Development of smart algae pond system for microalgae biomass production

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Abstract. The production of microalgae biomass is very promising as an alternative sustainable food, feed, high value biochemical, and 3\textsuperscript{rd} generation biofuel. However, the use of microalgae biomass for the production of biofuel is still considered less feasible at this time. The main obstacle is the scale up of biomass production, high processing costs and low efficiency using the conventional biomass production system. Therefore, the use of advanced digital technology such as sensors, automation applications and the Internet of Things (IoT) was applied in this study. This research aimed to develop a Smart Algae Pond system equipped with three main functions of smart mixing, control of pH and CO\textsubscript{2} supply, and the automatic harvesting system. The results revealed that the use of advanced digital technology and IoT could improve the productivity as well as control the production of biomass effectively and efficiently. The tested optimum value of pH was achieved at 8.5-9.5 with the CO\textsubscript{2} concentration of 1 to 2% of the cultivation volume. Temperature was maintained from 25 to 35 °C, water velocity from 16 to 35 cm s\textsuperscript{-1}, and air velocity of 8.33 cm\textsuperscript{3} s\textsuperscript{-1}. Using the smart mixing system, the use of electrical energy was decreased from 0.5 to below 0.2 Kw/h. This study showed that microalgae biomass production can be measured using a water turbidity sensor.

1. Introduction

Microalgae are a very diverse group of unicellular microscopic photosynthetic plant-like organisms that have neither roots nor leafy shoots, and lack vascular tissues [1]. They mostly exist in freshwater, brackish or marine water. Autotrophic microalgae require inorganic compounds such as carbon dioxide (CO\textsubscript{2}), salts and light energy for growth [2]. Microalgae cultures, especially the large-scale systems, are classified into an open system where the culture is directly exposed to the environment such as a raceway pond, and a closed system where the whole culture is enclosed within the culture vessel [3, 4]. Microalgae are a promising source of superior biomass as an alternative to sustainable food, high value products, and 3rd generation biofuel commodities [5, 6].
However, the use of microalgae especially for the production of biofuels still has obstacles because it is considered as ineffective at present. The development of precision agriculture systems in the production of microalgae biomass using advanced digital technology, i.e., wireless sensor-based monitoring, the Internet of Things (IoT) and automation of microalgae cultivation operations is very important to significantly increase precision and yield with the aim of achieving more effective and efficient microalgae biomass production [7, 8]. Sensor monitoring will improve management and proper operation of environmental factors and microalgae growth and controlled supply of nutrients. The IoT is shown to assist the proper management and decision of microalgae biomass production [9].

Appropriate measurements and controls, for example nutrient concentrations and environmental conditions, can be applied to obtain optimal conditions from biomass production. Therefore, productivity can be maintained optimally by controlling growth, excess nutrients or environmental conditions, which will have an impact on production costs. The reduction of production costs and lower energy requirements are important factors and will increase productivity and feasibility of microalgae biomass production systems [10]. This study aimed to develop a prototype of Smart Algae Pond system with three main functions of smart mixing, pH and CO₂ supply control, and the automatic harvesting system.

2. Materials and Methods

2.1. Microalgae raceway pond

The microalgae raceway pond with a volume of 120 L was designed and used in this study. The pond was constructed using fiber supported by a metal frame. The design of the raceway pond is depicted in Figure 1.

![Figure 1. Design of microalgae raceway pond.](image_url)

2.2. Design of Paddle wheel speed control based on sunlight radiation

The materials used for the paddlewheel’s fins were acrylic. Other hardwares used were iron rod, axle, bearing, arduino nano, lux meter, PZEM-004T V2, LCD display, DSB1820, ESP32, MOSFET, thyristor AC switch, 3-phase electric motor, INVT GD20 inverter, 2K potentiometer, servo motor, switch, LLC (logic level control), step down module, step up module, 12V 3.2 A power supply,
4700 ohm resistor, and USB step down 5V. The softwares used in this research were Arduino IDE, Fritzing, and Sketch Up software.

