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Development of Microalgae Growth Monitoring System Using TSD-10 Sensor and ThingSpeak Platform

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ABSTRACT

Microalgae chlorella sp. is one of the low-level plants that has many benefits and need to be harvested when they have reached optimum density. This study aims to develop a microalgae density monitoring system using the TSD-10 sensor and the ThingSpeak platform. The output voltage from the TSD-10 sensor was calibrated into microalgae density using hemocytometer and then sent wirelessly to the ThingSpeak cloud server using the ESP8266 module. A linear equation of $y = -1.633\ x + 1421.3$ *was obtained from the calibration process where y is microalgae density (cell/ml) and x is analog to digital conversion (ADC) value of the TSD-10 sensor. The determination coefficient of the calibration and validation process is 0.9921 and 0.938 respectively. The measurement stability was quite good with a standard deviation ranging from* 1.15×10^4 *cell/ml to* 2×10^4 *cells/ml of culture medium. The measurement accuracy of the validation process using the RMSE (Root Mean Square Error) formula is 3.25. The time response of the sensor after power on is 5.85 s and the time it takes to display data on the ThingSpeak cloud is 16.03 s. Thus the measuring instrument developed can be said to have a fairly good performance.*

1. INTRODUCTION

Microalgae is a low-level plant that has many uses, including as natural feed for fish and shrimp cultivation (Mufidah *et al*., 2018), as a biosorbent for absorption of heavy metals such as nickel in waters (Zakir *et al*., 2022), as a liquid waste treatment such as Palm Oil Mill Effluent (POME) (Muria *et al*., 2020), as a renewable energy source (Gultom, 2018;Elystia et al., 2019), as an anti-inflammatory drug (Kurnia *et al*., 2019).

The growth stages of microalgae include the adaptation phase, the exponential phase, the stationary phase, and the death phase (Krishnan *et al*., 2015;Prayitno, 2016). In the adaptation phase, microalgae begin to adapt to the growing media and environmental conditions. After passing through the adaptation phase, microalgae begin to grow and divide so that their density increases. When the growth rate is equal to the death rate, the density of microalgae will remain constant, which is called the stationary phase. The decrease in the rate of cell division is generally due to the reduced amount of nutrients in the media. A decrease in the rate of cell division is also followed by an increase in the rate of death so that the density decreases and is known as the death phase. Apart from nutrition, the growth rate of microalgae is also influenced by several factors including light intensity, dissolved oxygen (DO) content, temperature, salinity, and acidity (pH) (Widiyanto *et al*., 2014). It was reported that the growth rate of chlorella sp. more dominantly influenced by the intensity of light and the amount of dissolved oxygen (DO).

Microalgae need to be harvested periodically before reaching the optimum density so that the density of the remaining microalgae in the media is reduced and with the addition of nutrients as needed by the microalgae, cell division will occur so that the density will increase again (Ma'rufatin, 2016;Prayitno *et al*., 2020). The optimum density occurs during the transition from the exponential phase to the stationary phase. So far, the growth or density of microalgae is measured in the laboratory using a combination of hemocytometer and microscope (Regista *et al*., 2017;Zakir *et al*., 2022) but measurement with this method takes a long time. Microalgae density measuring instruments used by several previous researchers apart from hemocytometers include: Wardhani *et al*., (2015) designed a microalgae density measuring instrument using a photodiode sensor and ATMega 16 microcontroller with a measurement error of 4% in stopped flow conditions. Zamani & Muhaemin, (2016) used a spectrophotometer to measure microalgae density, but it is expensive and measurements cannot be done in real time, therefore a measuring instrument is needed that is capable of measuring microalgae density quickly and in real time.

Internet of Things (IoT) is a method that is widely used to build monitoring systems in real time (Ridwan & Sari, K. M., 2021; Safira *et al*., 2023). ThingSpeak is an IoT-based monitoring system platform whose settings are quite easy and quite popular (Akbar *et al*., 2019;Gani *et al*., 2019;Miry & Aramice, 2020;Hutabarat *et al*., 2023). Data is sent to the ThingSpeak cloud using HTTP POST. Apart from being displayed on the ThingSpeak cloud, microalgae density data can also be displayed on a smartphone using the ThingView application (Kurniawan *et al*., 2021). The purpose of this study was to develop and test the performance of a microalgae density monitoring system using the TSD-10 sensor and the ThingSpeak platform.

