Development of an Arduino-Based Closed Algal Culturing System with Growth Monitoring using Image Processing through Artificial Neural Network

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Abstract – **This study presents the development of a closed algal culturing system which automatically monitors and controls significant bio-environmental parameters to optimize the growth of the microalgae Spirulina platensis, used as fish feeds. The system is composed of three major parts: the detection system, which monitors the pH level, temperature and dissolved oxygen (DO); the correction system, which maintains the important parameters for optimum growth of the culture, 29 to 32 degree Celsius for temperature and 8.5 to 11 for pH; the vision system which measures the cell density of the culture without a microscope through an artificial neural network (ANN) model. The ANN model correlates the RGB and lux value from the vision system in order to read the current cell density and to check whether the culture has reached its matured phase and is ready for harvest. Based on the results of the experimental setups performed by the researchers the culture was able to reach its matured phase on its 5th day for controlled and on the 7th day for uncontrolled. In addition, based on the regression analysis conducted wherein the growth rate for the controlled set-up is 0.0519 and 0.0372 for the uncontrolled set-up, the growth of *Spirulina platensis* has increased by 39.52% when the culture parameters are controlled.**

Keywords— Spirulina platensis, microalgae, artificial neural network, image processing

I. INTRODUCTION

Many microalgae, including Spirulina platensis, gained attention from various field of research for its highly applicable potentials on many global problems. The three major applications are food/ feed, biofuels, and by-products/ co-products [1-6]. According to National Bank for Agriculture and Rural Development (NABARD), 5000 tons per year is the estimated demand for *Spirulina platensis* worldwide, however, only 2000 tons are being produced annually leaded by US, followed by Thailand, India and China. Today, its global demand is rising consistently at more than 30% per year which gives reasons for different country to plan microalgae production. [7-8]

With this growth in microalgae industry, the Philippines have big plans underway, and one of the plan's pathways lead to development of microalgae as aqua feeds since aquaculture contributes significantly to the country's food security, employment and foreign exchange earnings.

Aquaculture feeds have been considered a minor sub-sector of the feed milling industry. In 1997, the fish feed production is the fastest growing feed market since the trend in aquaculture is intensive farming wherein feed is one of the major production inputs. The use of formulated diets that are economical and viable is being resorted to [9].

The development of high-rate algal production system and photo-bioreactor technology leads to mass production of microalgae results to a great progress both in aquaculture development, and microalgae industry.

In the previous years, there are some study conducted in order to improve the culturing process of different microalgae. To mention some of it, Malinowski et.al (2014) developed a wireless network to monitor temperature, pH level, and dissolved oxygen for cultivating algae. However, the result shows that there is a problem with regards to power optimization and inaccuracy in measuring the pH level and temperature level of the culture [10]. Jia and Fei in 2005 developed a multi-wavelength optical based sensor unit in order to monitor microalgae growth in real time. Unfortunately, results shows that there are inaccurate measurement of optical density during night time [11]. Lastly, Kim, Lee, & Yoon in 2013 uses a web cam for easy monitoring of the growth of organisms continuous image data monitoring for long term bioprocesses but the said system is not yet automated and needs to capture the image manually [12].

The most critical part in culturing microalgae is determining its harvest time. Based on the inefficiency from the previous studies mention, an idea of a closed algal culturing system that automatically monitors and control the significant bio-environmental parameters to optimize the growth of the microalgae *Spirulina platensis* came up. This study will benefit the aquaculture industry, specifically, aqua farmers and feed millers in producing affordable and high class fish feeds even without an on-site supervision of microalgae expert. In addition, the research study is also beneficial in the continuous mass production of Spirulina in the Philippines and in the future research on new application of technology and techniques that will provide comparison of effectiveness with the existing aquaculture technology.

II. METHODOLOGY

A. Block Diagram

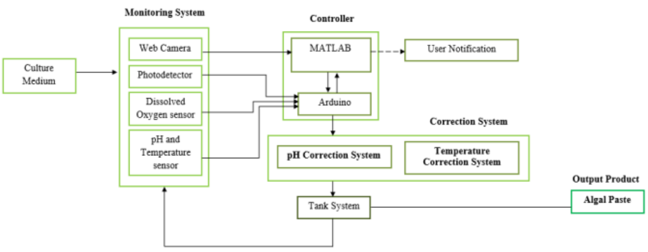

Fig.1 System's Block Diagram

Figure 1 shows the block diagram for the automated closed algal culturing system. The system is composed of three major parts: the monitoring system, the correction system and the vision system driven by the Arduino microcontroller. The vision system correlate the RGB and lux value in order to detect the cell density of the culture by image processing through artificial neural network.