The basic principle for the paddlewheel is that the speed varied based on the light intensity. The sensors for temperature gauges, current and electric voltage sensors and sensors to read the light intensity, were controlled by microcontroller and from the microcontroller, data from the reading results was sent to ESP32 and, then ESP32 transferred data to the HTTP protocol to be sent to the MySQL database. This procedure ensures that the paddlewheel only moves at the appropriate speed based on the light intensity. In this case when there is no light, for example at night when there is no photosynthesis, the paddlewheel will stop or move as necessary. The design for the paddlewheel system is illustrated in Figure 2.

Figure 2. Design of the smart mixing (paddlewheel) system.

2.3. Design of CO2 flow control based on pH and water velocity

Components used to manufacture controller circuits for the inlet and outlet of CO2 flow were an acrylic box, PU hose, air valve, aerator, ESP32, 12V 2A power supply, LLC, LCD, USB power 5V, Arduino Nano, Ardupilot MPXV7002DP, DFRobot V2 pH sensor, DFRobot sensor encoder, 28BYJ-48 stepper motor, mosfet module, 12V fan, LM2596 step-down, PCB, and iron frame. Figure 3 shows the controller for the CO2 flow controller.

Figure 3. CO2 flow controller.
The principle is that CO₂ concentration affects pH. pH is one of the important parameters in the microalgal cultivation system [11] and by maintaining the proper pH balance it is expected that the microalgal cultivation system can maintain the appropriate environmental condition at all times.

2.4. Design of harvesting system

The materials used in the manufacturing of harvesting systems were Arduino Nano, limit switch, DC motor, 2 channel relay, LM2596, MG996 servo, pulley and belt, axle and bearing, turbidity sensor, water level, and thyristor.

There were several processes in the harvesting system that are built, which are pre-harvest, harvest, and post-harvest process. In the pre-harvest process, a periodic turbidity value check (NTU) was carried out. When the turbidity sensor reading value has not reached the appropriate NTU value, then the duration (day) check for nutrition addition in the form of Walne fertilizer was carried out. Nutrition addition was carried out once a week (7 days) and started from the beginning of cultivation (day 0).

At harvest time, the culture that can be harvested for a raceway pond volume of 120 liters is 80 liters. When the harvest conditions were achieved, the harvest valve opened and the culture flow to the harvesting tank. There was a water level sensor that can detect when the water level in the raceway pond arrived at the desired value (in this case 40 L), then the harvest valve was automatically closed to proceed to the harvesting function. The pre-harvest process was completed by the closing of the harvest valve. Harvesting tools were designed similar to scrapers that move back and forth. The movement of the harvesting device was regulated using a limit switch.

The post-harvest function can be run in conjunction with the harvest function and was carried out after the harvest valve was closed. The postharvest function was a function to re-cultivate the remaining microalgae. Figure 4 shows the main schematic of the harvesting system.

![Figure 4. Harvesting system schematic.](image)

3. Results and Discussions

3.1. Paddlewheel speed control based on sunlight radiation

Based on the testing results, the photosynthesis process can be optimized by controlling the mixing in a microalgal pond automatically based on the incoming light intensity. The higher the intensity of sunlight the bigger the rotation of the servo degree, and when at night or there was no light intensity, the paddlewheel automatically stopped. The monitoring of electricity usage in the activity of turning on the paddlewheel actuator based on the light intensity was observed. The result is that the paddlewheel can reach the maximum speed by using less electricity.

