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Evaluation of System Performance for Microalga Cultivation in Photobioreactor with IOTs (Internet of Things)

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Abstract

Photobioreactors are a closed system concept of microalgae cultivation which is mostly done to control the development of intensive cultivation. The use of the internet to control microalgae has been carried out so that cyber physic interaction occurs by using the Internet of Things (IOTs) where this concept is an evolution of the concept of internet use that aims to expand the benefits of internet connectivity that is connected continuously with the ability to control remotely (remote control), data sharing (data sharing), continuous monitoring (real time monitoring) and up to date (up to date). This research aims to design a microalgae cultivation system as a source of food and energy for the future with a photobioreactor integrated with IOTs, so that it can be monitored continuously, controlled and used as a model for the development of greater microalgae cultivation technology. Development of automation in the cultivation of microalgae needs to be done to improve productivity and maintain quality so that the cultivation of microalgae can lead to industrialization, so that the development of microalgae as raw material for various needs can be optimized. Cultivation in a closed system photobioreactor, will produce microalgae that are not contaminated by external contaminants, growth analysis can be done based on the parameters that affect it, including the cultivation room temperature, lighting level (luminance), and the color of water in the process of photosynthesis microalgae, and also control of water circulation by using air lift (aerator).

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All processes carried out in this cultivation are done semi-automatically, because there is still a process of human interaction in setting parameters and controls in the process of harvesting microalgae. In this study microalgae was evaluated by using 4 cultivation tubes using 2 treatments giving fertilizer with different doses, where 2 tubes had the same dose, while 2 other tubes with different dosages. One tube with the same dose is used as a control. Visualization of controlled parameters includes, temperature parameters, light intensity, water color changes. The observed parameters will be displayed in a graphical user interface (GUI) in real time using the internet. The liitation of this studi is how the system for microalga cultivation in a fotobioreactor can monitored by sensor and visualization in a remote monitoring such as computer connected to internet and also any ather devices. The target of this research is to obtined time series data that can be analized and monitored.

Keywords: microalga cultivations; photobioreactor; IOTs (internet of things).

1. Introduction

Current economic and industrial activities are inseparable from the provision of large amounts of energy to be able to carry out its processes and activities. Currently around 80% of global energy demand is produced from fossil fuels. However, widespread use of fossil fuels has caused global climate change, environmental pollution, and health problems [1]. Many countries turn their attention to the development of new, renewable energy sources that are clean, and sustainable. Among the various potential renewable energy sources, one of which is biofuel and is in great demand, so it is expected to play an important role in the global energy infrastructure in the future. Biodiesel is one of the most commonly used biofuels, recognized as an ideal source of energy that can be recycled and renewable, thus also the future can be a primary energy source [2]. Commercial biodiesel is currently produced from animal fats, frying oils and vegetable oils [3], where competition with vegetable oils for agricultural land remains a controversial issue [4]. As a result, microalgae that can grow quickly and convert solar energy into chemical energy through CO_2 fixation in photosynthesis are now considered promising sources of oil to make biodiesel [4].

