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Portable Filtration with Solar Photovoltaic-Powered IoT-Based Water Quality Monitoring System for Aquaponics

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Abstract: This paper introduces a solar-powered portable filtration system and an Internet of Things (IoT) based water quality monitoring setup to elevate traditional aquaponics into intelligent ecosystems. The filtration scheme addresses noxious elements like ammonia, pH fluctuations, and particulate pollutants that can harm fish and plants. It employs a three-stage process encompassing radial flow, mechanical, and biological filters. Yet, the maintenance demands of the mechanical filter led to the creation of a portable substitute. Simultaneously, an IoT water quality monitoring system is indispensable for real-time assessment of parameters like dissolved oxygen, pH, total dissolved solids, turbidity, and temperature. Notably, the portable filtration system demonstrates substantial efficacy, correcting pH levels from 6.07 to 7.21, reducing concentrations from 105 ppm to 70 ppm, and ameliorating water clarity. Calibration of IoT sensors highlights precise temperature measurements (±0.5°C), accurate total dissolved solids (TDS) readings for both soap water (13000 ppm) and plain water (77 ppm), and well-aligned turbidity measurements for varying water densities. The system design emphasizes user-friendliness, cost-efficiency, and sustained effectiveness, rendering it versatile for diverse agricultural and aquacultural applications. By combining solar energy and IoT technology, this innovation enhances control, sustainability, and the overall vitality of aquaponic environments. The solar-powered PonicsMon prototype showcases a viable battery charging duration of approximately 17.28 hours, solidifying its practicality.

Keywords: Smart Aquaponics, Portable Mechanical Filtration, Solar-Photovoltaic Powered, Iot Water Quality Monitoring

1. Introduction

The concept of aquaponics involves the coexistence of fish and plants in a soil-less system, where nutrient-rich water from fish production is utilized to feed the plants. This self-sustaining method combines recirculating aquaculture with hydroponic plant cultivation, ensuring effective and profitable food production [1]. Among the various aquaponic growth techniques, the Nutrient Film Technique

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(NFT) is considered one of the most efficient, enabling plant roots to acquire necessary nutrients, water, and oxygen through thin gutters [2].

However, maintaining optimal water quality in aquaponic systems is crucial for the well-being and productivity of both fish and plants. Poor water quality can lead to decreased fish production, hindered plant growth, and even mortality among cultured species. The filtering system plays a vital role in improving water quality, with the traditional mechanical filters being manually arranged and prone to misalignment, which can obstruct water flow and cause maintenance difficulties. Additionally, the lack of an automated water quality monitoring system poses challenges in assessing and maintaining the system's parameters. In traditional methods, users rely on visual observation of water turbidity and indicators such as fish mortality or plant fertility to gauge water quality levels.

Photovoltaic (PV) panels, a cornerstone of solar energy, symbolize the project's eco-conscious ethos [3]. Similarly, the Portable Aquaponics Filtration & IoT Monitoring system represents a step forward in sustainable agriculture, ensuring the harmony of plant and fish cultivation while maintaining optimal water quality. Just as solar energy empowers communities with clean power, this innovation empowers aquaponics practitioners with real-time insights into their systems' water conditions, facilitated through IoT-driven monitoring.

To address these challenges, this research objective of this research work are to design and develop a user-friendly portable filtration system for the aquaponics system, implement the solar-powered IoT monitoring system called PonicsMon as a water quality checker in aquaponics, and lastly, analyze and measure important parameters to monitor water quality before and after the project implementation.

2. Methods and Materials

2.1 Designing of portable filtration

The filtration system utilizes a porous barrier to retain suspended particles by blocking their flow. If the barrier is thin and has uniform-sized holes, filtration occurs solely on the upstream surface of the medium. Larger particles remain on the surface while smaller particles pass through the pores. This process is illustrated in Figure 1, representing the flow stage in the filtration system [4].

i Coral stone possesses a porous structure that absorbs impurities, including bacteria and heavy metal ions [5]. Fossil coral's porous nature enables the absorption of contaminants, ultimately shifting acidic water towards alkalinity.
ii Oyster shell possesses exceptional water filtration capabilities, effectively enhancing the quality of water by filtering algae, nutrients, and suspended particles from the surrounding seawater [6].
iii Manganese greensand, coated with manganese oxide through a controlled process [7], is specialized in removing iron, manganese, and hydrogen sulfide from water.
iv Activated carbon is a versatile and effective adsorbent used for the removal of unwanted flavor, color, and various organic and inorganic contaminants [8]. It is a form of carbon that has been specially treated to create a highly porous structure, providing a large surface area for adsorption or chemical reactions to take place.
v Zeolites are crystalline microporous materials with clearly defined features. Typically, their framework is made of silicon, aluminum, and oxygen, and their pores are filled with cations, water, and/or other molecules [9].
vi Silica sand is commonly used in ceramic water filters that cleanse water by forcing it through ceramic pores under pressure, removing germs, rust, and other impurities for safe consumption [10].