Light intensity and light/dark cycle are important factors on the growth, metabolism, and biochemical composition of microalgae [12, 13]. Microalgal growth is limited by too little light, but too much light can also result in inhibition of biomass production [14], photoinhibition, and can potentially damage the photosystems [15, 16].
In the uncontrolled paddlewheel speed testing, the electrical energy produced was high at around 0.500 Kw/h. For the controlled paddlewheel speed with variations of 9, 12, 15, and 18 rpm, the use of electrical energy was lower with an average of below 0.200 Kw/h. The controlled paddlewheel thus able to use less electricity and use electricity more efficiently compared to the uncontrolled paddlewheel which was always on for 24 h (Table 1). The reduced energy requirements were helpful toward increasing the net energy ratio (NER) of the final product.

| No. | Paddlewheel Speed (rpm) | Voltage (V) | Electric Current (A) | Duration (Hours) | Energy (Kw/h) |
|-----|-------------------------|-------------|---------------------|-----------------|---------------|
| 1   | Uncontrolled            | 230         | 0.070               | 24              | 0.500         |
| 2   | 9                       | 215         | 0.015               | 13              | 0.042         |
| 3   | 12                      | 218         | 0.029               | 13              | 0.082         |
| 4   | 15                      | 223         | 0.047               | 13              | 0.137         |
| 5   | 18                      | 227         | 0.064               | 13              | 0.190         |

3.2. Control of CO2 flow based on pH and water speed

Testing was performed in the form of functionality testing of each sensor with a predetermined unit. The first test was the pH that was performed by comparing to the buffer used as shown in Table 2.

| No | PH sensor value | Average sensor value | Buffer | Difference value (buffer - average) | Percentage of Error |
|----|-----------------|----------------------|--------|-------------------------------------|---------------------|
| 1  | 3.90-4.01       | 3.95                 | 4.00   | 0.05                                | 1.25%               |
| 2  | 6.79-6.81       | 6.80                 | 7.00   | 0.20                                | 2.85%               |
| 3  | 9.04-9.10       | 9.07                 | 9.18   | 0.11                                | 1.19%               |
| 4  | 9.98-10.09      | 10.03                | 10.01  | 0.02                                | 0.19%               |
|    | Average         |                      |        |                                     | 1.37%               |

Table 2 shows that the CO2 sensor and control can control the range of CO2 supply precisely according to the standard value, so that the photosynthesis and respiration processes run more optimally with the correct range and supply of CO2 as needed. The resulting pH is more stable than when there is no control on the CO2 supply. For the optimum microalgae biomass production, the correct range of CO2 concentration also needs to be considered. Both high and low CO2 concentrations may lead to growth inhibition, and these concentrations vary from one species to another, and are not adequately known [17]. For instance, addition of CO2 at constant pH (pH-stat) resulted in an increase in Pleurochrysis carterae biomass productivity, while CO2 addition lowered Emiliania huxleyi biomass production [11].

3.3. Harvesting system

The sensors implemented were the water level sensor and turbidity sensor. The water level sensor was made with a comparator circuit that compared two voltage inputs divided by a resistor. The turbidity sensor used was SEN0189 which is a product of DFRobot. The output of these sensors can be analog signals and digital signals. This sensor worked at a 5V DC voltage. The analog output of this sensor was 0-4.5 V, and the digital output for high/low conditions was adjusted by a potentiometer.

Testing was performed on turbidity sensors. This test was needed to determine the density of microalgae until it is ready for harvest. Referring to the field observations, microalgae density was measured with a spectrophotometer that produces an output of absorbance value. When the absorbance
value reaches 1.00, *Spirulina* sp. was ready to harvest. Pareek and Srivastava [18] reported that the growth of *Spirulina* sp. can be measured by the turbidity value (NTU) in water. To confirm the relationship between absorbance and turbidity values, the testing results are presented in Table 3.