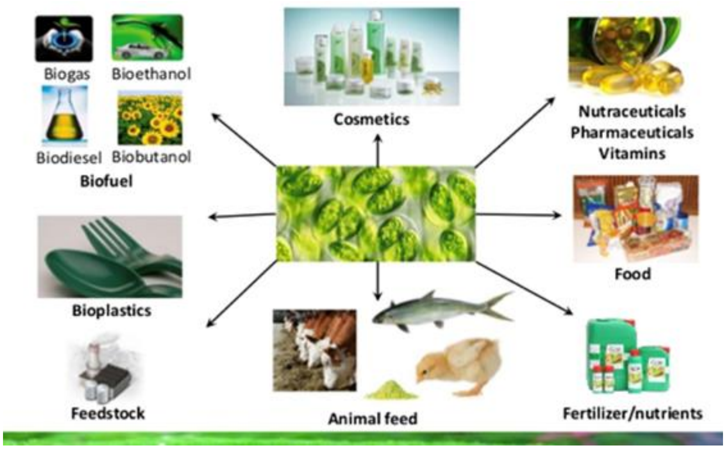

Figure 1: Various product from microalga

Global warming caused by CO_2 emissions has become an important concern in both energy and environmental aspects. Biophysical uptake of CO_2 by photosynthetic microalgae is an important CO_2 mitigation method from different sources, especially industrial exhaust gases and coal-fired power plants. Previous studies have suggested that industrial exhaust gases that are rich in CO_2 can be used to grow large-scale microalgae [5]. CO_2, which is a gas that is easily subjected to changes in shape in the atmosphere, in several studies carried out control of the concentration of CO_2 that enters the algae bioreactor system. To be able to monitor the concentration of CO_2 in the cultivation system, it is needed an instrumentation system that can control and monitor its presence so that it can be used by microalgae for growth. Closed system photobioreactors are considered as important and high potential photobioreactors because of photosynthetic efficiency and higher biomass productivity, because they are easily controlled and conditioned by their cultivation environment for optimal microalgae growth. Under suitable culture conditions, some microalgae species are able to accumulate up to 50-70% oil/lipid per dry weight [2]. Microalgae oil fatty acid profile is very suitable for biodiesel synthesis. The main attraction of using microalgae oil for biodiesel is the extraordinary oil production capacity by microalgae, because it can produce oil up to 58,700 L per hectare, in this case it can be one or two times higher than other energy plants [2]. However, mass production of microalgal oil faces a number of technical obstacles that make the development of the algae industry currently economically unfeasible. In addition, it is also necessary, but very difficult, to develop cost-effective technologies that enable efficient harvesting of biomass and oil extraction. However, because the production of microalgae is considered a feasible approach to reduce global warming, it is clear that producing oil from microalgae biomass will provide significant benefits, besides fuel. Microalgae is widely known as a raw material for third generation biofuels [2]. As an alternative raw material for biodiesel production, microalgae has the following advantages compared to conventional oil plants such as soybean: 1) microalgae has a simple structure, but photosynthetic efficiency is high with a doubling time of growth of less than 24 hours. Moreover, microalgae can be produced throughout the year. Some data in Table 1 shows that microalgae is the only source of biodiesel that has the potential to replace fossil fuels; 2) Abundance of species and biodiversity of microalgae over the climate spectrum and broad geographical areas make seasonal and geographical restrictions less received attention compared to other lipid food ingredients. Microalgae can be processed in fresh water, saltwater lakes with eutrophication, oceans, marginal lands, deserts, etc; 3) Microalgae can effectively remove nutrients such as nitrogen and phosphorus, and heavy metals from wastewater; 4) Extracting large amounts of carbon microalgae through photosynthesis, for example, the efficiency of Chlorella vulgaris CO_2 fixation reaches 260 $mg \cdot L^{-1} \cdot h^{-1}$ in membrane photobioreactors. Utilization of CO_2 from thermal power plants with large-scale microalgae production facilities can reduce many of the greenhouse gas emissions blamed for global warming; 5) Production and use of microalgae biodiesel contribute to near zero clean CO_2 and sulfur into the atmosphere; 6) Microalgae can produce a number of valuable products, such as protein, polysaccharides, pigments, animal feed, fertilizers, and so on. In short, microalgae is a source of biomass that is still very little utilized for the production of renewable energy.

Table 1: Comparison of several biodiesel feedstock sources

Raw material	Oil content (% in biomass dry weight)	Oil yield (L/ha/year)	Land used (m^2/year/kg biodiesel)	Biodiesel productivity (kg biodiesel/ ha/year)
Soybeans	18	636	18	562
Rapeseed	41	974	12	862
Sunflower	40	1070	11	946
Palm oil	36	5366	2	4747
Castor	48	1307	9	1156
Microalgae	70	136,900	0.1	121,104

Source: Mata, T. M., A. A. Martins, and N. S. Caetano. 2010. Microalgae for biodiesel production and other applications: A review. *Renewable and Sustainable Energy Reviews* 14 (1): 217–232.

