Design and development of an automated spirulina (*Arthrospira platensis*) algae cultivator

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ABSTRACT

The cultivation of algae has gotten more attention from algae enthusiasts who have seen the benefits of algae in many uses. To maximize productivity, the parameters for growth of this algae must be controlled, such as pH, turbidity, light intensity, and the mixture solution for optimal growth. In this paper, an automated spirulina algae cultivator is designed and developed in a small-scale pond to replace the existing manual process. The system developed is composed of compact and modular cultivation unit, ph sensor, water level sensor, turbidity sensor, light intensity sensor, and motor actuators for mixing solutions. Each parameter was controlled individually in an on-off control system. A simple nutrient addition program (SNAP) solution is also used for better growth productivity by maximizing its nutrient contents. The pH is maintained at 9 to 12 for a healthy biomass output. Daily weight measurement was conducted using an analytical balance to monitor its growth. Using the developed prototype recorded a 33% higher rate of productivity over the manual process. This setup can potentially be used as a model for mass production of spirulina algae.

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1. INTRODUCTION

Algal species are capable of fast and efficient source of biomass as compared to other plants. In their natural environment, microalgae can achieve substantial biomass levels under eutrophic circumstances. However, from the perspective of mass cultivation, even these concentrations fall short of being adequate. Over the past decade, a considerable body of research has been dedicated to refining conditions that optimally enhance algal growth rates or induce heightened production of specific compounds in controlled growth settings. Nevertheless, a significant challenge in large-scale algal cultivation remains the development of an economically viable production system that is both efficient and timesaving. In this context, a wide array of techniques for cultivating algae present varying degrees of control overgrowth and product output, each entailing distinct capital and operational expenses [1].

A lot of evidence of the increasing use of Spirulina algae have been recorded. It has been beneficial in many applications such as food, health [2], [3] and agricultural uses. It has been cultured since the 1970s because of its advantageous uses [4]. The growing study of the production of spirulina has been conducted in different regions across the globe. It was found out that there are different factors that affect the growth of spirulina algae such as ph, light intensity, and temperature [5].

The primary light source of the pond depends on the environment. The light intensity plays an important role in production of microalgae photosynthesis [6], [7]. Generally, a simple method of microalgae cultivation such as an open culture system demands low operation, energy, and maintenance cost. The challenges for an open pond set up are the changing weather conditions, inability to control water temperature, lighting, and low-efficiency utilization of CO_2 [8]. Although life support systems exist for the indoor production of microalgae [9], [10], a system that works for local farmers and even for home use are still preferred in some regions in the Philippines where machinery is still at high cost. Therefore, a robust and effective automated system [11] is necessary that can increase the productivity of spirulina algae from local farmers. In this paper, an automated spirulina algae cultivator was designed and developed in small scale, that will serve as a model for large scale production of spirulina algae. A control system is presented which controls the following parameters: light intensity, pH, and turbidity, in which the amount of SNAP solution is supervised.

2. METHOD
2.1. Design and integration of components
The system is composed of input and output devices: sensors and actuators. A rectangular container which measures 1×1×0.5 m^3 (length, width, height) was used as an algae pond. In Figure 1, 2 cylindrical containers were used, where one has simple nutrient addition program (SNAP) solution, which was found effective in optimizing growth [12], [13], and the other one is mixed with baking soda. These containers are used as reservoirs for the water mixtures. A submersible pump can be found inside the container which turns on when the solutions inside the process tank is less than the desired level, or when the mixture pH and turbidity levels do not meet the required levels.

