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# Analysis of Spectral differences between Printers to detect the Counterfeit Medicine Packaging

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**ABSTRACT**

Counterfeited medicine is a major threat to the society and economy. The easiest way of producing fake medicine is counterfeiting the packages of medicine. Medicine package printing is generally counterfeited by scanning the original printed package using camera, scanner etc. and then reprinting it. When different mobiles, camera or scanners are used to scan the original print and reproduced scanned reprinted sample, then the color values of reprinted samples are not the same as the original print sample . When the scanned objects are reprinted with different printers, the color values may be different depending on the profile of the printer. The spectral data of the solid inks used cannot be corrected as it is dependent on the inherent characteristics of the inks used. In this study, the original prints are scanned and then reprinted with the original (reference) printer, as well as in three different (test) printers, to show difference of spectrums. The inequality of spectrum of solid colors has been analyzed for printed and reprinted samples. The differences between RMSE values have been analyzed for same and different printers for different color range domains of the visible spectrum. It has been assumed that these differences could be used to detect whether a print is original or not. It may be used to protect medicine packaging from counterfeiting**.**

**Keywords: Reflectance Spectrum, Scanned reprint, RMSE, CMYK, Printer Authentication.**

## I. INTRODUCTION

A new series of challenging problem is to protect and authenticate of documents from counterfeiters due to the increase and development of internet. To detect original sample color features can be used after scan and print attack. The color correction, quality evaluation, device calibration, and device characterization are performed by the Color Management System (CMS). It is not an easy task for non-conventional devices and non-conventional materials such as rotogravure printers and aluminum foils paper respectively to perform the color calibration. But on reflective materials it is a necessary task to preserve image quality of prints and to check if a print is original or not. In this study, the inequality of reflectance spectrum of printed colors has been studied in the visible range of red, green and blue domains. It has been analyzed that the scan and print processes create not only color distortions but also spectral distortions that cannot be compensated by any color correction method.

## II. LITERATURE REVIEW

The present study is based on gravure printing on blister foil substrate. To the best of our knowledge very few works has been done in this area. The aluminum foil substrate is very specular in nature and therefore the conventional color calibration methods do not perform well in general for such specular material [1]. Among various methods, a color calibration [2]

solution defined for digital cameras. This solution is based on a forward and inverse colorimetric characterization process which takes into account different lighting conditions. They proposed a calibration method based on two different processes in order to cancel the impact of lighting condition changes. Either the acquisitions done by digital cameras are performed under the similar conditions

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of lighting and in this case the method is based on their colorimetric characterization; or the acquisitions done by digital cameras are performed under different lighting conditions (e.g. D65 and D50) and in this case the method is based on the forward and inverse colorimetric characterizations (D65 → D50, and D50 → D65).Color calibration solution [3] was developed for display devices (monitor) , input devices (scanner or digital camera), and output devices (printer). A multi-dimensional look up table has been used by this solution to register the color values of each channel Table entries are then computed by interpolating these color values in the tetrahedron sample space. Reflection spectrum of halftone samples was used as color prediction model (Neugebauer model). This solution has the advantage to request less number of samples and physical parameters than some other methods to calibrate input/output devices.

Another problem on blister foil with gravure printing is that with a rotogravure printer the color samples printed on foils. Colorimetrically calibrate such printer is very difficult as many parameters, such as the concentration or ink viscosity [4], may impact the quality of the print. Furthermore, the print quality does not depend only of the color signature of the inks used but also of their spectral signature. A solution has proposed in some papers are based on the comparison of spectral signatures, among them spectral data and color values ( brightness, chroma, hue) has analyzed with two methods [5], the Principal Component Analysis (PCA) and Segment Classification (SC). They tested the accuracy of these two techniques in comparison with other color assessment methods. For printer characterization the Yule–Nielsen Spectral Neugebauer model has used. Thus they studied the feasibility of complex spectral characterization of binary printer [6]. Reflectance spectra difference has evaluated using a metameric index [7]. This index 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, Goodness of fit coefficient have been compared [8]. This study has shown that the performance is better for none of these metrics than other metrics and that the use of these metrics is dependent on the application.