As a photosynthetic organism, microalgae can absorb CO2 and synthesize organic compounds, such as lipids, proteins and carbohydrates in large quantities in a short period of time. The traditional method of cultivating microalgae based on the photoautotrophic method has many shortcomings, among which low cell density is a major problem causing low productivity. Therefore, a significant effort to commercialize microalgae biomass production is to develop a high-density cultivation process. Two approaches were developed including: (1) controlling metabolism; (2) the design of a cultivation system (cultivation system in a bioreactor). The development of electronic technology and the internet makes it possible to control, observe and analyze microalgae cultivation systems with electronic sensors that support cultivation, such as temperature, light intensity, pH and DO sensors and supporting actuators to activate fluid circulation as a medium in which microalgae grows . The entire sensory system and actuator are controlled by a microcomputer that is connected to the data transceiver (transmiter and receiver) system, so that data coming from the cultivation system will be able to analyzed. GUI system (*graphic user interface*) is the interface between the user and the system that can be operated locally or through the internet network. Recent studies in the field of microalgae in relation to the integration of the Internet of Things (IoT) are still rarely conducted. According to searches of the literature with Google Scholar, Google Scholarship, and Science Direct, there are 2 studies that are relevant to the research is conducted by Esposito S, Cafiero A,[(6)] Giannino F, Mazzoleni S, Diano M, (2017) for a Monitoring, Modeling and Decision Support System (DSS) for a Microalgae Production Plant based on the Internet of Things and also by the same researcher Giannino F[(7)], Esposito S, Diano M, Cuomo S, Toraldo G (2018) with the title "A predictive Decision Support System (DSS) for a microalgae production plant based on the Internet of Things paradigm, both reasearch is a new reasech relatid to microalga cultivations work using the internet, but the deference with the method and the aplication. Esposito and Gionino is decision support system fot helping field supervisor to control and monitored race a way microalga cultivation. Current technological developments by utilizing internet networks that can interact with hardware (hardware) is called IoT’s (Internet of Things). In this research, an integrated photobioreactor system with integrated with IoT (intenet of things) to monitor the physical parameters of microalgae cultivation in real time, so that an analysis of the development of microalgae cultivation can be carried out over time. This can be a breakthrough for the supply of microalgae cultivation stock for various derivative needs. The purpose of this research is:

1. Create an instrumentation system that is integrated with photobioreactors that can continuously control

and observe the cultivation of microalgae connected to the internet network

2. Obtain data continuously to observe algae cultivation from time to time
3. Evaluate the photobioreactor system with different fertilizer doses

2. Material and Methods

2.1 Materials

The material used in this research is shown in Table 2. As for the consumables, it can be seen in Table 3.

Table 2: Equipment list

No.	Name of Equipment	Function
1	Computer	Creating programs, displaying GUIs, accessing the internet, controlling the cultivation system
2	Mini PC/Raspberry Pi	Local server, to coordinate each sensor data and control system (relay) and send data to the internet via a GSM Router
3	Wemos D1 Microcontroller	Microcontroller for reading sensors and sending sensor data to Raspberries
4	Router	Raspberry Data Communication with an internet server
5	Zigsaw	Cutting
6	Sander	Smoothes
7	Cutting burrs	Cutting
8	Solder	Electronic equipment
9	Hand drill	Making a hole
10	Others equipment	Ruller, cutter, label, etc.

Table 3: Disposable Materials

No.	Name of Materials	Function
1	Photobioreactor platform material (paralon 4 ", Acrilic, Putty Sun Polax, Tinner, Emery, resin coloring)	Make mockups, prints and prints to the desired shape
2	Analog Electronic Components (Resistors, Capacitors)	Sensor buffers, signal amplifiers, electronic assembly
3	Digital electronic components	Electronic assembly
4	Microcontroller	The control system in the cultivation system in photobioreactors
5	Temperature sensor (Dallas)	Get temperature data
6	Visibility light sensor	Get light intensity data
7	Colour Sensor (TCS3200)	Get water color data
8	RTC (real time clock)	Get actual time
9	Selenoide valve	Water output from the reactor
11	Aerator	Give aeration to photobioreactors
14	Cables and accessories	Electronic assembly

