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THE DEVELOPMENT OF A FUZZY-BASED LIGHT ABSORBANCE MEASUREMENT DEVICE FOR CHEMICAL EDUCATION

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Abstract. *The chemical faculty provides the spectrophotometers which are light absorbance measurement devices as the educational equipment of the concentration measurement. Because of the high cost of the spectrophotometer and the high number of students, the faculty cannot purchase this device for every student sufficiently. For the improvement of the chemical education, we aim to design the low-cost educational light-absorbance equipment. The measurement of the conventional device is in accordance with the Beer-Lambert's law. It explains the relationship between the light absorbance and the concentration of solution. However, the conventional device is dissimilar with the commercial spectrophotometer. The light absorbance of both devices is different. There is no device which can memorize light absorbance difference for all concentration. The fuzzy weighted average is used to calculate the light absorbance difference between both devices in all concentration by some light absorbance value between both devices. It reduces the light absorbance difference between both devices. Therefore, the proposed light absorbance is adjusted to be approximate as the light absorbance of the commercial device which is set as the ideal device. As the result, this fuzzy weighted average theory makes the measurement of the proposed device as the Beer-Lambert's law better.*
Keywords: Light absorbance UV-spectrophotometer, Beer-Lambert's law, Coefficient of determination, Fuzzy weighted average

1. **Introduction.** In chemical experiments, the concentration of solution is important. However, there is no method for measuring the concentration of solution directly. The measurement must provide any means and convert the measured value to the concentration of solution [1]. There are many indirect methods, such as density measurement, light reflection measurement, and light absorbance measurement. In chemical analysis laboratories, a UV-spectrophotometer (ultra violet spectrophotometer), which is called a light absorbance measurement device, is usually used to measure the concentration of solution. This device measures the light intensity which the solution absorbs and calculates the light absorbance. To calculate the concentration of solution, the Beer-Lambert's law is utilized to obtain the relationship between the light absorbance and the concentration of solution [1]. In chemical faculty, the UV-spectrophotometer is educational equipment of the concentration measurement. Nonetheless, the UV-spectrophotometer is a very expensive device. Because of a large number of students belonging to the chemical faculty, it is difficult to purchase many devices for every student. Hence, we develop a low-cost light absorbance measurement device for improving the efficiency of chemical education.

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In the past studies, there are many researches which are about developing the light absorbance measurement device. The light absorbance device has 2 main parts, a measurement part and a calculation part. The light absorbance calculation is based on the Beer-Lambert's law. Therefore, the calculation part has lesser problems than the measurement part. Consequently, a lot of researchers focus on the measurement part. The color of the light affects the light absorbance of solution. Every color of solution absorbs the color of light differently. In order to have the high performance of the concentration calculation, the experiment must provide the color of the light source properly with the solution. Therefore, there are many researches which provide a monochromator [2,3]. The monochromator is a device creating the monochromatic light from the visible light by diffraction. The diffracted light is the rainbow light. It is covered by a slit for choosing the color of light. Conversely, in some experiments, scientists diffract the transmitted light and measure the rainbow light by the photodiode array [4,5]. Because of the large space of the diffraction, the difficult set, and the high light source, some researchers use many color light-emitting diodes (LEDs) as a light source [6,7]. On the other hand, some researchers use the signal amplification by an operational amplifier (OP-AMP) for easy observation and calculation of the concentration of solution [2,8].

However, the development of the light absorbance device, which can make result same as a commercial output, is difficult. To reduce the difference between the measured light absorbance and the commercial light absorbance, the fuzzy weighted average is utilized. This theory is provided to solve the different problems by some data for averaging all data [9]. It can be used to design the feedback control system [10], solve the electronic problem [11], etc. Furthermore, it is based on many theories [12-14]. This fuzzy weighted average employs the light absorbance values of both devices in some concentration to calculate the light absorbance difference of both devices in all concentration. When the light absorbance is measured, the light absorbance difference of both devices is calculated also. After that, the measured light absorbance is deducted by the calculated light absorbance difference. Therefore, the proposed light absorbance is approximate with the commercial light absorbance. In the experiment, the commercial light absorbance is set as the ideal value in which the coefficient of determination is 1. When the proposed light absorbance is same or approximate as the commercial light absorbance, the coefficient of determination of the proposed device is approximate with 1. It shows that the accuracy of the proposed device is increased.

This paper is organized as follows. The literature is in Section 2. It explains the advantages and disadvantages of the previous device. The 3rd section is a theory. It explains the theory relating to the light absorbance measurement. Next section is the proposed method. This section explains the circuit of the proposed device, the processes of the proposed device and the simulation of the fuzzy theory. Next section shows the experimental setup and the experimental result. It shows the results of the red, blue and green solution measurement. There is the coefficient of determination from the measurement which is the efficiency as the education equipment and calibration curve. Next part is a discussion part. It explains the advantages and disadvantages of the proposed device. The last section is the conclusion.

2. **Literature Survey.** In this section, it will explain the advantages and the disadvantages of many past studies. There are many ways to develop the spectrophotometer. The development of the light absorbance measurement has many problems such as the low voltage output, the insufficient light intensity of the light source, bulky and heavy device.

2.1. **Monochromator.** The monochromator is a device which makes the monochromatic light from the visible light. The monochromatic light is used as light source following the molar absorptivity of solution. Figure 1 shows the process of the monochromator. Firstly, the visible light absorbance from the light source goes to the diffraction part (prism or grating). In some devices, there are uses of the curve mirror or convex lens for focusing on the diffraction part. The diffracted light is shown in the rainbow light. After that, the diffracted light goes to the wavelength selector (slit). A lot of the light is covered by the slit. The transmitted light is monochromatic light. The selection of the wavelength of light is operated by the rotation of the diffraction part. In some cases, before the rainbow light goes to slit, there is the addition of one more curve mirror to extend the width of each wavelength of light.

