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# DESIGN OF A HAND-MADE LIGHT ABSORBANCE MEASUREMENT DEVICE FOR CHEMICAL EDUCATION

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Abstract. *This target of this research is the design of a light absorbance measurement device for chemical education. In the present, the concentration of solution still cannot be measured. The measurement must be indirect and convert to concentration. In the chemical laboratory, a UV-spectrophotometer is used to measure the concentration of solution. It uses the light for checking the absorbance of solution by Beer-Lambert law. Although the UV-spectrophotometer is usually used in the chemical laboratories, it is very expensive. Therefore, it is not enough for students in the class. However, students do not use all of function of the UV-spectrophotometer in the chemical class. To achieve efficient chemical education, we decrease the inessential functions of the UV-spectrophotometer and develop a simple light absorbance measurement device to be proper for chemical education. The proposed device is cheaper and lighter than the commercial UV-spectrophotometer. Therefore, it can purchase for many students in class. Moreover, to improve understanding of students about light absorbance, the program collecting and calculating the data in Microsoft Excel is written.*
**Keywords:** Light absorbance, UV-spectrophotometer, Beer's law, Calibration curve, Coefficient of determination, Linear regression

1. **Introduction.** In the present, the concentration of solution is important in many fields. For example, in medical field, the concentration is used for making the medicine, and it is used for making the composition of food in a food factory. However, the concentration cannot be measured directly. The measurement must be indirect and convert to concentration [1]. In chemistry laboratories, a UV-spectrophotometer (UV-Vis spectrophotometer), to calculate the light absorbance, utilizes the Beer-Lambert law, which explains the relation between light absorbance and concentration of solution. If the light absorbance is known, the concentration of solution is also known. Although the UV-spectrophotometer is generally used in laboratories, it is very expensive. The university's faculty of science where there are many students cannot afford to purchase UV-spectrophotometer for every student in the class. Furthermore, the UV-spectrophotometer is heavy and bulky. It cannot be moved to use outside laboratory and is not convenient to use for every student in the class. For this reason, the efficiency of the chemical education may be decreased.

To improve chemical education, we surveyed previous light absorbance devices to make the proposed device. The previous researches created the spectrophotometer which uses many ways to measure the light absorbance. Each solution responds to each wavelength light differently. Therefore, the light source must have many light for measuring. The general UV-spectrophotometer used the monochromator for measuring the solution. The monochromator can change the wavelength of light. Some researches created the hand made monochromator. For example, the Bano's spectrophotometer used the compact CD in [2] and using grating reported in [3]. Furthermore, many LEDs were used for replacing the monochromator in [4,5].

On the other hand, the measurement by light has a problem. Observing the changing of the light absorbance is very difficult because the output voltage changing is very low. The voltage is calculated to find the light absorbance. If each voltage is very near, the light absorbance is also near. Therefore, the light absorbance is observed more difficultly. The research in [5] solved this problem by using many LEDs and many light detectors. Another research in [6] solved this problem by using the OP-AMP. OP-AMP amplifies the output voltage for obvious light absorbance.

To create the proposed device, we use above research as base and apply the proposed device to be proper with education. The proposed device must have efficiency enough for education. It must be cheap for purchasing many devices. The device should be small, light and portable for many students in class. Furthermore, the experiment must collect the data measured. The proposed device must send the light absorbance data to a computer and save in the Microsoft Excel.

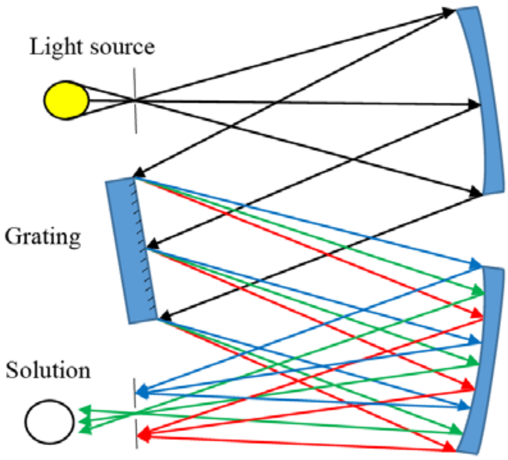


Figure 1. General monochromator

2. **Previous Spectrophotometer.** The previous spectrophotometer used the monochromator for choosing the wavelength which is in the general spectrophotometer. There are many ways for creating the monochromator such as grating shown in Figure 1 and prism in Figure 2. They are used for diffracting the light. The light is chosen from diffracted light by passing slit.

Figure 1 illustrates the general monochromator using in the spectrophotometer. The light passes the slit to the curve mirror. The curve mirror reflects and collimates the light to grating. The collimated light is diffracted from the grating to another mirror. The diffracted light is collected by another mirror which focuses on the light again. The focused light is aimed to the silt. The light passing the slit is used for measuring the solution. This monochromator uses light reflection of grating to choose the wavelength passing the slit.

This research in [3] uses this monochromator also. However, the light aimed in the first slit is light transmitting the solution. Furthermore, another slit was not used. The photodiode array is used as a light detector which can measure many light at the same time. Therefore, the measurement one time can measure the solution by every wavelength.