2.2. Methods

The Photobioreactors are assembled using 4 reactors with the dimension 20 cm x 2m cm x 80 cm (length x width x height), made of acrylic with a thickness of 5 mm. To stabilize the water temperature, a large chamber filled with water with a length of 90 cm, width 60 cm and height 50 cm is used. Photobioreactor control uses a microcomputer as a control base. There are 2 microcomputers used, namely WEMOS D1 which is directly related to the sensor, where the sensor used is a temperature sensor (Dallas, DS18B20), amounting to 1 for each reactor, and 1 environment temperature sensor which is placed in a large chamber, so 5 temperature sensors used. Light sensors (TSL2561 light sensors) and color sensors (RGB sensors, TCS3200), are also connected to Wemos D1 so that the number of sensors connected to the WEMOS D1 Microcomputer is 3 pieces, respectively, so for 4 reactors, sensors need 4 temperature sensors, 4 light intensity sensors and 4 color sensors and 1 temperature sensor are inserted in 1 port slot on one of WEMOS D1. To read data from WEMOS D1, Raspberry Pi is used, as the center of control, because Raspberry Pi will give commands and receive instructions to the system. Sensor data from Wemos D1 will then be made into a data format that accommodates all sensors and is sent via a Router by Raspberry Pi. so it will be connected to the internet network. Raspberry will also instruct the actuator to continue the control message that comes from the GUI (graphical user interface) from an external device, can use a PC or gadget that is connected to the internet network. So that the hardware can work then the software as its spirit, where with the software the hardware can work according to the command. There are 3 software systems, namely microcontroller programming using Arduino sketch, Raspberry Pi mini PC programming using Python 3.2 and internet programming. Arduino sketch programming is reading data from the three sensors used, namely temperature sensor, brightness sensor and color sensor, then combining the three sensor values into a predetermined data format based on each reactor ID. Programming on a Raspberry Pi mini PC is divided into several parts, namely first, programming to integrate all data from the four reactors to be sent to the server. Second, the program for automatic control of reactor temperature where the program will read the sensor value on the reactor and the threshold value on the server. If the temperature value is lower than the threshold value specified in the database server, the heater will turn on and vice versa. The third program in the mini PC section is a program for lighting control where the program will continuously check the value in the database server that indicates each lamp is on or off, if there is a difference in value then the program will adjust the on / off of each lamp. Internet programming is done using Apache and PHP web services while for the database using MySQL. There are two main functions in internet programming, namely to display data or graphs of sensor values in realtime and to control lights and heaters. In accordance with the objectives of the design of the photobioreactor system, that it can carry out continuous monitoring of microalgae cultivation, therefore the system will operate continuously in accordance with the time of cultivation. The limiting parameters to do is to set the desired temperature to be stabilized, in accordance with the conditions of growth for the cultivation of microalgae. The system block diagram are shown at Figure 2.

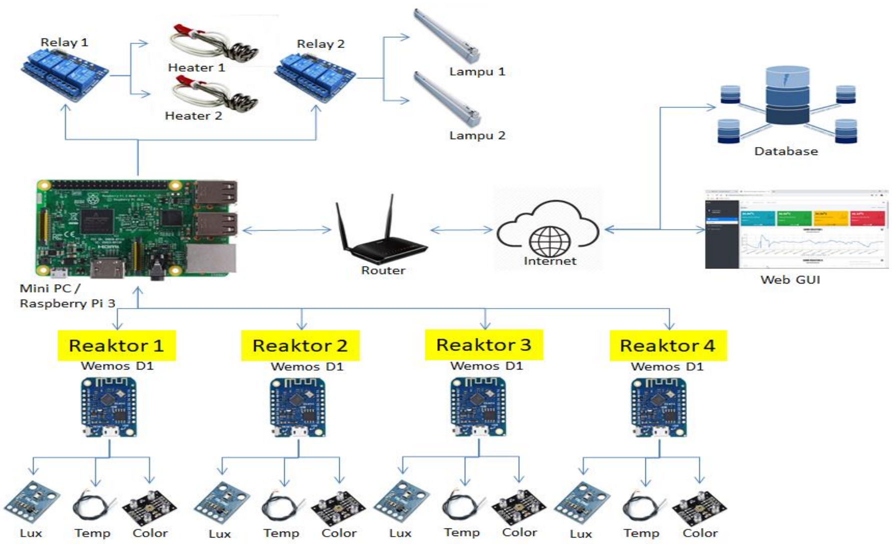

Figure 2: System Block Diagram

3. Results and Discussion

3.1. Photobioreactor Design

This photobioreactors consist of 4 reactors, each of which is independently controlled. The control consists of controlling and stabilizing the water temperature of each reactor and the environmental temperature which will affect the temperature of the water in the reactor. An illustration of the design of the built photobioreactor platform can be seen in Figure 3. The reactor that was built from transparent acrylic, where the design was adjusted to the hypothesis that was built, that the cultivated microalgae photosynthesized so that it needed light as a limiting parameter, as well as the cultivation temperature that could be adjusted according to the optimum temperature of life of the microalgae so that cultivation could run well.

