# Quality Analysis and Colour Decoding of Printed Matters using a Portable 2D Chroma Meter

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Abstract: The paper presents an optical imaging system for the colour distribution measurement of objects. It has the advantages of portable, accuracy and high resolution. The lens barrel and the ring sunlight LEDs are designed to achieve regional darkroom, high illumination uniformity and high color rendering. After using a small color chart for calibration, the average color deviation (△E*ab) of the imaging system will be lower than 3. The uniformity of the printed papers could be successfully analysed and achieve color encryption application. This technology provides a useful solution for imaging and print technology that is very demanding on color correctness.

## 1 INTRODUCTION

Color is a kind of human visual characteristic. In the visible spectrum, all the wavelengths of light mixed together is known as white light. The eyes collect the lights bounced off by the objects and form a color perception in the brain (Nathans, 1999). The color reflects the spectral results of the interaction of light and material. Colors categories can be numerically identified by the coordinates in various color space or the wavelength range of electromagnetic radiation. In physical space, the presentation reproduces of color need to compare the measured result and traceable standard sample by a calibration device. The color space is an effective mathematical model to serve as the basis for the calibration process (Connolly, 1997). The CIELAB color space defined by the International Commission on Illumination (CIE) in 1976 is a commonly used standard because it contains all colors that humans can see (Luo,2001) (Schanda, 2007). The LAB color space expressed through three parameters: L for the lightness and a and b for the green–red and blue–yellow components. In general, the color measuring instrument of object is a chroma meter or spectrophotometer (Gras, 1990) (Martínez, 2001) (Smith, 1931). An optical sensor with filters or a spectrometer was used to separate the wavelength of light, and then calculate an accuracy numerical value of color (Zhang, 1997). They can measure the color of flat material such as paper, plastics and metal, to help the people to specify and communicate the color accuracy. However, these devices have a non-negligible disadvantage. That is, each measurement can only obtain a single value. We believe that the single point of measurement cannot represent the condition of entire sample.

In this study, an optical imaging system for the color distribution measurement of objects was developed. The purpose is to make a specific chroma meter that can obtain two-dimensional information of samples. This system is composed of white light LED, darkroom tube and optical imaging device. The system achieves color analysis capability with high accuracy, repeatability and resolution characteristics through a complete color calibration process. Compared to conventional chroma meter, the developed system was designed for multi-point measurement. Therefore, the uniformity and distribution of color on objects can be measured and analyzed. This system has advantage of being portable and is not affected by the external environment during measurement. In the experiment, the measured samples are standard color charts and printed papers. The printing industry has always attached great importance to color deviation. However, many kinds of printing equipment may not be able to supply stable and consistent color quality for paper. In this system, the average ΔE*ab between the measured results and the standard color



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chart is less than 3 (Xu, 2012) (Gómez-Polo, 2016). This means that the system can identify color difference which is hard to recognize by human eyes. After measuring the printed samples, the color distribution and statistical contribution in LAB color space was successfully acquired. For cipher application, four colors with smaller ΔE*ab value was picked up to make a special color card with them. In addition, there are other similar colors that are randomly distributed in the card. It is difficult to distinguish from the naked eye. Through this system, the color distribution of this color card can be obtained correctly. The RGB values of the top five major colors are used as a tool for encryption coding. Inaccurate color measurement will not get the correct private key. The development of this instrument will contribute to the researches of colorimetry in the field of print, cipher and relative applications.

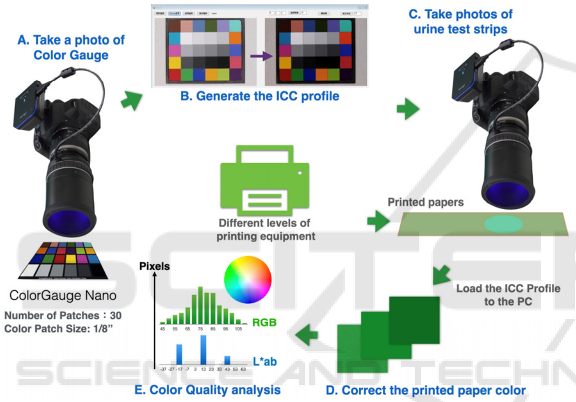


Figure 1: The experimental setup of the 2D chroma meter for the measurement of printed papers.