The main goal of our study is to address the issue of authentication of printed artworks printed by a rotogravure printer on foil substrate. Unfortunately in the state of the art most of the papers studying the prints quality which are based on ink jet printers, furthermore few studies, such as [9], studied the quality of gravure spot color reproduction. Print quality has computed on different types of substrate for gravure printing [10]. The quality of gravure printing is influenced by various factors, such as viscosity, ink chemistry, substrate properties, rheological behavior, doctor's blade angle, cylinder pressure, drying printing speed, solvent evaporation rate, etc. They studied print quality on non-porous substrates like milky poly, polyester and BOPP. The density and dot gain values for Cyan, Magenta, Yellow and Black (CMYK) channels were compared for these three types of substrates. They reported that, the density value of black (K) color is almost the same for all substrates, and for C,M,Y colors the density values are higher for milky-poly and polyester substrates and for BOPP substrate the values are almost same, with the same trend for C,M,Y colors. From all tint levels (10%-100%) ,all C, M, Y and K colors showed almost similar trend with different values of dot gain. They also showed that the least dot gain had obtained for process Y color and maximum dot gain value for K color. But the print quality was different for different substrates.

Among all papers dealing with an algorithm for detecting counterfeited bills produced by a scanning and printing technology [11]. They developed a deep learning algorithm based on a convolution neural network (CNN) model to detect counterfeit bills and forgery devices used. To identify the used forgery devices, the grey level co-occurrence matrix has used to extract the noise features from printing devices. They analyzed their algorithm using three different laser printers. They demonstrated that the detection accuracy increase with the increase of epochs. By using their algorithm they have claimed that they could identify the used forgery devices and discriminate the original and counterfeit bills.

## III. METHOD, PROCEDURE AND TESTS

In this study, an Electro-mechanical engraved process was used to engrave the artwork IT8.7/3 Color Chart (See Fig. 1) as reference image on a gravure cylinder. Then, in a printing factory on several foil substrates a different 4-color gravure machine (CMYK printer) was used to print the engraved artwork. A specific set of printing parameters such as, gravure speed, cylinder making process, humidity, heating, ink viscosity, cylinder size , surround temperature , angle of doctor's blade setting, ,screen ruling, have maintained to print the reference artwork. These parameters were set as follows: gravure speed: 17MPM, screen ruling: 150LPI, temperature: 31ºC, cylinder size: 325x500mm, humidity: 75%, Electro-mechanical engraved , angle of doctor's blade: 30º, process:, heating: 70ºC-80ºC, pressure

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of rubber roller: 2.5 kg/cm$^2$ (for each unit), pressure of doctor's blade: 1kg/cm$^2$ (for each unit).The objective of our study was not to study the effect of these parameters on the results, but to check that the print and reprint conditions were the same, so that the changes of any values reported are not due to change in the printing parameters. We did our best to maintain the same conditions for the printing and reprinting process.

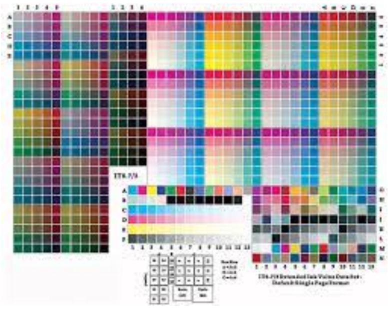

**Fig.1.**IT8.7/3 Color Chart

The reference image was printed on blister foils with CMYK colors, next a set of samples from the printed image were analyzed. A Sony alpha 350(digital camera) was used to capture an image of each print sample selected to get the reprint samples. The set of printed and reprinted samples analyzed in this study were measured with the Gretagmacbeth Spectroscan. The spectrum and L*a*b* values of the samples were obtained from this device.

To analyze the effect of the scan and reprint process on spectral and color values, in comparison to the original printed artwork, and also to analyze the effect of different gravure printers, print and reprint samples (CMYK color) printed by different printers have been used. Root mean square error (RMSE) was used to analyze the inequality between reflectance spectrums in the visible domain for different printers.

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

Where $Rr(\lambda_i)$ is the measured original (reference) spectral data at the wavelength and $Rt(\lambda_i)$ is the tested spectral data at wavelength $\lambda_i$. k is the index of the color domain (R, G or B) considered. Reflectance spectrums of solid colors (Cyan, Magenta, and Yellow) were split into R, G and B ranges of visible spectrum and then standard deviation was used to compute statistically the inequality of spectrums of print and reprint samples for different printers.

The Goodness of Fit Coefficient (GFC) was also used to measure the inequality between original and tested spectral data.

$$GFC = \frac{|\sum R_r(\lambda_i) R_t(\lambda_i)|}{\sqrt{|\sum [R_r(\lambda_i)]^2|}\sqrt{|\sum [R_t(\lambda_i)^2|}}$$

Where $R_r(\lambda_i)$ is the measured original (reference) spectral data at the wavelength and $R_t(\lambda_i)$ is the tested spectral data at wavelength $\lambda_i$. GFC > 0.999 and GFC > 0.9999 are required for respectively good and excellent spectral matches, respectively.

