International Journal of Innovative
Computing, Information and Control
Volume **15**, Number **5**, October **2019**

ICIC International ©2019 ISSN 1349-4198
pp. **1763–1777**

DESIGN OF A MULTI-COMPONENT ANALYSIS SYSTEM BASED ON FUZZY THEORY

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Received March 2019; revised July 2019

Abstract. *In recent years, many concentration measurement techniques have been proposed. The light absorbance measurement is one of the effective concentration measurements. To make solutions or medicines, the pure solution is not used only. Because of the overlap of the light absorbance of all components in the mixture solution, the normal light absorbance measurement cannot analyze the mixture solution. For this reason, there are many multi-component analysis methods. To analyze the concentration of components in the mixture efficiently, the spectrophotometer is an essential device. However, some methods cannot be provided in the limited wavelength spectrophotometer. Therefore, we design a multi-component analysis system based on fuzzy theory in order to solve this problem. This proposed method offers the fuzzy theory calculating the concentration of the component by the relationship between light absorbance and concentration of solution. The relationship is obtained from the measurement of the solution in any level of known concentration. In the ideal case, the result by the fuzzy theory is the same as the other method. It can calculate the concentration that the accuracy is more than other methods even if the light absorbance does not vary with the concentration perfect directly.*

Keywords: Light absorbance, UV-spectrophotometer, Beer-Lambert's law, Multi-component analysis, Fuzzy theory

1. **Introduction.**

In chemical laboratory, the light absorbance measurement is one of the most important methods to measure the concentration of solution. To measure the light absorbance of solution, the chemists use the UV-spectrophotometer called the light absorbance measured device. The relationship between the light absorbance and the concentration of solution is expressed by Beer-Lambert's law [1-7]. In the present, there are many researches developing the light source of the spectrophotometer such as the monochromator [9], diffraction of the transmitted light [10] or many light source [5,11]. In the case of the pure solution, the concentration of solution can be calculated by using the light absorbance and the linear regression directly.

However, in the case of the mixture solution, the light absorbance is overlapped by the light absorbance of all components. Therefore, the concentration of the component cannot be obtained by the light absorbance of the mixture solution directly. There are many methods for analyzing the concentration of the component in the mixture solution explaining in Section 2. In the ideal case, the calculation of previous method by molar absorptivity is perfect. However, in the error case, the molar absorptivity between the light absorbance and the concentration is not equal at all light absorbance. Thus, the calculation of the previous method by the averaged molar absorptivity has many errors.

DOI: 10.24507/ijicic.15.05.1763

Furthermore, some previous techniques provide the derivative. It requires many wavelength of light. The limited wavelength spectrophotometer cannot utilize the derivative method. Moreover, the spectrophotometer which has the derivative function is more expensive than the limited wavelength spectrophotometer extremely. The science faculty which has many students cannot purchase the expensive device for every student.

To reduce the error of the calculation in the error case and calculate the concentration of the component in mixture solution by the limited wavelength spectrophotometer, we design a novel multi-component analysis system based on the fuzzy theory. The fuzzy theory can control the output by the relationship between the input and output. In this research, the relationship between the light absorbance and the concentration of solution is employed to calculate the concentration of component. The relationship is the measured light absorbance of the known concentration. The fuzzy theory adjusts the light absorbance at the measured light absorbance to the measured concentration. The light absorbance between the measured light absorbance is adjusted to the concentration by averaging the 2 most approximate measured concentration. Each gap between the measured light absorbance is adjusted by difference ratio. It is like using many molar absorptivity. Therefore, the error of the proposed method is less than the previous method. Furthermore, the fuzzy theory provides the number of the light absorbance equal to the number of the components same as the other methods. It can be used in the limited wavelength spectrophotometer or be installed into the handmade device.

This research paper is organized as follows. Section 2 explains the previous multi-component analysis method. It explains many methods of the multi-component analysis, and advantages and disadvantages of individual method are shown clearly. Section 3 describes a light absorbance analysis theory. It explains about the light absorbance measurement and the calculation of the concentration. Section 4 presents the proposed method. This section explains the calculation of the concentration of solution step by step. In Section 5, experimental setup and the result are shown. It explains the setup of the measured data in the system and the experimental results by spectrophotometer. Section 6 shows discussion part. It clarifies the advantages and disadvantages of the proposed method. Section 7 gives the conclusion.

2. Previous Multi-Component Analysis Method.

In this section, the explanation about the previous multi-component analysis method, advantage, and disadvantage of the individual method are shown. There are many multi-component analysis methods. Each method has a different calculation process.

2.1. Simultaneous equation method.

The simultaneous equation method is the simple mathematics to calculate the concentration of solution. This technique provides the number of the light absorbance in any wavelength which is equal to the number of the components [8,12,13]. For example, the following case shows the 2 component solution. The light absorbance (A_1, A_2) is measured by λ_1 and λ_2 shown in (1) and (2), respectively. The concentration of the x component and y component is c_x and c_y, respectively. The molar absorptivity of x at λ_1 and λ_2 is a_{x_1} and a_{x_2}, respectively. The absorptivity of y at λ_1 and λ_2 is a_{y_1} and a_{y_2}, respectively. The path length (l) of the light transmitting is 1 cm.

$$A_1 = a_{x_1} c_x l + a_{y_1} c_y l \tag{1}$$

$$A_2 = a_{x_2} c_x l + a_{y_2} c_y l \tag{2}$$

The simultaneous equation method rewrites and substitutes the disinterest component variable of Equations (1) and (2). Equations (3) and (4) are obtained to calculate the concentration of the component x and component y, respectively.

$$c_x = \frac{a_{y_1}A_2 - a_{y_2}A_1}{a_{x_2}a_{y_1} - a_{y_2}a_{x_1}} \tag{3}$$

$$c_y = \frac{a_{x_2}A_1 - a_{x_1}A_2}{a_{x_2}a_{y_1} - a_{y_2}a_{x_1}} \tag{4}$$

The determination of this method is simple mathematics and does not employ the concentration of another component. Furthermore, this method can be utilized by the limited wavelength light source of the spectrophotometer. However, this method must provide the molar absorptivity of all cases which are between the solution and the wavelength.