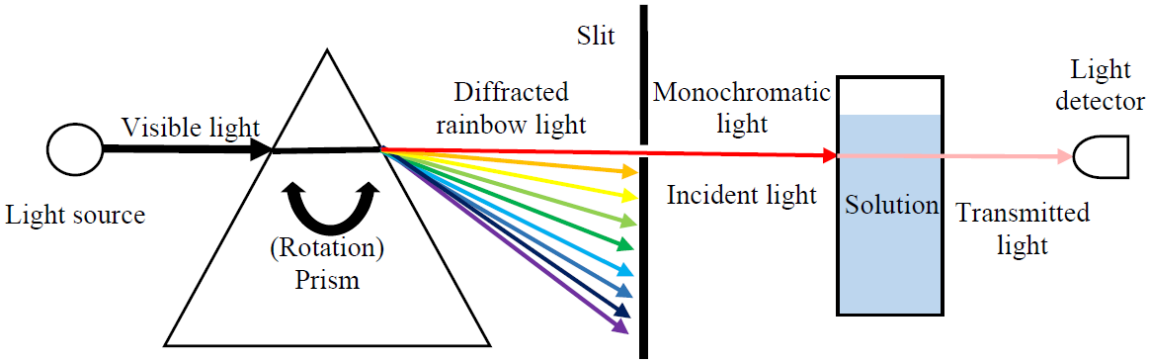

FIGURE 1. Monochromator

In order to make the monochromator, Bano and Ashfaque's spectrophotometer provides CD as the monochromator [2,3]. However, this method requires the high-intensity light source because of the slit covering a lot of light. The response of the light detector in each concentration is too approximate. Bano's device provides the 60-watt bulb as the light source.

2.2. **Diffraction of the transmitted light.** This method provides the visible light as a light source and diffracts the transmitted light from solution [4-6]. This method can measure all color of light which the solution absorbs. The photodiode array is used to measure. However, the measurement of the weak signal or the low photosensitivity signal is disturbed by the noise. It is a general problem which happens in the spectrophotometer.

The diffraction of the light must require the large space. If the length between the diffraction part and the slit is too near, the light source transmitting from the slit has many colors. When the light source is not monochromatic light, the experiment has errors.

2.3. **Many light-emitting diodes (LEDs) as light source.** Tai-Sheng and Lukasz's spectrophotometer provides many LEDs as light source replacing the monochromator in which the large space is sufficient [7,8,15,16]. Nonetheless, there is a limit of the color of the LEDs. This method cannot produce the light absorbance same as the light absorbance of the commercial device.

2.4. **Output amplification.** Tavener and Bano's spectrophotometers provide OP-AMP [2,9]. The OP-AMP amplifies the insufficient voltage for easy observation and calculation. However, the light absorbance which is amplified by OP-AMP is not direct variation with the concentration of solution. It has noise when the light is not falling on the light detector.

2.5. **Other methods.** Flores et al. use the 2 lights for calculating the light absorbance of the glucose in the solution in Equation (8) [17]. It is insufficient to measure the solvent when the parameter is changed. Nonetheless, the output light absorbance is logarithm growth. It is not following the Beer's law. Wang and Bembnowicz's spectrophotometer provides the optic fiber as the passageway of the incident light and transmitted light [18,19]. The light from light source is bright, strong color and has diverse colors. However, it consists of the Azo compounds with low toxicity to human. Being distinct from such light absorbance measurement techniques, there are many approaches for the development of spectrophotometers. For example, Niyonambaza et al. proposed a microfluidic-based spectrophotometer for neurotransmitters sensing [20]. This spectrophotometer was developed to detect neurotransmitters using visible light by using vertical-cavity surface-emitting laser as light sources.

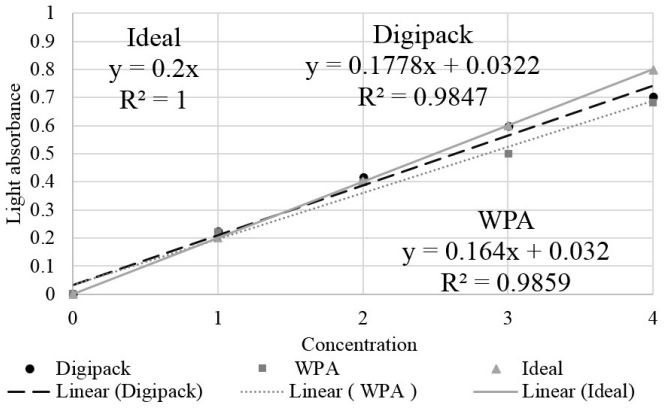

FIGURE 2. Light absorbance of red solution by 490nm wavelength

TABLE 1. Red solution result

Concentration level	Digital test pack multi SP	Biochrom WPA CO7500 colorimeter
0	0	0
1	0.223	0.22
2	0.416	0.4
3	0.599	0.5
4	0.701	0.68

Figure 2 and Table 1 show the light absorbance result of the red solution by 490nm of wavelength. These results were obtained by using Kyoritsu chemical-check Lab's digital test pack multi SP and Biochrom WPA CO7500 colorimeter. The result shows that the light absorbance between both commercial devices is not the same. Therefore, it is very difficult to develop the device which gives the same output as other's output. The light absorbance depends on several parameters such as the type of light sources, and characteristics of the light detector. Therefore, the fuzzy theory is employed to reduce the difference of outputs between both devices. Moreover, the fuzzy theory can be provided in other cases. For example, in education, it is provided to make the educational system. This system makes the homework and choose the questions suitable for the level of student ability [21].

