Automatic Calibration of the Optical System in Passive Component Inspection

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Abstract: A passive component inspection machine is to obtain a image of a passive component by using a specific lighting and camera, and to detect defects on the image of the component. It inspects all the aspects of the component based on the image which is captured by using the lightings and cameras. The number of the lightings and cameras are proportional to the number of the component aspects. To detect the defects of the component effectively, the difference between the image quality by each camera should be minimized. Even if the light conditions are calibrated automatically, the average intensities of the images are different because of influence of Bayer filter which is used in CCD camera in the passive component inspection machine. Moreover, there is one more problem that the range of the light intensity cannot cover the range of the component reflectance. Sometimes, it is needed to calibrate a gain value and white balance ratios of the camera manually. In order to solve the problems, we propose an automatic calibration method of the optical system in passive component inspection machine. The proposed method minimizes the influence of Bayer filter, does not use any initial camera calibration, and find the optimal values for the overall gain and white balance ratios of red, green, blue colors automatically. To reduce the influence of Bayer filter, we perform to find the optimal values of all colors balance ratio iteratively and formulate a relation between the overall gain and the white balance ratios to control all the parameters automatically. The proposed method is simple and the experimental results show that the proposed method provides faster and more precise than the previous method.

1 INTRODUCTION

A passive component is a component that consumes, accumulates, and emits electric power supplied from the outside. It means that the part is incapable of an active function. It includes various types of chips: MLCC (Multi-Layer Ceramic Capacitor), BLCC (Boundary Layer Ceramic Capacitor), VLC (Vertically Laminated Capacitor), EMC (Electro Magnetic Compatibility), etc. One of the production processes for the passive components is a visual inspection that inspect a chip visually. Prior to visual inspection, electrical properties inspection finishes to ship the chip without any visual defects. A passive component inspection machine (Liu et al., 2007) (Kim et al., 2013) (chieh Tseng et al., 2006) (chieh Tseng et al., 2009) is to capture an image of the passive component by using a specific lighting and camera, and to judge whether the chip has defects. The passive component inspection machine is shown in Figure 1 and the flow of the machine is shown in Figure 2. It inspects all the aspects of the component based on the image captured by the lightings and cameras. The number of the lightings and cameras are proportional to the number of the component aspects. For effective detection, the difference in image quality by each camera should be minimized. More and more different image quality between cameras can cause higher false-positive and false-negative. Therefore, it is important that the inspection machine should secure uniformity of the image quality and calibrate its optical system to minimize the difference of the image quality between each camera. The number of the lighting for inspection is 12 based on two lanes six sides machine which is shown in Figure 2, and the number of the lighting channel is 128. And the number of the used cameras is also twelve and it is necessary to calibrate the overall gain value, red, green, blue balance ratios. Previously, those are calibrated by operators manually. Thus, obtained image qualities vary as shown in Figure 3 because the calibration by each operator is different. Moreover, it takes around 240 minutes averagely per a machine to set the optical system manually. In order to improve the

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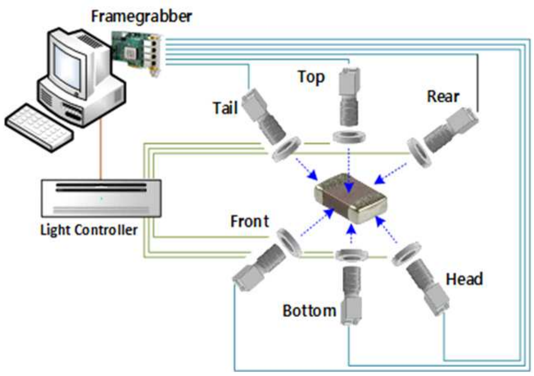


Figure 1: Vision system of passive component inspection.