2. MATERIALS AND METHODS

2.1. Materials and Tool

The materials used in this study included: glass aquarium with dimensions of 30 cm x 25 cm x 25 cm, chlorella sp microalgae seeds, walne fertilizer, fresh water, PE plastic, turbidity sensor (TSD-10), 18 watt LED TL lamp, microcontroller Arduino uno, ESP8266 WiFi module, WiFi router to connect the ESP8266 to the internet network, 16x 2 LCD display. The tools used include: Asus X200CA laptop with Arduino IDE application, hemocytometer, vintage correct Seiwa optical microscope, Samsung Galaxy J5 smartphone, Aerator Rosston L2. The research was conducted in the Microbiology Laboratory, Department of Biology, Faculty of Mathematics and Natural Sciences, Bogor Agricultural University, Dramaga District, Bogor Regency. The research was conducted from December 2021 to January 2023.

2.2. Hardware Design of Microalgae Density Measurement System

The microalgae density measuring instrument was designed using a TSD-10 optical sensor. The output analog voltage value from the TSD-10 sensor which is connected to the analog input line A0 of the Arduino uno microcontroller is converted into digital data with 10-bit resolution. The digital values that have been converted to microalgae density values are then displayed on a 16 cell x 2 line LCD display. The density value of the chlorella sp microalgae is also sent via the ESP8266 WiFi module and WiFi Router to the ThingSpeak cloud system. All electronic devices are powered by a battery with a capacity of 22,400 mAH with an output voltage of 5 volts DC. Schematic diagram of the electronic circuit for microalgae density measurement system is shown in Figure 1.

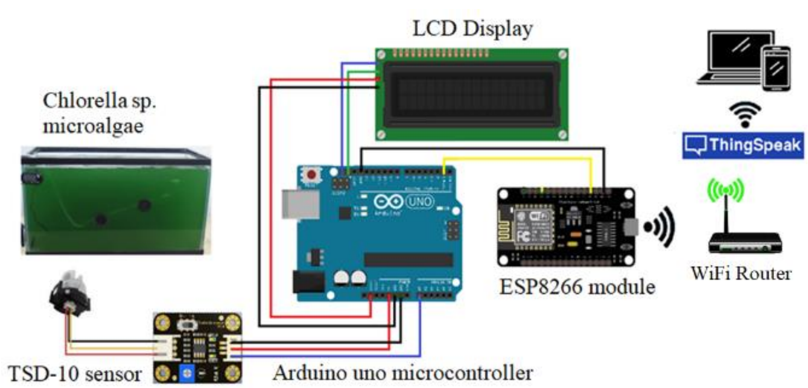


Figure 1. Electronic design of the microalgae chlorella sp density measurement system.

2.3. Software Design of Microalgae Density Measurement System

The monitoring system software consists of software used to read the output value from the TSD-10 sensor and display the microalgae density value on the LCD display, software to wirelessly transmit the microalgae density value to the ThingSpeak cloud.

Designing a monitoring system with the ThingSpeak platform is carried out in the following steps: first, create an account via the URL https://thingspeak.com, then sign up using a specific email address and password until a display appears that says "your profile was verified". Creating a ThingSpeak Channel is done by signing in using the email address and password that have been registered via the URL https://thingspeak.com. In the ThingSpeak application, create a new channel by writing the project name, project description, and fields to display measurement data. On the application screen, the Channel ID will be displayed which will be used by the ESP8266 module to communicate with the ThingSpeak platform. Press the API key button on the application screen to get the API code used by the ESP8266 module for the purpose of writing (write API key) and reading (read API key) data on the ThingSpeak platform. Write down the SSID and password of the WiFi Router in the ESP8266 module software so that measurement data can be sent via the internet. The programming algorithm for measuring and sending data wirelessly is shown in Figure 2.

2.4. Preparation of Microalgae Culture Media

In this study, microalgae chlorella sp were cultivated in a glass aquarium with dimensions of 30 cm x 25 cm x 25 cm. Fresh water used as a cultivation medium is first boiled and then cooled. A total of 9 liters of cold fresh water is then put into the aquarium. The dissolved oxygen content in the water medium was increased using an aerator device and light was provided using an 18 watt TL lamp. A total of 250 ml of a mixture of vitamin and walne fertilizers was put into the water medium that had been given an aerator, then 1 liter of chlorella sp seeds was added. In this research, the

