Applications of Colorimeter in Machine Visions for Checking Printed-Circuit Boards

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Abstract

Application of colorimetry in color identification for checking printed-circuit boards (PCBs) is proposed. Inspection of electronic components during the assembly of the printed circuit boards (PCBs) can be done by an analysis of color image. This method significantly enhances the image-processing speed. Additionally, the inspection accuracy can be attained by the use of color isodiscrimination contour criterio.

Keywords: colorimetry, machine vision, automated visual inspections, isodiscrimination contour, and color identification

1. INTRODUCTION

Automated visual inspections of color image have been limited by several factors for use in industry. These factors are hardware complexity, high cost, large memory requirements and long processing time [1]-[8]. Machine vision for checking electronic components can be done by color image analysis in RGB coordinates [1]. Color comparison between the reference and inspected sample can be done by the dot product of two RGB vector coordinates.

In this paper, application of colorimetry in color identification for checking electronic components is proposed. The inspection of PCB or paper can be done by color image processing, which involves color discrimination between the reference PCB and the sample to be inspected. Criterion for color discrimination will be based on the Commission Internationale de l'Eclairage (CIE) standard. Then CIE-Luv color coordinates will be used.

2. PRINCIPLES

In the automated visual inspection system of PCB, we use a digital camera to capture the images of PCB. We apply a CIE-Luv criterion, which bases on perception of human observer that cannot discriminate between two colors if they can be described within isodiscrimination contour. Firstly, the qualitative description of color in RGB and CIE-Luv coordinates will be discussed. Secondly, the fundamental of CIE-Luv isodiscrimination contour will be calculated for the inspection of the PCB. Then, image acquisition and processing will be discussed. Finally, threshold criteria for checking electronic components will be mentioned.

2.1 Color representations

One of popular color coordinates for computer applications is RGB coordinate. However, an Euclidean distance in this coordinate cannot be used for color comparison, while the distance in the CIE-Luv coordinate can [2]. The RGB to Luv transformation can be expressed as

$$L = \begin{cases} 116(\frac{Y}{Y_n})^{1/3} - 16 & (\frac{Y}{Y_n}) > 0.008856 \\ 903.3(\frac{Y}{Y_n}) & (\frac{Y}{Y_n}) < 0.008856 \end{cases} \quad ,(1)$$

$$u = 13L(\frac{4X}{X+15Y+3Z} - \frac{4X_n}{X_n+15Y_n+3Z_n})$$

$$v = 13L(\frac{9Y}{X+15Y+3Z} - \frac{9Y_n}{X_n+15Y_n+3Z_n})$$

where X_n, Y_n, and Z_n are constants of values 0.9504, 1.0, and 1.09, respectively. The definition of X, Y, and Z can be described by

$$X = (0.4306 * R + 0.3415 * G + 0.1784 * B)/255 \quad , (4)$$

$$Y = (0.2220 * R + 0.7067 * G + 0.0713 * B)/255 \quad , (5)$$

$$Z = (0.0202 * R + 0.1295 * G + 0.9394 * B)/255 \quad , (6)$$

where R, G, and B are values of red, green, and blue, respectively, in the RGB coordinate. Each prime color (R, G, or B) has 256 different values (ranging from 0 to 255) or 2^8 and can be represented by 8 bits of binary data in computer. The 24-bit (three 8-bit representations of R, G, and B) RGB color coordinate will be used for our system. Color images of the PCB are transferred to a PC. Then images will be processed and determined if there are any components missing for the PCB.

2.2 Criterion for same color: isodiscrimination contour

The Euclidean distance of two colors (between reference and measured color) in CIE-Luv coordinate is given by

$$\Delta E_{Luv} = \sqrt{(\Delta L)^2 + (\Delta u)^2 + (\Delta v)^2} \quad , (7)$$

where Δ quantities on the right hand side of the equation represent differences between the corresponding coordinates of the two colors. For color comparison, if value of the Euclidean distance in CIE-Luv coordinate, which was shown experimentally for color discrimination of human perception, is 1, two colors can be reliably discerned by a human observer. It is also known as isodiscrimination contour. Checking for error in electronic components can be done by comparing the average color of reference PCB (in Luv coordinate) to the average color of the PCB to be inspected. First, the average (R,G,B) value of the all pixels in the image can be evaluated by

$$RGB_{avg} = \frac{1}{N}(\sum R, \sum G, \sum B) \quad , (8)$$

where N is the number of pixels in the frame. Then, the RGB_{avg} of the reference and the PCB to be checked will be converted to two Luv coordinates and the (4) ΔE_{Luv} in eq. (7) will then be calculated.

