Study on Color Gamut to Authenticate the Gravure Printers Output

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ABSTRACT
Counterfeiting pharmaceutical packaging has become a major challenge due to the increase of new technologies. Nowadays this issue has spread worldwide and it has become a major threat to the society and economy. The counterfeited pharmaceutical products are unauthorized, stolen, expired, reused and/or manipulated packages which are similar to the original. The main problem is that it is difficult to see visual differences between original and fake packaging, and the lack of solutions to identify the authentic packaging. So packaging authentication is a very important need in pharmaceutical industry.The simplest way to produce fake samples of printed packaging is to scan the image of the original package by different devices, such as digital camera, mobile camera, scanner etc., next to print the scanned image by printers. The printer's color gamut corresponds to the volume of the color solid defined colorimetrically, produced by a particular set of inks and substrate, which contains all the colors that the printer can produce. Since most of the pharmaceutical products are packed in aluminum foils, gravure printing is used as printing technology. In this study, blister foils have been used as printing substrate to identify an original print printed on it, using different gravure printing machines. In this preliminary study, an image of a reference color chart (IT8.7/3) was printed with three different 4-color gravure printing machines. The volume of the color gamut of a printed sample (original) and a scanned reprinted sample (fake) have been studied to identify the difference between them. Experimental results show that when a scanned sample is reprinted with different printers, the gamut volume differences are much higher than when the original artwork if printed with different gravure printers.

General Terms
Authentication, Counterfeit.

Keywords
Color gamut, CMYK, reflectance spectrum, Gravure printing

1. INTRODUCTION
In printing industry, maintaining the consistency of prints, and of printing quality is a very important requirement. Generally, in pharmaceutical packaging**,** printers with four process inks(cyan, magenta, yellow and black)are used to print samples. The color gamut of a printer characterizes the set of colors that can be printed by a printer. A wider color gamut provides more vivid colors and more depth in color. In general ,out of gamut colors are mapped to the color gamut by different gamut mapping algorithms. On the other hand, it is difficult to map a reduced color gamut to a wider color gamut. In this research, we studied the volume of the color gamut of an image printed on blister foil substrate, and compared it with the volume of the color gamut of an image after scan and print process. We also performed comparisons of spectral data from RMSE values using two different inks. Experimental results have shown in this paper demonstrate that scan and print processes create color distortions which not only impact color gamut but also spectral data when using different inks. These effects cannot be compensated by any color correction method or mapping algorithms.

1.1 Background
Deshpande et al.[1] compared color gamut and quantified the difference between color gamut using Gamut Comparison Index (GCI). The gamut of devices compared was evaluated by users using GCI and other gamut metrics against standard color gamut. Lee et al.[2]introduced a gamut-based color sampling algorithm for printers to minimize the error related to the color conversion. They analyzed the performance of different color conversion processes, from device dependent to device independent color spaces, for inkjet printer. They showed the importance of the set of color samples used for the computation of the color gamut of a printer. Three primaries, three secondary colors and a black color were used to determine the volume of the color gamut of a printer. Sun et al.[3] introduced a method for color printer calibration based on a gamut division algorithm. To adjust the black color (K) for different images they proposed a CMYK separation algorithm method based on gamut division. This method divides the printer gamut into seven sub-gamut according to the K values of sample data. They showed that the color range of sub-gamut decreases along the CIEL* coordinate when the K value increases. In the CIELAB color space, a color may belong to more than one sub-gamut, that means it can correspond to several CMYK colors. This method was used to convert a color sample from CIELAB color space to CMYK color space. The final CMYK color is defined by a combination of all CMYKs with black generation coefficient. Chen et al.[4] defined a method to maximize the size of printing color gamut by using the spectral properties of three or four colors inks. They measured the absorption and scattering ratio from spectral reflectance of single inks printed on substrate (paper) to define the homogeneousness of colored layers in a virtual printing model. The Yule-Nielsen Spectral Neugebauer (YNSN) model was used to minimize the spectral root mean square error [10] between prediction and measurements based on printed one color ramps. They evaluated the performance of this virtual printing model