3. **Theory.** This section explains the method relating to the light absorbance measurement.

3.1. **Light absorbance.** The light absorbance is the effect when the light goes through the object [1]. The object absorbs, scatters and reflects one part of the light. The light absorbance is calculated by minus logarithm of the transmitted light intensity (I) divided by the incident light intensity (I_0) shown in (1) [1,2].

$$A = -\log \frac{I}{I_0} \tag{1}$$

3.2. **Beer-Lambert's law.** To calculate the concentration of the solution, Beer-Lambert's law is considered. Beer-Lambert's law is a method that explains the relation between the light absorbance (A), the concentration of solution (c) and the path length (l). The light absorbance of the monochromatic radiation varies directly with the concentration of solution and the path length for the parallel beam. The Beer-Lambert's law equation is shown in (2) [1,7,8,22].

$$A = \varepsilon cl \tag{2}$$

ε is the molar absorptivity. It is a coefficient constant value which depends on the color of solution and the wavelength of the light. From the Beer-Lambert's law in Equation (2), when the concentration is 0 (solvent), the light absorbance is 0. Therefore, the incident light intensity is changed to the light intensity transmitting the solvent ($I_{solvent}$) in which the concentration is 0 and the transmitted light intensity is changed to the light intensity transmitting ($I_{solution}$) the solution shown in (3).

$$A = -\log \frac{I_{solution}}{I_{solvent}} \tag{3}$$

However, there is no light intensity in the electronic circuit. Therefore, the light intensity value ($I_{solution}, I_{solvent}$) is changed to the voltage ($V_{solution}, V_{solvent}$) shown in (4).

$$A = -\log \frac{V_{solution}}{V_{solvent}} \tag{4}$$

Nevertheless, the light absorbance has errors in some case. Therefore, to reduce the noise, the voltage when there is no light falling on the light detector (V_0) is declined as shown in (5).

$$A = -\log \frac{V_{solution} - V_0}{V_{solvent} - V_0} \tag{5}$$

3.3. **Coefficient of determination.** The coefficient of determination is a square of the correlation coefficient (R^2) [23]. It is a value that indicates how well data fit with a statistic model. The range of the coefficient of determination is from 0 to 1. The ideal value is 1 when y varied directly with x shown in Figure 2. It is used to check how well of the relationship between the light absorbance and the concentration of the solution following Beer-Lambert's law [18,24]. Therefore, to calculate the concentration of solution, the light source that the coefficient of determination is near 1 is utilized. When the measurement is following the Beer-Lambert's law, it shows that the accuracy of the measurement is high. The coefficient of determination is calculated by (6).

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

3.4. **Calibration curve and linear regression.** To calculate the concentration of solution from the light absorbance by Beer-Lambert's law, the calibration curve and linear regression are utilized. The calibration curve is a line approaching the relationship between the light absorbance and the concentration of the solution by Beer's law [22]. The linear regression is an equation calculated from the calibration curve. It is a linear equation in (7). Therefore, the coefficient of determination of the calibration curve is 1.

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

Y is light absorbance. X is concentration. b is the slope of the graph which is calculated by (8). a is the light absorbance when the concentration is 0 which it is calculated by (9). n is a number of the data (the number of the measured concentration).

$$b = \frac{\sum_{n=0}^{k} X_n Y_n - \frac{\sum_{n=0}^{k} X_n \sum_{n=0}^{k} Y_n}{n}}{\sum_{n=0}^{k} X_n^2 - n\left(\bar{X}\right)^2} \tag{8}$$

$$a = \bar{Y} - b\bar{X} \tag{9}$$

In the case of Beer-Lambert's law in (2), b is molar absorptivity and path length, a is light absorbance when the concentration is 0. In the ideal term, this value must be 0 following Beer's laws equation in (2). However, in reality, the solvent absorbs the light intensity a little. Therefore, a is almost zero shown in Figure 2.

4. **Proposed Method.** From above researches, they show that the previous light absorbance has 3 main processes shown in Figure 3. Firstly, it is the light intensity measurement process. The second part is the voltage amplification process. The amplified voltage (V_{amp}) is shown in (10). a denotes the gain of voltage amplification. c is constant which occurs by amplification. The third is calculation process. The light absorbance of the conventional device (A_{con}) which is calculated by (7) is shown in (11).

$$V_{amp} = a(V_{solution}) + c \tag{10}$$

$$A_{con} = -\log \frac{a(V_{solution}) + c - V_0}{a(V_{solvent}) + c - V_0} \tag{11}$$

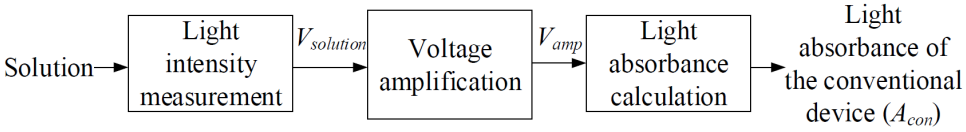

FIGURE 3. Operation of the conventional device

When the constant value is subtracted by V_0, the light absorbance (A_{con}) is same with Equation (5) shown in (12). Equation (12) shows that the amplification gains the voltage for easier calculation.

$$A_{con} = -\log \frac{V_{solution}}{V_{solvent}} \tag{12}$$

The proposed device has 3 processes same with the previous method shown in Figure 4. The first process is the light intensity measurement process. The second process is the light absorbance calculation process. The third process is the light amplification by the fuzzy theory. It calculates the difference of the light absorbance (ΔA) between the measured light absorbance (A_{me}) and the commercial device (A_{com}). After that, the measured light absorbance is subtracted by the difference of the light absorbance (ΔA). Therefore, the light absorbance of the proposed device ($A_{proposed}$) approximates with the commercial light absorbance (A_{com}).