2.2. **Derivative spectrophotometry.** This method alters the absorption spectra or the zero-order spectrum to the first order-derivative spectrum or the high order [8,14,15]. It can decide the maximum amplitude (λ_{MAX}) and the minimum amplitude (λ_{MIN}) of the spectrum in the zero-order that is 0 in the first-order derivative. It is called zero-crossing point.

Figure 1 shows a light absorbance spectra example of the 2 component solution and the mixture. The mixture solution consists of x component and y component. The derivative first-order of the light absorbance is obtained by (5). The first-order derivative of the light absorbance spectra is illustrated in Figure 2.

$$\frac{d[A]}{d\lambda} = c_x l \frac{d[\varepsilon_x]}{d\lambda} + c_y l \frac{d[\varepsilon_y]}{d\lambda} \tag{5}$$

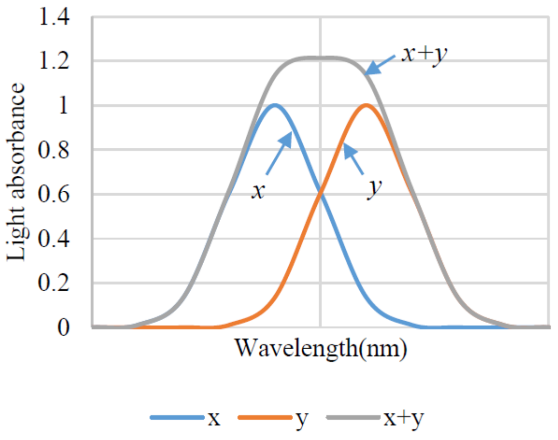

FIGURE 1. Spectrum analysis of the solution x and y

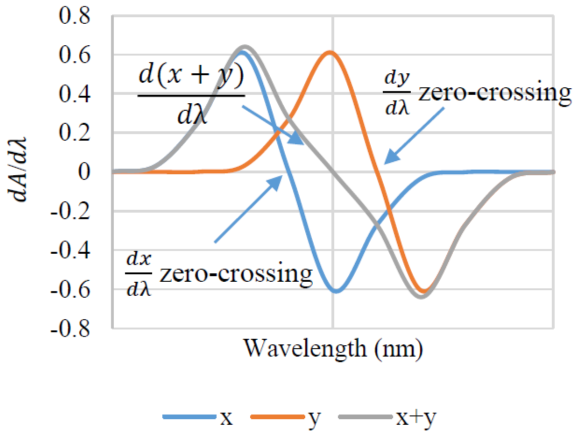

FIGURE 2. First-order derivative spectrum of the solution x and y

The zero-crossing point is provided to eliminate the disinterest component variable, where the zero-order light absorbance is maximum amplitude or minimum amplitude. Equation (6) is the first-order derivative of the light absorbance at the zero-crossing when the light absorbance of the x component is maximum amplitude.

$$\frac{d[A]}{d\lambda} = c_y l \frac{d[\varepsilon_y]}{d\lambda} \tag{6}$$

From (6), the concentration of solution is direct variation with the first-order derivative of the light absorbance spectra as same as the zero-order. Therefore, the first-order derivative of the light absorbance spectra can be obtained to calculate the concentration of solution. This method does not provide many variables as the simultaneous equation method. However, it must provide the many wavelengths to find the wavelength of the zero-crossing. If the wavelength is incorrect, there is an error of the other component.

2.3. **Absorb ratio method.** This method utilizes the ratio of the light absorbance between the mixture and the standard solution of one component [8,16,17]. Equation (7) is the ratio between the mixture light absorbance between x component and y component and the standard solution of x component (A_x^0).

$$\frac{A_M}{A_x^0} = \frac{a_x c_x + a_y c_y}{a_x c_x^0} \tag{7}$$

The rearrangement eliminates the variable of the component which is provided as the standard solution. Equation (8) is obtained as

$$\frac{A_M}{A_x^0} = \frac{c_x}{c_x^0} + \frac{A_y}{A_x^0} \tag{8}$$

The example division variable in (8) is shown in Figure 3, where $\frac{A_x}{A_x^0}$ is the constant in every wavelength. Therefore, $\frac{c_x}{c_x^0}$ is also constant and can be eliminated by another wavelength. Equation (9) shows that the light absorbance ratio between the mixture and the standard solution is subtracted by the light absorbance ratio between the mixture and the standard solution in another wavelength.

$$\left[\frac{A_M}{A_x^0}\right]_{\lambda_1} - \left[\frac{A_M}{A_x^0}\right]_{\lambda_2} = \left[\frac{A_y}{A_x^0}\right]_{\lambda_1} - \left[\frac{A_y}{A_x^0}\right]_{\lambda_2} \tag{9}$$

