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CALCULATION OF A LIGHT ABSORBANCE MEASUREMENT DEVICE BY DOUBLE AVERAGING AND FEEDBACK PROCESSES

Soranut Kittpanyangam, Wang Lok Do and Kei Eguchi

Department of Material Science and Production Engineering
Fukuoka Institute of Technology
3-30-1, Wajirohigashi, Higashi-ku, Fukuoka 811-0295, Japan
Soranutac123@gmail.com; dw112345@naver.com; eguti@fit.ac.jp

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Abstract. *In the present, many spectrophotometers are developed. However, the light absorbance from the conventional spectrophotometer is not the same as the commercial spectrophotometer. Therefore, we try to develop the spectrophotometer which gives the light absorbance as same as that of the commercial spectrophotometer. Furthermore, because of the sensitivity of the light detector, there is still output swing problem. Therefore, this research aims to develop the calculation of device which solves the swing problem and the different output. To solve the swing problem, the program averages the light absorbance, deletes the most different light absorbance, and receives the new data. Moreover, to amplify the output of the proposed device closer to the output of the commercial spectrophotometer, the proposed device employs the output from the commercial spectrophotometer for calculation. The output of light absorbance from the proposed device is stable and closer with the data from the commercial spectrophotometer.*
Keywords: Light absorbance, Beer's law, Averaging and feedback process

1. **Introduction.** There are many methods to measure the concentration of solution. For example, the density of Raoult's law [1], light reflection measurement [2] and light absorbance measurement [3]. In an analysis chemical room, the UV-spectrophotometer is employed for measuring the concentration of solution by the monochromatic light following Beer's law. It explains the relation between the concentration and light absorbance. However, the cost of the spectrophotometer is very high. The number of devices is not enough for every student in the science faculty. Therefore, there are many researches deverloping the spectrophotometer in [4-8]. The output of spectrophotometer in [4] was not the same as the commercial spectrophotometer. The spectrophotometer in [5] was not compared with the commercial spectrophotometer. It cannot know the efficiency of the proposed device compared with the spectrophotometer. The spectrophotometer in [6] which has high efficiency uses the CD compact. However, the diffraction of light must use many spaces which is not proper in classroom. Furthermore, it shows the data only $KMnO_4$. If the solution is changed, the conventional device of [6] may not be available or the output is not the same as the spectrophotometer. The spectrophotometer in [7] is created for measuring the pH of the solution. It uses many light sources which the changing of the light source is complicated. The spectrophotometer in [8] uses the grating to spread the light to rainbow light and uses the photodiode array as a detector. However, the setting up of light diffraction is difficult. Furthermore, the photodiode array cannot be purchased in a general electronic store. Therefore, we try to develop the spectrophotometer which gives the light absorbance closely with the light absorbance of the commercial spectrophotometer. Because of the specification of the solution, the light absorbance is different when the solution is measured by different color of light [3]. For this reason, to amplify the output, the color of light source and the color of solution must be known. The amplification ratio uses the target output of the commercial spectrophotometer and

the output of the proposed device. In this point, the proposed device can amplify the output to any target spectrophotometer. Therefore, the device must have 3 parts: a color light sensor part, a color solution sensor part and a calculation part. This research is only the development of calculation part which calculates the light absorbance. Therefore, the amplification ratio is set manually by choosing the color of light source and color of solution without the first two parts. Moreover, there is one more problem. It is the swing of output. This problem occurs by sensibility of the light detector. The data observation is very difficult. Therefore, we develop the system to average the output and feedback to decrease the most error data. From the above development, the proposed device output is near with the commercial spectrophotometer output. Furthermore, the swing range of the proposed device output is decreased and very stable without decreasing of the efficiency. Moreover, the proposed device is portability, and it can be used in outside of laboratory.

2. Principle of Analysis.

2.1. **Light absorbance.** In everyday life, people can see the color of the object, because the object absorbs other color. The color reflected from the object is the color of the object. Also, the solution is the same case with the object. However, there is not only the reflection to see the color of the object, but also there is transition of color of light. The color of light transmitting the solution is the color of the solution. This effect is called that light absorbance [3]. The light absorbance in Figure 1 occurs when the light transmits the solution. The solution absorbs the one part of the light. The light absorbance (A) is calculated from minus common logarithm of the transmittance (T) shown in (1). Transmittance is the ratio between incident light intensity (I_0) and transmitted light intensity (I).

$$A = -\log T \tag{1}$$

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

Therefore, the light absorbance is common logarithm of the ratio between incident radiant light and transmitted radiant light through a solution shown in (2). For example in Figure 1, the light goes through the sample, and it absorbs the light intensity 20%. The transmitted light intensity is remained from 100% to 80%. The light absorbance is 0.097 as calculated in (2).