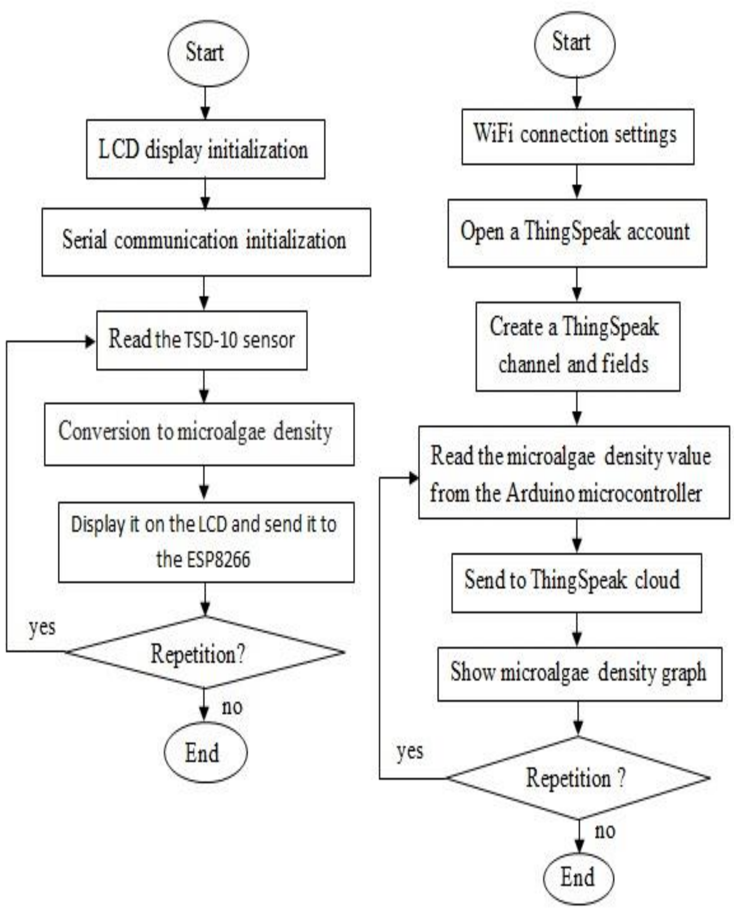


Figure 2. Programming algorithm for reading (left) and sending data (right).

Walne fertilizer concentration was given for five days of cultivation. Wardani *et al*., (2022) stated that Walne fertilizer is a synthetic medium that is often used for microalgae culture. Walne fertilizer with a concentration of 1.5ml/l of media is sufficient to meet the nutrient needs of microalgae cultivation. Buwono & Nurhasanah, (2018) stated that too little or too much Walne fertilizer content will inhibit the growth of microalgae.

2.5. TSD-10 Sensor Calibration

TSD-10 sensor calibration was carried out by measuring the density of chlorella sp microalgae every day for five days between 10 and 12 o'clock with three replications. The intensity of light at the time of measurement ranges from 100 to 250 lux. The density of microalgae that has been measured using the TSD-10 sensor is then sampled to be measured in the laboratory using a combination Hemocytometer and Microscope. In this study, only 5 of the 25 boxes on the hemocytometer were counted as marked in black colour in Figure 3. Cell density was then calculated using equation 1.

$$K_p = \frac{n}{5} \times 25 \times 10^4 \frac{sel}{ml} \tag{1}$$

where *Kp* is microalgae cell density value (cell/ml), and *n* is number of microalgae cells in 5 small boxes.

The relationship between ADC readings and microalgae density was then plotted to obtain a calibration equation. The validation process was carried out with the same procedure as the calibration process but in the validation process a calibrated TSD-10 sensor is used.

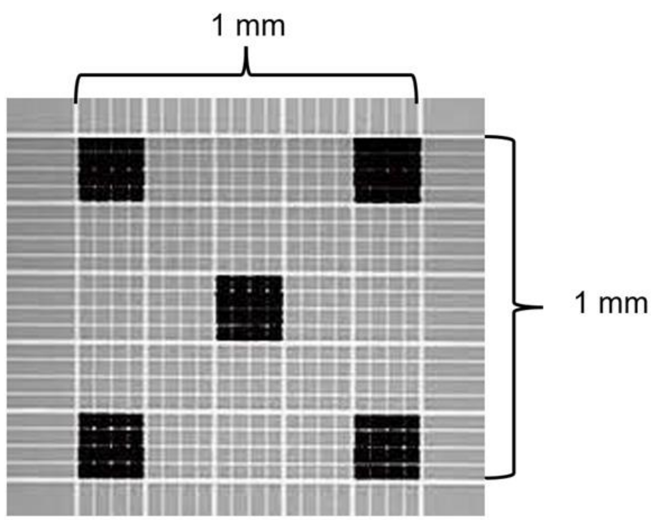


Figure 3. The position of the five squares on the hemocytometer to count the number of microalgae cells.