Bano's spectrophotometer used the 60 watt bulb as light source. The light is diffracted by the compact CD replacing with the general monochromator. It used a principle like

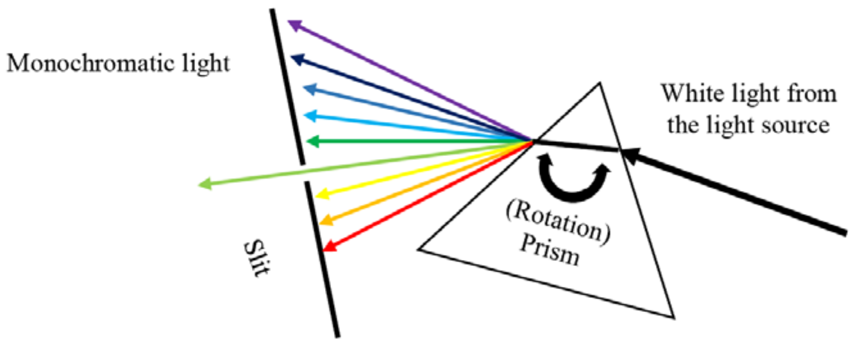


FIGURE 2. Monochromator by prism [2]

the monochromatic by the prism shown in Figure 2. The light is diffracted by the compact CD. The diffracted light passing the slit is used to measure the solution. The rotation of CD is used for changing the degree of the reflected light to choose the wavelength of light like the rotation of prism in Figure 2. This spectrophotometer uses Beer-Lambert law for calculating the light absorbance. The experiment of this research is measuring the $KMnO_4$ by the wavelength of 460nm. The light absorbance from Bano's spectrophotometer is similar to the commercial spectrophotometer (Jenway6300).

The spectrophotometer in [4,5] used many LEDs replacing with the monochromator. The PEDD photometry in [4] solves the low changing voltage problem by matching the LED with light detector. If the light detector responded to the LED well, the light detector resistance changing will be more. Moreover, the voltage changing and the light absorbance will be also more. The light absorbance will observe more easily. Each detector responded to each wavelength of light differently so matching best response between the LED and the light detector increases the changing voltage.

On the other hand, the research in [6] solves the low changing voltage by OP-AMP. The OP-AMP amplifies the voltage from the detector by resistors.

## 3. Principle of Analysis.

**3.1. Light absorbance.** In chemical experiment, light absorbance is the logarithm of the ration of incident to transmit radiant light through a material. If the solution has high concentration, the light absorbance is also high. Figure 3 illustrates the process of the light absorbance. When the light goes through the sample, the solution absorbs one part of the light. To know the concentration of solution, the light absorbance is measured in an analytical chemical laboratory. In the experiment, the measurement uses the color light that the color of the solution absorbs best. The color of solution absorbs every color of light, but each color has specific absorbance differently.

If the experiment uses the light that the solution absorbs hardly, the result is difficult to observe. Table 1 shows the relation between the color of solution and the color of light that the color of solution can absorb best. For example, the red solution absorbs the green-blue light best which is in 490-500nm.

**3.2. Beer-Lambert law.** Beer-Lambert law is the law explaining the relation between the concentration of solution and the light absorbance. The law explains that each layer of medium absorbs the proportion of the light intensity when the monochromatic light transmits the homogenous medium. For example, each layer absorbs the light intensity 30% as shown in Figure 3.

The light absorbance is calculated from the ration between the incident light intensity and the transmit light. Transmittance ($T$) [7] is the ratio between incident light intensity

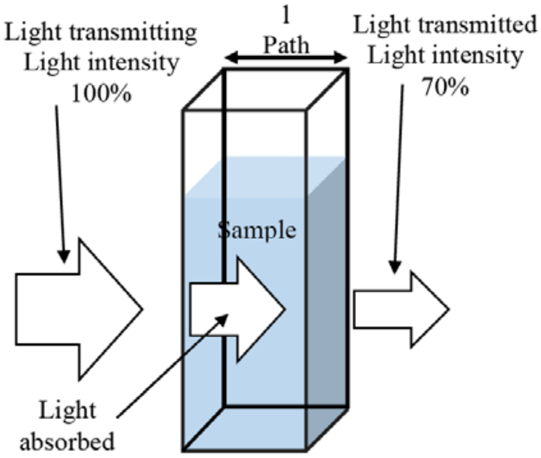


FIGURE 3. Light absorbance

TABLE 1. Light absorbance

| Wavelength (nm) | Absorbance color | Color of solution |
|---|---|---|
| 380-435 | Violet | Green-yellow |
| 435-480 | Blue | Yellow |
| 480-490 | Blue-green | Orange |
| 490-500 | Green-blue | Red |
| 500-560 | Green | Violet |
| 560-580 | Green-yellow | Violet |
| 580-595 | Yellow | Blue |
| 595-650 | Orange | Blue-green |
| 650-780 | Red | Green-blue |

$I_0$ and transmitted light intensity $I$ as (1).

$$T = \frac{I}{I_0} \tag{1}$$

The light absorbance is the logarithm of the ration of incident to transmit radiant light through a material. Therefore, the absorption of solution is expressed as follows:

$$A = -\log\frac{I}{I_0} = -\log T \tag{2}$$

Furthermore, the Beer's law also shows that the value of light intensity which is absorbed by solution directs variation with the concentration of solution. The Beer's law is rewritten as

$$A = \log\frac{I_0}{I} = \varepsilon c l \tag{3}$$

In (3), the absorbance $A$ is directly related to the concentration $c$ of compound, the path length of the sample $l$ and the molar absorption coefficient $\varepsilon$ that each solution has specific difference [6].