B. Hardware Development

- **Detection System**

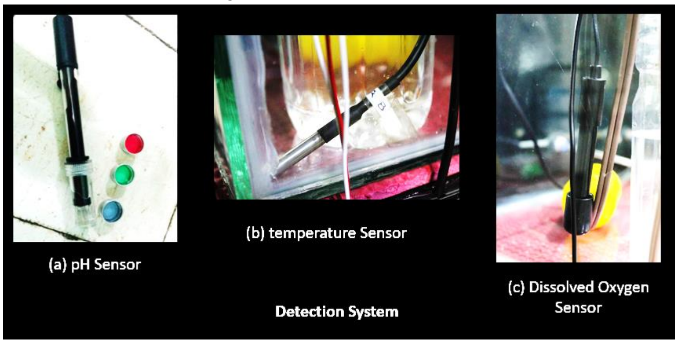

Fig. 2 Detection System

The detection system of the device is composed of three major sensors connected to the analog pins of the Arduino Uno Microcontroller: the temperature sensor, the pH sensor and the dissolved oxygen sensor. The sensor mentioned were submerged in the tank and are capable of monitoring each of the parameters needed.

- **Correction System**

In this study, there are only two parameters that is need to be corrected, the temperature and the pH level.

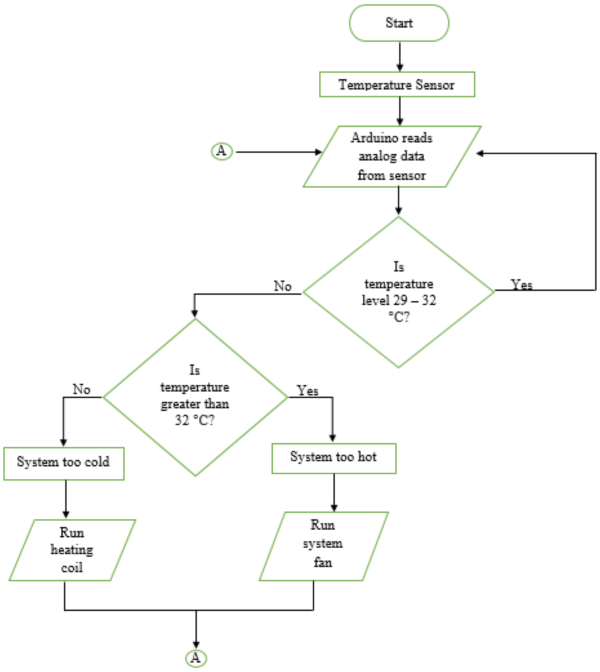

Fig 3. Temperature Correction System Flow Chart

The temperature correction system will function depending on the temperature parameter abnormality. In the digital pins of Arduino Uno Microcontroller, a relay driver is interfaced which the two 12 volts dc fan. The researchers used a standalone 100W submersible water heater with built in temperature correction. The temperature that the cultures need is 29 to 32 degree Celsius [13]. If temperature rises above the range the two cooling fan will turn on and when the temperature decline below the range the water heater will turn on until such time that the temperature normalized.

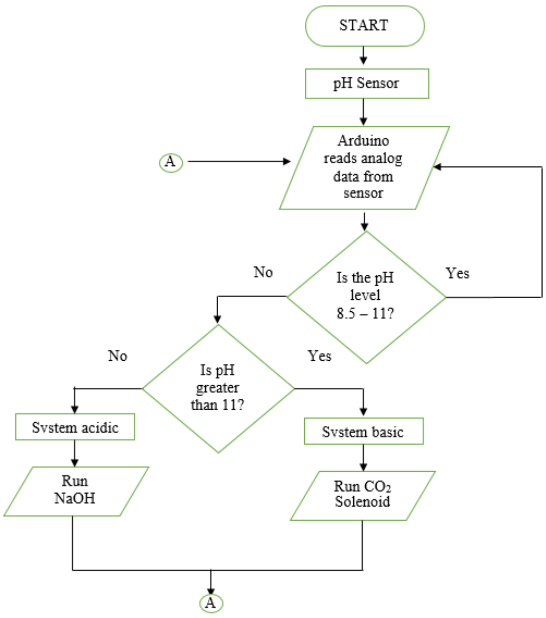

Fig. 4 pH Correction System Flow Chart

The pH correction system will function depending on the pH parameter abnormality. A relay driver is interfaced with a solenoid valve which control the carbon dioxide emission and the flow of NaOH. The pH level that the cultures need is 8.5 to 11 [14]. If pH rises above the range the system will emit carbon dioxide into the system and when the pH decline below the range the correction system will add NaOH until such time that the pH level normalized.