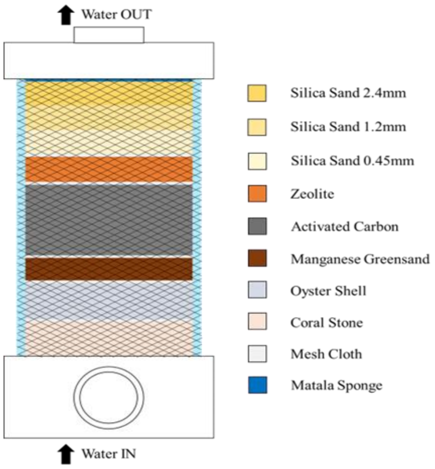


Figure 1: Flow of portable filtration system

2.2 IoT water quality monitoring (PonicsMon) system

Figure 2 and Figure 3 show the block diagram of PonicsMon and PonicsMon sensor, respectively. The PonicsMon system is designed to monitor water quality in aquaponics fish ponds. It utilizes sensors to measure temperature, pH level, turbidity, and TDS (total dissolved solids). These measurements are processed by a microcontroller, specifically, the NodeMCU ESP32, which offers Wi-Fi, Bluetooth, and low-power capabilities. The system provides two output options: a liquid crystal display (LCD) for on-site monitoring and a mobile application called Blynk App for remote control. Power is supplied by either a 12V lithium battery or solar photovoltaic (PV) energy, with a 10W PV module, PWM solar charge controller, and 12V 7.2Ah lead-acid battery being used. Overall, the PonicsMon system offers a comprehensive solution for monitoring and managing water quality in aquaponics, enhancing the efficiency and sustainability of the farming process.

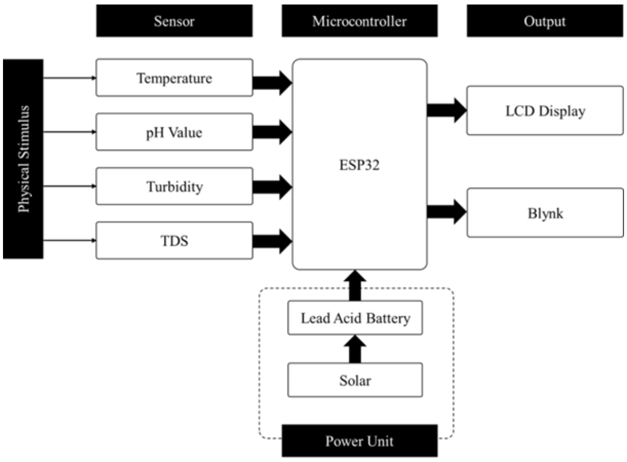


Figure 2: Block diagram of PonicsMon

Figure 3: PonicsMon sensor

The IoT monitoring system in Figure 4 follows a flowchart outlining its operation. The system begins by activating it through a button press. Sensors for pH, turbidity, TDS, and temperature are used to monitor the water. These sensors provide analog values, which are then processed by an Arduino Uno microcontroller. The temperature sensor connects to a digital pin, while the pH, TDS, and turbidity sensors utilize analog pins. If everything is functioning correctly, the I2C LCD system will display the measurements once per minute. Concurrently, the NodeMCU ESP32 is initialized and connects to the Blynk application via Wi-Fi to receive data. The Blynk app updates the values every minute. The system will continue monitoring water quality until an issue arises, such as the need for troubleshooting or a power supply failure.