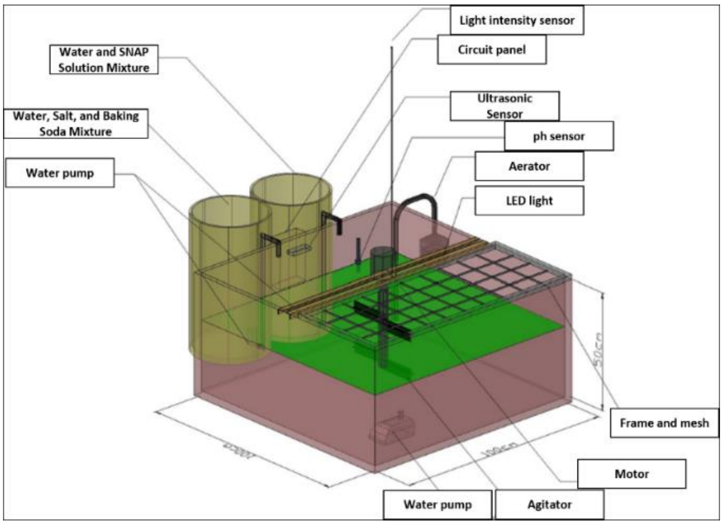


Figure 1. 3D design of the spirulina cultivator pond

2.2. Control system set up
There are three parameters that are being controlled to maximize the growth and production of spirulina algae, namely, pH, turbidity, water level, and light intensity. The control system block diagram is shown in Figure 2. The overview of the flow of the control system set up is presented in Figure 3. The correlation between parameters where not covered for the simplicity of the control system design.

2.2.1. pH control
An agitator and oxygen pump is activated when the system is turned on. This is done to give proper distribution of the minerals that the spirulina needs for optimum growth. The pH sensor detects the alkalinity of the algal pond [14], [15]. Water is pumped from a container into the 140 fine mesh screens to filter out the Spirulina during the harvesting process. The system will repeat after the harvesting process. If the pH is less than 9.5, the water, salt, and baking soda will be added to the pond through a submersible pump to improve alkalinity. The process can also be found in part A of the pH control in Figure 3.

2.2.2. Light intensity control

Spirulina algae are very sensitive to light intensity. It can be scorched when there is too much sunlight or any form of light. On the other hand, when the light intensity is not enough, spirulina algae can also be rotten. Therefore, the light intensity of the spirulina algae must be controlled [16]–[18]. A light sensor is used to detect the light intensity in the natural surroundings [19]. The light intensity must be kept greater than 2500 lux. An LED light is used as a source of light as an alternative in the evening. When the light sensor detects an intensity less than or equal to 2,500 LUX, the LED lights will switch on; otherwise, the LED lights will remain off. The process for light intensity control can be found in part C of Figure 3.

2.2.3. Turbidity control

Turbidity is measured using the turbidity sensor. When the turbidity is greater than 260 NTU, the pond will automatically harvest the matured algae. An ultrasonic sensor is used to detect the pond's water level. If the water level is higher than 26 cm, another cylindrical container containing water, salt, baking soda, and SNAP solution will be added to achieve the water level's set point. The process is presented in default part of Figure 3.