2.6. Data analysis

Data analysis was carried out to determine the performance of the TSD-10 sensor in estimating the density value of the microalgae *chlorella sp*. Data analysis included calibration and validation of the TSD-10 sensor, stability, response time, and accuracy of sensor measurement results. Stability was used to determine the sensor's ability to produce values that are almost the same when repeated measurements are made under the same conditions. Response time was used to determine the speed of the measuring instrument to produce stable values and the speed of the monitoring system to connect to the ThingSpeak cloud. Sensor measurement accuracy was calculated using the RMSE (*Root Mean Square Error*) formula as in equation 2.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{n}} \tag{2}$$

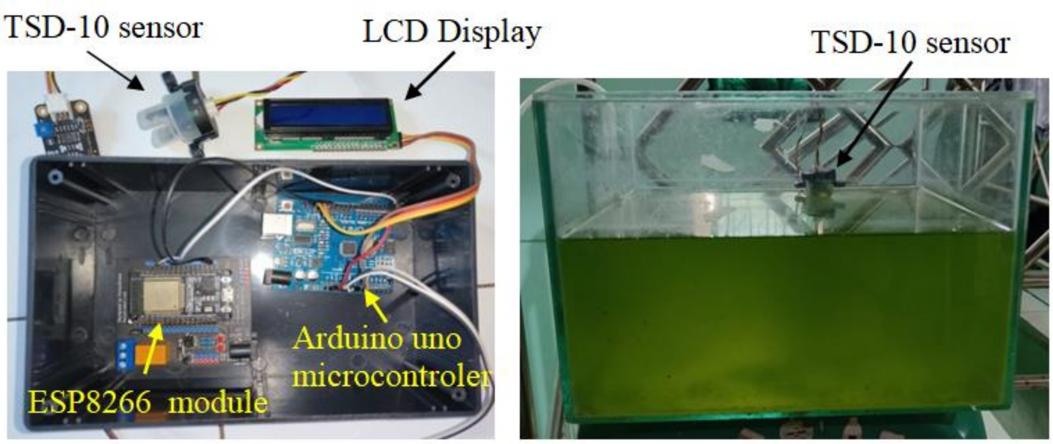
where x_i is the value of the i^{th} measurement from the TSD-10 sensor, y_i is the value of the i^{th} laboratory measurement, and *n* is the number of measurements.

3. RESULTS AND DISCUSSION

3.1. Electronic Circuit

The electronic circuit for monitoring the microalgae density is placed in a box with dimensions of 18 cm x 11 cm x 6.5 cm as shown in Figure 4a. The electronic components used include: Arduino Uno microcontroller, ESP8266 module, LCD display, and TSD-10 sensor module. The TSD-10 sensor is then placed on the surface of the microalgae cultivation media as shown in Figure 4b. The upper edge of the aquaculture aquarium is then covered with PE plastic to avoid contamination with other materials in the cultivation environment.

Microalgae density was measured daily for 7 days between 10:00 and 12:00 AM with 3 repetitions. The measurement results are then plotted on a graph of the relationship between the ADC conversion value and the laboratory measurement density value as shown in Figure 5. The graph in Figure 5 shows the microalgae density increased until the 3rd day and then decreased until the 7th day of measurement. Changes in the density of microalgae produced by Krishnan *et al.* (2015) also have the same pattern as the results of this study. Widiyanto *et al.* (2014) stated that the growth rate of chlorella sp microalgae was more dominantly influenced by light intensity and the amount of dissolved oxygen (DO). Therefore, the less optimum growth of microalgae in this study was probably caused by the concentration of dissolved oxygen and light intensity which was not optimal according to the needs of microalgae growth.