In the experiment, only one detector is used to measure the transmit light only. The variable in (3) must be changed properly. The incident light intensity $I_0$ and transmit light intensity $I$ are replaced to the light transmitting the solvent of sample $I_{solvent}$ and the sample $I_{sample}$ in (4). The light transmitting the solvent is used as a standard at the absorbance being 0.

$$A = -\log \frac{I_{sample}}{I_{solvent}} \tag{4}$$

In the proposed device, the variable of the light intensity is changed to voltage value. Furthermore, in order to decrease noise, the value of voltage is decreased with the voltage occurring when there is no incident light falling to the detector [6].

$$A = -\log \frac{V_{sample} - V_{zero}}{V_{solvent} - V_{zero}} \tag{5}$$

3.3. **Calibration curve.** Calibration curve is graph that explains the relation between the concentration of solution and the light absorbance by Beer's law [7]. The calibration curve is created from measuring the light absorbance of many concentration of solution at the same wavelength or same color light. Figure 4 shows the creation of calibration curve at the wavelength which is absorbed best. The calibration curve is always linear. Furthermore, there is calibration curve, and the linear regression is found.

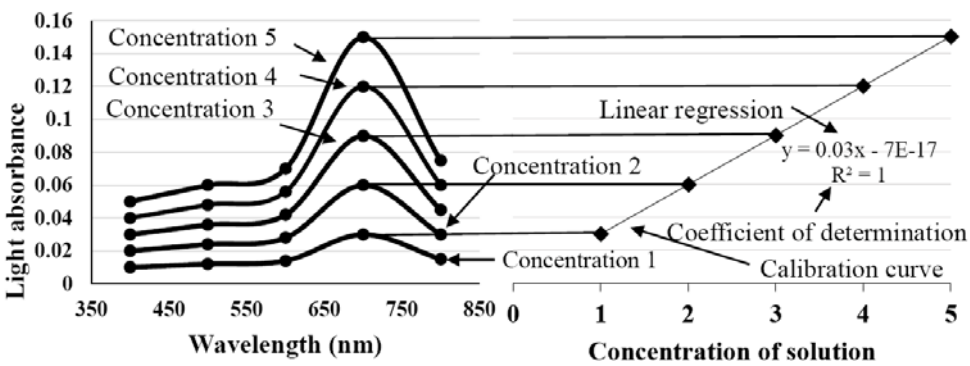


FIGURE 4. Creation of the calibration curve

3.4. **Coefficient of determination.** In statistics, the coefficient of determination, denoted $R^2$ (the square of the correlation coefficient), is a number that indicates how well data fit a statistical model. The main purpose is either the prediction of future come or the testing of hypotheses, on basis of other related information. It provides a measure at how well observed outcome is replicated by the model, as the proportion of total variation of outcomes.

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \right\}^2 \tag{6}$$

The coefficient of determination in (6) is the relation of values which is in the range $[0, 1]$. If the coefficient of determination is close to 1, it shows the good relationship.

The experiment uses the coefficient of determination to check the value of relationship between light absorbance and concentration of solution by the number of solution $n$, concentration of solutions $x_i$, mean of concentration of solution $\bar{x}$, light absorbance $(y_i)$, and mean of light absorbance $\bar{y}$ [8].

In this research, the coefficient of determination is used for checking the efficiency of the proposed device by comparing with the commercial spectrophotometer.

3.5. **Linear regression.** In statistics, the linear regression is an approach for modeling the relationship between a scalar dependent variable $y$ and one or more explanatory variables (or independent variable) denoted $X$. The linear regression is obtained from the calibration curve.

$$Y = a + bX \tag{7}$$

In experiment uses the linear regression (7) is used for finding unknown concentration of solution. In (7), $Y$ is concentration of solution and $X$ is light absorbance. In (7), $a$ is constant value when $X$ is 0 in $Y$ axis, and $b$ is slope [8].

4. **Circuit Configuration.** Figure 5 illustrates the circuit configuration of the proposed device. In Figure 5 many inessential pasts are removed to realize lighter and smaller device than UV-spectrophotometer. The proposed device has only one 9V power supply. Therefore, it is portable for using in outside laboratory. Regulator 7805 regulates the voltage from 9V to 5V for driving a microcontroller and an Xbee interface. The light source is power RGB LED to change the color of light. Also, the color of light intensity is changed by the input voltage (using the variable resistor). For this reason, the monochromator can be replaced to power RGB LED which is set up easier and realizes less space. The photo detector is realized by photo transistors. The coefficient of determination by photo transistor is better than the coefficient of determination by LDR and photodiode.