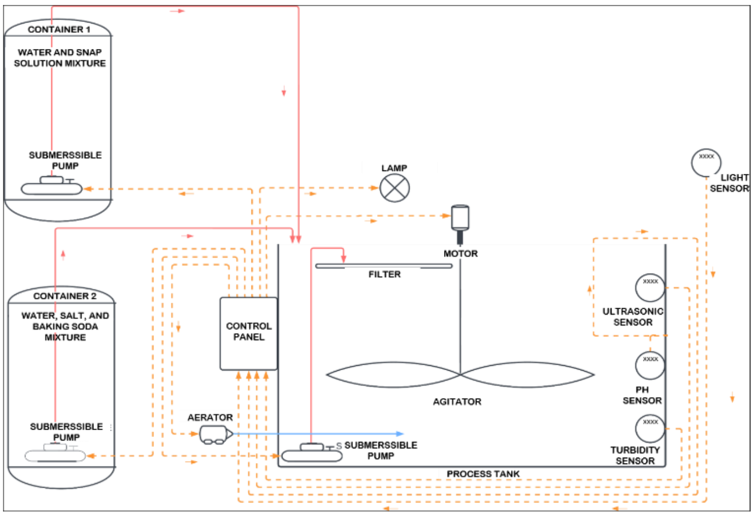


Figure 2. Control system block diagram

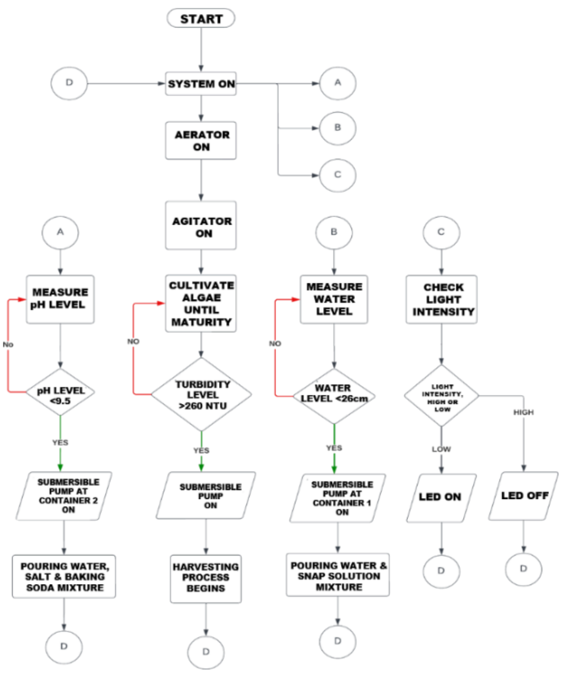
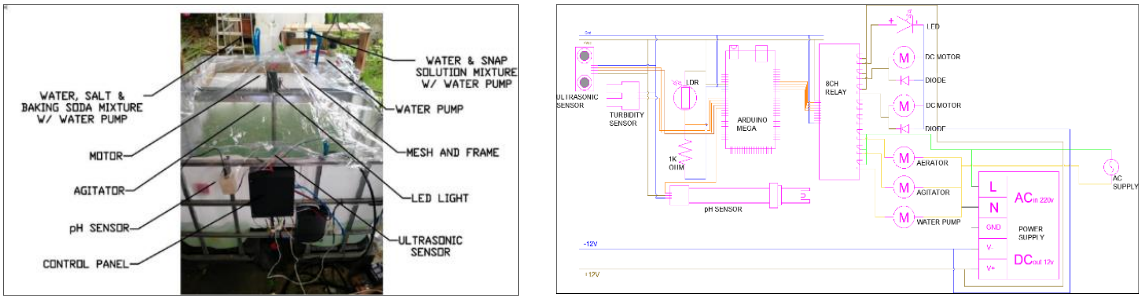


Figure 3. Control process flow diagram

3. RESULTS AND DISCUSSION

3.1. Fabrication and integration of components results

Figure 4 illustrates the complete system setup and wiring configuration. The algae pond shown in Figure 4(a) shows the actual setup and integration of components. The control panel is located in front of the pond for easy monitoring and setup. The pH sensor is submerged into the mixture enough that it can detect pH properly. The wiring diagram is presented in Figure 4(b). A 12 Vdc supply is needed for the DC motors. An 8-channel relay is used to both actuate the DC and AC components, such as the agitator, aerator, and water pump.



(a) (b)

Figure 4. Development of the algae pond cultivator (a) actual algae pond and (b) algae cultivator wiring diagram

3.2. Light intensity monitoring and control

A light-dependent resistor (LDR) sensor is used for detecting the light intensity. These activities are measured in hourly intervals where the beam of light is assumed to be inversely proportional to the resistance. The natural light fluctuates over the course of a 24-hour cycle, reaching its peak intensity during the day and its twilight hours. The incident light level varies as the sun rises and sets as presented in Figure 5.