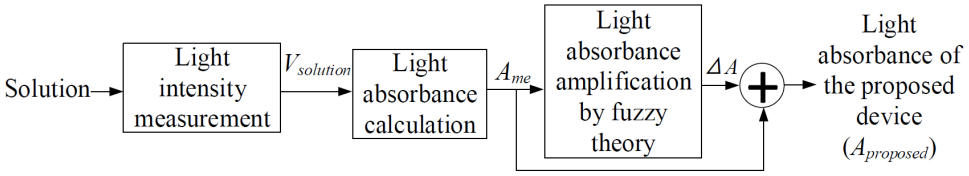

FIGURE 4. Operation of the proposed device

4.1. **Circuit configuration.** The proposed circuit configuration is illustrated in Figure 5 [16]. The most of the proposed circuit configuration is similar to the general light absorbance device. The circuit configuration consists of the measurement part, the calculation part, battery 9V as a power source and regulator 7805 for converting power source 9V to 5V for a microcontroller. The measurement parts are included by the power RGB LED (Red, Green, and Blue light-emitting diode) as a light source, a phototransistor as a light detector and resistors. The measurement part circuit is a voltage divider circuit. The calculation parts consist of the microcontroller PIC16F877A as a calculator, switches as a controller, crystal as frequency controller and display for showing the result. The incremental contribution is a function of the membership function setting. Three switches, such as Up, Down, and S_i set up, are provided to set membership functions. The setting of membership functions will be explained in Section 4.4.

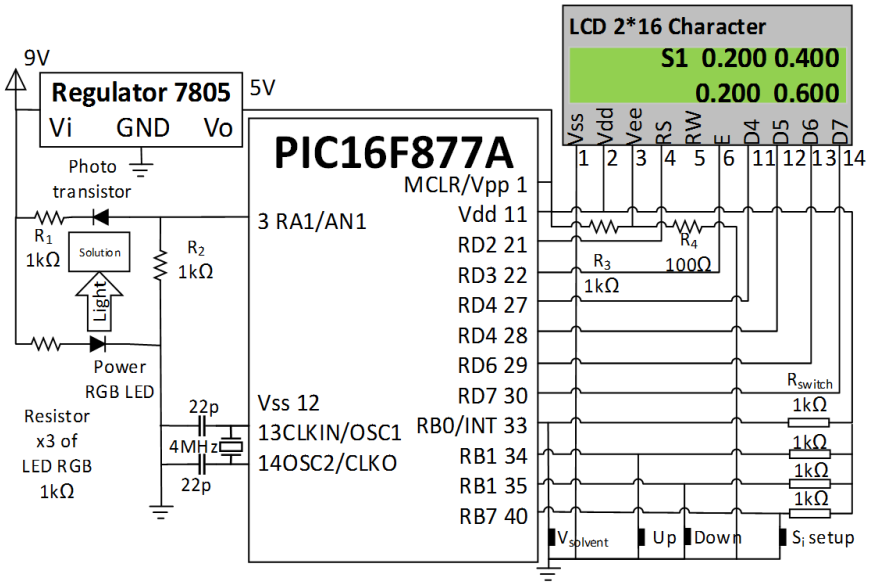

FIGURE 5. Proposed circuit configuration

4.2. **Measurement process.** The circuit of the measurement part is a voltage divider circuit. When the light from the light source goes through the solution, a phototransistor receives the transmitted light. The electric current can flow as the light intensity falling upon the phototransistor. When the current flows through the photodiode more, the voltage at the resistor R_2 will increase more. The microcontroller PIC16F877A is provided to measure the voltage dropped at R_2 for calculating the light absorbance.

4.3. **Light absorbance calculation process.** The output unit from the measurement process is an inverse variation of voltage with the concentration of solution. The light absorbance calculation process is applied from the voltage meter [25]. The microcontroller PIC16F877A measures the happened voltage dropped at R_2 by analog to digital function.

This function calculates the binary number 10 bit which starts from 0 to 1023 from the voltage 0V to 5V. The binary number 10 bit is used as $V_{solution}$ to calculate the light absorbance by (5). The $V_{solvent}$ button is employed to memorize $V_{solution}$ into $V_{solvent}$ by measuring the solvent and pushing the $V_{solvent}$ button. It is set zero of the light absorbance measurement.

4.4. **Light absorbance amplification process.** The amplification of the previous device gains the signal of the circuit for easy observation. However, it is difficult to make the output data same as the light absorbance of the commercial device. There is the difference ($Error_1$) between the light absorbance of the commercial device (A_{com}) and the measured light absorbance A_{me} shown in (13).

$$A_{com} = A_{me} + Error_1 \tag{13}$$

This process calculates the difference (ΔA) between the light absorbance of the commercial device (A_{com}) and the light absorbance from measurement (A_{me}). The difference (ΔA) is approximate with the difference ($Error_1$). After that, the difference (ΔA) is summed with the light absorbance from measurement (A_{me}) to calculate the proposed light absorbance ($A_{proposed}$). However, the microcontroller does not have the sufficient memory for all of the light absorbance differences. Therefore, some differences of light absorbance value between measurement ($A_{i,me}$) and commercial device ($A_{i,com}$) are provided as the value of set (S_i) of the fuzzy set. It is calculated by (14).