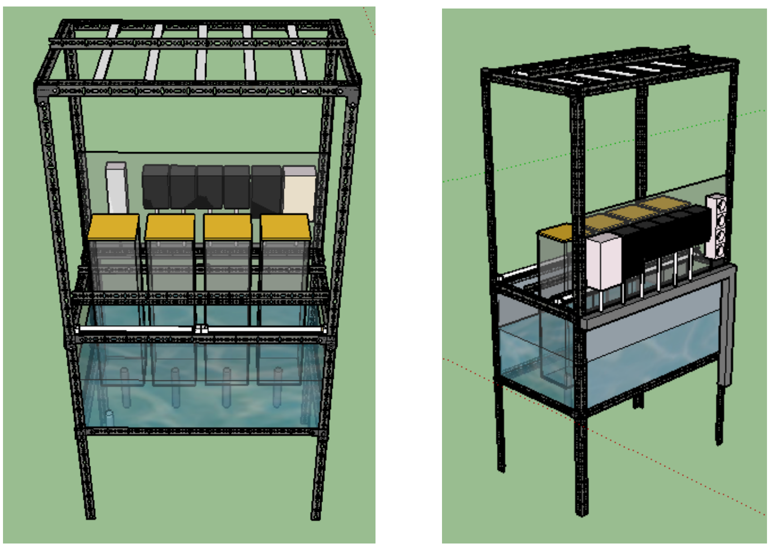

Figure 3: Fotobioreactor design (a) Front (b) Rear

Figure 4: Photobioreactor before and after the tarp closed

3.2. Cultivation

Figure The design photobioreactor is filled with microalgae with a volume of 10 Liters per reactor so that 4 reactors can accommodate 40 liters of microalgae cultivation. The cultivation process can be carried out by continuously observing the development of microalgae growth from day to day.The initial process is carried out by entering the microalgae seedlings with the concentration of each reactor is 1:9, meaning that 1 Liter concentration of microalgae with 9 Liters of Water, so that the total concentration per reactor is 10 Liters. Observations were made using a sensor system placed in each reactor consisting of a temperature sensor, light intensity sensor, and color sensor. Data from the sensor will be continuously transmitted to the GUI via the internet network. While the GUI can also carry out the activation order for the actuator contained in the cultivation system such as lights, heaters, and other actuator equipment, because in the relay system connected to the raspberry pi there are 8 slots. This command can be directly responded to by the system and activate as needed.

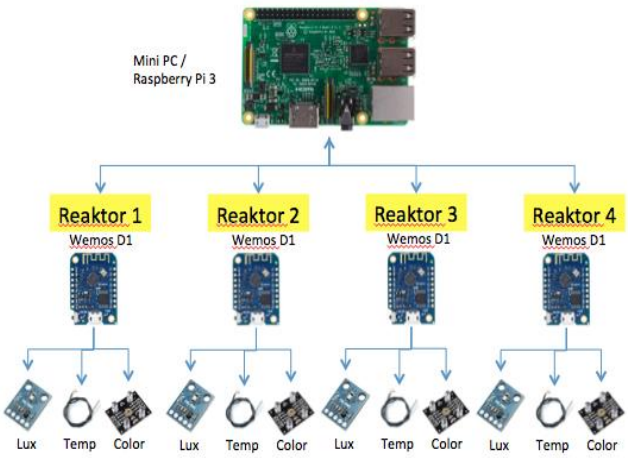

Figure 5: Sensor configuration of each reactor

Cyber-physic interaction is characteristic of a system of IOTs (internet of things) meaning that there is a reciprocal relationship that occurs between physical phenomena observed with a web server which is a control interface with the internet to display all parameters observed in this case using a GUI (*graphic user interface*). In Figure 6. Is the result of program execution to display and set the temperature point which is the target of stabilization. In the literature that the optimum temperature for cultivation is in the temperature range of 28-32 ^{o}C, so that the temperature control is done with a set point of 30 ^{o}C.