- **Vision System**

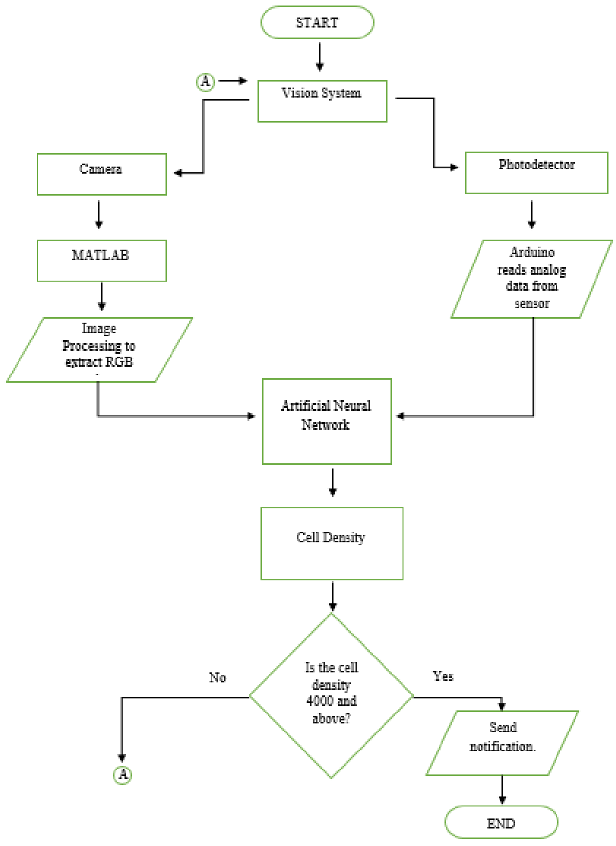

Fig. 5 Vision System Flow Chart

From the tank, a 12V water pump is used in order to fill the sampling cube inside the vision system. The vision system of the device gather two important data, RGB value and lux correlated by the Artificial Neural Network in order to detect the cell density of the culture. The researcher used a 12V LED as a light source, placed above the sampling cube, for the lux sensor which is located beneath the sampling cube. A polarizer is used in order to correct the light intensity coming from the LED.

C. *Artificial Neural Network Data Gathering and Training*

The artificial neural network (ANN) model developed for the system is a feed forward back propagation network whose network inputs are the RGB and the lux value and cell count for the network output. The network uses one layer with 24 nodes whose low mean-squared error is 0.0047813 that has a fast learning time of 2 seconds. The hidden layers are structured using MATLAB in order to optimize the yield of the system. Out of 300 samples, 200 samples are used as training data and the other 100 samples are used for validation.