$$S_i = A_{i,com} - A_{i,me} \tag{14}$$

Some light absorbance value from measurement ($A_{i,me}$) is provided to design the position of the membership function in the fuzzy set. The fuzzification calculates the degree of every membership function (W_i) by the fuzzy set. After that, the defuzzification provides the fuzzy weighted average [26]. Every value of set (S_i) is weighted by the degree of membership function and averaged by the sum of the degree of the membership function shown in (15). The defuzzification result is the difference (ΔA) of the light absorbance between the conventional device and the commercial device.

$$\Delta A = \frac{\sum_{i=0}^{k} S_i W_i}{\sum_{i=0}^{k} W_i} \tag{15}$$

From Equation (15), the proposed light absorbance depends on the membership function. The light absorbance is direct variation with the concentration of solution. Therefore, the light absorbance of both devices is direct variation with the concentration of solution also. Furthermore, the light absorbance difference between both devices is direct variation with the concentration of solution also. In the fuzzy weighted average, the triangular membership function makes the output direct variation with the concentration straightly same as the light absorbance difference. Therefore, the triangular membership function is proper with the calculation of the light absorbance difference between both devices. Moreover, when there is comparison with other membership function, the triangular membership function is only linear function. Therefore, in the calculation, the linear function is faster than other function such as exponential or logarithm.

To prove that this theory in Figure 6 can not only reduce the light absorbance difference ($Error_1$) between the commercial device and the measurement but also it can reduce the error which occurs from the property of the light detector, the light absorbance, which is calculated by (1) from the light transmittance which varies inversely with the concentration of solution, is provided as the measured light absorbance (A_{me}) shown in Figure 7 to simulate the efficiency of the fuzzy weighted average.

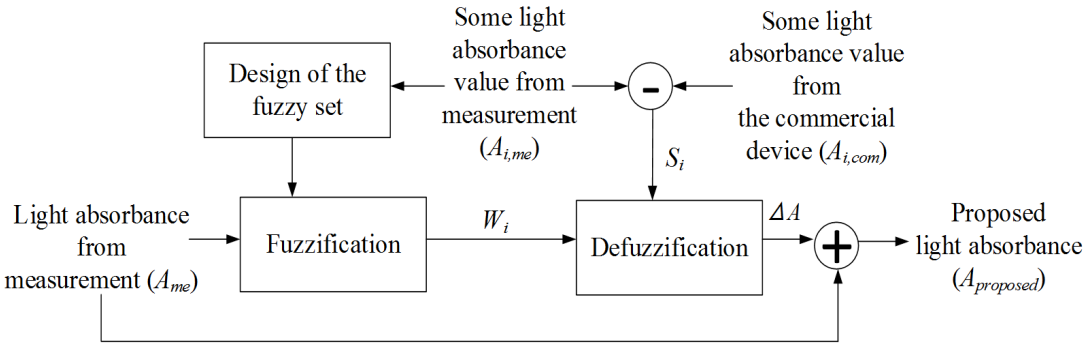

FIGURE 6. Light absorbance amplification process of the proposed device

The light absorbance is direct variation with the concentration of solution which follows Beer-Lambert's law. The calibration curve, in which the coefficient of determination is 1, is provided as the light absorbance of the commercial device (A_{com}). The linear regression of the calibration curve is calculated by (9). It is calculated by the light absorbance of 100 level of the concentration. Therefore, the linear regression of the calibration curve of the light absorbance is $y = 0.0175x + 0.0311$ as shown in Figure 7.

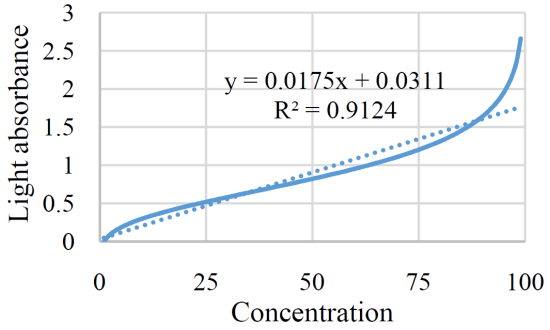

FIGURE 7. Ideal light absorbance from the conventional device

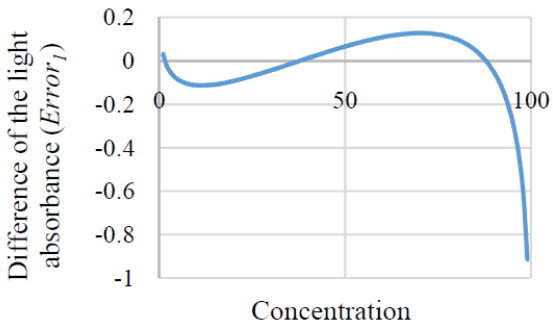

FIGURE 8. Different light absorbance

TABLE 2. Value of fuzzy set (S_i)

i	$A_{i,com}$	$A_{i,me}$	S_i	Level of the concentration
S_0	0.0311	0	0.0311	0
S_1	0.3811	0.4699	0.0888	25
S_2	0.7311	0.7130	−0.0181	50
S_3	1.0811	0.9692	0.1119	75
S_4	1.7461	2.6610	−0.9149	100

The difference of light absorbance ($Error_1$) between the calibration curve (A_{com}) and measurement (A_{me}) is shown in Figure 8. Some light absorbance difference (S_i) between the calibration curve (A_{com}) and measurement (A_{me}) is difference light absorbance in each 25 level of the concentration of solution shown in Table 2. The 5 membership function is decided by $A_{i,me}$ in Table 2 shown in Figure 9. The defuzzification result (ΔA) is shown in Figure 10. It is approximate as the difference of light absorbance ($Error_1$) in Figure 11.