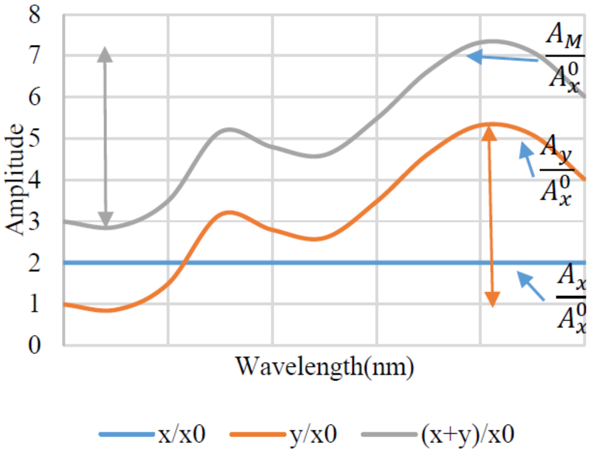

FIGURE 3. Ratio between the light absorbance of x, y and mixture and standard of x

The concentration of the y component (c_y) is factorized from the light absorbance of y component (A_y). It shows that the concentration of the y component is proportional to the difference amplitude between λ_1 and λ_2 of mixture light absorbance spectra. To get the difference amplitude efficiently, the calculation should provide the peak to peak amplitudes of the mixture absorbance spectra. This method is simple mathematics and it provides the number of variables less than the number of variables of the simultaneous equation method. However, it provides the knowing of another component for calculating the concentration of one component.

2.4. **Derivative ratio spectra method.** This method is developed from the absorb ratio method in (8) [8,18,19]. The derivation of (8) by wavelength is obtained as (10). $\frac{c_x}{c_x^0}$ is the constant value. Therefore, it is eliminated.

$$\frac{d}{d\lambda}\left[\frac{A_M}{A_x^0}\right] = \frac{d}{d\lambda}\left[\frac{A_y}{A_x^0}\right] \tag{10}$$

It shows that the derivative first-order of the light absorbance ratio of the mixture and the derivative first-order of the light absorbance ratio of the component y are equal. Figure 4 shows the derivative of the light absorbance ratio from Figure 3. The concentration of the component y depends on the derivative of the light absorbance ratio between mixture and the standard solution of component x and the derivative of the light absorbance ratio between the component y and the standard solution of the component x.

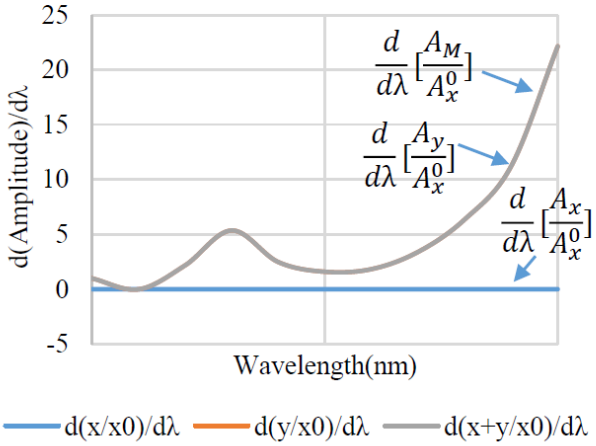

FIGURE 4. Derivative of the ratio of the light absorbance from Figure 3

This method is the same as the derivative method. Every wavelength is provided to calculate the derivative.

These four methods are a family of the multi-component analyses. From these previous methods, in order to calculate the concentration or the light absorbance of the individual component, the calculation must provide the light absorbance or molar absorptivity of the other component or eliminate the variable of the disinterest component.

3. **Light Absorbance Analysis Theory.** This section describes the fundamental theory for analyzing the light absorbance and calculating the concentration of the solution.

3.1. **Light absorbance.** The light absorbance is the volume of the light that is absorbed by the object [1,2]. To measure the light absorbance, the transmitting light is measured by the experiments.

3.2. **Beer-Lambert's law.** It is one theory that expresses the relationship between the concentration of the solution and the other value. In the Beer-Lambert's law, the light absorbance (A) varies the concentration (c) of solution directly. The molar absorptivity (ε) depends on the solution and the wavelength of the light source and l is path length which the light transmits the solution. In the case of the mixture solution, the light absorbance of the mixture is the sum of the light absorbance of all components shown in (1) and (2).

3.3. **Coefficient of determination.** The coefficient of determination is a value that indicates the degree of the relationship between the light absorbance and the concentration of solution [20,21]. The range of the coefficient of determination is from 0 to 1. When the light absorbance is direct variation with the concentration of solution perfectly, the coefficient of determination is 1. The coefficient of determination (R^2) is calculated by (11). In case of the pure solution, x is the concentration of solution and y is the light absorbance.

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \right\}^2 \tag{11}$$

3.4. **Calibration curve and linear regression.** The calibration curve is the graph for calculating the concentration of solution by comparing with the known concentration of solution. The linear regression is the approaching linear line of the relationship between the concentration of substance and the light absorbance. As shown in (12) [20,21], the equation of linear regression is the linear equation that is calculated from the many measured data.

$$Y = a + bX \tag{12}$$

Following the Beer-Lambert's law, the light absorbance is Y, the concentration of solution is X and the molar absorptivity is b. In the individual, there is no a. However, some error occurs in the measurement device. Therefore, a occurs from the error of the measurement which approaches 0. In the mixture component, a is the other component in the mixture solution. From the measured data, b is calculated by (13), where n is the number of the measured data and a is calculated by (14).

$$b = \frac{\sum_{n=0}^{k} X_n Y_n - \frac{\sum_{n=0}^{k} X_n \sum_{n=0}^{k} Y_n}{n}}{\sum_{n=0}^{k} X_n^2 - n\left(\bar{X}\right)^2} \tag{13}$$

$$a = \bar{Y} - b\bar{X} \tag{14}$$

4. **Proposed Method.** This section explains the calculation flow of the proposed method step by step. All previous multi-component analyses can calculate the concentration of solution in the ideal case perfectly. The previous method alters the light absorbance to the concentration of solution by the molar absorptivity. However, in the error case the molar absorptivity is not equal in all light absorbance. Therefore, the method which provides the averaged molar absorptivity has error shown in Figure 5. The fuzzy theory adjusts the light absorbance to the concentration by the measured data. All light absorbance is not adjusted by the same ratio. The amplified ratio is calculated by averaging the 2