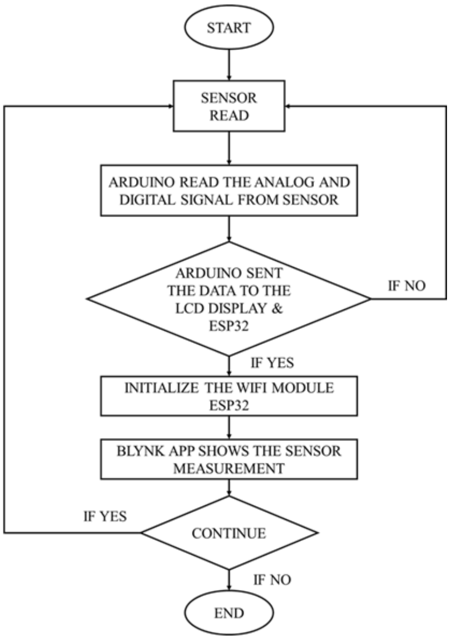


Figure 4: Flowchart of PonicsMon

The PonicsMon system is powered by a solar energy source, providing a sustainable and environmentally friendly solution for its operation. The solar power supply consists of a 10W solar panel with peak power capabilities, ensuring efficient energy capture from sunlight. The solar panel's specifications include voltage and current values at maximum power (Vmp and Imp), open circuit voltage (Voc), short circuit current (Isc), and power allowance range. With dimensions of 13.8 x 8.6 x 1.3 inches and weighing 1.8 pounds, the solar panel is compact and lightweight, facilitating easy integration into the PonicsMon setup.

To manage the energy flow from the solar panel to the system, a 10A PWM solar charge controller is employed. This controller efficiently regulates the solar power input and charging process, ensuring optimal battery performance. The solar charge controller is rated for both 12V and 24V systems and offers a variety of features, including an LCD display, LED status indicators, and multiple operation modes for load power scheduling. It also incorporates USB power outputs for additional versatility. With its compact dimensions of 134mm x 70mm x 30mm and weighing 0.13 kg, the solar charge controller seamlessly complements the solar power supply setup. The solar power supply system is further supported by a 12V 7.2Ah Lead Acid Battery. This rechargeable and recyclable battery provides a storage mechanism for the harvested solar energy, ensuring consistent power availability for the PonicsMon system. The battery's specifications, including its voltage, capacity, charging and discharging characteristics, dimensions, and weight, make it suitable for integration with the solar power supply system.

By harnessing solar energy as its primary power source, the PonicsMon system achieves a sustainable and self-sufficient operation, reducing reliance on conventional energy sources and contributing to the overall efficiency and eco-friendliness of the aquaponic ecosystem. Figure 5 shows the connection of the solar charger for PonicsMon.

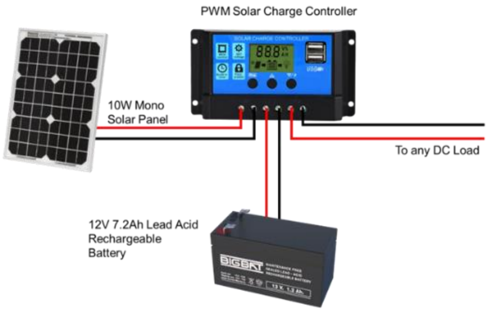


Figure 5: Solar charge connection of PonicsMon

2.4 Determining battery charging time for lead acid battery

The solar charger for PonicsMon depends on the battery recharge time, with lead acid batteries having an effective capacity of around 50% and requiring careful discharge management. The charging current should be 10% of the battery's total ampere-hour capacity. The total ampere-hour rating includes a 40% allowance for battery losses. While lead acid batteries have lower charge efficiency compared to lithium-ion batteries, the calculations consider the battery capacity as the true capacity. However, for the calculations using Eq. 1 to 4, the battery capacity will be considered the true capacity [10].