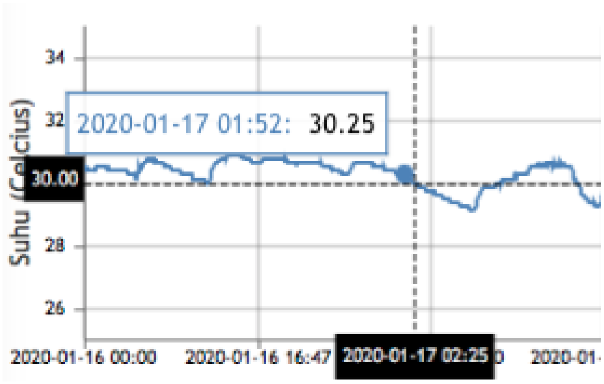

Figure 6: Temperature fluctuation at set point 30 ^{o}C

When the ambient temperature in a large aquarium chamber is lower than the set point temperature, the system will turn on the heater, until the temperature in the reactor is reached, so that the temperature in the reactor will be stable in accordance with the desired temperature. Measurement data will be stored in a database and can be stored in various data formats, so data processing can be done for various purposes by subsequent researchers. The data and database display system is displayed in the architecture in Figure 7 as follows:

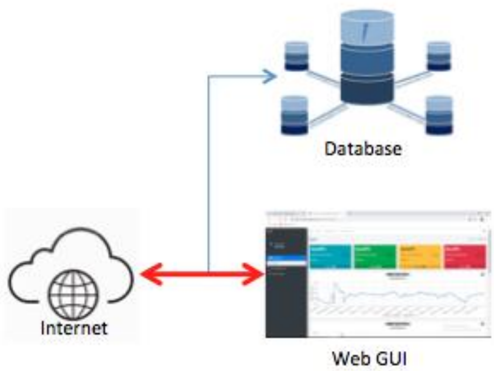

Figure 7: GUI and Database Webserver Architecture

In the webserver architecture above, the data obtained from the results of data transmission over the internet network will be stored in a database, while the real time data will be displayed directly through the web site https://kultivasimikroalga.com. The website will display the parameters sensed by the sensor, including the temperature sensor, light intensity sensor and color sensor. The data format sent by the sensor that was previously acquired by Raspberry data must first represent all the sensors used in cultivation, the data format must represent all observed parameters.

// date, time, temperature1, temperature2, temperature3, temperature4, intensity1, intensity2, intensity3, intensity4, red1, red2, red3, red4, green1, green2, green3, green4, blue1, blue2, blue3, blue4 //

From the data format, sensor measurement data will be sent which is then stored in a database. For the appearance of data on the website, it must first be sorted out on the website and displayed in graphical form. The incoming data will be sorted by the time the data was taken during the cultivation period and will be displayed continuously. The advantage of this system, the data will be continuously obtained in accordance with the real conditions in the field and will follow the development of cultivated microalgae. Figure 7 shows the data obtained from time to time and can be seen on the php web server. Data is collected at 30-second intervals and can also be set as needed by following the observed parameter changes. Determination of this observation time interval (time repetition rate, TRR) is very important because it will determine the changes that occur. For example the temperature can change quickly according to the micro climatic conditions around the location of the trial, then the speed of data retrieval and also the time interval of data retrieval is very important to get the accuracy of the data obtained. Likewise with the light intensity sensor, because the development of microalgae to multiply greatly influences the rate of density, the density of microalgae will affect the intensity of light entering the light intensity sensor. The same is true for color sensors, because color changes will be known simultaneously. Figure 8 shows the system is running which is controlled by a system with temperature stabilization with a set point at 30 OC. The set point is carried out on the PHP web server by editing temp_con as desired, so that it will greatly affect the activation of the actuator (heater) to stabilize the reactor temperature.

Server: 127.0.0.1 » Database: u623546179_chaidar » Table: data

Browse | Structure | SQL | Search | Insert | Export | Import | Operations | Triggers

