Quality Control of Color Printing on Banknotes by Image Processing

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The banknotes printing process is complex and delicate. It is necessary to print different patterns and color that make it difficult to forge and, at the same time maintain the beauty of the notes. Therefore, monitoring and quality control standard must be present at every stage to reduce the errors that will result in productivity losses. This work proposes a digital image processing method to measure the color of printed banknotes in the uniform color space CIELab color model. By measuring the colors of the ongoing printed notes against their specifications, any color deviation occurs in the printing process can be detected and the printing process can be corrected in real-time.

Keywords— Measuring color, CIELab color model

I. INTRODUCTION

Elaborate designs on the banknotes emerge from three printing methods, dry offset for background design, intaglio for raised design, and letterpress for numbers and signatures. Offset Printing is the first layer to be printed. The dry offset is printed on a specially designed printing press that is able to print high-precision color patterns on both sides of the sheets simultaneously. This makes it possible to produce the perfect front and back registered designs or the see through designs when viewed against transmitted light. These are one of efficient techniques to discourage counterfeiting.

Dry offset "Color Bars" (color control bars, color control strips, or proofing bars) are essentially test targets that are used to measure print and/or proof attributes [1]. Normally, it is printed in the trim area of the press sheet. In the process of offset printing, there is a color quality inspection by visual inspection the Color bars. Inspection by human beings often cannot keep pace with requirements for speed of production and quality of product. People get tired and make mistakes, and the criteria that they apply during inspections are inevitably subjective [2].

The color measurement is carried out by a spectrophotometer. Due to the limit of the speed of the measurement, it is not possible to verify every printed sheet. While it is certainly possible to measure the color of the actual live image area, the technology is expensive. The quality control is done by sampling several sheets from the press in a regular interval.

This study aims to improve the speed of color measurement using a high accuracy digital camera operated at high speed. The objectives are to analyze the color features and to calibrate the color measurement between a digital camera and the standard spectrophotometer.

II. MATERIAL AND METHODS

In general, a camera and computer system captures the color of each pixel within the image of the object using RGB color model, in which each sensor captures the intensity of the light in the red (R), green (G) or blue (B) spectrum, respectively. The RGB color space is not uniform, so the calculations of distance between colors are not straightforward. [3] In 1931 Commission Internationale d'Eclairage (CIE) created CIE XYZ color space. It is an early mathematically defined color space based on the physiological perception of light. XYZ space, a set of three color-matching functions, collectively called the Standard Observer, is related to the red, green and blue cones in the eye [4].

In this space, Y means the lightness, while X and Z are two primary virtual components, which look like red and blue sensitive curve of cones. However, XYZ does not represent color gradation in a uniform matter. For this reason, CIE 1976 (L*a*b*) or called CIELAB which are the non-linear transformation of XYZ, were brought out and are adopted in many color measuring instruments [4]. In the color measurement of food, L*a*b* color space is the most used one due to the uniform distribution of colors, and because it is perceptually uniform, i.e. the Euclidean distance between two different colors corresponds approximately to the color difference perceived by the human eye [5].

III. EXPERIMENT SETUP

A. *The color management system*

The system consists of the color digital camera Canon EOS 40D resolution 3888x2592 pixels, using color space sRGB, and output in RAW file format. The light sources are two uniform LED Lamps mounted on 45^{o} direction of light to the camera photo sensor to obtain uniform illumination condition. The background plate is a black homogeneous color to reduce color distortion from the reflection of light and to reduce the color interfering from background. The image capturing is taken in a dark room to control external interference such as an ambient lighting intensity changes, as show in Fig. 1.

Fig. 1. The color measurement system calibration

B. Calibration of the color measurement

A Munsell color checker X-rite is an array of 24 colored 40.0 x 40.0 millimeter squares in a wide range of colors. It provides the color measurement in CIELab values. The standards used in the measurement are illumination D50 2 degree observer and sRGB value for illumination D65.

In order to calibrate the color management system, the first step, the color checker were measured the color value of 24 colors. Each color was divided into 5 regions. In each region, the CIELab color values were measured using a TECHKON spectrophotometer, as show in Fig. 2.

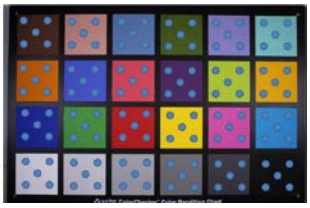

Fig. 2. The color measurement system calibration

The second step, the color checker captured 25 images in device dependent RGB color space, then output in TIF file format. The color values are transformed into a device independent CIELab color space and the mean value for each color value L, A and B in each region according to 24 color checker are computed, using a Matlab program.