$$I_{Charging} = Ah \times \left(\frac{1}{10}\right) \qquad Eq.1$$

$$L_{Batt} = I_{Total\_batt} \times 40\% \qquad Eq.2$$

$$I_{Total\_batt\_rating} = I_{Total_{batt}} + 40\% \qquad Eq.3$$

$$t_{Charging} = \frac{I_{Total\_batt\_rating}}{I_{Charging}} \qquad Eq.4$$

3. Results and Discussion

3.1 Results of portable filtration

Figure 6 shows the arrangement of media filters in portable filter cartridges. The implementation of a portable filtration system has been successfully carried out. The effectiveness of the filter has been tested, considering its impact on water quality in a catfish pond. A mini prototype of the filtering system was created, using similar substances and filter media to simulate real-world conditions. The initial observation of the water in the catfish pond revealed that it had a slightly dirty and yellowish appearance shown in Figure 7. This emphasizes the importance of maintaining favorable water quality for successful catfish cultivation. The optimal water conditions for catfish farming include specific ranges for pH level, pond water temperature, and water clarity. The water filtered by the system was intended for use in growing Pak Choi plants. Table 1 presents a comparison of the pH and concentration before and after filtration, measured using a water quality testing meter in Figure 8. The results demonstrate that the filter can adjust the pH level to fall within the desired range of 6 to 9, which is acceptable in aquaponics systems. Additionally, the filter effectively reduces the concentration of substances in the water, ensuring that it remains below the system's threshold of 100 ppm. Moreover, the filter also produces a noticeable change in watercolor, transforming it from a yellowish hue to a clear appearance.

These results suggest that the filter can serve as a mechanical filter in aquaponics systems, improving water quality and promoting favorable conditions for plant growth.

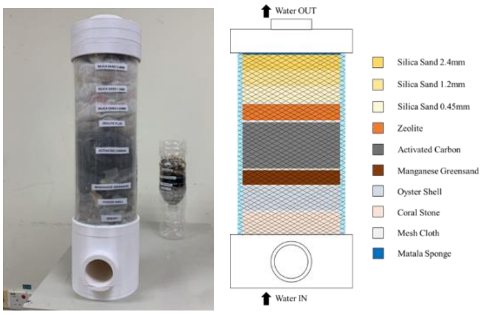


Figure 6: Portable filtration and the arrangement

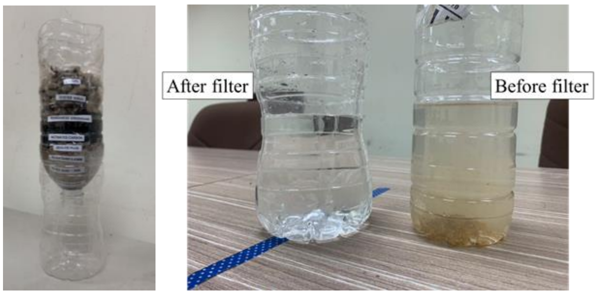


Figure 7: Result of filter features from mini prototype

Table 1: Result of filtering effect on catfish water sample

Condition	Temperature (°C)	pH	Concentration (ppm)	Colour
Before filter	27.9	6.07	105	Yellowish
After filter	28.1	7.21	70	Clear

Figure 8: Water quality meter

Figure 9 depicts the portable filtration that can facilitate maintenance. The filter is designed to have educational features, allowing users, especially students, to learn about its operation and the filter media used. The transparent cylinder enables observation of water flow, contaminant removal, and maintenance processes. The filter's portability is another advantage, offering flexibility, accessibility, educational opportunities, and backup functionality. It can be easily moved within or between aquaponics systems, facilitating maintenance and inspection. Students can gain hands-on experience and understand the importance of mechanical filtration. The portable filter can serve as a backup system during equipment failure or maintenance, ensuring continuous filtration and water quality stability. Considerations for optimal performance and convenience include filter size, ease of disassembly and reassembly, durability, and compatibility with system components.

Figure 9: Portable filtration can facilitate maintenance

3.2 Development of IoT water quality monitoring system

The PonicsMon system's circuit diagram is shown in Figure 10, demonstrating how the components are interconnected to meet the system's needs. A 12V battery powers the entire system, while the NodeMCU ESP32 serves as the central controller, connecting to the sensors and devices. In the Arduino IDE, the NodeMCU's pin connections with the sensors are defined. Furthermore, Figure 11 depicts the system connected to solar power, providing an alternative method to charge the battery when it gets drained.