To calculate the light absorbance by (5), the microcontroller PIC16F877A is used as a calculator. The program in the microcontroller is applied from the voltage meter in [9]. The proposed device displays the light absorbance on the LCD1 and sends data to a computer by serial port.

The proposed device is assembled for the chemical education. The price of list parts of device is shown in Table 2. The proposed device can be assembled by about 2300 JPY. In this price, the proposed device can be purchased by the faculty of science for education or can be created by yourself. The parts of the proposed device can be bought in the general electronic store.

To send data to a computer, the interface is essential. For this reason, Xbee is used. It is wireless interface produced by Digi International. It can create wireless network for sending data to a computer by many devices at the same time. The wireless network

TABLE 2. Parts list of proposed light absorbance measurement device

| Part name | Number | Price (JPY) |
|---|---|---|
| PIC16F877A | 1 | 550 |
| Battery box | 1 | 110 |
| IC7805 | 1 | 40 |
| LCD16 × 2 | 1 | 900 |
| RGB LED | 1 | 200 |
| Phototransistor | 1 | 20 |
| Resistor 1kΩ | 10 | 1 |
| Variable resistance | 3 | 40 |
| Capacitor 22pF | 1 | 2 |
| Switch 1 | 4 | 10 |
| Switch 2 | 3 | 50 |
| Battery 9V | 1 | 100 |
| Crystal 4MHz | 1 | 30 |
| Total | 27 | 2272 |