according to a printer and its CMYKGO (cyan, magenta, yellow, black, green, orange) inks set using Gaussian functions. They calculated the volume of the printing color gamut using the convex hull algorithm of MATLAB. The difference of volume size of two printing color gamuts was very small for four inks combination set. Tutak et al. [5] described the impact on color gamut due to different ink densities for printing purpose. They found that the size of the color gamut increases or decreases equally as the ink density values increase or decrease. They defined the color gamut resulting of an increased or a decrease of one color among CMYK colors, while remaining color density values were kept same. They compared different CMYK color gamuts and showed that their color gamut slightly increases as the density value of cyan increases. On the other hand, the color gamut does not change when magenta density and black density values increase. But, for yellow colors, the color gamut expands in yellow region when yellow density values increase, with offset printing. Perales et. al[6] compared the color gamut of different types of paper (matte, semi matte, glossy, coated matte, coated glossy etc.) using same inkjet printing technology. They showed that there is a linear relationship between the color values of a color chart printed on paper and the volume of the color gamut, and that there is no relationship between the colorimetric properties of the paper substrate and the color gamut volume associated with it. The metameric index [7] was defined in reference to the sensitivity of the human visual system to evaluate color differences and it is not dependent on the illuminant conditions. Different metrics like ratio of spectra, Root Mean Square Error (RMSE)[10], Goodness of fit coefficient are compared in [8].Mandal et al. [10,11] defined the lightfastness properties and waterfastness rate [12] of prints of different substrates (blister foil, plastic film) by gravure printers using spectral properties and Artificial Neural Network model .

2. METHODS, PROCEDURE & TESTS

The goal of this study to identify an authentic print sample from a reprint sample using the difference of color gamut of gravure printers. The assumption has drawn that it is very difficult to correct the color gamut of a printer by color mapping algorithms. Even if two different inks could be used to compensate color gamut differences, it has assumed that the spectral reflectance of inks cannot compensate color changes due to the scan and print process.

A 4-color gravure machine (CMYK printer) was used to print the engraved artwork (IT8.7/3 color chart) on aluminum foil samples using different color gravure printers of a printing factory. In this experiment, three different gravure printing machines were used for print-reprint process. This artwork was engraved on gravure input cylinders by electromechanical engraving process to print it in printing factory. In this study, three 4-color gravure printers have been used as output device and substrate respectively. These parameters were set as follows: temperature: 31^{o}C, humidity: 75%, gravure speed: 17 MPM, screen ruling: 150 LPI, angle of doctor's blade: 30^o, process: electro-mechanical engraved, heating: 70^o C - 80^o C, pressure of rubber roller: 2.5 kg/cm^2 (for each unit), pressure of doctor's blade: 1 kg/cm^2 (for each unit), cylinder size: 325x500 mm. The same conditions were maintained for the printing and reprinting process to neglect the effect of change of these parameters on the results.

The reference image was printed on blister foils with CMYK colors, next a set of samples (ie. of color patches) from the printed image were analyzed. The reflectance spectrum values of printed samples (ie. solid colors (C,M,Y,K)) were measured and analyzed using the Gretagmacbeth Spectroscan[13].Then, the printer profile of each gravure printer was computed. Next, a digital camera (Sony alpha 350) was used to capture an image of each print sample selected, for the three different gravure printing machines used, to get the color values of the reprint samples. Within controlled illumination condition, the image was captured by a digital camera (Sony alpha 350) in a lighting booth. After capturing the image, output data were converted from RGB mode to CMYK mode. The color channels were separated for prepress process in order to engrave color data on another set of 4 gravure cylinders (C, M, Y, K) using an electro-mechanical engraved process for reprint. Reprinted samples were measured and analyzed using the Gretagmacbeth Spectroscan. Then, the printer profile of each printer was computed. The Gamutvision 1.4 Software [14]was used to get the color gamut volume of printed and scanned reprinted samples for each gravure printer. The 3D color gamut of each sample was computed in the L*a*b* color space. The sRGB color gamut was taken as standard wider gamut and compared with measured color gamuts of print and reprint samples.

