implemented.

Prototyping and Testing

A prototype is an early product version used to test and refine a design, making it more user-friendly and precise. It aims to provide specifications for a real, working system rather than a theoretical one. Researchers will construct and test a functional version of their proposed plan to assess its effectiveness. These trials will be run for approximately 1 to 8 hours, depending on the parameters needed to collect. The test's objective is to collect typical results for the water quality of the sampled water.

Return on Investment (ROI) of the Project

Table 4.2. Return on Investment

Fingerlings-focused Using Direct Electricity

Total Income per year	Total invesment	Return of Investment	Income in a year – total cost in a year
Php 112,800	Php 21,196.55	0.1879 years	Php 91,603.45

Fingerlings-focused Using Solar panel

Total Income per year	Total invesment	Return of Investment	Income in a year – total cost in a year
Php 112,800	Php 26,329.67	0.2234 years	Php 86,470.33

Fully grown Tilapia Using Direct Electricity

Total Income per year	Total invesment	Return of Investment	Income in a year – total cost in a year
Php 89,072.64	Php 21,196.55	0.2380 years	Php 67,876.09

Fully grown Tilapia Using Solar Panel

Total Income per year	Total invesment	Return of Investment	Income in a year – total cost in a year
Php 89,072.64	Php 26,329.67	0.2956 years	Php 62,742.97

Table 4.2 displays annual income calculations for two scenarios: selling fully grown tilapia or fingerlings. The data suggests that prioritizing fingerling production is more profitable in the short term when using direct electricity. However, over the long term, a solar-powered setup becomes more cost-efficient and profitable due to reduced electricity costs. It's important to note that focusing solely on fingerling production may not meet market demand unless you have more than four aquaponic systems to scale production accordingly.

IV. RESULTS AND DISCUSSION

This chapter presents the hardware and the test simulations of the Low-cost Solar Powered Automated Modular Aquaponic System. The results of this study are divided into two parts based on the research objectives: technical performance of the aquaponics system and parameter-controlling results. Additionally, the results of this study were presented to and verified by the Tanauan City Demo Farm.

Prototype

Figure 5.1. Prototype VS Revised Prototype

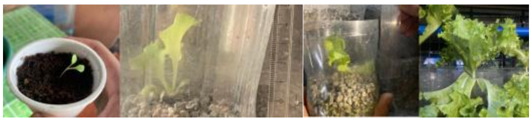

Figure 5.2. Lettuce growth progress

Figure 5.3. Fingerlings (2 weeks old) and Tilapia (6 months old)

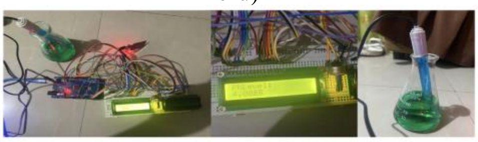

Figure 5.4. PH sensor Calibration

Figure 5.5. Water level sensor Calibration

Figure 5.6. PH controller

Technical performance of the Aquaponic System Accuracy

The Low-cost Solar Powered Automated Modular Aquaponic System was tested on the accuracy of the system regarding reading data. This test aims to compare the measured value from the sensor to the value acquired using the standard meter and reflect both values to the ideal value of each given solution.

Table 5.1. Parameter-reading data for pH Level

pH Level Sensor				
Solution	Sensor	Standard Meter	Ideal Value	Accuracy
Solution A (Tap Water)	7.8	8.2	6.5 - 8.5	95.12%
Solution B (Carbonated Drink)	3.1	3.4	2.5 - 3.5	91.18%
Solution C (Fabric Softener)	9.7	10	9.0 - 11.0	97%
Average Accuracy				94.43%

Table 5.1 shows the raw pH level data collected by the system's sensor and the standard meter. Based on the results for Solution A, the sensor has a reading of 7.8 pH level while the standard meter has a reading of 8.2. For Solution B, the sensor has a reading of 3.1 pH level, while the standard meter has a task of 3.4 pH level. Lastly, Solution C's sensor has a reading of 9.7 while the standard meter has a reading of 10 pH level.