	Id	tanggal	waktu	suhu1	suhu2	suhu3	suhu4	suhu5	intensitas1	intensitas2	intensitas3	intensitas4	red1	red2	red3	red4
Delete	1	2019-11-22	16:46:01	28.19	28.25	28.06	28.19	28.00	24.00	43.00	30.00	19.00	63	0	49	0
Delete	2	2019-11-22	17:06:45	28.31	28.37	28.19	28.44	28.06	21.00	47.00	31.00	21.00	70	0	56	84
Delete	3	2019-11-22	17:07:53	28.31	28.37	28.12	28.37	28.06	22.00	44.00	32.00	21.00	77	0	61	91
Delete	4	2019-11-22	17:07:54	28.31	28.37	28.19	-127.00	-127.00	22.00	48.00	31.00	19.00	87	0	68	88
Delete	5	2019-11-22	17:09:39	28.31	28.37	28.19	-127.00	-127.00	20.00	49.00	28.00	19.00	80	0	61	88
Delete	6	2019-11-22	17:10:39	28.31	28.37	28.19	-127.00	-127.00	20.00	49.00	28.00	19.00	80	0	61	88
Delete	7	2019-11-22	17:11:39	28.31	28.37	28.19	-127.00	-127.00	20.00	49.00	28.00	19.00	80	0	61	88
Delete	8	2019-11-22	17:12:20	28.31	28.37	28.19	28.31	28.12	22.00	50.00	30.00	19.00	70	0	63	88
Delete	9	2019-11-22	17:12:41	28.31	28.37	28.19	28.31	28.12	24.00	45.00	28.00	21.00	73	0	58	84
Delete	10	2019-11-22	17:13:20	28.31	28.37	28.19	28.31	28.06	22.00	43.00	31.00	22.00	80	0	51	91

Figure 8: Database on PHP web server

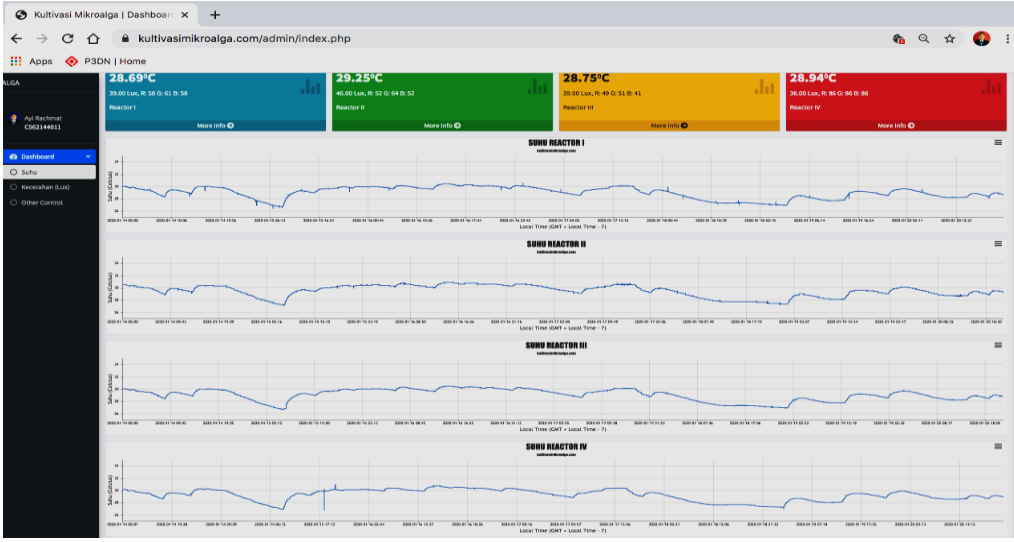

Figure 9: Display from the web https://kultivasimikroalga.com/admin/index.php on a graph display temperature monitored continuously at a set point 30 ^{o}C