To analyze the effect of the scan and reprint process on spectral values of solid colors, in comparison to an original print artwork, and also to analyze the effect of different inks on a same output device (gravure printer), the Root Mean Square Error (RMSE) was used to analyze the inequality between reflectance spectrums in the visible domain as defined in Eq.(1).

$$RMSE_k = \sqrt{\sum_{i=1}^{n} \frac{(R_r(\lambda_i) - R_t(\lambda_i))^2}{n}} \qquad \text{Eq.(1)}$$

where $Rr(\lambda_i)$ is the measured of the original (reference) spectral data at the wavelength $\lambda_i$and $Rt(\lambda_i)$ is the tested spectral data at wavelength λ_i. k is the index of the visible color domain considered. Using the RMSE, the differences of reflectance spectrums of solid colors (Cyan, Magenta, Yellow and Black) has been evaluated within the visible domain and then computed statistically the inequality of reflectance spectrums between print(original) and scanned reprint (counterfeited) samples for different inks printed with the same printer.

3. RESULTS& DISCUSSION:

In the following, a comparison of the gamut volume of printed and reprinted samples on blister foils is done for three different gravure 4-color printers.

a) Comparison of gamut volumes for Printer1, Printer2 & Printer3 (Figures 1 to 6).

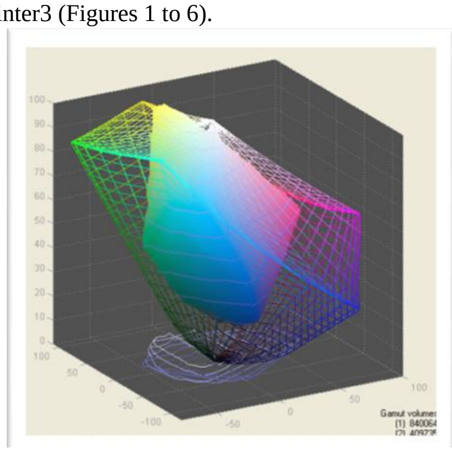

Fig.1: Gamut volume of printed sample for Printer1(P1)

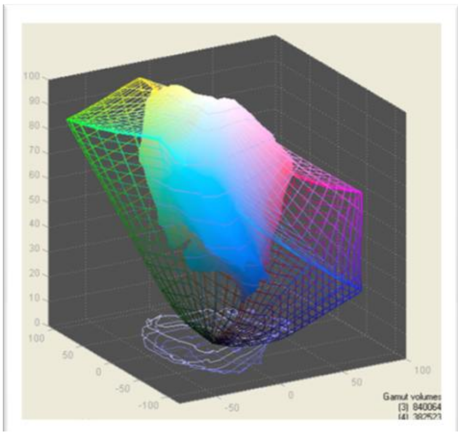

Fig.2: Gamut volume of reprinted sample for Printer1(P1)

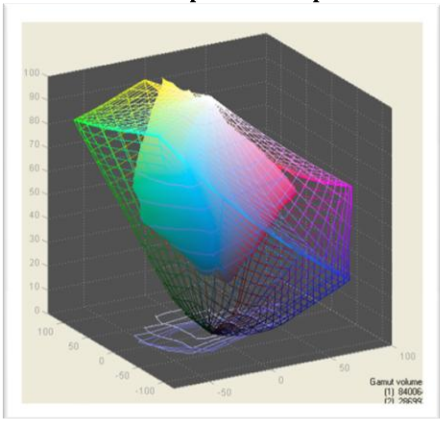

Fig.3: Gamut volume of printed sample for Printer2(P2)