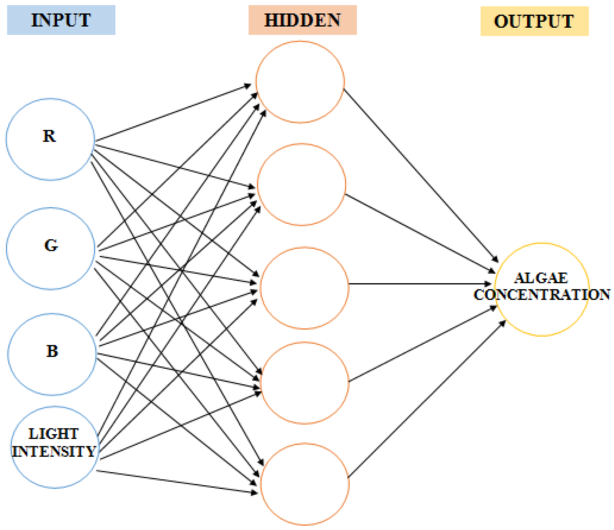

Fig. 6 ANN Model Structure

III. Results and Discussion

A. *Test Run of Automated Closed Algal Culturing System*

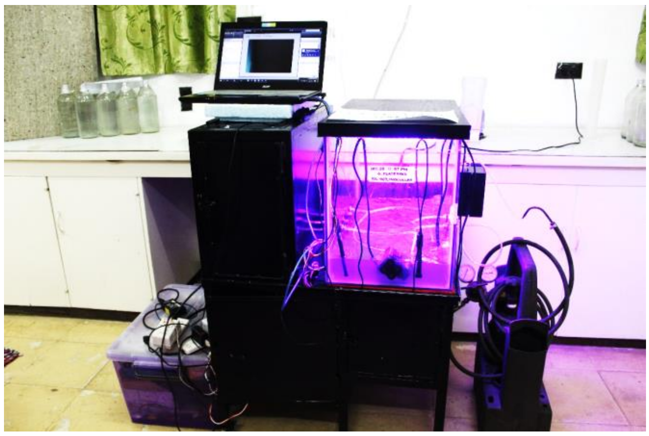

Fig. 7 System set-up for the test runs

The following test run were conducted by the researchers in order to evaluate the functionality of the automated closed algal culturing system. 10 liters of *Spirulina platensis* with 40% inoculum are prepared for both setups: controlled and uncontrolled. For the controlled set-up, both monitoring and correction system operates while for the uncontrolled setup, only the monitoring system is operating.

B. Sensor Reading of One Culture Cycle

- **Temperature**

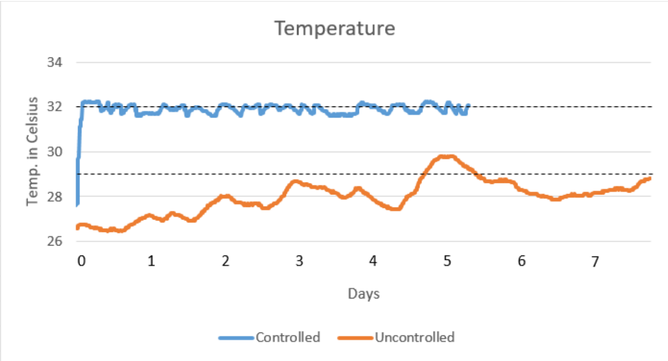

Fig. 8 Temperature plot for controlled and uncontrolled System

Based on the plot of the temperature measured in Figure 8, the data shows that the controlled system were able to correct the temperature abnormalities in the culture and maintain it to the ideal range (29 to 32 degree Celsius) unlike in uncontrolled system which stays beyond the ideal temperature range for most of the time.

- **pH Level**

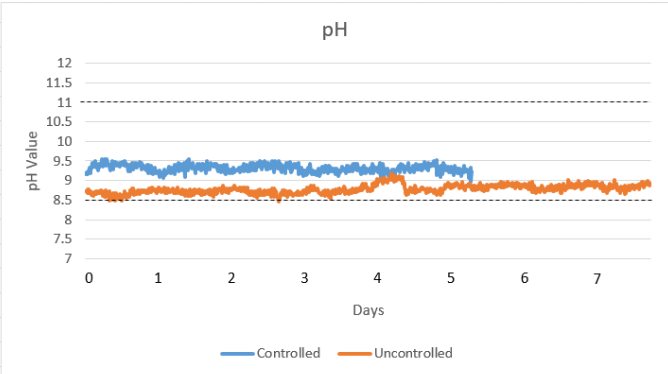

Fig. 9 pH level plot for controlled and uncontrolled System

In Figure 9, it appears from the data gathered that for both controlled and uncontrolled system, the pH of the culture remain on its ideal range (8.5 to 11). However, the pH reading for the controlled system is more stable than the uncontrolled system.

- **Dissolved Oxygen (DO) Level**

In Figure 10, the data shows that just like the pH parameter, the dissolved oxygen reading remains on its ideal range which is (10-25 mg per liter) [15] for both controlled and uncontrolled system. Moreover, the controlled system DO reading is more stable than the reading from the uncontrolled system.