(a) (b)

Figure 4. (a) Monitoring system circuit, and (b) TSD-10 sensor installation on microalgae culture media

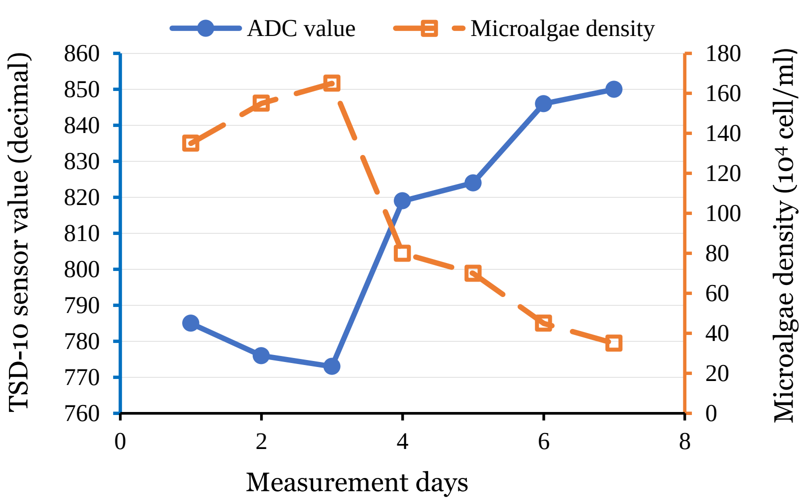


Figure 5. Pattern of change in measurement values and density of microalgae during 7 days of observation

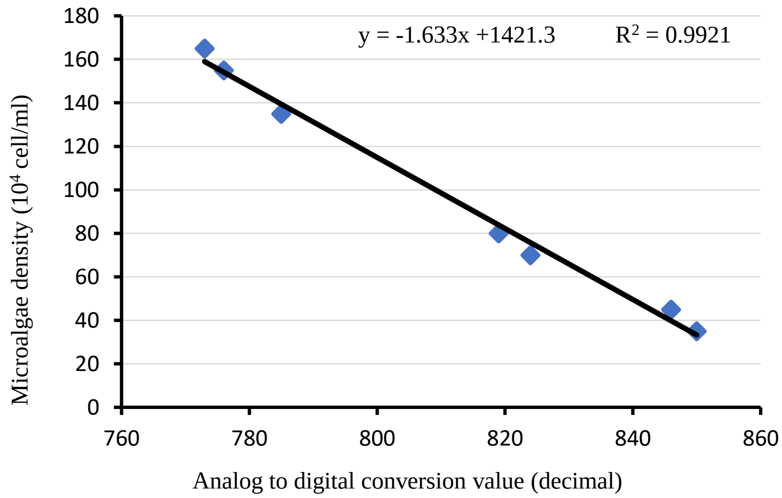


Figure 6. Graph of TSD-10 sensor calibration

The ADC conversion value from the analog output voltage of the TSD-10 sensor decreased as the microalgae density value increased and increased as the microalgae density value decreased. This phenomenon is in line with Wiranto et al., (2020) statement that particles suspended in a liquid medium will scatter light that passes through them in an amount proportional to the amount of suspended substance. The data in Figure 5 is then plotted in the form of a graph of the relationship between ADC conversion values and microalgae density values as shown in Figure 6. The calibration equation obtained from the graph in Figure 6 is shown in equation 3:

$$y = -1.633\,x + 1421.3 \tag{3}$$

where y is the density of microalgae (cell/ml), and x is the decimal value of the ADC conversion result.

3.3. Sensor Validation

The validation process is carried out to ensure that the calibrated TSD-10 sensor can be used to measure microalgae density with high accuracy. In the validation process, the microalgae chlorella sp. cultivation medium was prepared in the same way as in the calibration process but the microalgae density measurements were only carried out for five days with three repetitions (Figure 7). *Chlorela sp* microalgae are cultivated in aquariums with additional light sources because according to Elystia *et al*., (2019), light is an important energy source for the photosynthesis process, so the intensity of light are very important for the growth of microalgae.

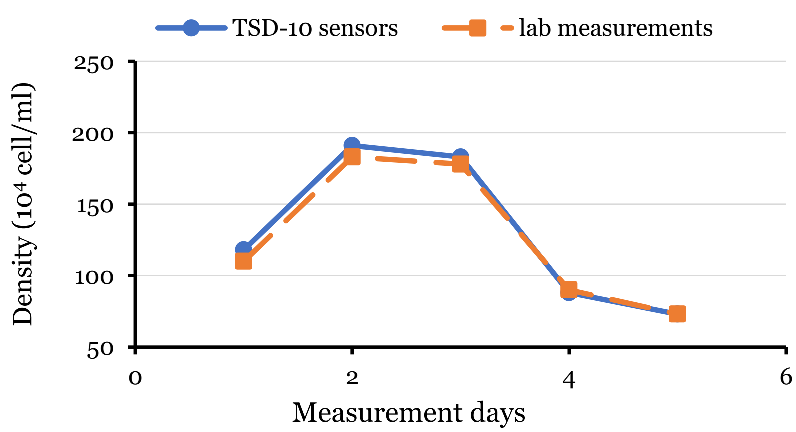


Figure 7. Graph of microalgae density for the TSD-10 sensor validation process at 5 days of measurement.