(5)

2.3 Image acquisitions and processing

(6)

Automated visual inspection shown in Figure 1 consists of color digital camera, image processing program, and a controlled illumination system. The printed circuit boards (PCB) is illuminated by daylight (D65- one of standard light sources using by CIE) lamps inside controlled environment because illumination or color of the light source affects apparent color of the PCB. The image processing for checking the electronic components can be done as follows:

1. The average RGB value (RGB_{avg}) of the reference PCB will be calculated by eq. (8). Several reference PCBs were used. The average RGB of these values will be used as our reference.
2. The value found in step 1 is then converted to CIE-Luv coordinate using eq. (1) to (6).
3. Threshold (ΔE_{Luv}) for missing or present detection can be calculated as follows (see next section):
   3.1 Find ΔE_{Luv} between the reference PCBs, which electronic components are present.
   3.2 Find ΔE_{Luv} between the reference PCBs and other sample PCBs, which some electronic components are missing.
   3.3 We can define the threshold for checking electronic components whether they are missing by the value found in steps 3.1 and 3.2.
4. To check electronics components, the value of ΔE_{Luv} between the

reference board and sample to be inspected will be compared to this threshold. If the value of ΔE_{Luv} is above the threshold, the sample will be rejected and put in a collecting bin by rejection mechanism such as a separation flap (not shown in Figure 1).

These processes can be done by the use of an image-processing program written for this purpose.

3. IMPLEMENTATIONS AND RESULTS

Automated visual inspection is shown in Figure 1. The images are captured by a digital camera and then stored in the computer in BMP format. Next, the computer performs image processing in steps discussed earlier. The PCBs with missing some electronic components such as resistors, integrated circuits (ICs), and broken connectors will be rejected.

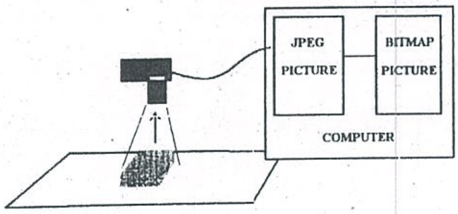
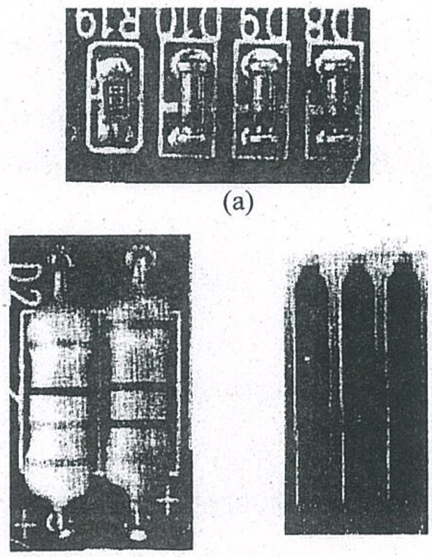


Figure 1 Experimental setup

The PCB has many electronic components such as diodes, resistors, slot connector, and etc. Electronic components will be separated into groups and image of each group will be zoomed and analyzed separately. In the first experiment, the difference between the reference and the sample images is the number of diode. In the second experiment, the difference between the reference and the sample images is the color stripes of the resistors. And in the last experiment, the difference between the reference and sample images is the absence of the slot connectors. Euclidean distances (ΔE_{Luv}) of sample files and a reference file of the experiment 1, 2, and 3 are shown in Table I, Table II, and Table III respectively.



(a) (b) (c)

Figure 2 (a) The reference image of the first experiment (232 pixels * 133 pixels, 28.346 pixels per cm.) with an average RGB value of (88.191467, 112.567853, 100.234055). (b) The reference image of the second experiment (132 pixels * 224 pixels, 28.346 pixels per cm.) with an average RGB value of (80.840332, 136.445847, 105.316119). (c) The reference image of the third experiment (60 pixels * 103 pixels, 28.346 pixels per cm.) with an average RGB value of (104.887054, 105.853882, 82.56699).