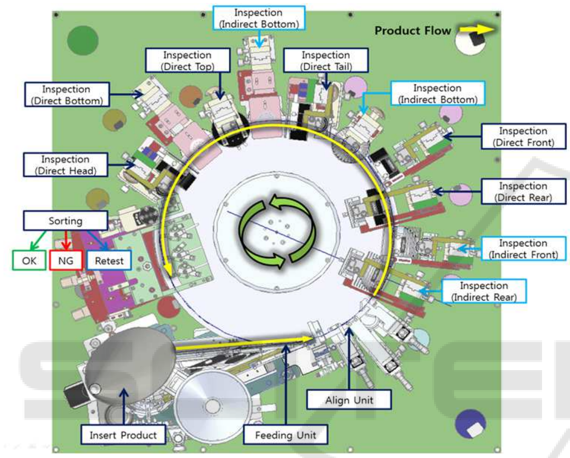


Figure 2: A flow of inspection machine.

existing manual calibration method, we used an automatic light calibration method of the optical system to make sure of uniform image quality and reduce the setting time.

The previous method makes the light channels grouping and set the directional ratio of lighting. Based on body area of the chip, user sets a target value of image intensity and change the light value to converge into the target value in order of red, green, and blue. However, the average image intensities are changed because the cameras in the inspection machine are CCD cameras which use Bayer filter (Hubel et al., 2004). The spectral response of CCD camera is shown in Figure 5. In Figure 5, wavelengthes are duplicated between red and green, and green and blue colors. Due to the duplicated wavelengths, blue intensity is not only changed, but also green intensity in the image can be changed when the blue light value is changed, and green intensity is not only changed, but also red and blue intensities are affected when the green light value is changed.

Furthermore, reflectance ratio is different per each type, model of chip, lot number, capacity. Even

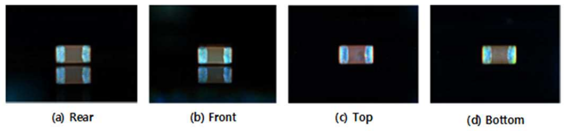


Figure 3: Chip images of four sides.

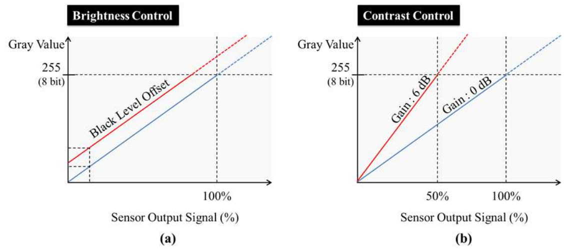


Figure 4: (a) brightness control by black level offset (b) Contrast control by gain.

though the lighting value is used as maximum value, the average intensity can be less than the target value. Or the average intensity can be higher than the target value even though the lighting value is set as minimum. In the case, the previous method considers the automatic lighting calibration as failed and need to calibrate again manually. It requires more often manual calibration, since there are lots of types of the passive components and various capacity differences.

There are two ways to improve amount of light normally. First way is to use brighter lens or change the light which can reflect more light on the target object. Second way is to amplify the electrical signal from output of the camera sensor by increasing gain and white level of camera sensor. Without changing hardware configuration, we should use second way. There are two values to amplify the output power of image sensor: Black level and white level. Black level is to change brightness and white level is to change contrast. In other words, black level is to adjust the offset in Input-Output graph which is shown in Figure 4 (a). However, it is normally used as initial value because dynamic range can be reduced and noise level can be increased when the offset is changed. On the other hand, gain and white level change the gradient of the graph in Figure 4 (b). The gain value functions to change the overall gradient and is represented in log scale. But the white level is functioned as white balance ratio in color sensor, changes the ratio of R, G, B colors, and is represented in integer scale.