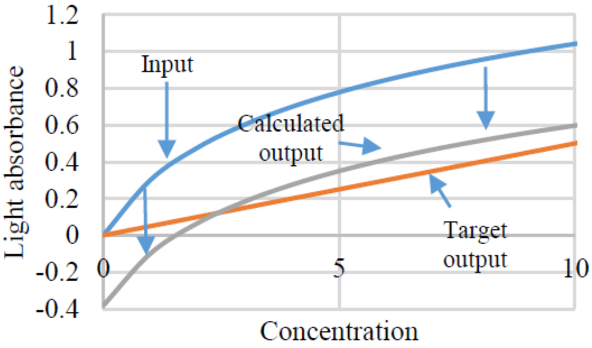

FIGURE 5. The adjustment of the previous method

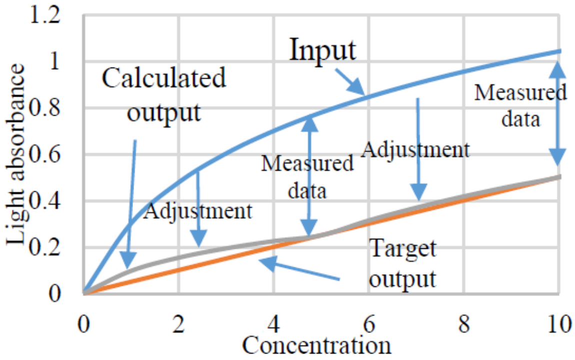

FIGURE 6. The adjustment of the proposed method

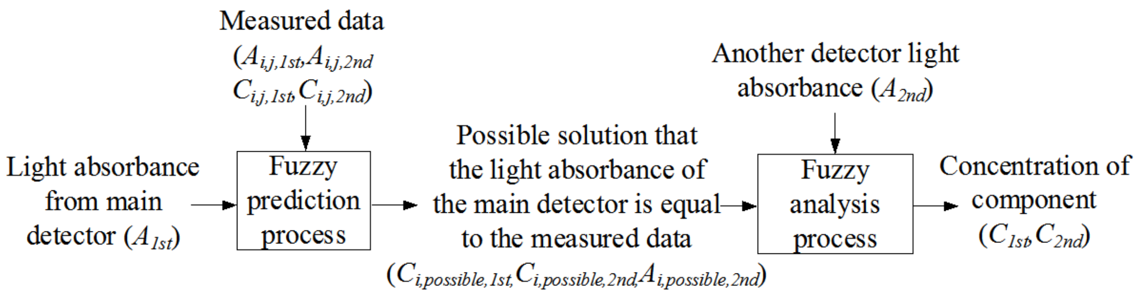

FIGURE 7. Analysis procedure of the proposed method in the case of the 2 components

most approximate concentrations. The calculated concentration of the proposed method is shown in Figure 6.

The proposed method employs the fuzzy theory for calculating the concentration of components in the mixture by using the measured data of the mixture solution. One measured data has the light absorbance of all detectors and the concentration of all components in any concentration level of the components. The measured data is used to make the relationship between the light absorbance of the individual wavelength and the concentration of the individual component. The fuzzy theory calculates the concentration of the component by this relationship [22,23]. Figure 7 shows the analysis process of the proposed method in the case of the 2 components. There are 2 main processes: fuzzy prediction process and fuzzy analysis process. In the case of the 2 components, the measured data has 4 variables, such as measured light absorbance of the 1st detector $(A_{i,j,1st})$, measured light absorbance of the 2nd detector $(A_{i,j,2nd})$, and the concentration of the 2 components $(C_{i,j,1st}, C_{i,j,2nd})$. Here, i and j are the concentration levels of the 1st component and 2nd component, respectively.

4.1. **Fuzzy prediction process.** As Figure 8 shows, the fuzzy prediction process is the first process of the proposed method. This process calculates the possible solution by the light absorbance and the main concentration from the measured data. The possible solution has 4 variables, such as the possible light absorbance of the 1st detector $(A_{i,possible,1st})$, the possible light absorbance of the 2nd detector light absorbance $(A_{i,possible,2nd})$, and the possible concentration of the 2 components $(C_{i,possible,1st}, C_{i,possible,2nd})$. The process of the fuzzy prediction is illustrated in Figure 8. In this process, the calculation fixes the concentration of the one component in any level as sub component. The light absorbance of the 1st detector (A_{1st}) is provided as the main detector, in order to make the fuzzy set in any level of the fixed sub component as shown in Figure 9. The membership function is