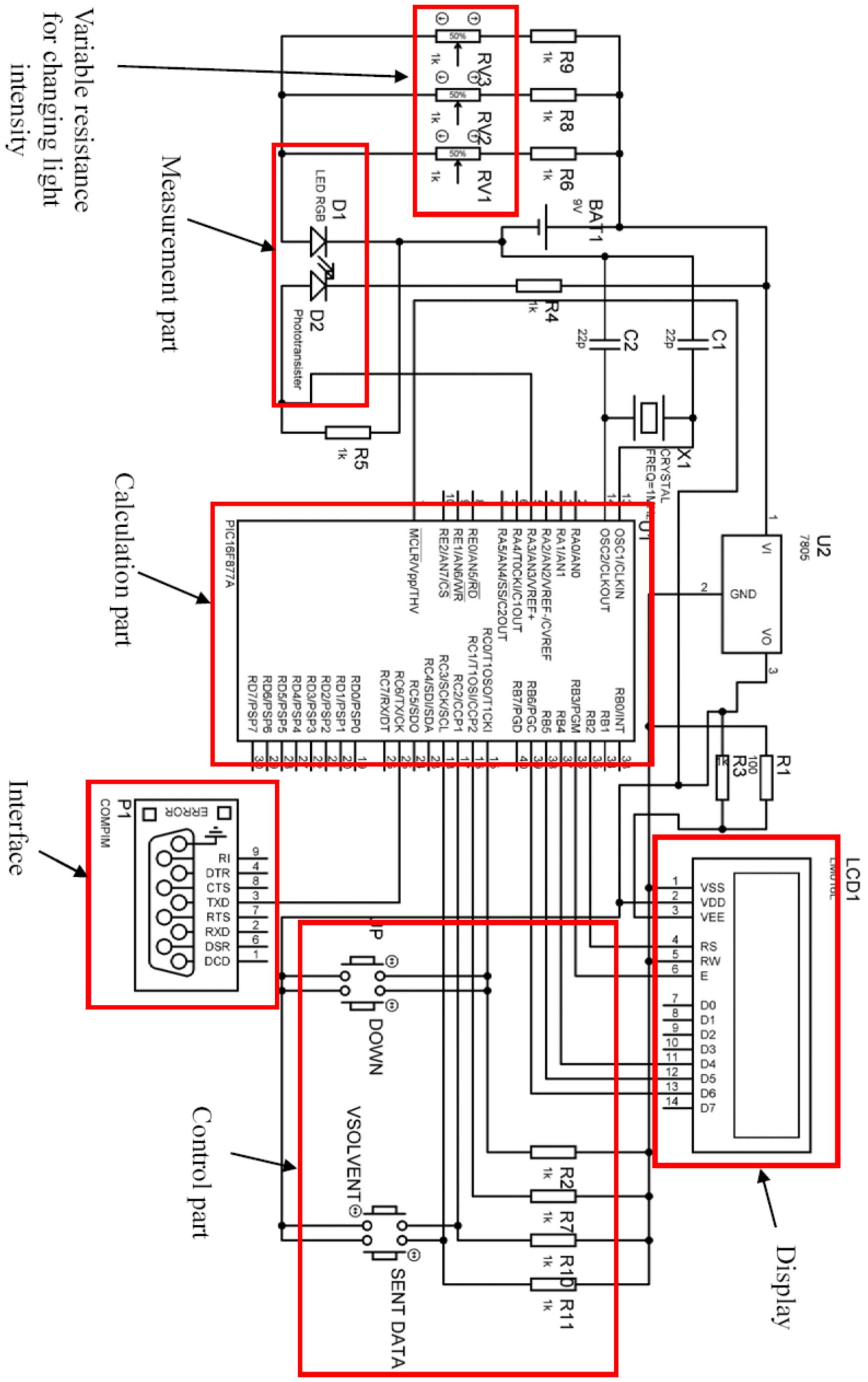


FIGURE 5. Circuit configuration

TABLE 3. Parts list of the interface by Xbee

| Part name | Number | Price (JPY) |
|---|---|---|
| Xbee module XB-24-Z7PIT-004 | 2 | 1700 |
| Xbee socket 2.54mm | 1 | 300 |
| Xbee USB-serial converter | 1 | 1280 |
| Micro USB (A-MicroB) cable | 1 | 458 |
| Total | 5 | 5438 |

is convenient for many students. The master device receiving data from slave devices is about 1700 JPY. The slave device sending data to master device is about 3700 JPY for one device. Table 3 shows cost of one master and a master-slave set.

5. **Operation.** The proposed device consists of the measurement part and the calculation part. The calculation part can send data to a computer. A computer receives the data from the proposed device by the program created in Microsoft Excel.

5.1. **Measurement part.** The measurement part of the proposed device consists of a power RGB LED, variable resistors, switches, a photo transistor, resistor and a battery 9V. The light source is a power RGB LED. It can change and mix colors by switches. Figure 6 illustrates the measurement of the proposed device. It transmits the light to the sample directly without diffracting the light. Furthermore, it can change light intensity of each color of light by variable resistors. In the experiment, when the light transmits the sample, the sample absorbs one part of the light as shown in Figure 3. The transmitted light falls to the photo transistor. When the phototransistor receives the light, the phototransistor will decrease its resistance. The resistance of the phototransistor determines the input voltage to the calculation part. The voltage is used for calculating the light absorbance in (5). The voltage when measuring the solvent is memorized in $V_{solvent}$ as standard at absorbance being 0. When the light transmits less, the voltage will decrease and the light absorbance will increase. The input voltage is divided by the half voltage divider in Figure 6 (R4 and R5). Therefore, when the light does not fall to the phototransistor, the maximum input does not exceed 4.5V.

5.2. **Calculation part.** The calculation part consists of microcontroller PIC16F877A, buttons, resistors, regulator 7805, crystal oscillator, capacitors, LCD16 × 2 character and Xbee. The crystal oscillator and capacitors decide the clock frequency of the microcontroller. The input voltage from the measurement part is sent to the microcontroller PIC16F877A. The program receives the voltage and calculates by (5). The voltage received from the proposed device is calculated as $V_{sample}$ in (5) currently. The $V_{solvent}$ is used to memorize the voltage of solvent in (5). When the $V_{solvent}$ is memorized, the light absorbance shown in LCD will be 0 which is standard value when concentration is 0.

This $V_{solvent}$ button is used for one light of one solvent. If the parameter changes except the concentration, the $V_{solvent}$ must be memorized again, because the $V_{solvent}$ is different

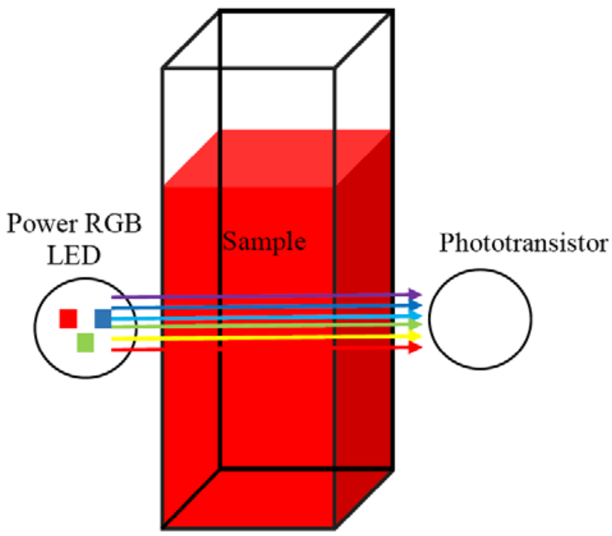


FIGURE 6. The proposed measurement

in each solvent of each light. For example, red solution can absorb green-blue light. The green light is used first and the next is blue. When the solvent is pushed to the holder, the $V_{solvent}$ button must be pushed to memorize the $V_{solvent}$ of green light of red solution. After the measuring of red solution by green light is finished, the light is changed to blue. The $V_{solvent}$ button must be pushed again to memorize $V_{solvent}$ of blue light of red solution.

The up and down buttons are used for changing the device number. The device number is used for collecting and listing the data in the Microsoft Excel. The sent data button is used for sending data to a computer as a text file as shown in Figure 7.