As mentioned above, image intensity is determined by the overall gain value and the white balance ratios of the camera besides lighting conditions. To reduce variables, the previous method fixes the gain value for each camera and measures the combination of ND filter and back light. Through the measure-

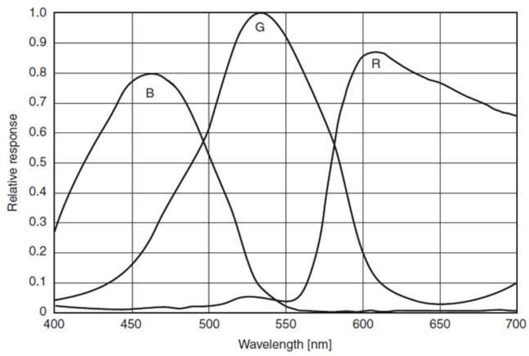


Figure 5: wavelength of color channels.

ment, the white balance ratio values are fixed by manual setting. To fix these values, twelve cameras, based on the 2 lanes 6 sides machine, are required to calibrate manually. However, it takes around 180 minutes for the initial calibration. In addition, the failure to converge on target value frequently occurs since the determined gain value is not proper to all the components. In the case of failure, ratio value of the failed color should be balanced manually. It also takes lots of time and the operator feels difficulty to adjust the values.

In this paper, we propose an automatic calibration method of the optical system in passive component inspection machine. The proposed method minimizes the influence of Bayer filter, does not use any initial camera calibration, and find the optimal values for the overall gain and white balance ratios of red, green, blue colors automatically. To reduce the influence of Bayer filter, we perform to find the optimal values of all colors balance ratio iteratively and formulate a relation between the overall gain and the white balance ratios to control all the parameters automatically. Due to the iterate steps, the required time can slow down, but it does not need the initial calibration process and any manual calibration. As a result, it can be calibrated automatically for more various models and lots.

The rest of this paper is organized as follows. The details of the automatic calibration method with camera control are proposed in Section2. In Section 3, the experimental results are presented. The experiments are performed on the actual inspection machines. The paper concludes in Section 4 with description of our future work.

2 AUTOMATIC CALIBRATION OF OPTICAL SYSTEM WITH CAMERA CONTROL

2.1 Automatic White Balance Ratio Calibration

To minimize the influence of Bayer filter and to converge to the target value by using similar lighting value, all colors of white balance ratios need to be adjusted. First of all, initial light calibration needs to be performed. If the initial light calibration successfully converges to the target value, the average of lighting values of all aspects can be calculated. After setting the average lighting value to all sides, the optimal white balance ratio value can be obtained. It can make image intensities matching with the target value. It means that image intensities converge to the target value under same lighting condition. If the images of all sides have same lighting condition, the influence of Bayer filter can be reduced. At this time, the camera calibration needs to be set similar white balance under similar lighting condition.

To minimize the influence of Bayer filter, we calibrate the white balance ratio in order of blue, green, red and recalibrate the blue one. Thereby, all cameras can converge to the target value with similar lighting condition. If there is a big difference between initial white balance ratio value and the optimal value, the image intensity can be higher or lower than the target value even though the lighting value reach maximum value or minimum value. In the case, the white balance ratio of the failed camera and color should be adjusted that the initial lighting ca be successfully calibrated. The process of the white balance ratio calibration is as follows.

Step 1. Initial Automatic lighting calibration

Step 1.1. Performing iterative lighting calibration for matching with the target value

Step 1.2. When the initial lighting calibration is failed, Changing balance ratio of the failed camera and color for matching with the target value with fixed lighting value

Step 2. Calibration of blue balance ratio

Step 2.1. Setting the light value of blue channel for all the cameras as the average value of the initial lighting values from Step 1

Step 2.2. Performing iterative calibration for blue white balance ratio with fixed blue light value from Step 2.1

Step 2.3. Performing the lighting calibration of green channel

Step 3. Calibration of green balance ratio

Step 3.1. Setting the light value of green channel for all the cameras as the average value of the initial lighting values from Step 2.3

Step 3.2. Performing iterative calibration for green white balance ratio with fixed green light value from Step 3.1

Step 3.3. Performing the lighting calibration of red channel

Step 4. Calibration of red balance ratio

Step 4.1. Setting the light value of red channel for all the cameras as the average value of the initial lighting values from Step 3.3