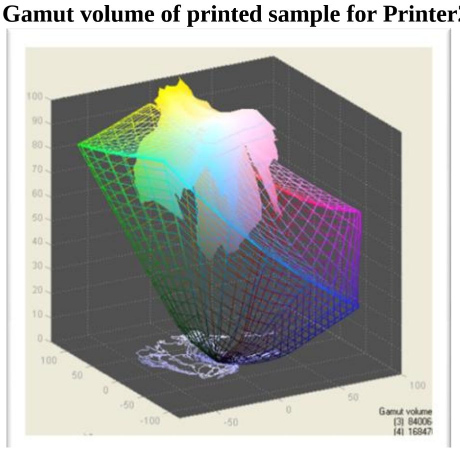

Fig.4: Gamut volume of reprinted sample for Printer2(P2)

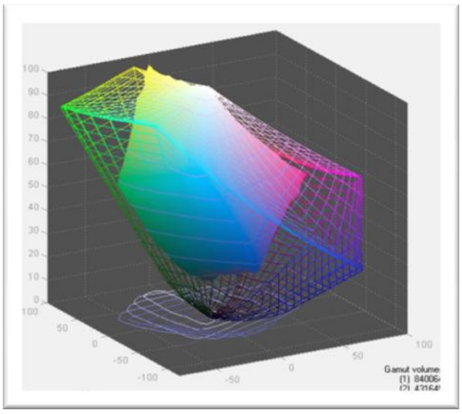

Fig.5: Gamut volume of printed sample for Printer3(P3)

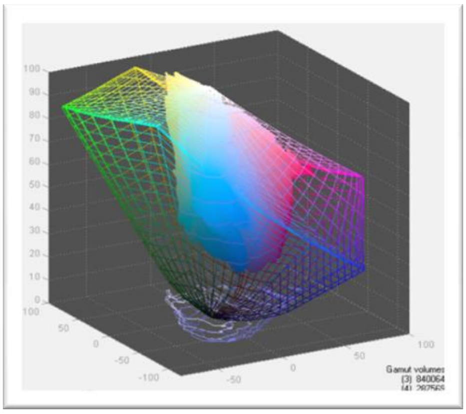

Fig.6: Gamut volume of reprinted sample for Printer3(P3)

In the above Figures(Fig.1 to 6), each print and reprint color gamut is represented as solid gamut, meanwhile the sRGB color gamut is used as standard color gamut with wider color volume. It has been observed that the volume of the color gamut of the print sample is more compact and bigger (in L*a*b* color space) than the color gamut volume of scanned and reprinted samples for the three gravure printers. Same ink and same blister foil substrate were used for each print. The color gamut volume of printed and reprinted samples for different gravure printers are reported in Table1.From these results it has drawn the assumption that the color gamut differences can be used as an indicator whether a print is original or not, and could be used to identify an original printer used to print a reference sample.

Table 1. Comparison of color gamut volumes of printed and reprinted samples for three different printers

Samples	Print (Gamut Volume)	Reprint (Gamut Volume)	Remarks
Printer1(P1)	**409735**	382523	When a sample is printed with different press, even if ink and foil are same, then the gamut volume is lower for reprinted sample than printed sample
Printer2(P2)	**286992**	168470	
Printer3(P3)	**431649**	287569	

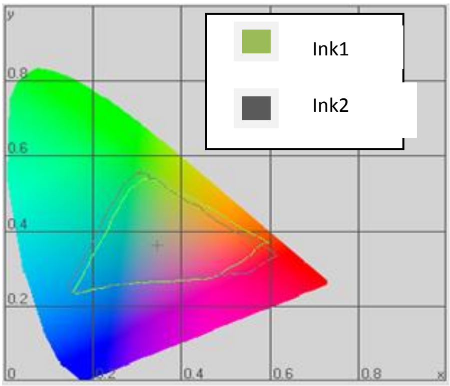

Fig.7: 2D gamut volume (in xy chromaticity diagram) of print artwork printed with Printer3 and with Ink1& Ink2

c) Comparison of reflectance spectrum of solid colors (cyan, magenta, yellow and black) of two different inks (DIC & SAKATA) printed with Printer3

i. Comparison of reflectance spectrums of solid color Cyan between Ink1 & Ink2 printed and reprinted withPrinter3 (Figures 8 to 9)

b) Comparison of gamut volumes for two different inks (DIC & SAKATA) printed with Printer3