The color transformation uses Direct Model to carry out the RGB to CIELab transformation in two steps. [6]

The first step carries out the RGB to XYZ transformation using equation (1)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} & M_{14} \\ M_{21} & M_{22} & M_{23} & M_{24} \\ M_{31} & M_{32} & M_{33} & M_{34} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \\ 1 \end{bmatrix}, \quad (1)$$

The second step computes the XYZ to Lab transformation using equation (2).

$$\hat{L}^* = \begin{cases} 116\left(\frac{Y}{Y_n}\right)^{1/3} - 16 & \text{if } \frac{Y}{Y_n} > 0.008856 \\ 903.3\left(\frac{Y}{Y_n}\right) & \text{if } \frac{Y}{Y_n} \leq 0.008856 \end{cases}$$
$$\hat{a}^* = 500\left[\left(\frac{X}{X_n}\right)^{1/3} - \left(\frac{Y}{Y_n}\right)^{1/3}\right],$$
$$\hat{b}^* = 200\left[\left(\frac{Y}{Y_n}\right)^{1/3} - \left(\frac{Z}{Z_n}\right)^{1/3}\right], \quad (2)$$

Over the years the CIE community has come up with several formulas to model uniform color difference. In 1976 the CIE published the first internationally endorsed color differencing equation, called ΔEab or ΔE76. This formula has been used in many ISO procedures such as 12647-2 for process control in the production of halftone color separations, proof and production prints. This color differencing equation made it possible to better communicate color differences under standard illuminants and observers. The color notation used for this equation was the L*a*b*-color space. The ΔEab equations are followed from [7].

The CIEDE1994 and CIEDE2000 standards are available, and are based on careful factor analysis. [8,9] The 1976 version is an older standard but has the benefit of computational simplicity [10]. The ΔE76 measures the Euclidean distance between the coordinates for the two stimuli [11]. The following equation (3) was used.

$$\Delta E^*_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (3)$$

The CIELab color values measured by spectrophotometer and the color management system, the results have been grouped by each color. The median value of each channel are L = 0.287, A = 0.754, B = 0.848. From Fig. 3 and Fig. 4, the standard deviation of the spread within a set of data of L, A, and B channel is low. It indicates that the data points tend to be very close to the mean value.

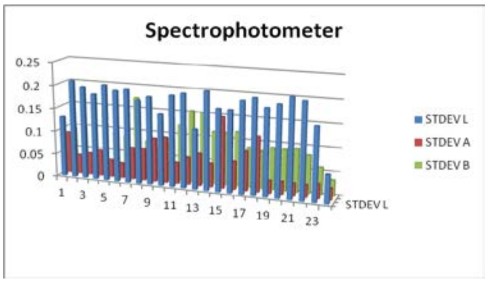

Fig. 3. The standard deviation of LAB from spectrophotometer

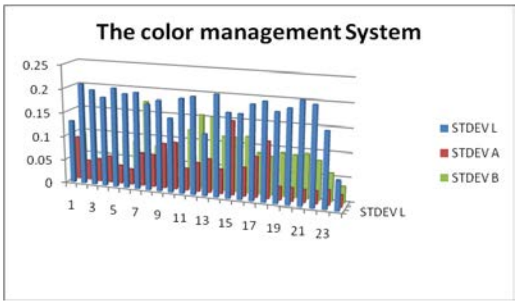

Fig. 4. The standard deviation of LAB from the color management system

The correlation between a Munsell color checker and spectrophotometer is high. However the color management system correlate with each other have reduce a little bit in lightness, L channel, and red-green channel as show in Table I.