Step 4.2. Performing iterative calibration for red white balance ratio with fixed red light value from Step 4.1

Step 4.3. Performing the lighting calibration of blue channel

Step 5. Re-calibration of blue balance ratio

Step 5.1. Setting the light value of blue channel for all the cameras as the average value of the initial lighting values from Step 4.3

Step 5.2. Performing iterative calibration for blue white balance ratio with fixed red light value from Step 5.1

Step 5.3. Performing the lighting calibration of all channels

2.2 Automatic Overall Gain Value Calibration

If the overall gain value is bigger or smaller than the optimal value, the captured image intensity cannot match with the target value even though the white balance ratios reach maximum or minimum values. And if the gain value is changed, the image intensity of all channels also changes. In order to keep the image intensity with changing the overall gain, all channels of white balance ratios should be changed. And, running time of the automatic calibration can increase hugely if we use iterative method for finding the optimal value of the overall gain. Therefore, we propose an automatic overall gain value calibration by using relation between gain and balance ratios. The relation is released in the camera manual.(reference) Through a verification experiment in Section 3, we verify the relation. The relation is formulated as follows.

$$
\begin{aligned}
y_{Red} &= 10^{0.0359G/20}\frac{B_{Red}}{64}x_{Red} \\
y_{Green} &= 10^{0.0359G/20}\frac{B_{Green}}{64}x_{Green} \\
y_{Blue} &= 10^{0.0359G/20}\frac{B_{Blue}}{64}x_{Blue}
\end{aligned} \tag{1}
$$

where $(y_{Red}, y_{Green}, y_{Blue})$ is the output power of red, green, blue channels, $(x_{Red}, x_{Green}, x_{Blue})$ is the input power of all channels, the unit of all the powers is dB. G is the setting value of overall gain. Originally, the gain is represented by dB unit, but represented by integer scale in this formula. $(B_{Red}, B_{Green}, B_{Blue})$ is the white balance ratios of all channels, the minimum value should be set as 64. Using these formulas, we need to obtain the relation between the variation of gain and the variation of each white balance ratio. To obtain those, we can represent the formulas as follows.

$$
\begin{aligned}
y_{Red} &= 10^{0.0359(G+\Delta G/20}\frac{B_{Red}+\Delta B_{Red}}{64}x_{Red} \\
y_{Green} &= 10^{0.0359(G+\Delta G)/20}\frac{B_{Green}+\Delta B_{Green}}{64}x_{Green} \\
y_{Blue} &= 10^{0.0359(G+\Delta G)/20}\frac{B_{Blue}+\Delta B_{Blue}}{64}x_{Blue}
\end{aligned} \tag{2}
$$

where ΔG is the variation of the gain value, and $(\Delta B_{Red}, \Delta B_{Green}, \Delta B_{Blue})$ are the variations of the white balances of all channels. By using (1) and (2), the relations can be rewritten as

$$
\Delta G = \frac{20}{0.0359}\log_{10}\frac{B_{Red}}{B_{Red}+\Delta B_{Red}} \tag{3}
$$

And using (3), we can calculate the relation between red and green balance ratios, the relation between red and blue balance ratios. Thus, we can rewrite as

$$
\begin{aligned}
\Delta B_{Green} &= B_{Red} - B_{Green} + \Delta B_{Red} \\
\Delta B_{Blue} &= B_{Red} - B_{Blue} + \Delta B_{Red}
\end{aligned} \tag{4}
$$

Using (3) and (4), we can obtain the deviation of the corresponding gain value and the deviations of the balance ratios of other channels when the red white balance ratio value is adjusted. Thus, the overall gain and other channels of balance ratios can be changed to maintain the image intensity when the white balance ratio reaches maximum or minimum value. By changing the gain and other channels of balance ratios, the optimal white balance ratio and gain can be obtained.

3 EXPERIMENTAL RESULT

In this section, we verify the formulas from Section 2 and evaluate the performance of the proposed method. And we compare the results of the proposed method to the results of the previous work.