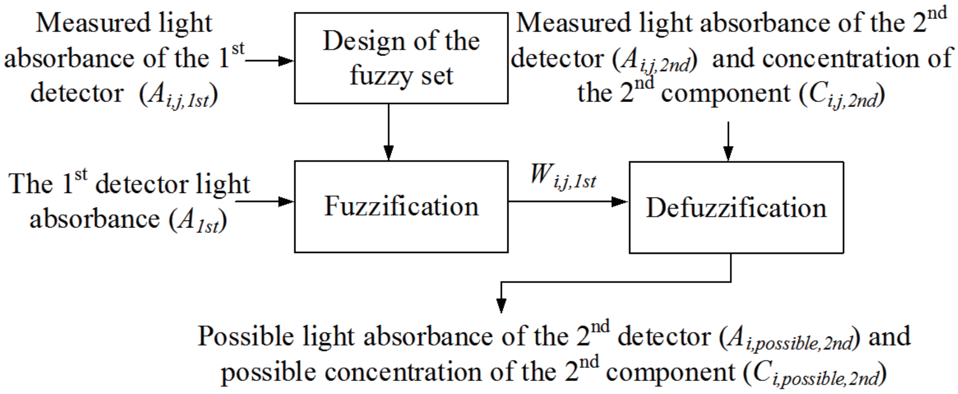

FIGURE 8. Fuzzy prediction process

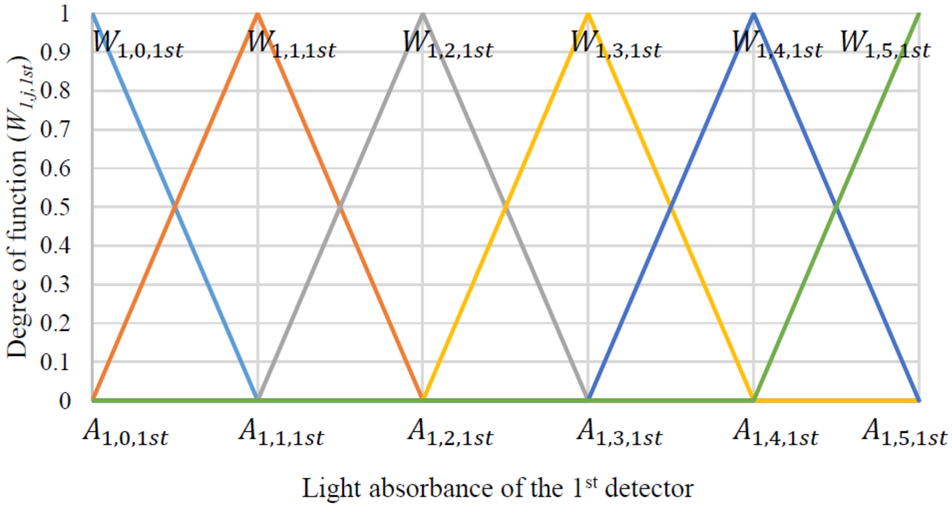

FIGURE 9. Fuzzy membership function for calculating value in the possible solution, where concentration of the 1st component is fixed in level 1

the triangle membership function. Since the light absorbance is direct variation with the concentration, the triangle membership function that is the linear equation and the input light absorbance is approximate linear. Therefore, to control the output to be linear, the triangle membership function is proper for the calculation of the possible solution. In addition, the calculation is not 1 time. If the membership function is complex, it takes time too much. After that, the fuzzification offers the light absorbance of the main detector (A_{1st}) to decide the degree of the function ($W_{i,j,1st}$) in the fuzzy set. The 1st of the degree variable means the fuzzy predict process (1st process). The parameters i and j are levels of the concentration of the 1st and 2nd detectors, respectively. Next, the defuzzification block utilizes the fuzzy weighted average to calculate the possible variable [24-27]. The possible light absorbance of another detector ($A_{i,possible,2nd}$) is calculated by (15) and the possible concentration of the 2nd detector ($C_{i,possible,2nd}$) is calculated by (16).

$$A_{i,possible,2nd} = \frac{\sum_{j=0}^{k} A_{i,j,2nd} W_{i,j,1st}}{\sum_{j=0}^{k} W_{i,j,1st}} \tag{15}$$

$$C_{i,possible,2nd} = \frac{\sum_{j=0}^{k} C_{i,j,2nd} W_{i,j,1st}}{\sum_{j=0}^{k} W_{i,j,1st}} \tag{16}$$

The possible concentration of the 1st component ($C_{i,possible,1st}$) is fixed at any concentration level. Therefore, the concentration is known.

The possible solution calculated from the fuzzy prediction process has main detector light absorbance (A_{1st}), the possible light absorbance of another detector ($A_{i,possible,2nd}$) fixed the sub-component concentration (1st component) in any level, and the possible concentration of the 1st component ($C_{i,possible,1st}$) and the possible concentration of the 2nd detector ($C_{i,possible,2nd}$).

4.2. **Fuzzy analysis process.** The second process is the fuzzy analysis process illustrated in Figure 10. The possible light absorbance of another detector ($A_{i,possible,2nd}$) is provided to make the fuzzy set. The fuzzification offers another detector light absorbance (A_{2nd}) to decide the degree of the function ($W_{i,possible,2nd}$). After that, the defuzzification block calculates the concentration of the component by the fuzzy weighted average. The concentration of the 1st component (C_{1st}) and the 2nd component (C_{2nd}) are calculated by (17) and (18), respectively. Therefore, the concentration is calculated from the light absorbance of 2 wavelengths.

$$C_{1st} = \frac{\sum_{i=0}^{k} C_{i,possible,1st} W_{i,possible,2nd}}{\sum_{i=0}^{k} W_{i,possible,2nd}} \tag{17}$$

$$C_{2nd} = \frac{\sum_{i=0}^{k} C_{i,possible,2nd} W_{i,possible,2nd}}{\sum_{i=0}^{k} W_{i,possible,2nd}} \tag{18}$$