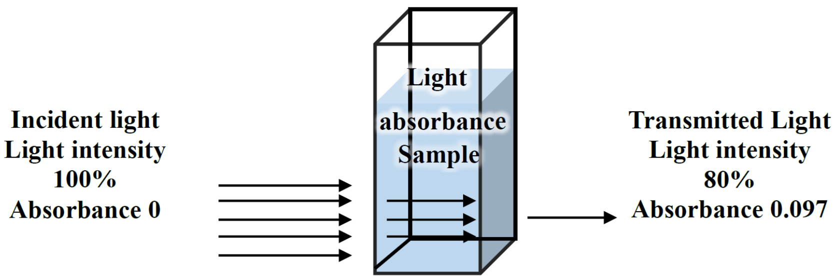

FIGURE 1. Light absorbance

2.2. **Beer-Lambert law.** It is the method that explains the relation between the light absorbance and the concentration of solution [3]. The light absorbance directs variation with the concentration of solution (c), length of the light transition (l) and absorbance coefficient of the color of solution (ε). The Beer's law equation is shown in (3).

$$A = \varepsilon c l \tag{3}$$

Next, Beer's law explains more that when the monochromatic light transmits the homogenous medium, each layer of medium absorbs the light intensity equally.

2.3. **Coefficient of determination.** It is the number showing how well relation of the statistical model is [9]. It is denoted the square of the correlation coefficient (R^2) [4]. The equation is shown in (4). The coefficient of determination is employed to check the relation between the light absorbance and the concentration of solution. The range of the coefficient of determination is between $[0, 1]$. The variable of the coefficient of determination is the number of solution (n), concentration of solution (x_i), mean of the concentration of solution ($\overline{x}$), light absorbance (y_i) and mean of light absorbance ($\overline{y}$). The coefficient of determination is not only used to check the relation of value, but also used for checking the efficiency of the proposed device and preparing the concentration of solution. The ideal coefficient of determination is shown in Figure 2.

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2 \sum_{i=1}^{n}(y_i - \overline{y})^2}} \right\}^2 \tag{4}$$

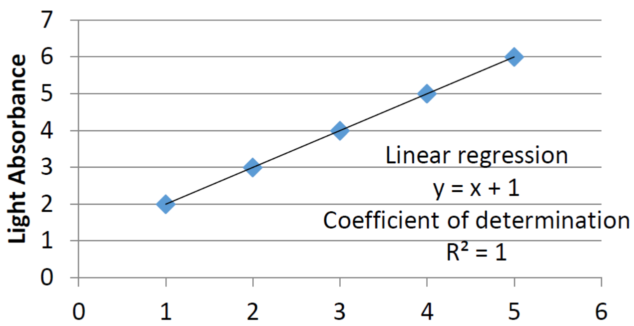

FIGURE 2. Ideal coefficient of determination linear regression and coefficient of determination

2.4. **Calibration curve.** Calibration curve or standard curve is used for determining the concentration of the solution. The calibration curve is plotted by variable of concentration and another signal which is indirect measurement for calculating the concentration [4]. The calibration curve is always linear. Figure 2 illustrates the ideal calibration curve.

2.5. **Linear regression.** The linear regression is a linear equation calculated from the calibration curve [9]. It can be used to predict the dependent variable y or the explanatory variable x [4]. The linear regression equation is shown in (5).

$$Y = a + bX \tag{5}$$

In the experiment, it is employed for calculation of the unknown concentration of solution. The variable of the linear equation is concentration of solution (X), light absorbance (Y), slope (a) and constant value when X is 0 in Y axis. The ideal linear regression is shown in Figure 2.