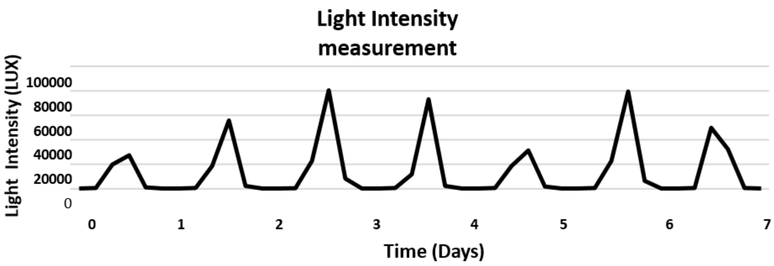


Figure 5. Light intensity monitoring in 7 days

3.3. Turbidity monitoring and control

Turbidity sensors are necessary for monitoring the environment and assessing the water's quality. These sensors measure a fluid's cloudiness or haziness, which is caused by suspended particles that scatter light. Turbidity in a water body could indicate a few increases, such as pollution, thick algae blooms, or a spirulina culture in high concentration [20]–[22]. A turbidity sensor graph reveals a perceptible increase in turbidity levels. The need to monitor turbidity and potential environmental problems may become clearer to researchers. Figure 6 shows the data in daily intervals in which there is an increase in pond algae as evidenced by the double increase over the previous days.

The Nephelometric Turbidity Sensor NTU determines the concentration of the cultured spirulina using ultrasonic pulses as shown in Figure 6. This kind of turbidity sensor is the most popular and works on the idea of scattering the light. The amount of light scattered back at the incident light at a 90-degree angle is measured and calculated. In applications for water treatment and environmental monitoring, Nephelometric turbidity sensors are frequently utilized [23], [24]. Since there may not be much light scattering from a low concentration of tiny algae particles, the lowest turbidity rating for spirulina algae will typically be very close to zero or very low. When there is little Spirulina algae present in the water and it is clear, the turbidity sensor NTU may display a low or negligible reading.

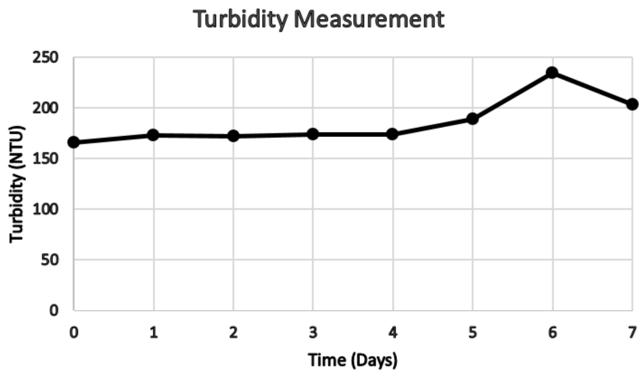


Figure 6. Turbidity monitoring for 7 days

3.4. Water level monitoring and control

The water level is monitored through the HC-SR04 ultrasonic distance sensor. The water level is controlled using an on-off control system. Figure 7 shows the water level monitoring for 7 days. The solution is added and poured into the pond when the level drops from the set point.

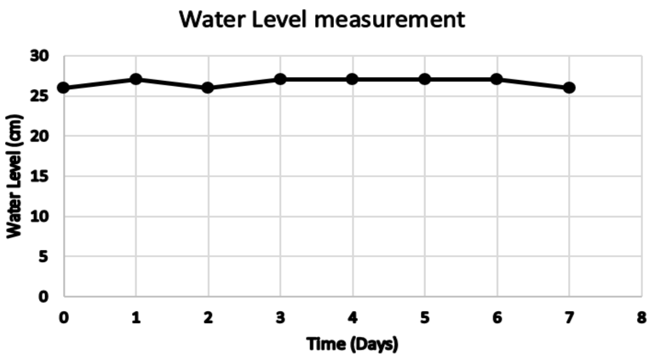


Figure 7. Water level monitoring in 7 days

3.5. pH monitoring and control

The pH is monitored and maintained between 9 and 12 for healthy biomass output. Biomass productivity at pH 9 or below was the lowest due to poor culture health and contamination by other microalgae species, which resulted in low biomass production [25]. Contaminants like mosquito larvae, viruses, fungi, and bacteria typically grow during open-pond cultivation at this level of pH. At various pH levels, shifting media, nutrient levels, and chemical species, biomass production can change [26]. Figure 8 shows the pH monitoring in growing spirulina algae in 7 days.