3.1 The Experimental Verification of Correlation between Image Sensor Gain and the White Balance Ratio

The gain value is defined differently by a manufacturer of the image sensor, normally it is separated into two types.

$$Gain_{dB} = A \times Gain_{raw} \tag{5}$$

$$Gain_{dB} = A \times \log \frac{Gain_{raw}}{B} \tag{6}$$

In (5), both system gain ($Gain_{dB}$) and raw gain ($Gain_{raw}$) are defined in dB scale, thus the system gain is increased in integer scale. In (6), the system gain is increased in exponential scale by raw gain. Also, the system gain is generally set to be increased in integer scale by balance ratios. In this section, we verify the output signal value of the input signal ($I_{camera-out}/I_{sensor-out}$) and the relation between the gain and balance ratios.

In the experiment, Basler Ace 640-GC camera (Basler Vision Technologies, 2015) is used to verify the relations. For the camera, $Gain_{dB}$ and $I_{camera-out}/I_{sensor_out}$ are as follows.

$$\begin{aligned} Gain_{dB} &= 0.0359 \times Gain_{raw} \\ \frac{I_{camera-out}}{I_{sensor-out}} &\propto 10^{\frac{0.0359 Gain_{raw}}{20}} \\ \frac{I_{camera-out}}{I_{sensor-out}} &\propto \frac{BalanceRatio_{raw}}{64} \end{aligned} \tag{7}$$

Before verifying the relations, we perform an experiment to check a linearity of camera sensor. The property of the linearity is related to generate current from quantum efficiency of sensor and convert it to voltage. Gain can determine how much amplify the electrical signal from the process. Thereby, we can predict the result by changing the amount of light if the linearity is verified. In the experiment, white LED dome is used and balance ratios are determined by putting pure white color target. In the experiment of the linearity, the current for lighting, the gain value, and balance ratios are kept constantly and exposure time of camera sensor is changed from $100\mu s$ to $10\mu s$ by decreasing $10\mu s$ in order to control the input power of sensor. And, we check that the intensities of the ten images are increased linearly. The experimental result is shown in Figure 6. We can figure out that the intensities of the images are increased by the exposure time of camera linearly in Figure 6(a). And the result of linearity by linear fitting is shown in Table 1. The value of R-square is 0.9999, and the result of fitting is reliable. Based on the result, the differences between the measured intensity and fitting value is displayed in Figure 6(b) and non-linearity is calculated by a equation as follow.

Table 1: Result of line fitting for linearity.

Equation	$y = A + B \times x$
Adj.R-Square	0.9999
A(intercept)	-2.0158
B(slope)	2.2253

Table 2: Result of curve fitting for increasing the gain value.

Equation	$y = A + B \times 10^{0.0359x/20}$
Adj.R-Square	1
A(intercept)	-0.2613
B(slope)	24.3031

$$Non-linearity(\%) = \frac{|+\Delta_{max}| + |-\Delta_{max}|}{maximum} \times 100 \tag{8}$$

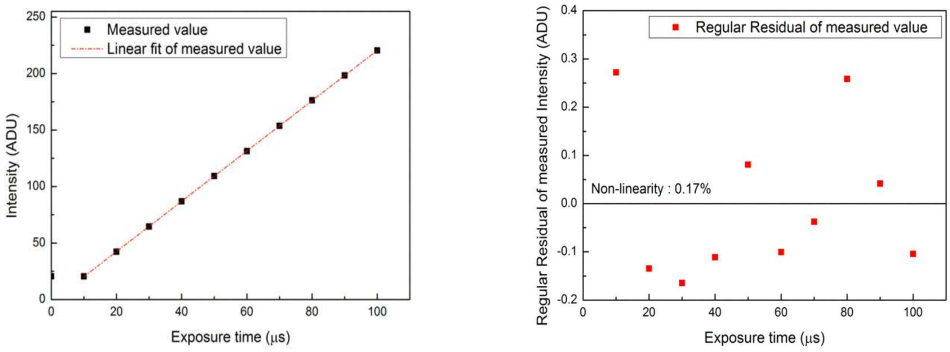
where $+\Delta_{max}$ is the maximum deviation of positive, $-\Delta_{max}$ is the maximum deviation of negative, and *maximum* is the maximum measured value. The result of the non-linearity is 0.17%, it means that the input of camera sensor and the output have a linear relation. Thus, we can conclude the output intensity can be increased linearly by the amount of input light.