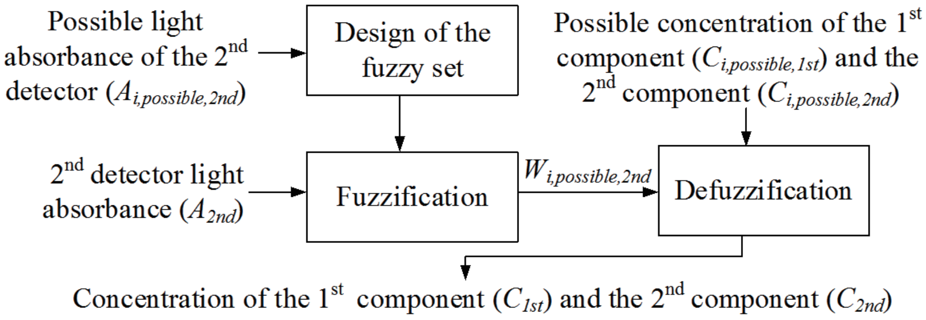

FIGURE 10. Fuzzy analysis process

4.3. **Simulation.** The simulation obtains the ideal light absorbance by the Beer-Lambert's law in (16). The solution is mixed by red substance as the 1st component and the green substance as the 2nd component. The measured light absorbances of the 1st detector ($A_{i,j,1st}$) and the 2nd detector ($A_{i,j,2nd}$) are shown in Table 1 and Table 2, respectively. The concentration of the component provides the level of the concentration. In the fuzzy prediction process, the 1st detector is used as the main detector and the red solution (1st component) is fixed at any concentration level. The result from the fuzzy prediction process is the possible light absorbance of the 2nd detector ($A_{i,possible,2nd}$) and the possible concentration of the 2nd component ($C_{i,possible,2nd}$) as shown in Tables 3 and 4, respectively. Table 5 shows the fixed possible concentration of the 1st component ($C_{i,possible,1st}$). The fuzzy analysis process calculates the 1st component (C_{1st}) and the 2nd component (C_{2nd}) by the 2nd detector light absorbance (A_{2nd}) from the calculated possible solution. Figure 11 shows the concentration of the component (C_{1st}, C_{2nd}) calculated from fuzzy analysis process by these 2 detectors. The cases of the minus concentration are eliminated.

In other word, the high line is the case of concentration of the green component is 0 and the low line is the case of the concentration of the red solution is 0. Therefore, the

Table 1. Light absorbance of the 1st detector

	G0	G1	G2	G3	G4	G5
R0	0.00	0.20	0.40	0.60	0.80	1.00
R1	0.15	0.35	0.55	0.75	0.95	1.15
R2	0.30	0.50	0.70	0.90	1.10	1.30
R3	0.45	0.65	0.85	1.05	1.25	1.45
R4	0.60	0.80	1.00	1.20	1.40	1.60
R5	0.75	0.95	1.15	1.35	1.55	1.75

Table 2. Light absorbance of the 2nd detector

	G0	G1	G2	G3	G4	G5
R0	0	0.15	0.3	0.45	0.6	0.75
R1	0.1	0.25	0.4	0.55	0.7	0.85
R2	0.2	0.35	0.5	0.65	0.8	0.95
R3	0.3	0.45	0.6	0.75	0.9	1.05
R4	0.4	0.55	0.7	0.85	1	1.15
R5	0.5	0.65	0.8	0.95	1.1	1.25

Table 3. Possible light absorbance of the 2nd detector

A_{1st}	$A_{0,possible,2nd}$	$A_{1,possible,2nd}$	$A_{2,possible,2nd}$	$A_{3,possible,2nd}$	$A_{4,possible,2nd}$	$A_{5,possible,2nd}$
0	0	-0.0125	-0.025	-0.0375	-0.05	-0.0625
0.2	0.15	0.1375	0.125	0.1125	0.1	0.0875
0.4	0.3	0.2875	0.275	0.2625	0.25	0.2375
0.6	0.45	0.4375	0.425	0.4125	0.4	0.3875
0.8	0.6	0.5875	0.575	0.5625	0.55	0.5375
1	0.75	0.7375	0.725	0.7125	0.7	0.6875
1.2	0.9	0.8875	0.875	0.8625	0.85	0.8375
1.4	1.05	1.0375	1.025	1.0125	1	0.9875
1.6	1.2	1.1875	1.175	1.1625	1.15	1.1375
1.8	1.35	1.3375	1.325	1.3125	1.3	1.2875
2	1.5	1.4875	1.475	1.4625	1.45	1.4375

Table 4. Possible concentration of the 2nd component

A_{1st}	$C_{0,possible,2nd}$	$C_{1,possible,2nd}$	$C_{2,possible,2nd}$	$C_{3,possible,2nd}$	$C_{4,possible,2nd}$	$C_{5,possible,2nd}$
0	0	-0.75	-1.5	-2.25	-3	-3.75
0.2	1	0.25	-0.5	-1.25	-2	-2.75
0.4	2	1.25	0.5	-0.25	-1	-1.75
0.6	3	2.25	1.5	0.75	0	-0.75
0.8	4	3.25	2.5	1.75	1	0.25
1	5	4.25	3.5	2.75	2	1.25
1.2	6	5.25	4.5	3.75	3	2.25
1.4	7	6.25	5.5	4.75	4	3.25
1.6	8	7.25	6.5	5.75	5	4.25
1.8	9	8.25	7.5	6.75	6	5.25
2	10	9.25	8.5	7.75	7	6.25

Table 5. Possible concentration of the 1st component

	Possible concentration of the 1st component
$C_{0,possible,1st}$	0
$C_{1,possible,1st}$	1
$C_{2,possible,1st}$	2
$C_{3,possible,1st}$	3
$C_{4,possible,1st}$	4
$C_{5,possible,1st}$	5