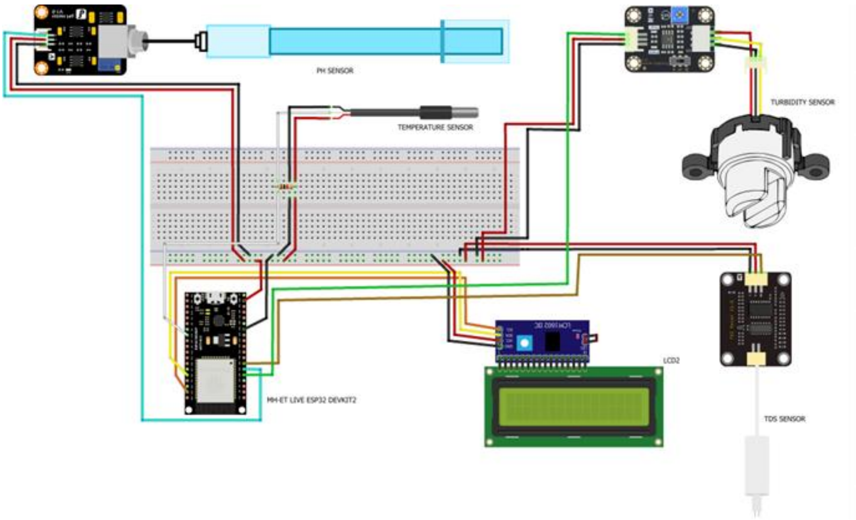


Figure 10: Circuit configuration of PonicsMon system

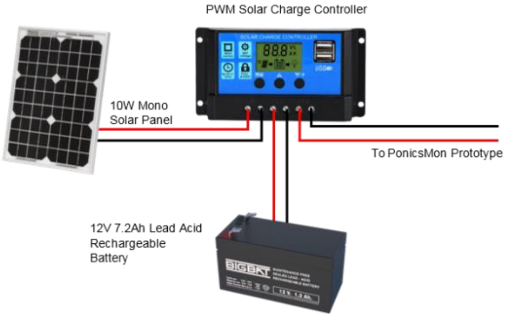


Figure 11: Solar PV panel acts as battery charger for PonicsMon system

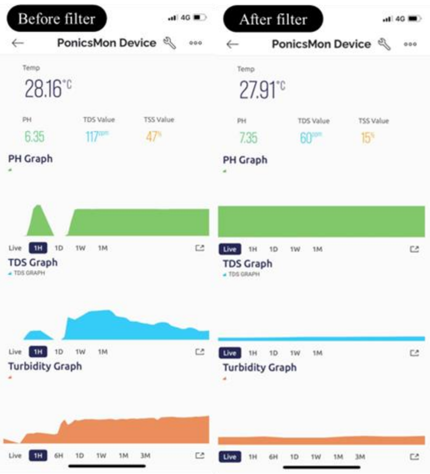
Figure 12 showcases the prototype of the PonicsMon system, which includes EC, pH, turbidity, and TDS sensors connected to a 12V battery. The prototype is enclosed within a junction box for protection against environmental elements and water. An LCD display is placed in front of the box, serving as the main interface for presenting information. Additionally, Figure 13 demonstrates the integration of a

Solar Charge with the PonicsMon system. This setup consists of a solar panel, a solar charge controller, and a spare battery, ensuring uninterrupted power supply for the PonicsMon device.

Figure 12: Solar charge PonicsMon device prototype

3.3 Analysis of the effectiveness of PonicsMon

Due to logistical constraints and ongoing maintenance at the UTHM aquaponics site, the installation of the portable filter and PonicsMon device was not possible. However, a small sample of contaminated water from the aquaponics site was collected for testing using a prototype mini filter. The effectiveness of the portable filter was evaluated by comparing the readings from the PonicsMon device before and after filtration. Figure 13 illustrates the comparison of water quality monitoring, while Table 2 presents the data collected from the PonicsMon device. Readings were taken at 60-second intervals to track the changes in water quality during the filtration process using the prototype mini filter. The readings clearly showed notable improvements in the quality of the filtered water. The PonicsMon device confirmed these positive changes, indicating that the filtration process successfully enhanced the water quality.



Before filter

PonicsMon Device

Temp 28.16°C

PH 6.35

TDS Value 117ppm

TSS Value 47%

After filter

PonicsMon Device

Temp 27.91°C

PH 7.35

TDS Value 60ppm

TSS Value 15%

Figure 13: Water quality Blynk monitoring before and after filtration

Table 2: Data collected from PonicsMon

	Before filter				After filter			
	Temp.	pH	TDS	Turb.	Temp.	pH	TDS	Turb.
Reading 1	28.16°C	6.35	117ppm	47%	27.92°C	7.35	60ppm	15%
Reading 2	28.14°C	6.35	112ppm	52%	28.10°C	7.36	61ppm	16%
Reading 3	27.96°C	6.39	116ppm	49%	27.94°C	7.35	60ppm	12%

3.4 Solar Charge analysis

The calculated value using Eq. 1 until Eq. 4 within the solar set specification has been tabulated in Table 3. The analysis reveals that the battery charging time, while initially lengthy, has a positive aspect as it can achieve a full recharge to 12V within 14 hours. Taking into account the estimated peak sun hours in a day, it is reasonable to expect the battery to fully charge within 2-3 days if it is completely drained. This arrangement guarantees uninterrupted charging as long as the battery sustains its connection to the solar PV source. To verify the efficacy of the solar PV system in achieving a full battery charge, a test was conducted.