To verify the relation between the gain and the balance ratios, we perform three experiments:1) verifying a relation between the gain and output image intensity, 2) a relation between the balance ratios and output image intensity, 3) a relation between the gain and balance ratios. To check the influence of the gain value to the output image intensity, the gain value is set as operational factor by increasing from 100 to 550, other factors are set as controlled factors. White LED dome light is also used in the experiment.

$$I_{camera-out} = A + B \times 10^{\frac{0.0359 \times Gain_{raw}}{20}} \tag{9}$$

The curve fitting result of (9) to the measured data is shown in Figure 7 and Table 2. In the result, the output value is increased nonlinearly, and the curve fitting result is completely matched with (9).

Next experiment is to verify the relation between the balance ratios and image intensity. The balance ratios are composed of three channels;red, green, and blue. Therefore, when the influence of a specific channel of the balance ratios is measured, the other channels of the balance ratios are set as 0 to remove their influences. The experiment measures the image intensity by increasing the balance ratio with an increment in 20. The relation to be verified is as follow.



(a) Result of linearity test (b) Result of Non-linearity analysis

Figure 6: Result of linearity test.

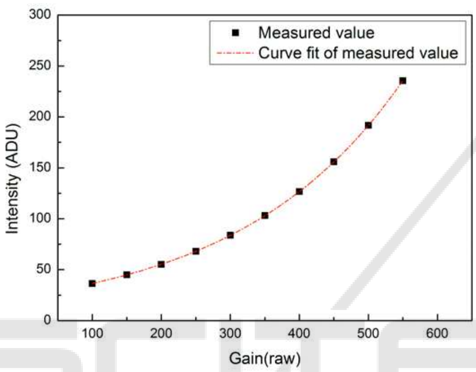


Figure 7: Relation graph for Image intensity and the gain value.

$$I_{camera-out} = A + B \times \frac{BalanceRatio_{raw}}{64} \tag{10}$$

If the relation between balance ratio and the intensity has a linearity, 10 can be verified. The measured outputs and the result of fitting (10) for each channel are shown in Figure 8 and Table 3. Also, the results show that all channels of the balance ratios are linear and (10) is matched to the results. In the results, each slope of channel is different because it is determined by spectral response of camera sensor.

Last experiment in this subsection is to verify how the gain and the balance ratios impact on image intensity. In the experiment, the gain value is fixed as 150, 250, and 350 for three times of measuring the intensity. As same as the previous experiment for the balance ratios, when the influence of a specific channel of the balance ratios is measured, the other channels of the balance ratios are set as 0 to remove their influences. The verifying relation is as follow.

$$I_{camera-out} = A + B \times 10^{\frac{0.0359 \times Gain_{raw}}{20}} \times \frac{BalanceRatio_{raw}}{64} \tag{11}$$

Using (11), each channel of the balance ratio is matched to the measured result. The fitting is a type