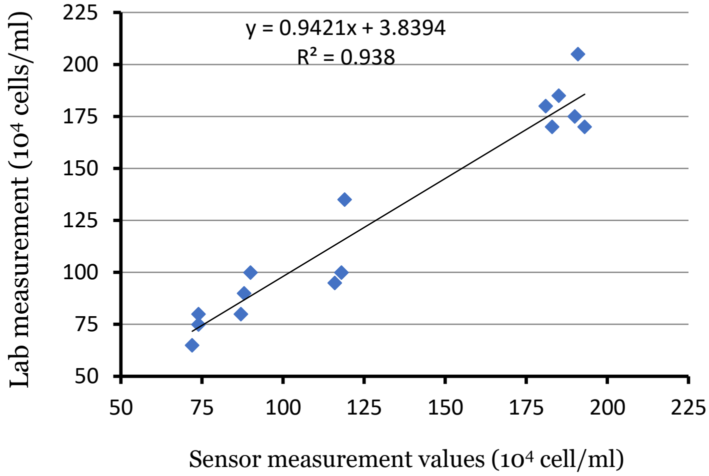


Figure 8. Graph of TSD-10 sensor validation

In the process of calibration and validation the maximum density of microalgae produced is quite low. This is supported by the results of research from Wardani *et al*. (2022) which states that the optimum fertilizer concentration for microalgae growth is 1.5 ml/l of culture media and applying excessive fertilizer concentrations causes microalgae to stress resulting in a decrease in biomass. Comparison of the TSD-10 sensor measurement values to laboratory measurement values in the validation process is shown in Figure 8.

3.4. Measurement Result Stability

From the five days of the validation process with three repetitions each (about 15 measurement data), stability data was obtained as shown in Figure 9. From Figure 9 it can be seen that the stability of microalgae density measurement results is quite good with a standard deviation ranging from 1.15×10^4cells/ml to 2×10^4cells/ml of cultivation medium. When compared with the average measurement value, the measurement error value ranges from 0.7% to 1.7% which is better than the research results by Wardhani *et al*., (2015) with a trend error of 4%.

3.5. Measurement Result Accuracy

From the 15 measurement data in the validation process, the RMSE (*Root Mean Square Error*) value was 3.25. This value is relatively small, which means that the measuring instrument developed has fairly good accuracy. This is supported by the coefficient of determination (R^2) which has a value of 0.9.

3.6. Response Time

The response time is measured to find out how fast the microalgae density measuring instrument is ready to collect data since the power supply is turned on and how fast the data can be displayed on the ThingSpeak cloud since it is sent via WiFi. The test was carried out 10 times with response times as shown in Table 1. Table 1 shows that the measuring instrument is ready to read data within 5.85 seconds after the power supply is turned on and after the data is sent via WiFi it will appear in the ThingSpeak cloud within 16.03 seconds. The length of time needed to display data on the ThingSpeak cloud is different from research results by Ayuni & Sari, (2019), which is 30 minutes. However, the time interval of 16.03 seconds is still sufficient for the purposes of microalgae density monitoring system.

3.7. ThingSpeak Based Monitoring System

Besides being displayed on the LCD display, the TSD-10 sensor measurement results are also sent wirelessly via WiFi to the ThingSpeak claud. The monitoring system design in this study uses only one field to display microalgae density graphs. Display of microalgae density values for the validation process is shown in Figure 10.

Table 1. Response time of the measuring instruments and data display on the ThingSpeak cloud.

No	TSD-10 sensor response time (s)	Data transmission time (s)			
		Repetition 1	Repetition 2	Repetition 3	Average
1	4.6	16	16	16	16.0
2	4.6	17	16	15	16.0
3	9.9	16	16	16	16.0
4	6.4	18	16	16	16.7
5	6.4	16	16	16	16.0
6	4.6	16	16	16	16.0
7	4.6	16	16	16	16.0
8	4.6	16	16	16	16.0
9	6.4	16	16	16	16.0
10	6.4	15	16	16	15.7
Average	5.85				16.03