In Figure 2 (b), even the resistor is placed upside-down, the concept of checking electronic components with average RGB value is still valid. But it is invalid in the case of Fig 2 (a) and Fig 2 (c). Position and alignment of the PCB in the system is important because this can affect the calculated average RGB value of the samples. The PCB should be held on a motor driven XY coordinate table so that in a future development, the system could automatically inspect large boards in a sequence of steps [1]. There are still issues that cause variation of average RGB value and affects accuracy of this approach. In production, apparent color of electronic components may vary from batch to batch. This requires adjustment of the color value of the reference PCB. Also, the components such as capacitors and inductors can be put in the board with different tilting angles. More work has to be done to understand and to be able to do PCB automated visual inspection.

Table I: ΔE_{Luv} of the reference and sample PCBs in the first experiment.

Sample No.	RED	GREEN	BLUE	ΔE_{Luv}
Reference	88.191	112.567	100.234	0
1	86.134	113.325	100.837	2.90218
2	84.650	115.938	103.249	5.697618
3	83.715	117.870	105.159	7.5419
4	85.640	112.452	99.879	3.262952

Table I-1: The presence of diode in each sample.

Sample No.	Left diode (D10)	Middle diode (D9)	Right diode (D8)
1	Absence	Exist	Exist
2	Absence	Absence	Exist
3	Absence	Absence	Absence

Table II: ΔE_{Luv} of the reference and sample PCBs in the second experiment.

Sample No.	RED	GREEN	BLUE	ΔE_{Luv}
Reference	88.191	112.567	100.234	0
1	79.593	136.389	104.338	1.56188
2	79.625	135.641	106.144	1.286257
3	79.888	134.621	105.619	0.907964
4	78.920	136.391	105.845	2.323217
5	79.928	135.612	105.028	0.969907
6	77.760	134.719	105.979	3.395738
7	78.740	134.325	102.786	2.305004
8	78.280	134.648	105.340	2.781056
9	80.749	137.316	105.158	0.418611

Table II-1 The change in the color stripe of resistors.

	Left resistor			Right resistor		
Sample No.	CS #1	CS #2	CS #3	CS #1	CS #2	CS #3
1	-	-	-	G	-	-
2	-	-	-	-	B	-
3	-	R	-	B	-	-
4	-	G	-	-	-	B
5	B	G	-	O	-	-
6	-	-	B	-	G	-
7	-	O	-	B	-	G
8	G	B	-	-	-	-
9	-	-	-	Y	Bk	-

Note: CS – color stripe of a resistor, CS#1 – the top color stripe, CS#2 – the second color stripe, CS#3 – the third color stripe, - = the color is not changed, G = Green, B= Blue, R = Red, Bl = Black, Y = Yellow, and O = Orange.

Table III: ΔE_{Luv} of the reference and sample files in the third experiment.

Sample No.	RED	GREEN	BLUE	ΔE_{Luv}
Reference	104.887	105.853	82.566	0
1	114.255	115.466	87.034	8.465094
2	124.696	126.294	92.205	17.339442
3	134.198	136.457	97.651	24.906611

Table III-1: The number of lines of slot connector of a sound card for Personal Computer (PC). There are several lines of PCI slot but three of them are shown.

Sample No.	Left Line	Middle Line	Right Line
1	Absence	Exist	Exist
2	Absence	Absence	Exist
3	Absence	Absence	Absence

From the tables, the smallest values of ΔE_{Luv} are 2.90218, 0.418611, and 8.465094 for the first, the second, and the third experiment respectively. We can find the threshold for each experiment by using 0.5 $(\Delta E_{Luv,\min} + \Delta E_{Luv,boards})$. In this paper, the value of $\Delta E_{Luv,boards}$, which is the variation of ΔE_{Luv} of the reference boards at different times, is very small and assumed to be zero. So, the threshold values are calculated from $0.5 * \Delta E_{Luv,\min}$. The threshold values are 1.45109, 0.209306, and 4.232547 for the first, the second, and the third experiment respectively.

4. DISCUSSIONS AND CONCLUSIONS

Automated visual inspection for checking electronic components can be done by color comparison using isodiscrimination contour and Euclidean distance, ΔE_{Luv}, in the CIE-Luv coordinates. This novel method can improve image-processing time and accuracy of inspection. The important factors for color image processing are lighting system (under controlled environment), color of electronic components (may vary from batch to batch, adjustment of threshold criterion may be required), position of PCBs, and inspection window to cover all groups of components.

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