3. **Circuit Configuration.** The circuit configuration of the proposed device is shown in Figure 3. It consists of a measurement part, a calculation part, a power source and a display. The power source is a battery 9V with the regulator 7805. The proposed device uses the 2 level of voltage 9V for a light source and light detector and 5V for a microcontroller and display. The measurement part has a light source and a light detector. The light source is a power RGB LED which can change and mix colors. The light detector is a phototransistor. The calculation part employs the microcontroller 16F877A which is used generally. The display uses LCD 16 × 2 characters. The switch $V_{solvent}$ is used for

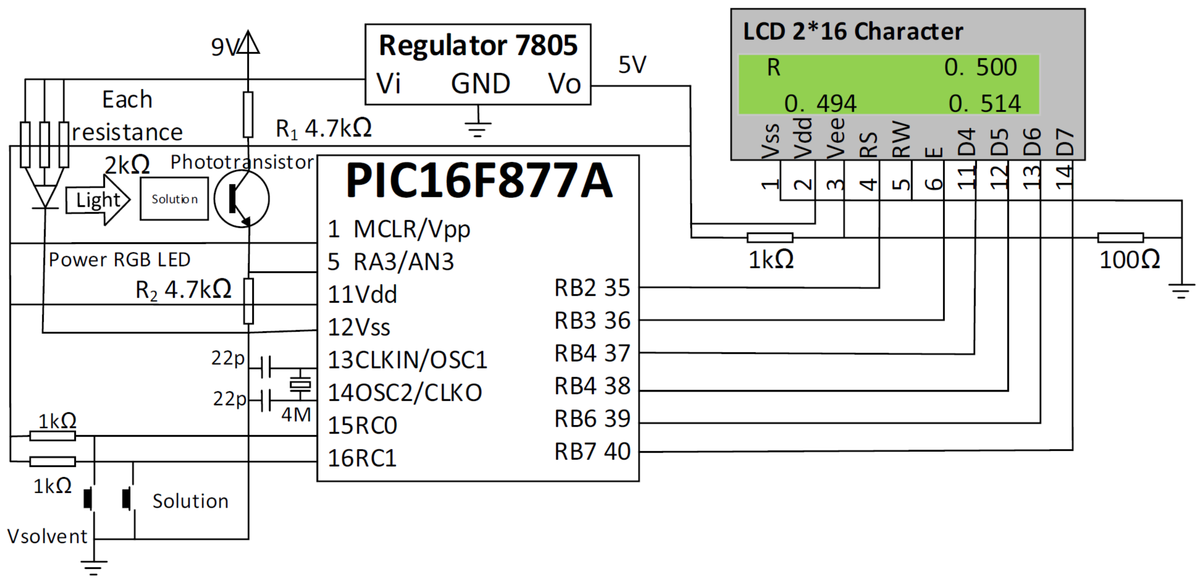

FIGURE 3. Circuit configuration

memorizing the voltage when the light transmits the solvent. The solution switch is used for changing the amplification ration. In display, it shows that the first line is the color of the solution which is amplification of this solution and the averaged light absorbance, and the second line is the amplified light absorbance and the current light absorbance.

4. **Calculation.** The calculation has 3 parts. There are a light absorbance calculation part, double averaging and feedback process part and amplification part.

4.1. **Light absorbance calculation.** Equation (2) is used for calculating the light absorbance. However, there is not the light intensity in the electric circuit. Therefore, the variable in the equation must be changed from the light intensity to the voltage in (6).

$$\frac{I}{I_0} = \frac{V_{sample}}{V_0} \tag{6}$$

Moreover, if the incident light and the transmitted light are used, there must be 2 light detectors. Therefore, we replace the voltage from the incident light to the voltage of the light transmitted from the solvent [3]. When the $V_{solvent}$ is measured, the V_{sample} equals $V_{solvent}$. Therefore, the light absorbance is 0 which is the same as the case of the incident light. The equation is shown in (7).

$$A = -\log \frac{V_{sample}}{V_{solvent}} \tag{7}$$

Furthermore, to decrease the noise when there are not light falling to the detector, the voltage (V_{zero}) must be calculated. The completed equation is shown in (8).

$$A = -\log \frac{V_{sample} - V_{zero}}{V_{solvent} - V_{zero}} \tag{8}$$

4.2. **Double averaging and feedback process.** The first step is average 10 data from (8) in (9). $\overline{y_m}$ is the first average. X_n is light absorbance. The second step is average 10 data from the first step in (10). Then, the second average is output. A_o is the second average. Next, the differences between the first 5 data from the first step average and the second average are calculated. The most different data (y_{error}) is deleted from the system for decreasing the error in (11). Then, the new average ($\overline{y_{m+11}}$) from the first step data is added in the system for averaging 10 data in (11) again.