**Table 3. Measurement of Absorbance and Turbidity (NTU).**

| Day | Culture 1 | | | Culture 2 | | |
|-----|-----------|---|---|-----------|---|---|
|     | ABS       | NTU | Vin| ABS       | NTU | Vin|
| 1   | 0.055     | 1.655 | 3.660 | 0.053     | 1.555 | 3.700 |
| 2   | 0.086     | 1.831 | 3.586 | 0.085     | 1.776 | 3.610 |
| 3   | 0.124     | 1.868 | 3.570 | 0.107     | 1.845 | 3.580 |
| 4   | 0.157     | 1.901 | 3.555 | 0.129     | 1.890 | 3.560 |
| 5   | 0.189     | 1.917 | 3.548 | 0.132     | 1.912 | 3.550 |
| 6   | 0.241     | 1.934 | 3.540 | 0.170     | 1.945 | 3.535 |
| 7   | 0.262     | 1.967 | 3.525 | 0.189     | 1.971 | 3.523 |
| 8   | 0.284     | 1.999 | 3.510 | 0.208     | 1.999 | 3.510 |
| 9   | 0.326     | 2.041 | 3.490 | 0.248     | 2.041 | 3.490 |
| 10  | 0.341     | 2.238 | 3.390 | 0.289     | 2.162 | 3.430 |
| 11  | 0.355     | 2.292 | 3.360 | 0.329     | 2.265 | 3.375 |
| 12  | 0.447     | 2.506 | 3.230 | 0.370     | 2.314 | 3.348 |
| 13  | 0.501     | 2.598 | 3.165 | 0.430     | 2.362 | 3.320 |
| 14  | 0.527     | 2.640 | 3.133 | 0.481     | 2.452 | 3.265 |
| 15  | 0.554     | 2.681 | 3.100 | 0.531     | 2.535 | 3.210 |
| 16  | 0.588     | 2.906 | 2.860 | 0.575     | 2.810 | 2.980 |
| 17  | 0.666     | 2.969 | 2.740 | 0.709     | 2.877 | 2.900 |
| 18  | 0.690     | 2.975 | 2.725 | 0.715     | 2.919 | 2.840 |
| 19  | 0.718     | 2.980 | 2.710 | 0.721     | 2.931 | 2.820 |
| 20  | 0.745     | 2.992 | 2.670 | 0.822     | 2.968 | 2.743 |
| 21  | 0.816     | 3.000 | 2.630 | 0.862     | 2.972 | 2.733 |
| 22  | 0.887     | 3.004 | 2.590 | 0.902     | 2.997 | 2.645 |
| 23  | 0.946     | 3.005 | 2.550 | 0.960     | 3.005 | 2.558 |
| 24  | 1.004     | 3.005 | 2.548 | 1.017     | 3.005 | 2.549 |

Table 3 shows that the higher absorbance value showed the higher NTU value. There was a correlation between absorbance and NTU values. Regression result from the two variables is shown in Figure 5. A function to calculate the ABS value based on the voltage read on Arduino was obtained as follows.

$$ABS = 2.776963177 + (-0.73774152 \times Vin)$$
4. Conclusions

This study revealed that the use of advanced digital technology and IoT could improve the productivity as well as control the production of microalgae biomass effectively and efficiently in a smart raceway pond. The process of photosynthesis and biomass production can be optimized by controlling the mixing automatically based on the incoming light intensity. The environmental conditions of culture were more stable and optimal with a continuous online measured pH monitoring and control of CO₂ supply as needed, compared to the uncontrolled CO₂ supply. The tested optimum value of pH was achieved at 8.5-9.5 with the CO₂ concentration of 1 to 2% of the cultivation volume. Temperature was monitored from 25 to 35 °C, water velocity from 16 to 35 cm s⁻¹, and aeration velocity of 8.33 cm³ s⁻¹. This study also showed that Spirulina sp. reached the stationary phase for harvesting within a period of 24 days. The results of the automatic harvesting process of Spirulina sp. showed that the turbidity value of culture and the growth of microalgae were correlated, so that microalgae biomass production can be measured using a water turbidity sensor. The data monitoring of culture parameters can be accessed real-time via the internet using the IoT system.

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