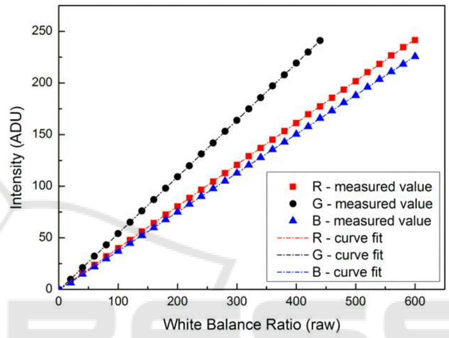
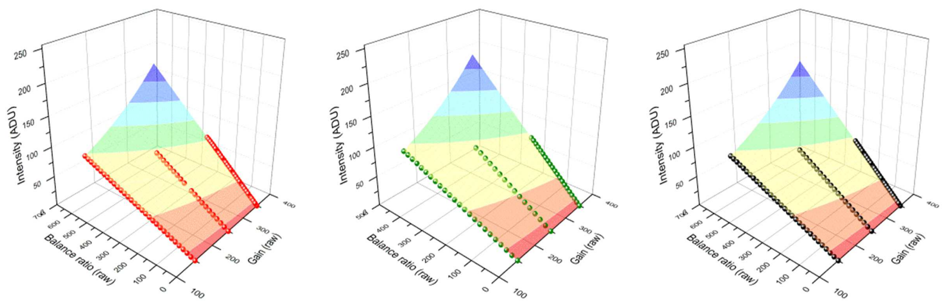


Figure 8: Relation graph for Image intensity and the balance ratios.

Table 3: Result of line fitting for increasing each balance ratios.

	Equation	$y = A + B \times (x/64)$
Red	Adj.R-Square	0.9999
Red	A(intercept)	-0.5166
Red	B(slope)	25.9076
Green	Adj.R-Square	0.9999
Green	A(intercept)	-0.80093
Green	B(slope)	35.1681
Blue	Adj.R-Square	0.9999
Blue	A(intercept)	-0.4936
Blue	B(slope)	24.1601

of surface fitting. If the data is placed on the surface, the relation can be verified. The result is shown in Figure9 and Table 4. In the result, the fitting results are perfectly placed on the surface. Therefore, we can verify the relation between the gain value and the balance ratios. And we can understand why color is not balanced when the gain value is adjusted because each color channel has a different factor.



(a) Red (b) Green (c) Blue

Figure 9: Result of Changing the gain and the balance ratios.

Table 4: Result of surface fitting for increasing gain and each balance ratios.

	Equation	$y = A + B \times 10^{\frac{0.0359y}{20}\frac{x}{64}}$
Red	Adj.R-Square	0.9999
Red	A(intercept)	-0.1234
Red	B(slope)	4.3491
Green	Adj.R-Square	0.9999
Green	A(intercept)	-0.1708
Green	B(slope)	6.3044
Blue	Adj.R-Square	1.0000
Blue	A(intercept)	-0.1324
Blue	B(slope)	4.6417

Table 5: Comparison for average required time.

	Average required time(sec)
The previous work	55.6
Manual calibration	602.3
The proposed method	60.1

3.2 The Experimental Results of the Proposed Method

In this subsection, we evaluate the performance of the proposed method with real products and compare the results of the proposed method to the results of the previous work and the manual calibration. The experiments measure the required time, a deviation of lighting values between all cameras, and a deviation of average gray scale value for each camera. In our experiment, seven machines which are used in actual field are used to measure the time and quality. And it is applied to 50 different lots. Since the results of manual calibration for the gain and balance ratios can be different by each operator, an expert in understanding how to calibrate adjusts the camera setting.

The result of required time is shown in Table 5. In Table 5, the previous method can be finished within shortest time, and the manual calibration which calibrate the image deviation within 10 gray scale value takes almost ten minutes. When the operator in field calibrates it, it takes over than twice. The proposed method takes longer than previous method, but it takes hugely less than the manual calibration. However, the required time for the proposed method just includes the succeeded cases except the failed cases.

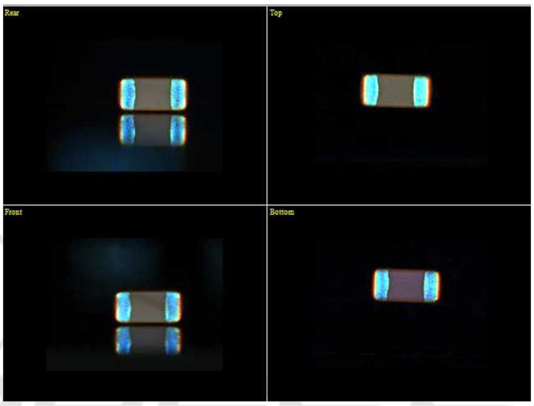


Figure 10: The result of the previous work.