Table 5.2. Parameter-reading data for Water Temperatures

Water Temperature Sensor			
Solution	Sensor	Standard Meter	Accuracy
Solution A (Tap Water)	23.5°C	24.45°C	96.11%
Solution B (Carbonated Drink)	5.2°C	4.8°C	91.67%
Solution C (Fabric Softener)	27.3°C	28.4°C	96%
Average Accuracy			94.59%

Table 5.2 compares the Water Temperature data from the system's sensor and a standard meter. In Solution A, the sensor reads 23.5°C vs. 24.45°C from the standard meter. In Solution B, the sensor reads 5.2°C vs. 4.8°C from the standard meter. In Solution C, the sensor reads 27.3°C vs. 28.4°C from the standard meter.

Table 5.3. Parameter-reading data for Water Level Sensor

Water Level Sensor			
Solution	Sensor	Standard Meter	Accuracy
Solution A (Tap Water)	19mm	20mm	95.00%
Solution B (Carbonated Drink)	29mm	30mm	96.55%
Solution C (Fabric Softener)	41mm	40mm	98%
Average Accuracy			96.52%

Table 5.3 compares Water Temperature data from the system's sensor and a standard meter. In Solution A, the sensor reads 19mm vs. 20mm from the standard meter. In Solution B, the sensor reads 29mm vs. 30mm from the standard meter. In Solution C, the sensor reads 41mm vs. 40mm from the standard meter.

Efficiency

The system was evaluated for power efficiency, specifically examining the solar panel setup's capacity to sustain the entire system.

As shown in Figure5.8, to charge a 40Ah lead acid battery, the computation would be (40Ah/7.5h) x 12V = 64W. Then, to allow for conversion losses, divide the computed value by 0.65, which resulted in 98.46W. Therefore, a 100W 18V solar panel will charge a 12V 40Ah battery in 7.5 hours or less.

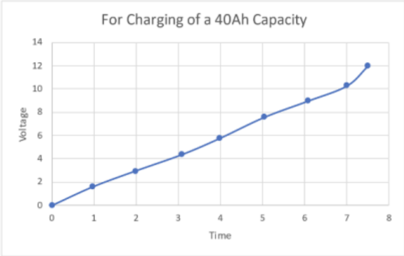

Figure 5.7. Battery Charging without any load

A lead acid battery should be at most 25% of its capacity given that it has a total of 40Ah; only 30Ah will be used to prolong the battery life. The device on the system consumes 7.11A. The computed battery life is about 4.219 hours using the battery life formula. This is shown in Figure 5.9.

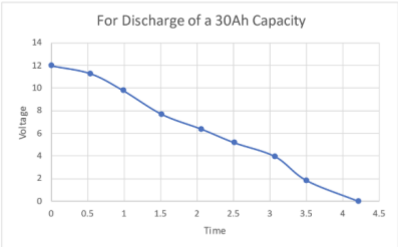

Figure 5.8. Battery discharge without any load

Reliability

The Low-cost Solar Powered Automated Modular Aquaponic System was assessed for its reliability in controlling observed parameters by testing its algorithm in various possible scenarios.

Table 5.4. Reliability of the System on Adjusting pH Level

pH levels			
Case	Trial 1	Trial 2	Trial 3
pH level = 5.5 - 6.5	no servo motor worked	no servo motor worked	no servo motor worked
pH level = >6.5	Servo motor worked (pH down)	Servo motor worked (pH down)	Servo motor worked (pH down)
pH level = < 5.5	Servo motor worked (pH up)	Servo motor worked (pH up)	Servo motor worked (pH up)

Table 5.4 shows the reliability of the system in adjusting the pH Level. It presents three scenarios that result in different operations that will happen when the detected pH level is within or below the range of the Ph level in the given scenario.

Table 5.5. Reliability of the System in adjusting water temperature

Water Temperature			
Case	Trial 1	Trial 2	Trial 3
Temperature = 21 - 25°C	no heater worked	no heater worked	no heater worked
Temperature = < 21°C	heater initiated	heater initiated	heater initiated

Table 5.5 shows the system's reliability in adjusting the water temperature. It presents the operation when the detected temperature is above or below the set range of maintaining the recommended water temperature.

Table 5.6. Reliability of the automatic fish feeders

Fish Feeders			
Feeding Time	Trial 1	Trial 2	Trial 3
Morning	Servo motor worked	Servo motor worked	Servo motor worked
Afternoon	Servo motor worked	Servo motor worked	Servo motor worked
Evening	Servo motor worked	Servo motor worked	Servo motor worked

Table 5.6 shows the system's reliability in initiating the automatic fish feeders during 3 feeding sessions.