$$\overline{y_m} = \frac{\sum_{n=1}^{10} X_n}{10} \tag{9}$$

$$\overline{A_o} = \frac{\sum_{m=x+1}^{X+10} \overline{y_m}}{10} \tag{10}$$

$$\overline{A_o} = \frac{\sum_{m=x+1}^{X+10} (\overline{y_m} - y_{error}) + \overline{y_{m+11}}}{10} \tag{11}$$

The system is shown in Figure 4. This method looks like average of 100 data by using only 20 memory data. It can save the memory of the microcontroller which can be used to write other programs. Furthermore, one of the first 5 data is chosen to delete, because of average of data. If the new data is deleted before it has effect on the average data, the output cannot be changed. Therefore, the program deletes only the one of first 5 data for decreasing the error. In addition, this process looks like the feedback control system. However, there are not effects to the input in this system. It has effect to the output only which value of the effect is depended on the light detector. The feedback control system controls the input to be near the reference data.

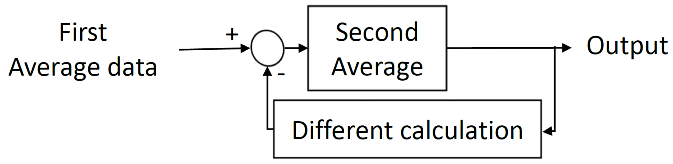

Figure 4. Average feedback

4.3. **Amplification.** The amplification of this proposed device uses the cross-multiplication of linear regression between the commercial spectrophotometer and the proposed device by passing the concentration of solution. The equation is shown in (12).

$$Y_{spec} = a_{spec}\left(\frac{Y_{proposed} - b_{proposed}}{a_{proposed}}\right) + b_{spec} \tag{12}$$

Y_{spec} is light absorbance of the commercial spectrophotometer which is the target of calculation. $Y_{proposed}$ is light absorbance of the proposed device. a_{spec} is slope of the linear regression of the spectrophotometer. $a_{proposed}$ is slope of the linear regression of the proposed device. b_{spec} and $b_{proposed}$ are constant in the linear regression of the commercial spectrophotometer and that of the proposed device.

5. **Experimental Setup and Experimental Result.** The 3 main colors of solution, red, blue and green are used in experiment. Each color of solution is prepared by color of light source which gives the highest light absorbance. Furthermore, each color of solution is prepared more than 5 concentration which the coefficient of determination is more than 0.99XX. If there is much concentration, the accuracy of the coefficient of determination is high. Table 1 shows the range of light absorbance output from the proposed device. The left column is calculated only light absorbance which is the same as the [4,5]. The right

TABLE 1. Comparison between the calculated data and double average and feedback data

Red		Green		Blue	
Calculated data	Averaged data	Calculated data	Averaged data	Calculated data	Averaged data
0.11-0.117	0.116	0.249-0.265	0.25	0.097-0.108	0.1
0.288-0.296	0.296	0.41-0.43	0.41, 0.42	0.202-0.213	0.2
0.469-0.483	0.476	0.656-0.697	0.67, 0.68	0.279-0.292	0.28
0.601-0.619	0.606, 0.616	0.923-0.957	0.93, 0.94	0.4-0.425	0.41
0.759-0.776	0.766	1.054-1.137	1.07-1.11	0.503-0.532	0.51