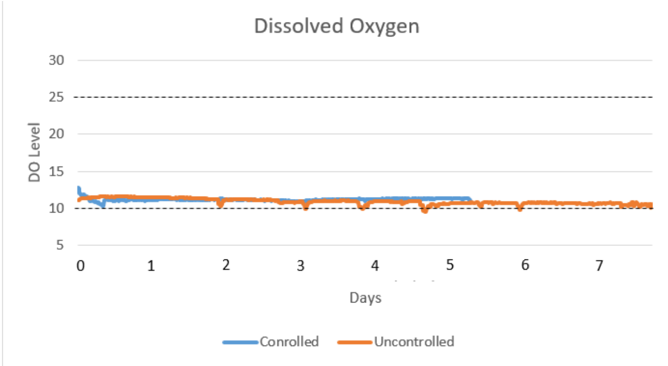

Fig. 10 DO level plot for controlled and uncontrolled System

C. Cell Count

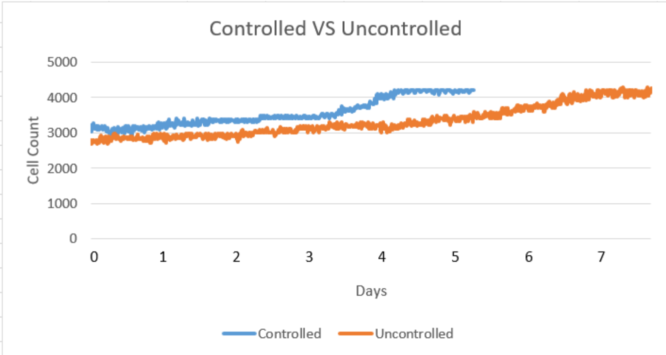

Fig. 11 Cell density plot for controlled vs. Uncontrolled System

Figure 11 shows the growth curve of Spirulina platensis for controlled and uncontrolled system. The results shows that using the controlled system, it only takes 5 days for the culturing process to reach its matured phase which has a cell density of around 4200 while the uncontrolled system takes 7 days.

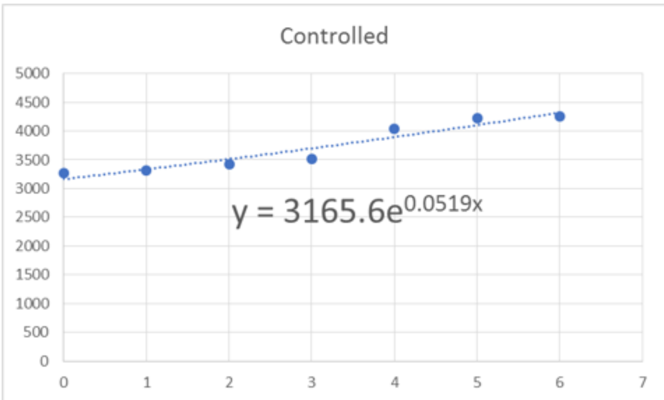

Fig. 12 Regression Plot for the Controlled System Growth Rate

Figure 12 shows the scatter plot and the trend line for the controlled set-up made from the growth data summarized per day. The rate at which the culture grows is modeled using regression analysis and exponential functions. From the equation acquired, the growth rate for the controlled set-up is 0.0519.

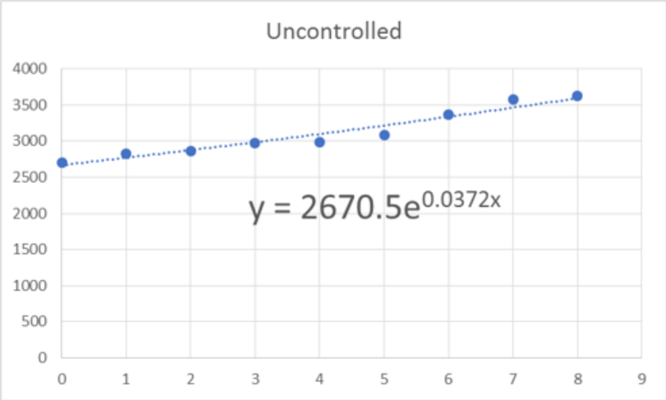

Fig. 13 Regression Plot for the Uncontrolled System Growth Rate

For the uncontrolled set-up which is summarized per day, a growth rate of 0.0372 was acquired based on the scatter plot and trend line shown in Figure 13 whose rate at which the culture grows is modelled using regression analysis and exponential functions.

From the results shown above, it can observe that the controlled set-up has a higher growth rate than that of the uncontrolled one which tells that the parameter correction successfully improved the rate at which the culture grows by 39.52%.

IV. Conclusion

Based on the testing conducted and data gathered by the researchers, it can be inferred that the Arduino Based Closed Algal Culturing System developed by the researcher is highly comparable than the traditional way of culturing microalgae, specifically, *Spirulina platensis*. The device were able to successfully monitored and correct the environmental parameters which are essential in the culturing process. Lastly, the system developed increase the growth rate of *Spirulina platensis* by 39.52% based on the regression analysis conducted wherein the growth for the controlled set-up is 0.0519 and 0.0372 for the uncontrolled set-up.

Acknowledgment

The researchers would like to acknowledge South East Asian Fisheries Development Center – Aquaculture Department (SEAFDEC – AQD) for providing assistance in order to conduct various experimentation associated with the studies. The researchers also thank their dearest professors in providing assistance and guidance in completing the research study. To the researchers parents for providing financial assistance and moral supports.

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