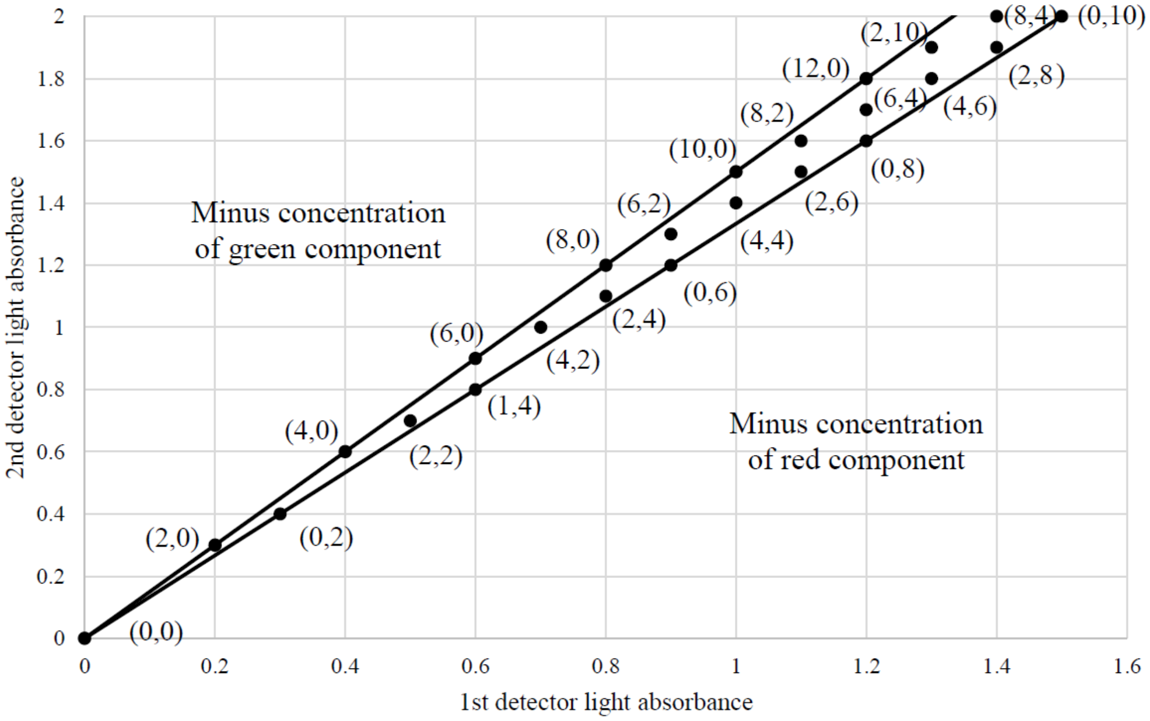

Figure 11. Concentration of the mixture solution (C_{1st}, C_{2nd})

possible case of the mixture solution is between the high line and low line. The simulation result is the same as the result of the simultaneous equation method.

5. **Experimental Setup and Result.** The experiment measures the mixed solution between the red component and the green component.

5.1. **Experimental setup.** As a pre-process, many mixed solutions are prepared in any concentration level of the component by WPA CO7500 colorimeter. The volume of one solution is 3.3 ml. The one concentration level of each component is the 0.3 ml and the remained volume is the distilled water. For example, the mixed solution between the level 3 of red solution and the level 5 of the green solution consists of 0.9 ml of the red solution, 1.5 ml of the green solution and 0.9 ml of the distilled water. After preparing the solution, they are measured by the 2 wavelengths of the light source. In this experiment, 470 nm and 490 nm of the wavelength are used. The light absorbances of the mixed solution between the red solution and green solution in any concentration level by 470 nm and 490 nm are shown in Tables 6 and 7, respectively. The concentration of the component

Table 6. Measured light absorbance of the 470 nm

470 nm	G0	G1	G2	G3	G4	G5
R0	0	0.32	0.57	0.77	1.01	1.09
R1	0.17	0.47	0.73	0.97	1.07	1.27
R2	0.33	0.71	0.95	1.14	1.35	1.53
R3	0.49	0.88	1.15	1.37	1.56	1.67
R4	0.66	1.03	1.38	1.62	1.81	1.98
R5	0.8	1.24	1.54	1.8	2	2

Table 7. Measured light absorbance of the 490 nm

490 nm	G0	G1	G2	G3	G4	G5
R0	0	0.11	0.22	0.31	0.45	0.48
R1	0.23	0.34	0.45	0.56	0.6	0.71
R2	0.46	0.59	0.69	0.77	0.86	0.95
R3	0.69	0.85	0.94	1.03	1.12	1.17
R4	0.99	1.04	1.22	1.29	1.38	1.48
R5	1.13	1.31	1.43	1.52	1.63	1.68

Table 8. The coefficient of determination and molar absorptivity

Fixed substance	Green and 470 nm	Green and 490 nm	Fixed substance	Red and 470 nm	Red and 490 nm
	Coefficient/Molar	Coefficient/Molar		Coefficient/Molar	Coefficient/Molar
R0	0.9762/0.2206	0.9850/0.1003	G0	0.9994/0.1609	0.9951/0.2331
R1	0.9773/0.2154	0.9869/0.0940	G1	0.9963/0.1843	0.9987/0.2389
R2	0.9803/0.2317	0.9936/0.0954	G2	0.9975/0.2000	0.9989/0.2460
R3	0.9634/0.2331	0.9739/0.0943	G3	0.9970/0.2094	0.9992/0.2429
R4	0.9734/0.2623	0.9818/0.1011	G4	0.9842/0.2109	0.9948/0.2429
R5	0.9260/0.2440	0.9703/0.1086	G5	0.9734/0.1949	0.9977/0.2437

determines the level of the concentration of solution. Table 8 shows the coefficient of the determination and the molar absorptivity between the individual component and the individual wavelength that the concentration of another component is fixed concentration in any level.