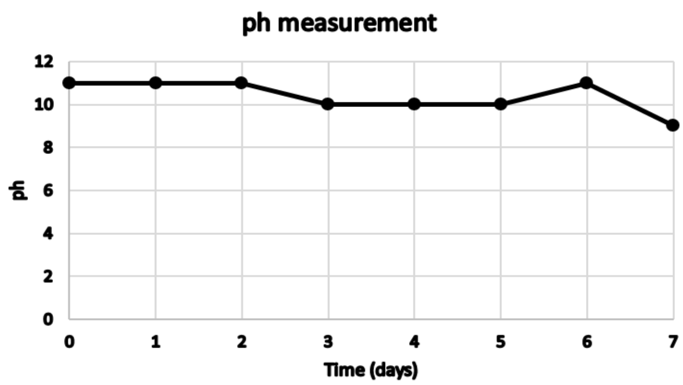


Figure 8. pH monitoring of spirulina algae production in 7 days

3.6. Spirulina algae quality analysis

The spirulina algae were analyzed by getting some samples which were examined using a 4nm compound microscope. Figure 9 shows the analysis of the samples taken during the production of spirulina algae in 7 days.The array of deftly structured cellular structures and an abundance of brilliant colors were shown in Figure 9(a). The spirulina grows in a spherical structure. This result was taken in a 4 days' production which is near its maturity. Figure 9(b) shows the calibration of the analytical balance. During the production process, a sample is taken each day and weighed and recorded as presented in Figure 9(c). Figure 9(d) shows the actual weighing of samples using the analytical balance.

(a) (b) (c) (d)

Figure 9. Spirulina algae analysis: (a) Spirulina algae specimen seen in 4nm compound microscope, (b) device calibration, (c) samples taken from day 1 to 7, and (d) weight measurement using analytical weigh balance

The weight measurements are done daily for 7 days. The samples in one liter are weighed 3 times and are averaged. The growth trend can be seen in Figure 10, which was taken daily for 7 days. This shows the biomass productivity, which, for many producers of algae, is very popular.

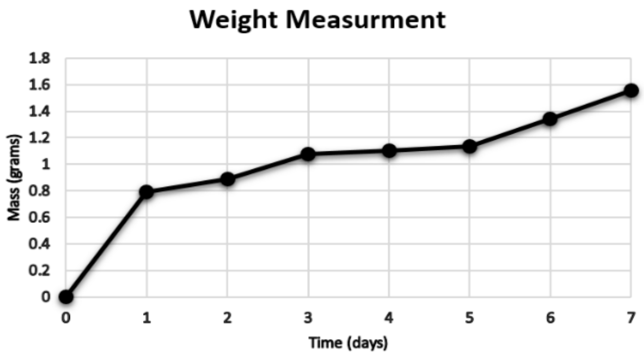


Figure 10. Biomass productivity samples in 7 days. The weight measurement of 1-liter sample per day of spirulina

4. CONCLUSION

In this project, an automated spirulina algae cultivator was successfully created and studied. It is composed of sensors and a control system for controlling the pH, light intensity, and the water level in the built cultivator pond. The prototype is well suited for small-scale cultivation only. This automated system was proven to be much more productive in terms of yield and efficiency of production compared to the manual process. In the manual process, 60 liters or equal to 70 grams of algae was cultivated. Using the automated system, 300 liters or 466 grams of algae was cultivated. An increase of 33% is observed using the automated system.

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Mark Joseph B. Enojas	✓	✓			✓	✓		✓	✓	✓	✓	✓	✓	
Daryll C. Balolong							✓	✓						
Charissa Zandra B. Correa	✓	✓			✓	✓	✓	✓			✓	✓	✓	✓
Lemmuel Keith C. Roldan			✓	✓			✓	✓						✓
Mark Lester Teves			✓	✓			✓							✓
Christian Mari Dela Cruz			✓	✓			✓				✓			✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

- The data that support the findings of this study are available from the corresponding author, Mark Joseph B. Enojas, upon reasonable request.

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