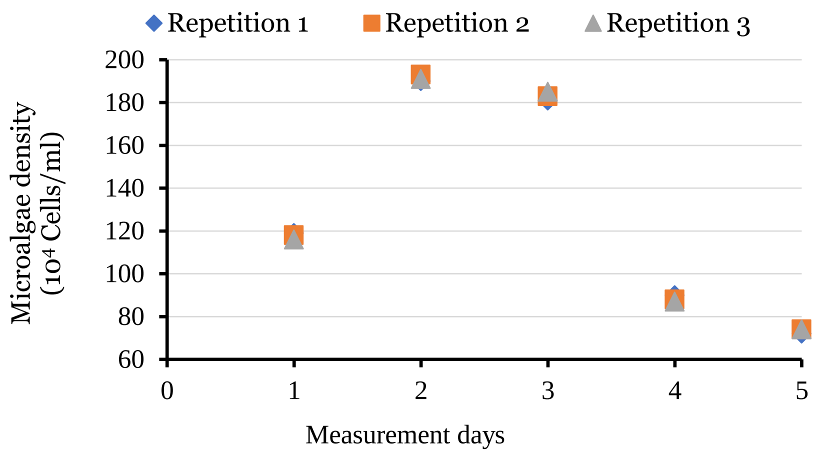


Figure 9. Graph of microalgae density measurement stability

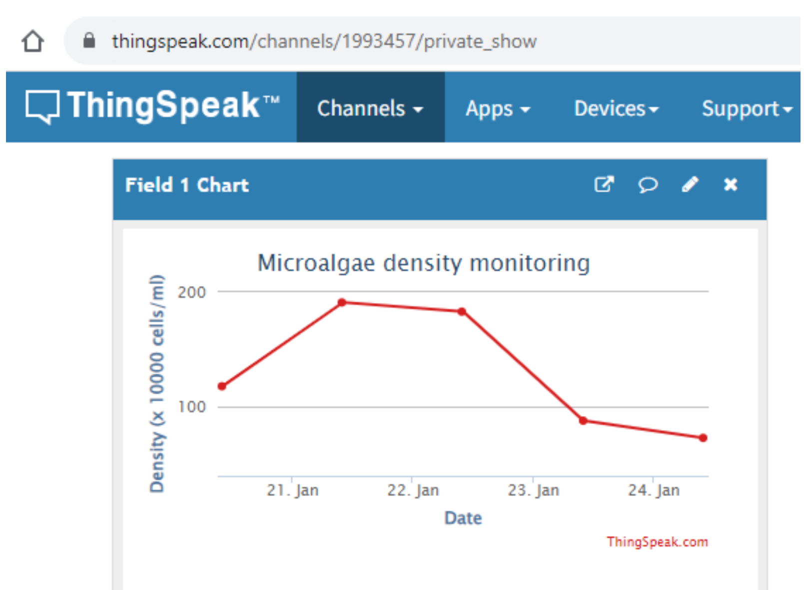


Figure 10. Display of microalgae density values on the ThingSpeak web for the validation process.

In this study, the microalgae density measurements data were also attempted to be sent periodically every 10 minutes for 6 hours (about 40 measurement data) as shown in Figure 11. Data that has been sent to the ThingSpeak cloud can be displayed on a smart phone via the ThingView application as shown in Figure 12. Microalgae density data that has been sent to the ThingSpeak cloud can be displayed on a smartphone in any location as long as there is a WiFi signal. The ESP8266 module needs to be placed at a maximum distance of 15 m from the WiFi router so that the ESP module is connected to the internet network.