Table 5.7. Tabulation for Testing the System's Reliability

Operation	Number of Cases	Number of Trials	Number of Correct Operation	Number of Incorrect Operation
Adjusting pH level	3	3	9	0
Adjusting Water Temperature	2	3	6	0
Automatic Fish Feeding	3	3	9	0

The system demonstrates good reliability in controlling key parameters and triggering automatic fish feeders accurately. The table records instances each with 2-3 scenarios.

For pH control, when the pH exceeds 6.5, a servo motor dispenses a small amount of vinegar to lower it. When it drops below 5.5, another servo motor adds baking soda to raise it. In the ideal pH range, no adjustments are made.

Regarding water temperature, if it falls below 21°C, a heater activates to warm the water. Automatic fish feeders dispense food in the morning, afternoon, and evening, aligning with ideal feeding times for Tilapia.

Results Comparison of Testing with the system and without the system

The Low-cost Solar Powered Automated Modular Aquaponic System was tested compared to a non-automated system. This was identified to give grounds for the system's performance in controlling the parameters.

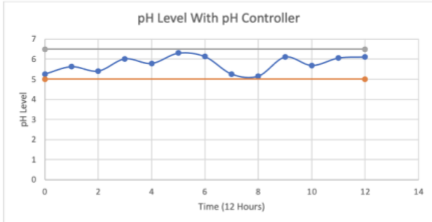

Figure 5.9. pH Level Time Graph for aquaponics with the system

Analyzing the presented data in Figure 5.14, the system maintained the pH level of the solution within the ideal range.

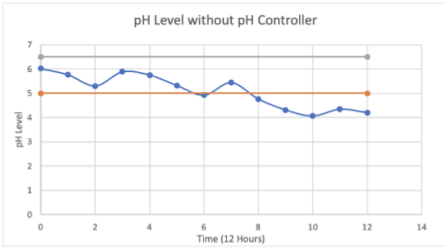

Figure 5.10. pH Level Time Graph for aquaponics without the system

Figure 5.11 shows the decreasing pH level within a specific time range. Since the system consists of several fish, the pH level of the water gradually decreases over time.

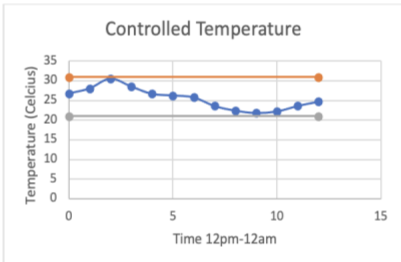

Figure 5.11. Water Temperature Time Graph for Aquaponics with the System

The system maintained the temperature level of the water within the ideal range, according to the test results. As shown in Figure 5.16, the system increased the temperature level when it fell below 22°C and decreased when it reached 30°C.

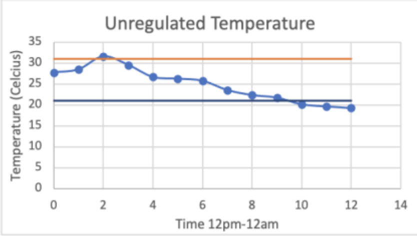

Figure 5.12. Water Temperature Time Graph for aquaponics without the system

Observing the temperature levels in Figure 5.17, the values gradually decrease. Based on the findings, it can be stated that using a heater and an actuator can regulate the system's temperature requirements.

V. Conclusions and Recommendations

Conclusions

Following extensive testing and data collection, the project successfully designed an aquaponic system costing under Php 25,000. This system effectively monitors and controls critical water quality parameters - pH level, temperature, and water level - using a microcontroller. Additionally, it incorporates an automatic fish feeder to dispense the appropriate amount of feed for the fish. A solar panel integration generates ample energy, stored in batteries, to power the system throughout a full day of operation. Notably, the system achieves over a 90% accuracy rate in monitoring water quality.

Recommendation

After conducting the study titled Low-Cost Solar-Powered Automated Modular Aquaponic System, the proponents recommend exploring cost-effective component alternatives, incorporating features which makes the system more user-friendly, adding a rainwater catcher for sustainability, testing compatibility with different species of plants and fish, and considering indoor installation and layout variations to expand the system's versatility.

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