Table 3: Battery charging time

Characteristics		**Unit**
Charging current	:	0.72A
Losses of battery	:	2.88Ah
Total battery rating (Ah)	:	10.08Ah
Battery charging time	:	14hours

Table 4 and Figure 14 present the results of battery voltage and current measurements during the charging process. The measurements were taken randomly from 11:00 am to 7:00 pm. Upon observation, it becomes evident that the battery achieved a full charge around 4:00 pm, with its voltage reaching approximately 12.5 V. The accompanying Figure graphically illustrates this trend, depicting a gradual increase in voltage up to 13.5 V (maintenance voltage), followed by a slight decrease to 12.5 V (nominal voltage). Notably, maintenance voltage, or float voltage, is a controlled level applied to fully charged batteries.

Table 4: Battery voltage and current during charging over the time

Time	Battery voltage (V)	Current (A)
11.00am	10.92	0.69
11.35 am	11.21	0.68
12.00 pm	11.56	0.68
12.40 pm	11.82	0.67
1.25 pm	12.89	0.61
1.55 pm	13.05	0.52
2.30 pm	13.21	0.52
3.04pm	13.54	0.48
3.43 pm	12.92	0.24
4.16 pm	12.55	0.21
5.01pm	12.52	0.15
5.39 pm	12.52	0.13
6.05 pm	12.51	0.13
6.41 pm	12.51	0.12

It is observed from Figure 14 that there is a decline in battery current. Initially, prior to the solar panels harnessing sunlight, the current exhibited high values, attributable to the battery's greater capacity to accept charge. Subsequently, as solar PV battery charging enters the middle stage, distinct changes are observed. The formidable charging current starts to wane as the battery approaches full capacity, much like the upward trend of its voltage. This current reduction occurs due to the battery's heightened resistance against current flow when nearing its limit. As the charging process progresses to its final stage, the battery approaches full charge status. Consequently, the charging current diminishes significantly owing to the battery's elevated internal resistance. Despite this, the solar panels continue to supply a modest current to maintain optimal charge, avoiding undue strain on the battery. This delicate equilibrium safeguards the battery's operational readiness without risking its integrity.

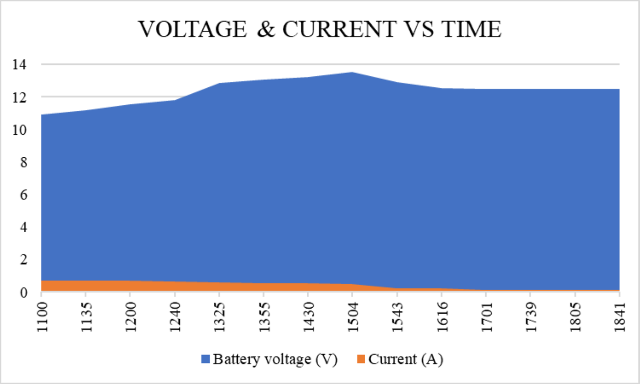


Figure 14: Battery voltage and current measurement graph

The coupling of solar power with battery charging seamlessly aligns with product sustainability. Through solar energy utilization, dependence on conventional power sources diminishes, leading to reduced carbon emissions and the promotion of cleaner energy. This approach not only prolongs product lifespans via gentle, controlled charging techniques but also contributes to an environmentally conscious ethos. Solar-charged batteries facilitate devices with minimal environmental impact, fostering a circular economy characterized by prolonged product lifecycles, waste reduction, and responsible energy consumption.

4. Conclusion

In conclusion, the project has made significant progress toward developing portable filtration with solar PV-powered IoT water quality monitoring for aquaponics. The portable filter has demonstrated its effectiveness in improving water quality, providing mineral enrichment, purification, and odor elimination. The PonicsMon device has been successful in monitoring various aspects of water quality, although further improvement is needed in pH monitoring. Recommendations for future work include conducting extensive field testing, adding an auto-filler feature, researching filter lifespan, identifying affordable sensors, incorporating multifunction sensors, integrating filtration and monitoring into a single prototype, and enhancing power efficiency. These recommendations will contribute to the continued development and optimization of the project.

Acknowledgement

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