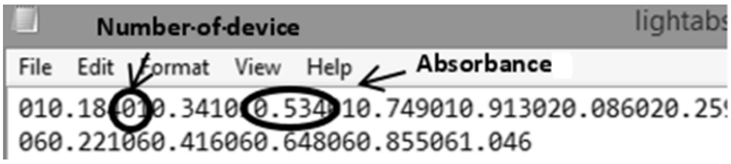


FIGURE 7. Text files from device

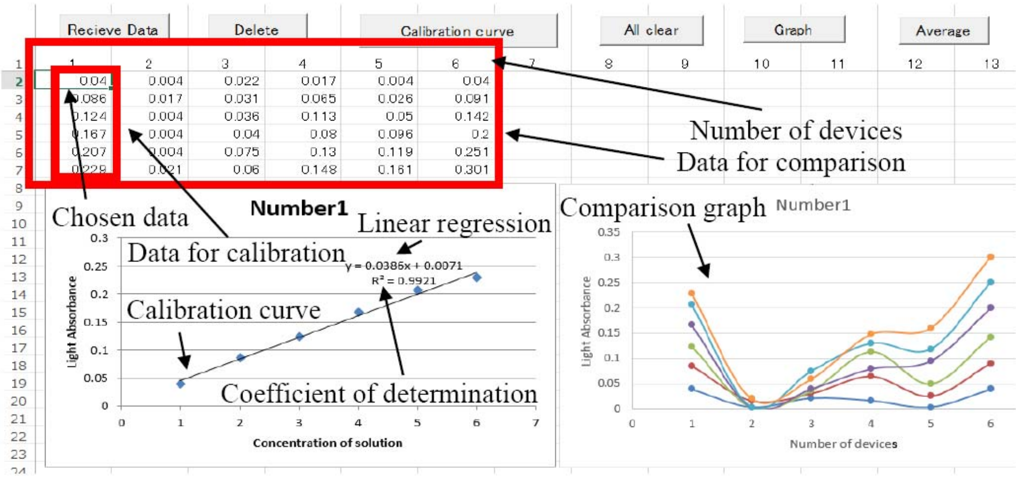


FIGURE 8. Creation calibration curve and comparison graph

5.3. **Program.** Program is written in Microsoft Excel by Visual basic. The program has many functions for receiving, saving, listing and calculating the data from the proposed device by Xbee. The data sent from the proposed device is text file in Figure 7. At one time, 7 characters are sent from the proposed device. The first two characters denote the device number or solution number which can change by up and down buttons for choosing the number. The next five characters are the data of a light absorbance. The number of devices decides the column which the light absorbance puts in the cell. The data from many devices are listed in Microsoft Excel as shown in Figure 8. Furthermore, the program can make a calibration curve and calculate coefficient of determination and linear regression by checking 1 button only as shown in Figure 8. Moreover, the program can create the comparison graph for comparing the light absorbance of many colors of light in Figure 8. This function is used for finding the color light absorbed best.

6. **Experimental Setup.** In the experiment concerning the proposed device, the 3 colors of solutions that were red, green and blue of 5 concentrations were used. If the experiment has more concentration of solution, the coefficient of determination will be more accurate. The five or six concentrations of solution were used in this experiment. The experiment finds the light absorbance from concentration of solution.

First, the experiment must find the color light of the proposed device and wavelength of commercial spectrophotometer, that solution absorbs best, by using every color and wavelength. When there was light absorbance of the color light and wavelength which solution absorbs best, those light absorbance is used for plotting the calibration curve and calculating the concentration of determination. The coefficient of determination of the proposed device was compared with the coefficient of determination of the commercial spectrophotometer for checking the efficiency and error. In an ideal case, the spectrophotometer's coefficient of determination is 1.

6.1. **Red solution result.** The first is the result of red solution. The light absorbance result from the commercial spectrophotometer is shown in Figure 9. The graph shows that solution absorbs the light about 500nm which is green-blue light best. On the other hand, the light over 600nm cannot be absorbed or absorbed a little which over 600nm light is mixed by red light shown in Table 1.

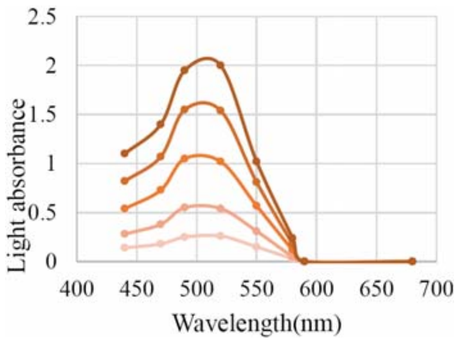


FIGURE 9. Result of red solution from spectrophotometer

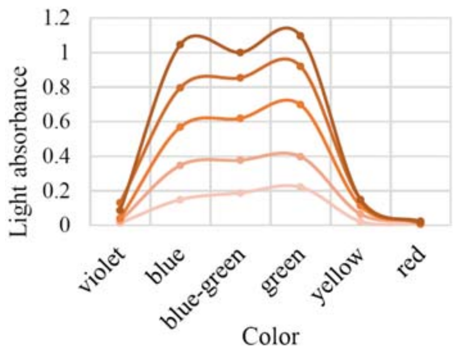


FIGURE 10. Result of red solution from proposed device

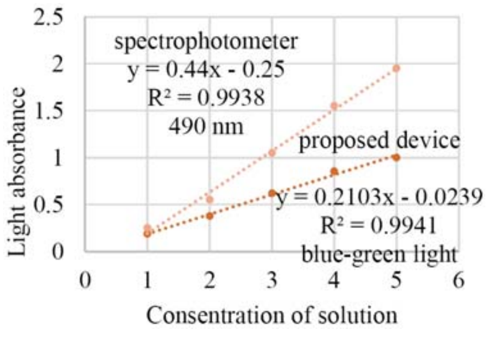


FIGURE 11. Red solution result comparison between spectrophotometer and proposed device