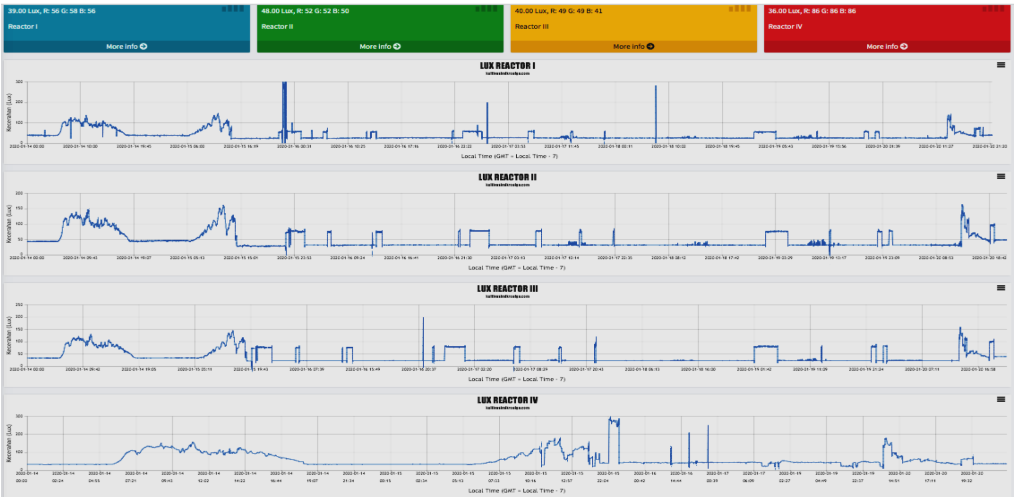

Figure 10: Display from the web https://kultivasimikroalga.com/admin/index.php in the light intensity graph display (lux) which is monitored continuously

Figure 10: Interaction between GUI and actuator

Figure 9 shows the system is running which is controlled by a system with temperature stabilization with a set point at 30 OC. The set point is carried out on the PHP web server by editing temp_con as desired, so it will greatly affect the activation of the actuator (heater) to stabilize the reactor temperature. Figure 10 shows time series data from time to time for light intensity. On the visible light intensity graph there is a fluctuation of the test results, where during the daytime there is lighting from sunlight which is more dominant so that the intensity increases, then an experiment is carried out by closing the whole reactor with a black tarpaulin, so that there is no lighting from the outside environment, but at the time of the experiments conducted outside the room, a lot of opening and closing of the tarpaulin used as a cover, so recorded by the system, therefore the system has worked well by responding to all activities that occur during the trial process cultivation.

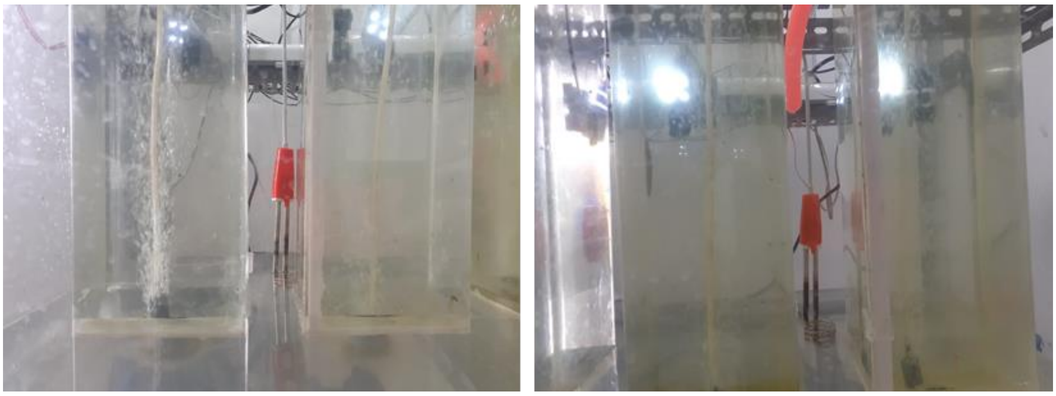

Figure 11: Alga growth at 3rd days cultivation (the system response continuesly) and still active on day 3 cultivation system is still operating well and can respond to any changes that occur from the physical parameters observed by the sensor continuously

4. Conclusions

The The design of photobioreactors in microalgae cultivation integrated with the internet network (Internet of things) has been successfully carried out, this is by obtaining two-way cyber physic interaction in controlling microalgae cultivation. This system involves sensors placed in cultivation that will monitor continuously and up to date with an intermediate GUI (*graphical user interface*) that is built and the system is able to control the actuators on the cultivation system according to cultivation needs. The parameters observed in this case are temperature, light intensity and color sensor can be displayed and the data is obtained from time to time, while the actuator is controlled in the form of a heater to stabilize the cultivation water temperature at the reactors used as microalgae cultivation sites.

5. Recommendations

Research on photobioreactors for microalgae cultivation using the internet of things is research that can help researchers in optimally uncovering the phenomenon of microalgae culture by involving various sensors. in this study only a few sensors are used namely temperature, light and color sensors (RGB Sensor) so that other sensors are needed that can support the growth of microalgae life that can be monitored from time to time, such as CO2 sensor, nitrate, nitrite and other nutrient sensors. Likewise, the time of research should be done by paying attention to the many cycles of microalgae cultivation, so that they can know for certain the behavior of the growth of microalgae from time to time.

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