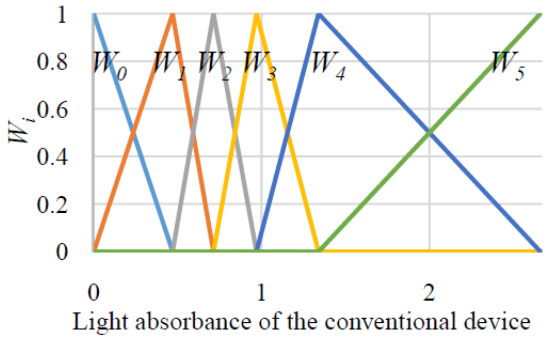

FIGURE 9. Fuzzy set of the simulation

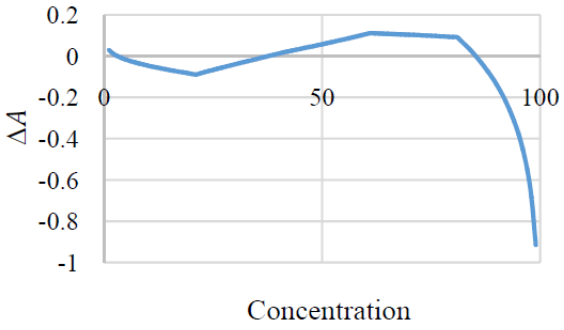

FIGURE 10. Defuzzification result

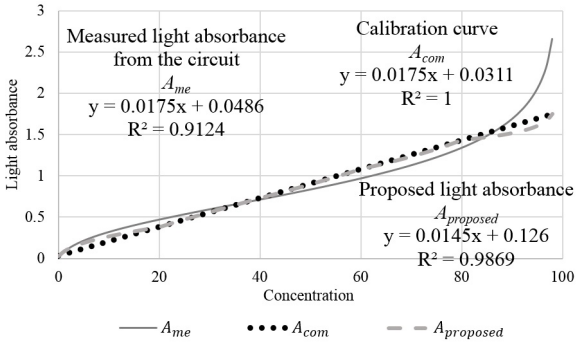

FIGURE 11. Result of the simulation

However, the defuzzification result (ΔA) is not as smooth as the difference of light absorbance ($Error_1$) between the commercial device and the measurement. The result of proposed light absorbance ($A_{proposed}$) is shown in Figure 11. It shows that the proposed light absorbance ($A_{proposed}$) is approximate as the light absorbance of the calibration curve (A_{com}). Furthermore, the coefficient of determination is increased after amplification. The light absorbance difference ($Error_2$) between the calibration curve (A_{com}) and the proposed light absoebance ($A_{proposed}$) is shown in (16).

Table 3 shows the averaged absolute difference ($|Error_2|$) of the 100 level of concentration when the membership function is in many cases of the number of the membership function. It shows that the averaged absolute difference ($|Error_2|$) between calibration curve (A_{com}) and the proposed device ($A_{proposed}$) is lower than the light absorbance difference ($Error_1$) between the commercial device (A_{com}) and the measurement (A_{me}).

$$A_{com} = A_{proposed} + Error_2 \tag{16}$$

Furthermore, when the number of the membership function is increased, the averaged absolute difference ($|Error_2|$) is reduced. Moreover, Table 4 shows the coefficient of determination of many cases of the light absorbance. When the number of membership

TABLE 3. Averaged absolute difference

Number of membership function	Averaged absolute difference
0 ($|Error_1|$)	0.1024
5	0.0265
11	0.0067
21	0.0016

TABLE 4. Coefficient of determination of the amplified result

Number of membership functions	Coefficient of determination
A_{com}	0.9124
5	0.9982
11	0.9998
21	1

functions is increased, the coefficient of determination is increased. Therefore, the light absorbance amplification process can reduce the light absorbance difference between both devices and increase the efficiency of the measurement approximately with the light absorbance of the commercial device. Form simulation result, it shows that the amplification by fuzzy theory does not reduce the difference as the direct variation only, but also it can reduce the difference of other cases.

4.5. **Setting up the membership function.** However, the one fuzzy set can amplify only one case [27]. The experiment does not have only one solution. Therefore, the proposed device has a function for editing the value of the set (S_i) and the range of the membership function. The value of each membership function is light absorbance difference value between the commercial device ($A_{i,com}$) and the measurement ($A_{i,me}$) in any concentration shown in (14). Therefore, to set up value of each set (S_i), it only sets some light absorbance value between the commercial device ($A_{i,com}$) and the measurement ($A_{i,me}$) shown in Figure 12. The range of the membership function depends on the position of $A_{i,me}$. Figure 13 shows the setting of the membership function. Some measured light absorbance ($A_{i,me}$) is the peak of the W_i function, the rising point of the W_{i+1} function and the fallen point of the W_{i-1} function.

In Figure 5, the first line of LCD displays the order of the function (i), the light absorbance of the measurement ($A_{i,me}$) and the light absorbance of the commercial device ($A_{i,com}$). The second line of LCD shows the light absorbance of the commercial device (A_{com}) which can be set by the user and the amplified light absorbance ($A_{proposed}$). The light absorbance of the commercial device (A_{com}) can be edited by Up and Down buttons. The order of function (i) can be changed by the short push of the S_i button. The long push of the S_i button is used to memorize the measured light absorbance (A_{me}) into the light absorbance of the proposed device ($A_{i,me}$) and the light absorbance of the target (A_{com}) into the light absorbance of the commercial device ($A_{i,com}$).