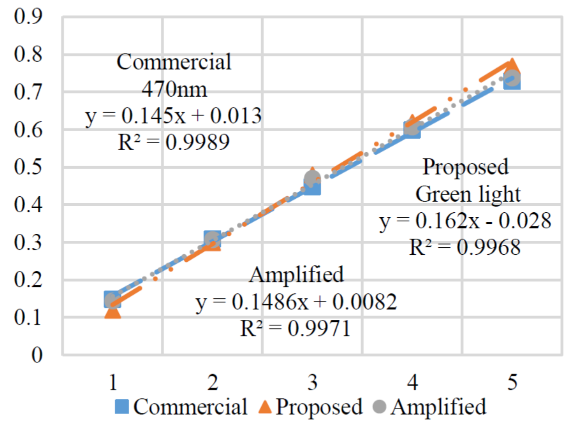

FIGURE 5. Result of red solution

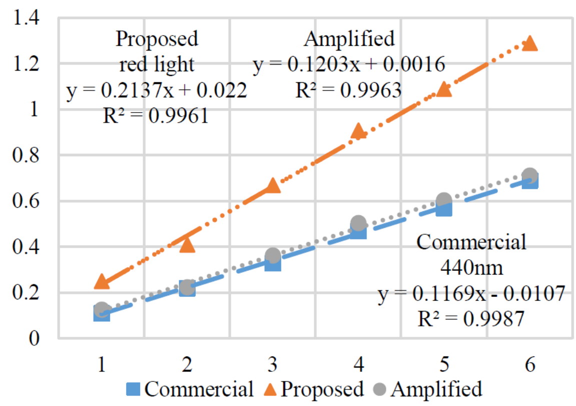

FIGURE 6. Result of green solution

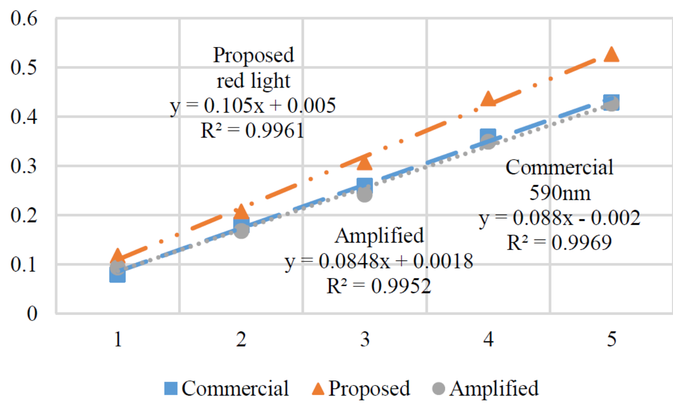

FIGURE 7. Result of blue solution

column is averaged light absorbance. Furthermore, Figures 5-7 show linear regression and coefficient of determination of commercial spectrophotometer and the proposed device.

5.1. **Red solution.** In the case of the commercial spectrophotometer, the red solution absorbs the 470nm of light best. In the case of the proposed device, the red solution absorbs green light best. Figure 5 shows the result of the red solution.

5.2. **Green solution.** In the case of the commercial spectrophotometer, the green solution absorbs the 440nm of light best. In the case of the proposed device, the green solution absorbs the red solution best. Figure 6 illustrates the result of the green solution.

5.3. **Blue solution.** In the case of the commercial spectrophotometer, the blue solution absorbs the 590nm of light best. In the case of the proposed device, the blue solution absorbs the red solution best. Figure 7 illustrates the result of the blue solution.

6. **Discussion.** This proposed device is developed from [4]. It decreases the light intensity of the light source by increasing the resistor. There are cases of linear regression which is closer and farther to the commercial spectrophotometer linear regression than before. It can be seen at slope and constant. The double averaging and feedback process makes the output more stable than output of [4]. Furthermore, it can decrease the swing range of the output. Moreover, when the output passes the amplification, the amplified linear regression is near with the linear regression of the commercial spectrophotometer. Therefore, the light absorbance of the proposed device is near with the light absorbance of the commercial spectrophotometer also.

7. **Conclusion.** The calculation of the light absorbance measurement device by double averaging and feedback processes has been proposed in this paper. It can calculate the light absorbance and give the light absorbance closing to the data from the commercial spectrophotometer. Furthermore, it can make stability of output. To use this proposed device in the classroom, the coefficient of determination is required more than 0.99XX. From the experimental result, the coefficient of determination of 3 colors of the proposed device is more than 0.99XX. Although the output data is amplified, the coefficient of determination is more than 0.99XX. Therefore, the proposed device can be replaced with the commercial spectrophotometer in the classroom and uses in outside of laboratory by small circuit.

8. **Future Study.** The calculation of the light absorbance measurement device by double average and feedback is developed in this research. It is one part of three parts of the proposed spectrophotometer. The amplification ratio must be still selected manually. If the color light sensor part and color solution sensor part are finished and they are combined, the proposed device will be completed. The amplification ratio can change automatically by calculation of color light and color of solution. The color light sensor is used when the solvent is measured. The color solution sensor is used when the solution is measured.

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