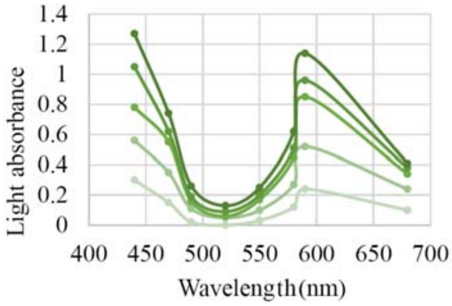


FIGURE 12. Result of green solution from spectrophotometer

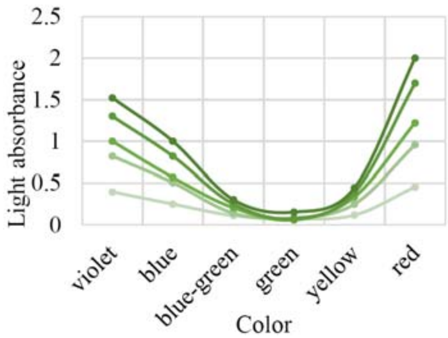


FIGURE 13. Result of green solution from proposed device

The light absorbance result from the proposed device is shown in Figure 10. It shows that the red solution absorbs the color green-blue light period best. However, the red solution cannot be absorbed red light or absorbed a little like the data from the commercial spectrophotometer also.

Figure 11 demonstrates the comparison graph of red solution between the commercial spectrophotometer and the proposed device. The data are brought from Figure 9 and Figure 10. The data from the spectrophotometer uses the data of 490nm and the data from the proposed device uses data of green-blue light. The graph shows the calibration curve, coefficient of determination and linear regression of both data. The spectrophotometer's coefficient of determination is 0.9938 and the proposed device's coefficient of determination measured is 0.9941. The error between the proposed device and UV-spectrophotometer is 0.03%.

6.2. **Green solution result.** The second is the result of the green solution. The light absorbance result from the commercial spectrophotometer is shown in Figure 12. The graph shows that solution absorbs the light about 450nm which is blue light best. On the other hand, the light absorbance that is about 500nm is low that the light in this period is mixed by green light shown in Table 1.

The light absorbance result from the proposed device is shown in Figure 13. It shows that the green solution absorbs the color red light best. However, the light absorbance is very low in green light period like the data from the commercial spectrophotometer, too.

Figure 14 demonstrates the comparison graph of green solution between the commercial spectrophotometer and the proposed device. The data are brought from Figure 12 and Figure 13. The data from the spectrophotometer uses the data of 440nm and the data from the proposed device uses data of red light. The graph shows the calibration curve, coefficient of determination and linear regression of both data. The spectrophotometer's coefficient of determination is 0.999 and the proposed device's coefficient of determination

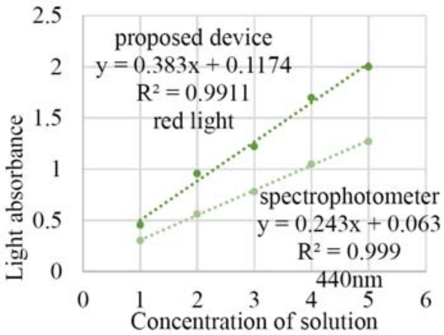


Figure 14. Green solution result comparison between spectrophotometer and proposed device

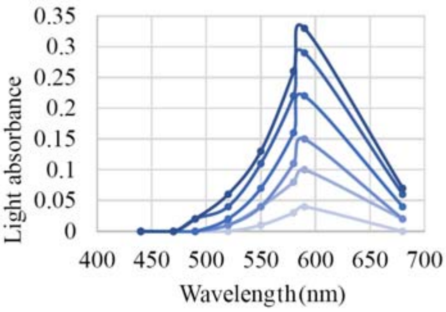


Figure 15. Result of blue solution from spectrophotometer

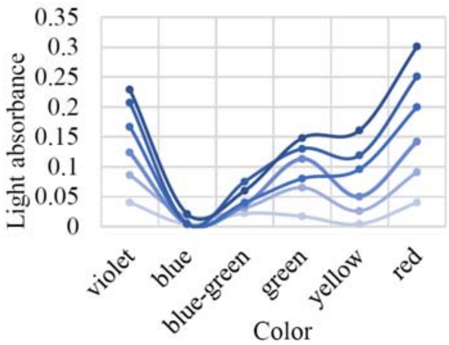


Figure 16. Result of blue solution from proposed device

measured is 0.9911. The error between the proposed device and UV-spectrophotometer is 0.79%.