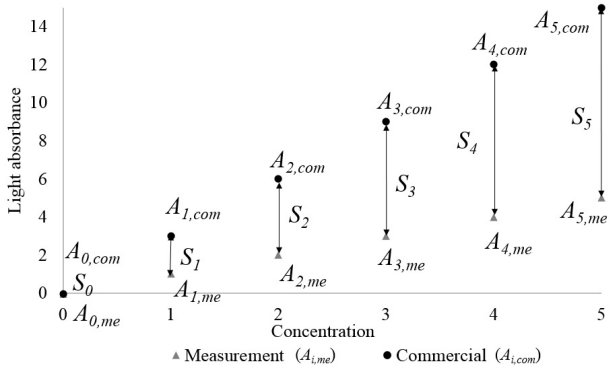

FIGURE 12. Setting up of S_i in light absorbance graph

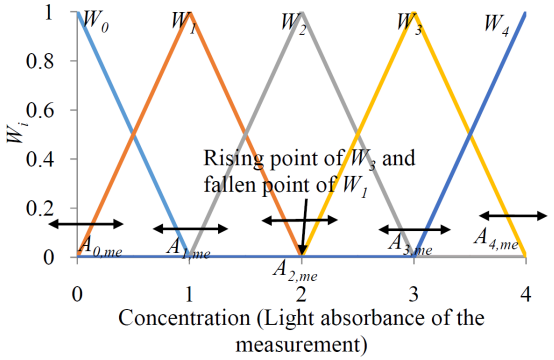

FIGURE 13. Setting the membership function

5. **Experimental Setup and Result.** In the experiment, there are measurements of the 3 solutions which are the main colors of light, red solution, green solution, and blue solution. There are 3 colors of light sources same as the color of the solution. The solution is measured by the use of different color-light sources. The light absorbance amplification is set up by 4-5 concentrations of solution. The experimental result shows the light absorbance of the commercial device, the light absorbance of the measurement (no amplification), the proposed light absorbance and the coefficient of determination of every light absorbance.

5.1. **Light absorbance of the red solution.** The red solution is measured by the green light and the blue light. The light absorbance by green light is shown in Figure 14 and by blue light is shown in Figure 15. The commercial device provides the wavelength of 470nm as a light source. From the 2 results, the 3-light-absorbance are similar. Therefore, the results are not clear about the light absorbance difference. The result can be observed that the coefficient of determination is increased when the light absorbance is amplified.

5.2. **Light absorbance of the green solution.** The green solution is measured by red light and blue light. The light absorbance by red light is shown in Figure 16 and by blue light is shown in Figure 17. The commercial device provides the wavelength of 590nm as a light source. This difference of the result can be observed easier than the red solution result. When the light absorbance is amplified, the light absorbance is approximate with the light absorbance of the commercial device. Furthermore, the

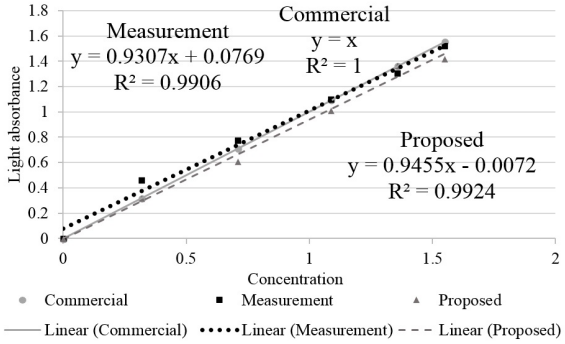

FIGURE 14. Light absorbance result of the red solution by green light

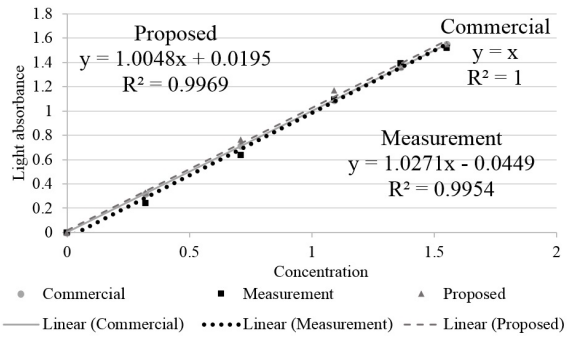

FIGURE 15. Light absorbance result of the red solution by blue light

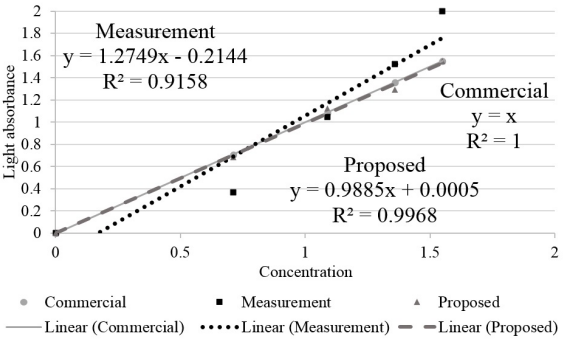

FIGURE 16. Light absorbance result of the green solution by red light

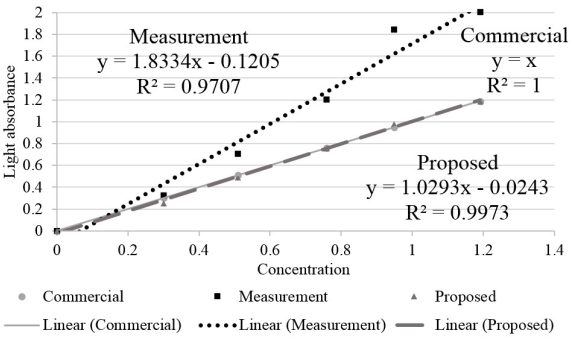

FIGURE 17. Light absorbance result of the green solution by blue light

coefficient of determination of the proposed light absorbance ($A_{proposed}$) is more than the coefficient of determination of the light absorbance from measurement (A_{me}). The light absorbance result of the green solution by red light has 5 concentrations because the light absorbance of 6$^{\text{th}}$ concentration from the measurement is more than 2. The light absorbance measurement device cannot measure the light absorbance more than 2.