TABLE I. CORRELATION OF MUNSELL & SPECTRO. & CAMERA

Correlation	L	a	b
Munsell & Spectro.	0.9996	0.9991	0.9997
Munsell & Camera	0.9528	0.9723	0.9932
Spectro. & Camera	0.9476	0.9771	0.9933

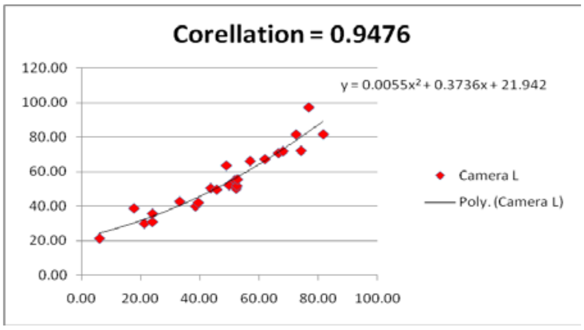

Fig. 5. L channel correlation between munsell & camera

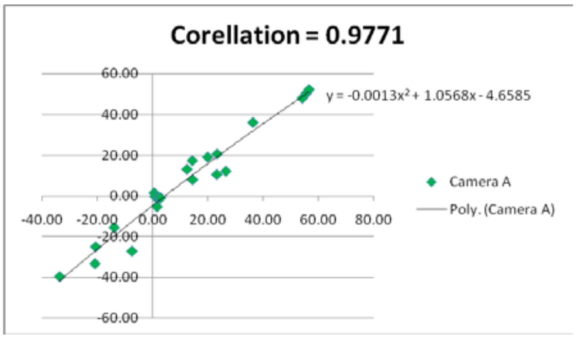

Fig. 6. A channel correlation between munsell & camera

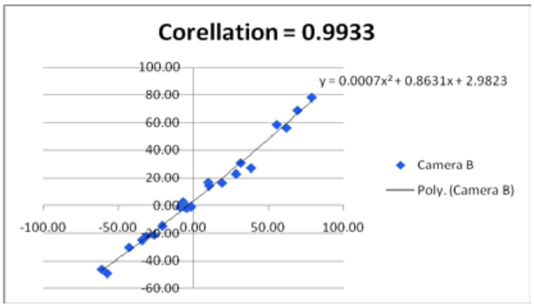

Fig. 7. B channel correlation between munsell & camera

The 25 examples of "Color Bar" selected in random from 25,000 samples were measured using a spectrophotometer. The 60 images captured for 25 samples were used to demonstrate the performance of the color measurement system as show in Fig. 8.

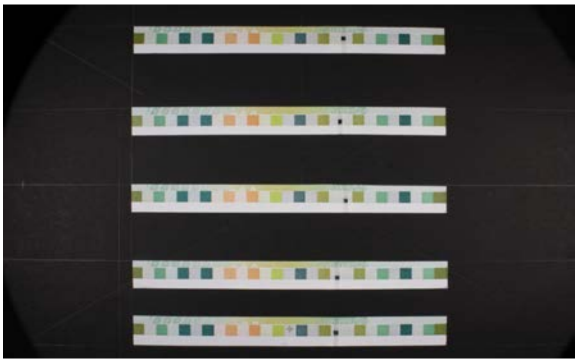

Fig. 8. "Color Bar" images captured

III. RESULT

As a result a color correction profile can be constructed by computing the color difference between the spectrophotometer and color management system using CIELab value. To interpolate the data values, the quadratic polynomial model is used to fit the data as show in Table II.

TABLE II. CORRELATION AFTER APPLY THE QUADRATIC POLYNOMIAL MODEL

Correlation	L	a	b
Spectro. & Camera	0.9476	0.9771	0.9933
Quadratic Poly.	0.9566	0.9778	0.9939

TABLE III. SHOW THE RESULT OF ΔEAB AFTER APPLY THE QUADRATIC POLYNOMIAL MODEL

ΔE Spectro.	ΔE Camera
21.578	10.111
11.404	7.823
11.969	2.560
11.364	7.198
11.384	2.664
15.056	6.776
15.012	12.271
19.452	9.679
7.201	4.121
8.950	4.059
7.546	8.550
4.911	7.621
18.713	11.645
6.724	2.464
12.540	10.680
1.288	9.712
7.833	4.825
23.263	15.847
22.912	15.338
11.807	4.684
8.356	2.086
8.677	2.089
12.611	2.456
15.426	5.371

IV. CONCLUSION

This paper presents a simple method that uses a digital camera to measure color, and the Matlab program to transform color space. The term ''measure'' means that the digital camera is used to obtain the color values of the pixels on the "Color Bar". The term ''analyze'' means that Matlab is used to manipulate those color values to obtain color distribution, averages, and so on. With a proper calibration between a digital camera and the standard spectrophotometer, the accuracy of the color measurement can be ensured. A modern digital camera can be operated at high speed; hence it overcomes the speed limitation of using the standard spectrophotometer in monitoring process of the printed banknotes. Therefore, a continuous monitoring and correcting of the printed banknotes is possible using the proposed method.

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