## 2 EXPERIMENTAL SETUP AND SAMPLE PREPARTION

Fig. 1 shows the schematic diagram of the color correction procedure of the developed instrument. The system is designed for the color distribution measurement of printed papers. A CCD camera (Canon, 77D) and a macro lens (EF-S 60 mm)were used to capture the optical images of samples. The field of view of this optical system is 50 mm × 30 mm, and the resolution is about 15 µm. For uniform illumination and reflection measurement, a ring light module that has sunlight LEDs was used. The uniformity of lighting is better than 95% and the spectrum of the LEDs is similar to sunlight. In order to isolate the ambient light, a darkroom module was used between the lens and sample. A small color checker（ColorGauge Nano, Matte, Edumnd optics）was measured by the system and provides a calibration standard. Through the compensation of ICC profile, the relatively accurate colors could be obtained by the system. We have verified that the system can achieve that the average ΔE*ab is less than 3. The experimental samples are various printed papers, as shown in Fig.2. The first one is a commercial color chart without a rigorous calibration standard. The second and third ones are normal paper printed by the business and home printer, respectively. The specified color parameter when printing is R:0 G:255 B:0. This means that they theoretically are all pure green.

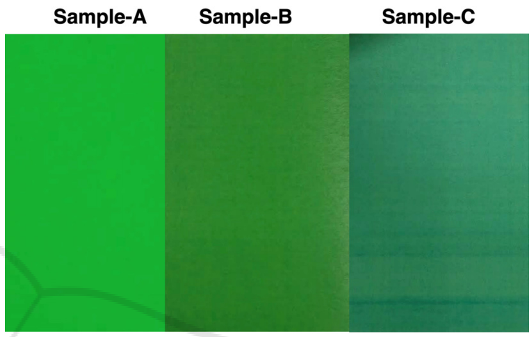


Figure 2: Various printed papers were measured and analysed by the 2D chroma meter.

## 3 RESULTS AND DISCUSSION

The measured results are shown in Fig. 3. The color of each pixel in the measured optical image is correctly described and located in the Lab color space. Since the printed papers are green, the measured values should be within the third and fourth quadrants of color space, as shown in the red frame of Fig 3(a). Figure (b), (c) and (d) indicate the color distribution of color chart, professional print and general print in Lab color space. For easy viewing, only the a-b plane is shown. It indicates that the 3D color space is flattened to display only pure color information. Therefore, the lightness (L value) in Figure 3 may not be correct. This does not actually affect the results of the analysis. Obviously, it can be found that a perfect monochrome does not exist in all kinds of printed matter. The distributions of colors are regional, not single points. Excellent print quality of color chart allows color to be concentrated in a very small area, as shown in Fig 3(a). High end and entry printer will also cause obvious differences in the degree of color centralizing, as shown in Fig 3(b) and (c). Although the color uniformity should be related to printer level, ink quality, paper material and environment, this system provide people a 2D visualization function to perform the quality judgment for the final printing product.

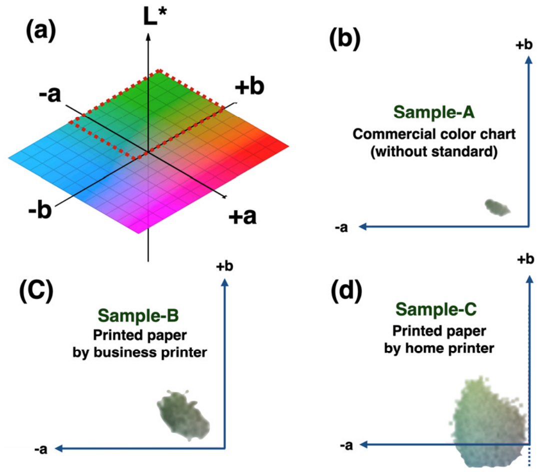


Figure 3: Color distributions of the various printed papers in Lab color space (Only ab plane).