Table2. Comparisons of color gamut volume of printed and reprinted samples for Ink1 & Ink2 for one gravure printer

Samples	P3&Ink1(Gamut Volume)	P3&Ink2(Gamut Volume)
Print Sample	**431649**	368792
Reprint Sample	**287569**	104236

As reported in Table2,some difference between color gamut volumes can be observed. Under the same illuminant condition and same printing procedure, when substrate and press are same but inks are different, then differences between color gamut can be observed (see Fig. 7). To print the artwork with a 4-color gravure printing machine four cylinders (cyan, magenta, yellow and black) were needed. After scanning the printed artwork, four cylinders were required to engrave the scanned artwork on four new cylinders and reprint it. So after reprint process (with different ink than the first print, but same press),the volume color gamut has decreased in comparison with the volume of the color gamut of the oringinal printed artwork which was printed with same press

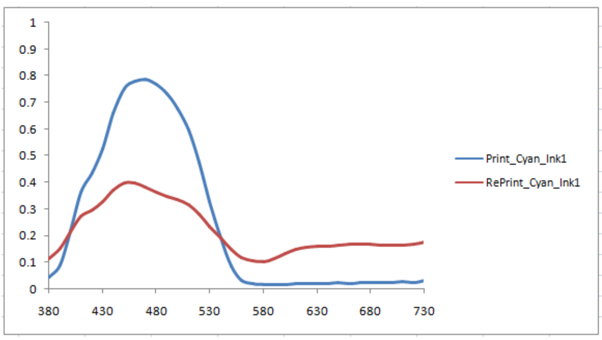

Fig.8: Reflectance spectrum of solid color Cyan of Ink1 for Printer3

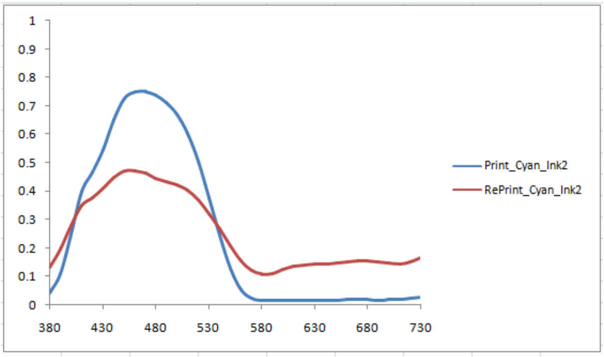

Fig.9: Reflectance spectrum of solid color Cyan of Ink2 for Printer3

ii. Comparison of reflectance spectrums of solid color Magenta between Ink1 & Ink2 printed and reprinted with Printer3 (Figures 10 to 11).