5.2. **Experimental result.** The experiment measures the mixture in any concentration level of the individual component. The light absorbance of 2 wavelengths is calculated to compare the proposed method with the simultaneous equation method [8-10] and absorb ratio method [8,13,14]. The derivative spectrophotometry [8,11,12] and absorb ratio method [8,15,16] requires the derivative function which the WPA CO7500 colorimeter does not have this function. In the simulation, the result of these 3 methods is equal. The simultaneous equation method provides the average of the molar absorptivity to calculate the concentration of the component. Table 9 shows the concentration of each component calculated by 3 methods, the ideal concentration and the light absorbance measured by 470 nm and 490 nm of wavelengths. The volume of each solution is 3.3 ml. It is mixed by red and green solution in any volume. From the result in Table 9, it shows that the concentration of the proposed method is more accurate than the concentration of the other method. Table 10 shows the error of each component.

In the measurement, there are many errors from human, external interference and internal interference. All errors of the concentration between the proposed device and

TABLE 9. The concentration of the component result

Mixed solution		Ideal		Measured light absorbance		Proposed method		Simultaneous equation method [9]		Absorb ratio method [13]	
Red	Green	Red	Green	470 nm	490 nm	Red	Green	Red	Green	Red	Green
0 ml	5 ml	0	1.666	0.43	0.16	−0.006	1.508	−0.134	1.944	0.071	1.306
5 ml	0 ml	1.666	0	0.27	0.39	1.73	−0.092	1.729	−0.27	1.732	−0.076
5 ml	5 ml	1.666	1.666	0.8	0.58	1.674	1.519	1.519	2.159	1.778	1.556
5 ml	10 ml	1.666	3.333	1.16	0.73	1.624	3.605	1.507	3.704	1.93	2.56
10 ml	5 ml	3.333	1.666	1.11	0.99	3.410	1.596	3.268	2.038	3.546	1.585
10 ml	10 ml	3.333	3.333	1.53	1.16	3.424	3.343	3.222	3.867	3.695	2.818

TABLE 10. The error of the concentration of the component result

Mixed solution		Ideal		Proposed method		Simultaneous equation method [9]		Absorb ratio method [13]	
Red	Green	Red	Green	Red	Green	Red	Green	Red	Green
0 ml	5 ml	0	1.666	–	9.483%	–	26.171%	–	0.216%
5 ml	0 ml	1.666	0	3.842%	–	3.842%	–	3.962%	–
5 ml	5 ml	1.666	1.666	0.441%	8.836%	8.843%	29.583%	6.722%	6.6%
5 ml	10 ml	1.666	3.333	2.540%	8.162%	9.555%	11.123%	15.84%	23.19%
10 ml	5 ml	3.333	1.666	2.310%	4.182%	1.964%	22.358%	6.39%	4.862%
10 ml	10 ml	3.333	3.333	2.742%	0.306%	3.320%	16.011%	10.861%	16.021%

the ideal value are less than 10% that is less than the error of other method. The error occurs from that the light absorbance is not direct variation with the concentration. It can be observed from the coefficient of determination. The average coefficient of the determination of the green component is about 0.974 which it does not attain to 0.99XX. It shows that the relationship between the concentration and the light absorbance of the green component is not good. Therefore, the molar absorptivity has many errors. However, the averaged coefficient of the determination of the red component is 0.994. It shows that the relationship between the concentration and the light absorbance of the red component is good. The error affects the calculation of the other method. In this point, it shows that the proposed method can solve the problem that the light absorbance is not direct variation with the concentration perfectly. The concentration of each component is fixed in any level by the measured light absorbance. Therefore, it is not necessary to calculate the molar absorptivity and get the accurate result from the setup. The accuracy depends on the volume of this setup in the method.

6. **Discussion.** The proposed method was designed for the limited wavelength of the spectrophotometer and installing in a handmade spectrophotometer. The proposed method is not perfect method. It cannot analyze the concentration in all cases. In the case that the measured light absorbance of a main detector or another detector does not increase when the concentration increases, there is possibility that an error will occur in the measurement or calculation. For example, in the case of very low molar absorptivity, the increase of the light absorbance cannot be observed. It can be solved by changing the light source. In the case of the high concentration, the light absorbance measurement device can measure the light absorbance until 2. Therefore, the concentration of the

solution that the light absorbance is higher than 2 cannot be calculated. In this case, the proposed method can solve by averaging the measured data. However, the accuracy of the determination is less than that of the output which is in the extent of the measured data. The main detector and the main component can be changed that the simulation result does not change. However, in the experiment, there are many errors. Therefore, when the main component or main detector is changed, the output is also changed a little bit. The accuracy of the determination depends on the number of the measured solutions. If the number of the measured solutions increases, the accuracy will be improved.

7. **Conclusions.** The design of the multi-component analysis system based on fuzzy theory has been proposed in this paper. It was developed to calculate the concentration of the component in the mixture solution for the limited wavelength of a spectrophotometer or installing the program into a handmade device. The proposed method can analyze the component in the mixture. Furthermore, this method can solve the problem that the light absorbance is not direct variation with the concentration of solution as the experiment. The averaged error of the proposed method is 4.284% that is less than 13.277% of error of the simultaneous equation method and 9.466% of error of the absorb ratio method. In addition, the proposed method does not only calculate the concentration of the component, but also it can calculate the light absorbance of the other wavelength also by replacing into the concentration of component.

In the calculation of the concentration of the component in the error case, it was found that there are some results which the proposed method and the previous method are not approximate to the real concentration extremely. Therefore, the future research is reduction of those errors.

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