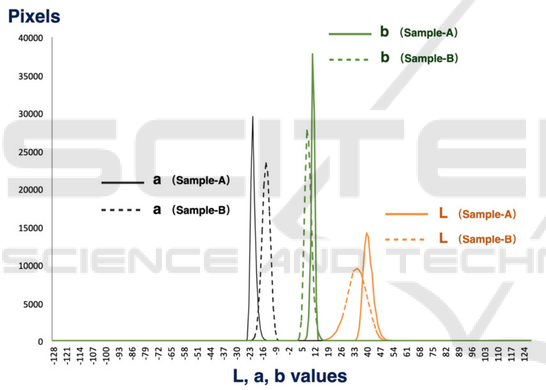


Figure 4: Comparing the colour numerical distribution of the color chart and paper printed by the business printer.

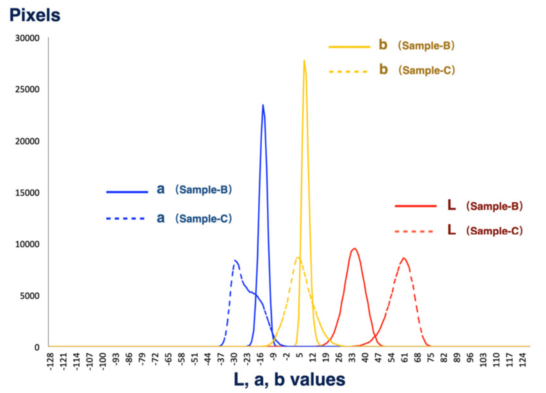


Figure 5: Comparing the colour numerical distribution of the papers printed by the home and business printer.

The color distributions of samples were quantified by drawing the statistical charts. Figure 4 shows the colour numerical distributions of the color chart and paper printed by the business printer. Figure 5 shows the colour numerical distributions of the paper printed by the home and business printer. The vertical axis of the figure is the amount of pixels, and the horizontal axis is the values of Lab. In contrast to the printed papers, most pixels of the color chart image are concentrated in a narrow band. It is easy to understand that the larger the bandwidth, the poorer the print quality. The peak of each distribution represents the dominant color of the image in Lab color space. Therefore, the peak deviation represents the degree of color difference between the samples. The dominant color of any kinds of sample could be easily decided by the statistical chart. For example, the dominant color of the color chart (sample-A) should be: a: -21, b: 11. Also, the respective contribution of the border color could be obtained by comparing the Fig. 3 and 4. We believe that this 2D chroma meter is very useful. The future work is improving the color accuracy to ΔE*ab <1.


Figure 6: Four colors with relatively small color deviation were selected for encoding.

In addition to the quality analysis of printed materials, the system can also develop cryptography in printing and display, such as anti-counterfeiting, identification and digital keys. Password information is hidden in the image in a color-distributed manner. A precise two-dimensional colorimeter can get the correct color values and perform subsequent calculations. In order to select the color that is morer suitable for encoding, we measured and calculated the color deviation of the system. The smaller the color deviation, the better the color is suitable for decoding through the system. Figure 6 shows the ΔE*ab values for 25 typical colors. Although white has good color accuracy, it is not flexible for color printing. In Fig. 6, the selected color is ticked. They are blue (0.7), yellow (0.5), and green (1.1). The color of the red series is generally not too small, which is due to the original condition of the camera itself. The pink with an ΔE*ab value of 1.5 is chosen. These colors will be used as the primary colors for encoding. If the print or display shows these colors, the developed system will be able to morer accurately distinguish its color.

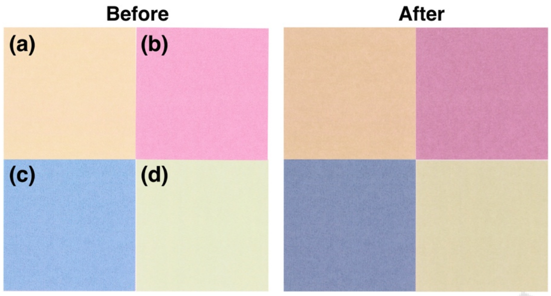


Figure 7: Color blocks with data encryption: (a) Before color calibration, (b) After color calibration.