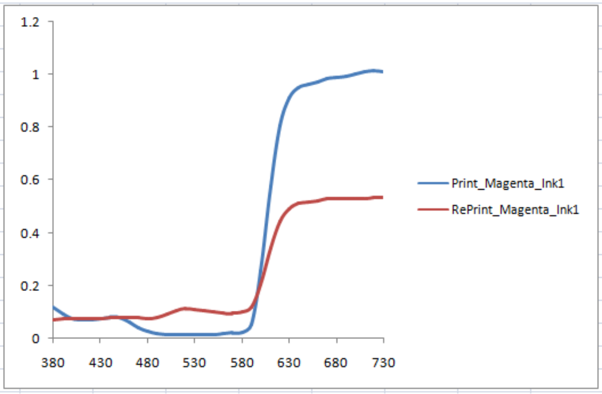

Fig.10: Reflectance spectrum of solid color Magenta of Ink1 for Printer3

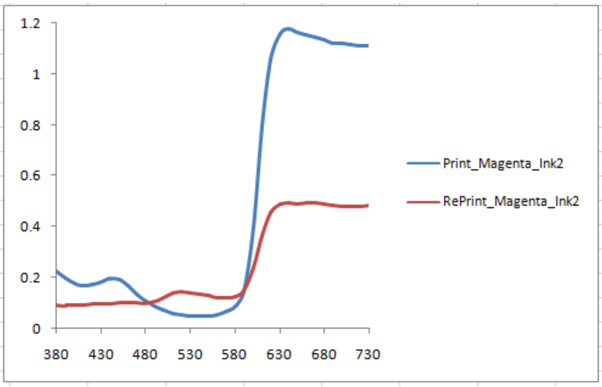

Fig.11: Reflectance spectrum of solid color Magenta of Ink2for Printer3

iii. Comparison of reflectance spectrums of solid color Yellow between Ink1 & Ink2 printed and reprinted with Printer3 (Figures 12 to 13).

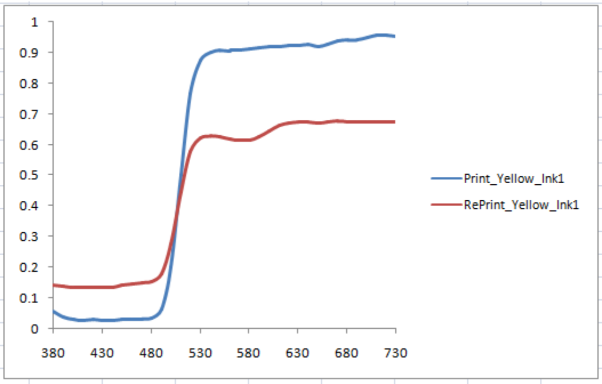

Fig.12: Reflectance spectrum of solid color Yellow of Ink1 for Printer3

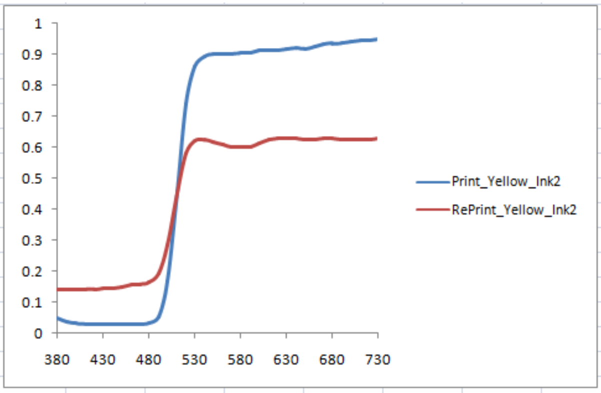

Fig.13: Reflectance spectrum of solid color Yellow of Ink2 for Printer3

iv. Comparison of reflectance spectrums of solid color Black between Ink1 & Ink2 printed and reprinted with Printer3 (Figures 14 to 15).

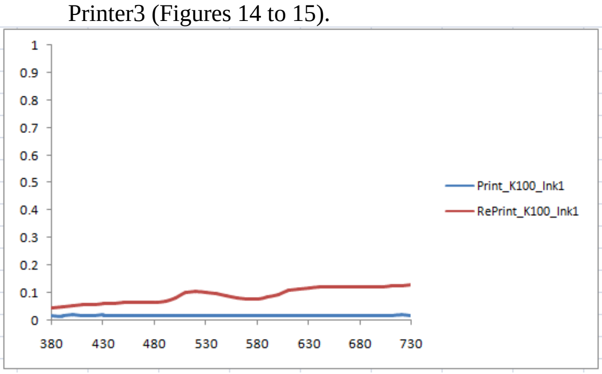

Fig.14: Reflectance spectrum of solid color Black of Ink1 for Printer3 (P3)

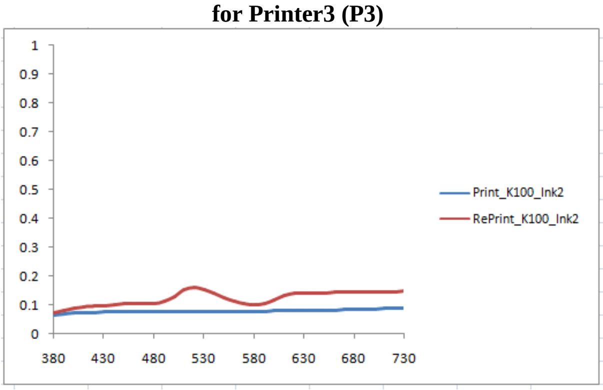

Fig.15: Reflectance spectrum of solid color Black of Ink2 for Printer3 (P3)