6.3. **Blue solution result.** The last is the result of the blue solution. The light absorbance result from the commercial spectrophotometer is shown in Figure 15. The graph shows that solution absorbs the light about 600nm which is orange light best. On the other hand, the light about cannot be absorbed or absorbed a little that the light about 450nm light is mixed by blue light shown in Table 1.

The light absorbance result from the proposed device is shown in Figure 16. It shows that the blue solution absorbs the color red light best. However, the light absorbance is low in blue light period like the data from the commercial spectrophotometer also.

Figure 17 demonstrates the comparison graph of green solution between the commercial spectrophotometer and the proposed device. The data are brought from Figure 15 and Figure 16. The data from the spectrophotometer uses the data of 590nm and the data

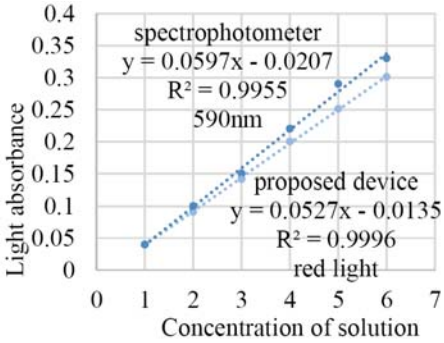


FIGURE 17. Blue solution result comparison between spectrophotometer and proposed device

from the proposed device uses data of red light. The graph shows the calibration curve, coefficient of determination and linear regression of both data. The spectrophotometer's coefficient of determination is 0.9955 and the proposed device's coefficient of determination measured is 0.9996. The error between the proposed device and UV-spectrophotometer is 0.41%.

7. **Comparison.** The previous spectrophotometer used the monochromator which must use many space for diffracting the visible light to rainbow light. If the sample or detector is near the diffracted light source, the measuring light will have many colors or wavelengths. Furthermore, the creation of the device is difficult. The reflection of light must use accurate degree. If the mirror just rotates a few, the wavelength will change. Moreover, the measurement must use the high light intensity because the low light cannot change the resistance of the detector more for observing the light absorbance following [2] that uses the 60 watt bulb.

In the proposed device, the power RGB LED 3 watt is used as light source. It does not use many space or high light intensity source and does not complicate to set up the light source. The proposed device used the power RGB LED transmitting light to sample directly in Figure 7. Therefore, the proposed device is smaller than the previous spectrophotometers.

The low changing voltage problem is solved by matching the power RGB LED and the phototransistor without amplifier like [6]. The power RGB LED gives high light intensity and can change color which is inessential to have many LED. The phototransistor responds with the power RGB LED well and gives the high efficiency from the above experiment.

Moreover, the proposed device uses the resistor to control the color light and light intensity. The majority of the spectrophotometer does not have a light intensity controller so the light absorbance in some case cannot be observed.

The parts of the proposed device can be bought in the general electronic store. Hence, the proposed device can be created by yourself.

8. **Conclusions.** The portable spectrophotometer for chemical education has been proposed in this paper. It solves many problems to create the low cost absorbance device. To replace the commercial UV-spectrophotometer for education, the proposed device's coefficient of determination is compared with spectrophotometer's coefficient of determination that is 1 in an ideal. Furthermore, the scientist needs the coefficient of determination more than 0.99XX. In other words, the error of proposed device comparing with the spectrophotometer must be less than 1%. From the experimental results of 3 colors, the error of the proposed device comparing with the spectrophotometer is less than 1%. It shows the

efficiency of the proposed device is near the general spectrophotometer more than 99%. Therefore, the efficiency of the proposed device can be replaced with spectrophotometer for learning.

The proposed device used the power RGB LED replacing the monochromotor. It made the proposed device smaller and lighter. Furthermore, the proposed device was portable by 9V battery. Moreover, the program used with the proposed device can collect the data from many devices. The data was collected in the Microsoft Excel that is easy to apply before. For those reasons, the proposed device is convenient for learning in the many student class.

The price of the device is shown in Table 2. It is created about 2300 JPY. This price is very cheap when compared with the commercial spectrophotometer. In this price, many devices can be purchased for education by faculty of science or can be made by myself. To collect the data, Xbee interface is used. The master device is about 1700 JPY. The slave device is about 3700 JPY for one device.

In the measurement, the conventional device's light source is LED which knows light of wavelength but the RGB of LED does not know the wavelength when the colors of light are mixed. In this point, the conventional device is better than the proposed device if the scientist needs the details such as the wavelength when measuring the solution or light absorbance in ultra violet wavelength period. However, the proposed device is created for chemical education. The students must have knowledge about the relationship between the color of light and the wavelength of light. It is not serious problem for education.

From the result of the proposed device, measuring the solution sometime is not following the relation of light absorbance between the color of solution and the color light in Table 1. This case occurs by response of the detector. In this case, it is found that the detector responded light which is about 780-1300nm of wavelength in the green and blue solution result. Therefore, before the experiment started, the color light absorbed best should be checked. From this case, we think that matching the color light with the light detector will increase the efficiency of the proposed device in future study.

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