Figure 7 shows a photograph printed with these four colors. (a) is yellow, (b) is pink, (c) is blue, and (d) is green. The image on the left represents the image before the color calibration, and the image on the right represents the image after the calibration. It's not easy to find the morer color information were hidden in the photo. In other words, these color blocks are not monochromatic. Each color block contains other colors that are randomly distributed. These colors are very similar to each other and are difficult to distinguish. If the optical system for measuring color has a large deviation (ΔE*ab >1.5), the obtained color information will be wrong, and the decoding will fail. The insertion of color for data encryption can be designed according to the opinion of each manufacturer. In this study, it is proposed to perform coding or decoding in the form of color quantity statistics. Since the encrypted information is independent to visual perception of the human eye, it is not represented by the statistical graph of Lab color gamut. The RGB gamut is consistent with digital sensation and easier for numerical processing. The number of colors in each color block of Fig. 7 is counted and analyzed.

Figure 8 shows the quantitative statistics of colors in each color block of Fig. 7. Only the five colors that contribute the most are displayed. The horizontal axis is the RGB value of the color, and the vertical axis is the pixel amount. Four square blocks shown in Fig. 8 represents the color block of Fig. 7 image described only in five main colors. It can be found that these key colors are enough to represent the entire image, but the differences between them are indistinguishable to the naked eye. If applied to image encryption, the image does not have to be square, or it can be a cartoon image or any geometric shape. Traditionally, the cipher colors hidden in regular areas might be mistaken for uneven printing. However, the system has high color accuracy and resolution, and can distinguish very small color differences. That is to say, the printed matter can be made almost uniform. Data encryption can be easily accomplished as long as a very small color difference can be formed. Taking this method as an example, the output of the color information is:

$$(\mathrm{R}_{iq}, G_{iq}, B_{iq})_{i=a\sim d,\ q=1\sim 5}$$

There are 20 numbers available. If you want to establish a password of 009-075-010, you can simply define as follows:

$$\left| (\mathrm{R}_{iq}, G_{iq}, B_{iq})_{i=b,\ q=1} - (\mathrm{R}_{iq}, G_{iq}, B_{iq})_{i=d,\ q=3} \right|$$

Of course, the real password architecture is always not so simple, and there are endless ways to design this part. When the value measured by the optical system is slightly deviated, the final calculated value will be incorrect. Therefore, if the darkroom module, high color rendering lighting and color calibration program of the system are lacking, this goal cannot be achieved. This study proposes an innovative concept for color data encryption of print matters using a two-dimensional colorimeter. Printing technology also requires complete color management to print images with the correct code. If the home display will all have enough color accuracy in the future, the concept of this study can also be extended to related applications.

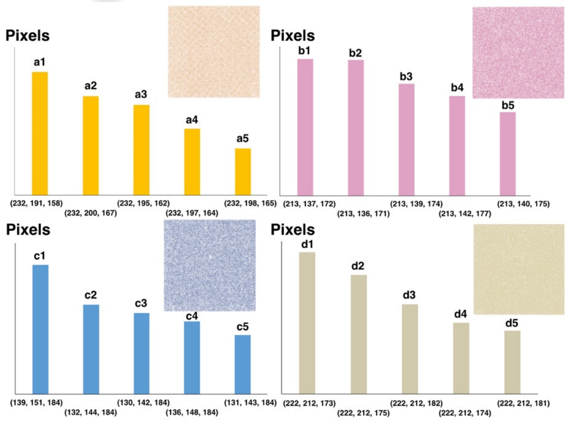


Figure 8: Quantitative statistics of colors in each color block and the RGB values of the five most contributing colors.

## 4 CONCLUSIONS

This study succeeded in developing a portable, rapid and accurate system for the color measurement. The information it captures is two-dimensional, so all kinds of images can be directly measured. Through darkroom modules, ring sunlight LED illumination and standard color calibration procedures, the average color deviation of the system is less than 3. In experiment, various printed papers were measured by the system. Color distribution in Lab space and colour numerical distribution of the samples were sucssufully analysed. This system can also be applied to the field of color encoding or encryption. Colors with data information are hidden in color blocks and can be decoded correctly. This technology can be widely used in the fields of printing, display, cipher and relative applications.

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