Figures 8 to 15 illustrate the reflectance spectrums of solid color cyan, magenta, yellow and black of two different inks (DIC & SAKATA) used to print and reprintthe reference artwork on blister foil by same gravure printer. Same printing conditions, same output device (gravure printer), same substarte (blister foil), were used for print and reprint, but printing cylinders were different (one for print and another one for reprint process) and inks were different between first print (with Ink 1) and second print (with Ink 2).Whatever the ink, for solid colors cyan, magenta, yellow, the intensity of reflectance spectrum of the print sample is higher than the scanned reprint sample. Such difference could be used to authenticate an original print sample among different reprint samples. Some differences have been observed from reflectance spectrums when using another ink (Ink2) by keeping the same output device and substrate (under same printing condition). These spectral differences has been analyzed using the Root Mean Squared Error (RMSE) values between the two inks used for gravure printing (Ink 2 vs Ink 1). The RMSE values between an original print artwork and a scanned and reprint sample are reported in Table3.The RMSE values are quite similar.

Table3: Comparisons of reflectance spectrum of solid colors Cyan, Magenta, Yellow Black between a print and a reprint artwork, printed with Ink1 & Ink2, for one gravure printer (Printer 3).

Samples	P3&Ink1	P3&Ink2
Solid Cyan_RMSE	0.201	0.155
Solid Magenta_RMSE	0.268	0.386
Solid Yellow_RMSE	0.219	0.239
Solid Black_RMSE	0.079	0.048

4. CONCLUSION

For an image reproduction printing workflow, color gamut volume is useful to analyze an image gamut against printer device gamut. In this study, it has showed that after scan and print process (i.e. a reprint) the volume and the size of the color gamut of a gravure printer differ from the one of an original print. In both cases print samples were printed on blister foil. Experimental results showed that the volume and the size of the color gamut of a scanned reprinted (fake) sample are smaller than those of the color gamut of an original print sample, and this for three different gravure printing machines. It has been demonstrated that the color gamut of print artworks is primarily affected by the change of input gravure cylinders and also by a change of output device (gravure printing machines). The reduced color gamut is responsible of color inconsistencies observed between an original print artwork and a reprint artwork after scanned and print process. To minimize these color inconsistencies color corrections could be applied, but it is very challenging to compensate out-of-gamut colors resulting from the reprint process (i.e. to expand the volume of the color gamut of a reprint artwork to fit the wider gamut of an original print artwork). In the experiments it also investigate the effect on gamut boundaries related to a change of ink for same gravure printer and same printing conditions. It has also analyzed that, using of two different inks, some color inconsistencies observed between an original print artwork and a reprint artwork after scanned and print process. These inconsistencies can be observed when it compared the corresponding color gamuts and the shape of the spectral curves of solid colors. From this study, it has drawn the assumption that as the shape of spectral curve of each ink is unique, when a printed sample is scanned and reprinted by same output device (gravure) than the original print but with another ink than the original one, then the spectral signature of the reprint differs from the one of the original print. Experimental results showed that the spectral curves of solid CMYK colors (corresponding to cyan, magenta, yellow and black inks) printed and reprinted on blister foils are different for two different inks. This property could be used to identify an original printer. Hence, if a print is scanned and reprinted, it could be easily demonstrated whether it was printed by an original printer or not. It was also shown that between print and reprinted samples, the RMSE Root Mean Square Error) values are different for different inks, for same color regions of the visible domain. Hence, RMSE (Root Mean Square Error) between print and reprinted samples could also be used to authenticate a print sample among different prints printed with different inks.

In future work more print and reprint samples will be taken for test purpose with more inks, and will develop an accurate model to identify authentic devices among other devices used to create counterfeited samples.

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