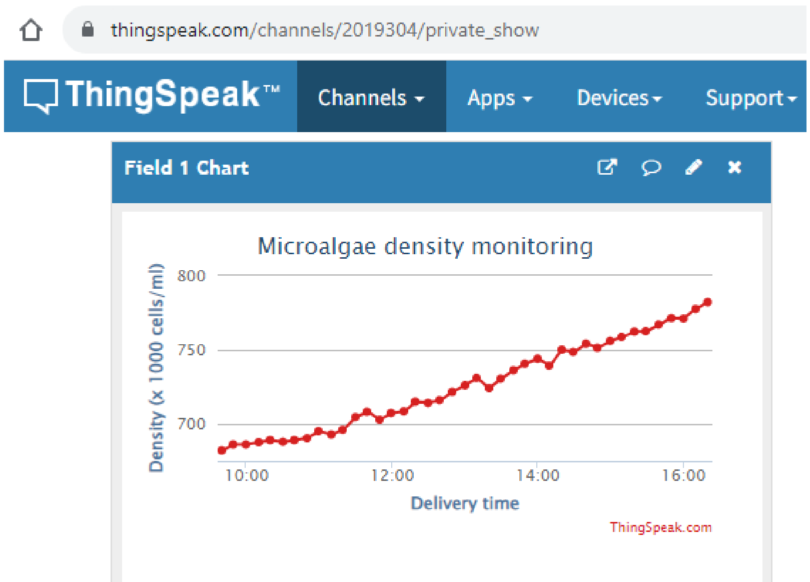
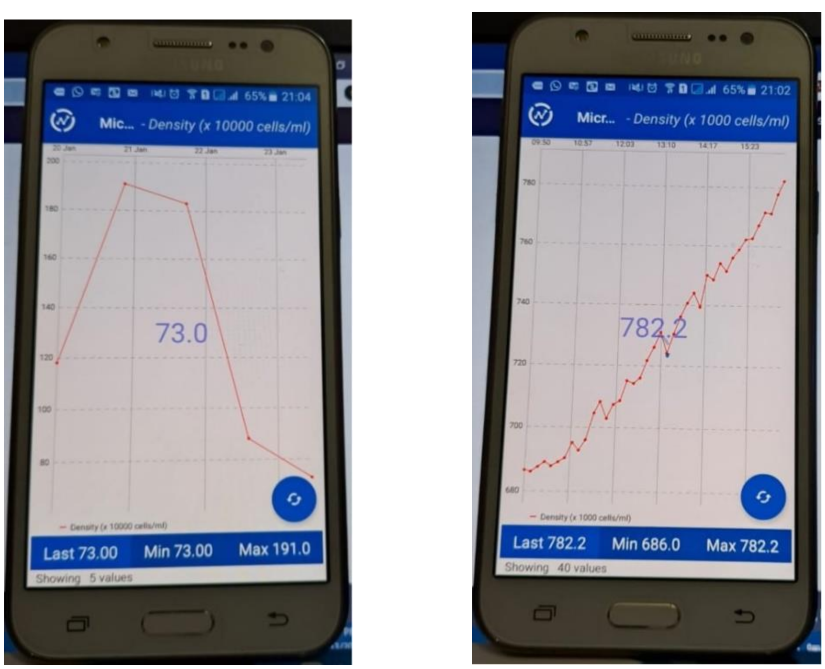


Figure 11. Data display on the ThingSpeak web which is sent periodically every 10 minutes for 6 hours.



(a) (b)

Figure 12. Display on a smart phone: a) validation data sent every day, and b) data sent periodically every 10 minutes for 6 hours.

From five days of validation data, the equation for the relationship between microalgae density (y) cells/ml and cultivation time (t) day was: $y = -18.833\ t^2 + 93.833\ t + 56.4$. The optimum density is obtained when the first derivative of the equation is equal to zero, namely 2.5 days from the start of cultivation. In the real conditions, the density of microalgae is said to reach optimum conditions when the slope of the curve changes from rising to horizontal. In this experiment, the microalgae growth was poor, possibly due to excessive Walne fertilizer.

4. CONCLUSIONS

Microalgae chlorella sp. density monitoring system. has been successfully developed using the TSD-10 optical sensor and the ThingSpeak platform. The TSD-10 sensor is calibrated using a combination of hemocytometer and microscope which produces a linear equation y = -1.633 x +1421.3 where y is the microalgae density value (cells/ml) and x is the ADC conversion value from the analog voltage output of the TSD-10 sensor. The coefficient of determination of the calibration equation is 0.99. The results of the validation test obtained the correction equation y = 0.9376x + 4.3544 with y being the microalgae density value from lab measurements (cells/ml) and x being the microalgae density value from the TSD-10 sensor reading. The stability of microalgae density measurement results was quite good with a standard deviation ranging from 1.15 x 104 cells/ml to 2 x 104 cells/ml of culture medium. The accuracy of the measurement results in the validation process which is calculated using the RMSE (*Root Mean Square Error*) formula is 3.25. From five days of validation data, the equation for microalgae density was obtained: $y=-18.833t^2+93.833\ t+56.4$ where y is the density in cells/ml and t is the time (days). Optimum density was obtained on day 2.5 of cultivation. The time it takes for the measuring instrument to be ready to read data after the power supply is turned on is 5.85 seconds and the time it takes to display data on the ThingSpeak cloud is 16.03 seconds. Therefore, the measuring instrument developed can be said to have a fairly good performance.

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