5.3. **Light absorbance of the blue solution.** The blue solution is measured by red light and by green light. The light absorbance by red light is shown in Figure 18 and green light is shown in Figure 19. The proposed light absorbance approximates to the light absorbance of the commercial device same as above 2 solution results. The coefficient of determination is increased after the light absorbance is amplified as 2 above results.

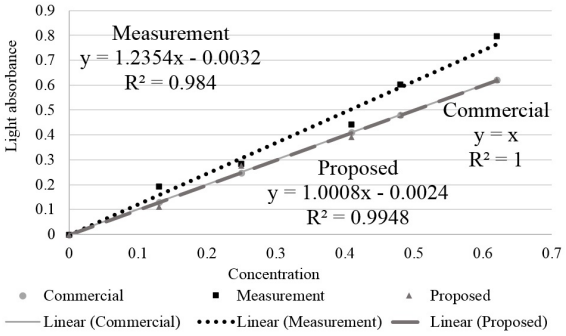

FIGURE 18. Light absorbance result of the blue solution by red light

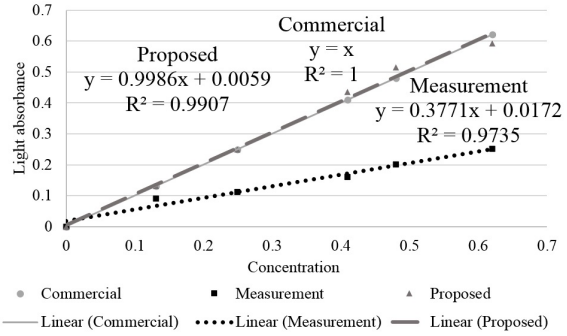

FIGURE 19. Light absorbance result of the blue solution by green light

The results of 3 solutions show that the amplification by fuzzy theory can amplify the light absorbance approximately to the light absorbance of the commercial device in many cases. Furthermore, it can increase the coefficient of determination of measure. It means that this method can increase the accuracy of the measurement.

6. **Discussion.** The proposed device is developed for chemical education. Therefore, the cost of the device is not expensive to purchase for many students. The part cost of the proposed device excluding package is about 1600JPY. It provides the power RGB LED as a light source which gives 3 main monochromatic lights, red, green and blue. Therefore, the large diffraction space is not sufficient. The proposed device is small and can be used outside by battery 9V. Furthermore, the high-intensity light source is insufficient because the light from the light source goes to the solution directly without other processes. As a result, the proposed device does not provide the high-power source. Because of the limit of the color of the light source, the molar absorptivity of every case in the measured light absorbance might not approximate with the commercial device. Consequently, the proposed device has the fuzzy weighted average for decreasing the difference of the light absorbance between both values. In addition, this method can increase the efficiency of the measurement as the Beer-Lambert's law by calculation without the complicated circuit design.

The light absorbance measurement device might not be a perfect device. It can measure only the solution which the light can transmit. Therefore, it cannot measure colloid, the solution having the bubble and semimetal solution, etc. The previous device [18] measures the light absorbance of the soft drink. The carbon-dioxide that contains in solutions must be removed before measurement. Furthermore, the range of the concentration which the light absorbance measurement device can measure is from 0 to 2. Therefore, the proposed

device cannot measure the 6^{th} concentration of the green solution by the red light. This is a general problem of the light absorbance measurement device. It can solve by changing a parameter in the experiment [28,29]. There are many problems in the light absorbance measurement. The users must recognize to solve this experimental problem.

In the amplification process, the fuzzy weighted average cannot be used in the case in which the light absorbance of the proposed device is stable when the light absorbance of the commercial device is not stable. The calculation does not analyze the difference of each concentration. Moreover, the range of the amplification is from $A_{0,me}$ to $A_{k,me}$ which is the last function of the light absorbance from the measurement. The amplification of the measured light absorbance, which is direct variation with the concentration of solution, to the light absorbance of the other device, which is direct variation with the concentration of solution, does not have a problem. It depends on the number of the membership function. However, in the other case, it depends on the position of the $A_{i,me}$ also.

The possibility in further developing a proposed device is incredibly opened. To edit the fuzzy set easier, the proposed device can be installed the numeric keypad instead of the button. To move or increase the range of the measurement, there are many parameters which can be changed such as light intensity, detector or light source. It extends the number of possible cases which can be measured.

7. **Conclusion.** The development of a fuzzy-based light absorbance measurement device for chemical education is proposed in this paper. The proposed device can measure the solution following Beer-Lambert's law. The proposed device does not require the wide space to make the monochromatic light. Therefore, the proposed device is smaller and lightweight compared with the previous device. For this result, the proposed device is portable. Furthermore, the amplification of the fuzzy theory can reduce the difference light absorbance between the conventional device and the commercial device. Therefore, the amplification of the proposed device can make the measured light absorbance be approximate the light absorbance of the conventional device to the light absorbance of the commercial device. Furthermore, it can increase the coefficient of determination of the measurement. It shows that the fuzzy theory can raise the accuracy of the measurement. Additionally, the membership function can be edited. As a result, the measurement by the fuzzy weighted average can amplify the light absorbance in many cases. Moreover, because of the direct variation of the light absorbance with the concentration of solution, this proposed device can amplify the measured light absorbance to the concentration of solution directly same as the light absorbance of the commercial device case.

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