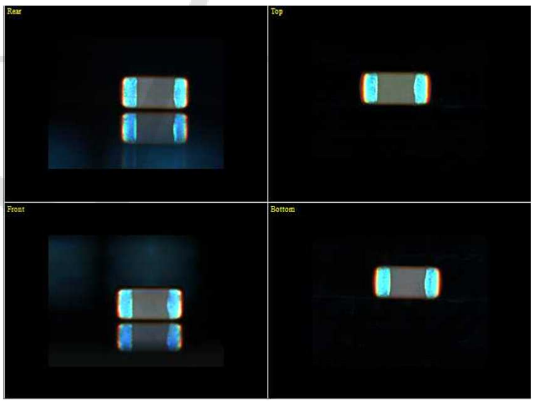


Figure 11: The result of the manual calibration.

Next comparison is the deviation of lighting values and average gray scale values. If the deviation of lighting values is huge, the deviation of gray scale value for all the color channels is increased due to im-

Table 6: Comparison for deviations of light values and gray-scale.

	deviation of light value(R,G,B)	gray-scale(R,G,B)
The previous work	(80,81,46)	(9.6,19.6,13.4)
Manual calibration	(74,44,26)	(8.7,9.0,10.1)
The proposed method	(9,10,6)	(3.9,4.1,5.1)

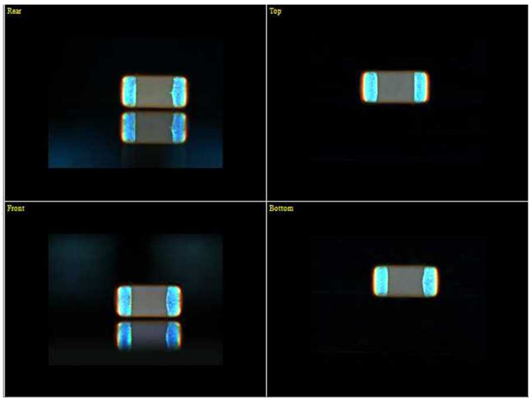


Figure 12: The result of the proposed method.

pact of Bayer filter. In addition, in the case that the deviation of lighting value is high but it is converged, the camera calibration which should make similar gray-scale values with same light values is not proper. The deviation of gray-scale values is measured on the center area of body in the product. The deviation of light values and the average gray-scale values are shown in Table 6. The result of the previous work does not include the failed cases. Because the previous work does not calibrate the gain value and the balance ratios, the deviation of light values is huge and the deviation of average gray-scale values is over than 10. Moreover, 35 of the total 50 lots are failed to converge to the target, and it needs to be calibrated manually. The manual inspection gives better image quality within 10 difference of gray-scale values, but the deviation of the light values is large. It means that the difference of colors is improved but the camera calibration is improper. On the other hand, the proposed method can provide the deviation of the gray-scale values within 5 and the deviation of the light values within 10. And, all the lot with the proposed method are successfully calibrated. The results of the calibrations are shown in Fig 10, Fig 11, and Fig 12.

4 CONCLUSIONS

In this paper, an automatic calibration method of the optical system has been proposed for passive component inspection. The proposed method calibrated the gain and white balance ratios of the inspection cameras using the relation between the gain and the balance ratios. The proposed method set the gain and the balance ratios to make the obtained images similar with same light conditions and make the differences of the image intensities and the light values minimized. In the experiment, we compared the proposed method to the previous method and the manual calibration method. The proposed method gave better performance than previous work and the manual calibration method. It took less time to calibrate the optical system and minimized the difference of the image intensities.

Since the experiment was performed for 50 lots, we have a plan to experiment more various models and lots. Furthermore, we need to reduce the required time for the calibration and apply the calibration method to other camera models.

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