The Spectral Angle Mapper (SAM) was also used to measure the inequality between original and tested spectral data. The SAM, also known as vector-included angle cosine method, assesses similarity by computing the angle between two spectral data sets in a n-dimensional space, as follow:

$$\alpha = Cos^{-1}\left(\frac{R_r . R_t}{|R_r||R_t|}\right)$$
$$= Cos^{-1}\left(\sum_{i=1}^{n} R_r(\lambda_i) R_t\right.$$
$$\left./\left(\sqrt{\sum_{i=1}^{n} R_r(\lambda_i) R_r(\lambda_i)}\ \sqrt{\sum_{i=1}^{n} R_t(\lambda_i) R_t(\lambda_i)}\right.\right)$$

Where n is the spectral range, $R_r$ and $R_t$ refer to the measured original (reference) spectral data and to the tested spectral data, respectively, and $\alpha$ refers to the spectral angle. The higher the SAM value, the lower the similarity of the two spectral vectors [12], SAM values vary in the range [0, 1].

Lastly, the color difference formula$\Delta E_{00}$ was used to assess if color differences [13] between original (print) and tested (reprint) are noticeable, or not, for a human observer.

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## IV. RESULTS& DISCUSSION

In the following, reflectance spectrums of solid colors (Cyan, Magenta, Yellow and Black) printed on blister foils are compared between printed and reprinted samples (reference vs. test) for three different gravure color printers.

a) Comparison of reflectance spectrums of Solid Cyan for Printer1, Printer2 & Printer3 (Figures 2 to 4).

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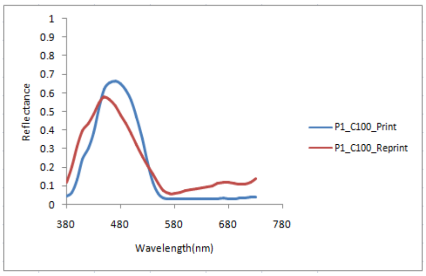


Fig2: Reflectance Spectrum of Solid Cyan for Printer1 (P1)

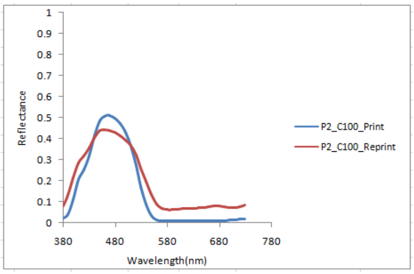


Fig3: Reflectance Spectrum of Solid Cyan for Printer2 (P2)

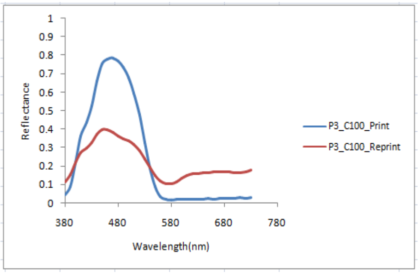


Fig4: Reflectance Spectrum of Solid Cyan for Printer3 (P3)

These spectrums were measured from different printed foil papers and four different positions per foil paper for the same cyan patch. It was observed that the spectrums were similar in nature. It was also observed that the print sample has a blue peak at 470 nm with a higher intensity value than the reprint sample for all printers, and that the peak is a little bit shifted on each reprint. These deviations could be used as a first indicator whether a print is original or not and might be used to identify the original printer used to print the reference sample.

b) Comparison of reflectance spectrums of Solid Magenta for Printer1, Printer2 & Printer3 (Figures 5 to 7).

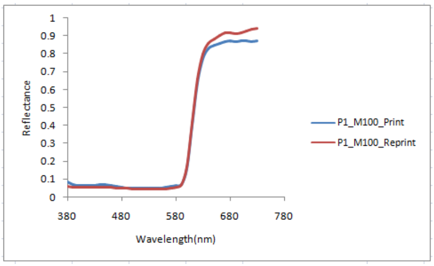


Fig5: Reflectance Spectrum of Solid Magenta for Printer1 (P1)

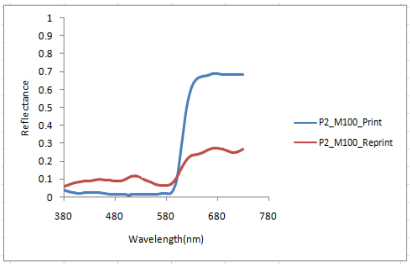


Fig6: Reflectance Spectrum of Solid Magenta for Printer2 (P2)

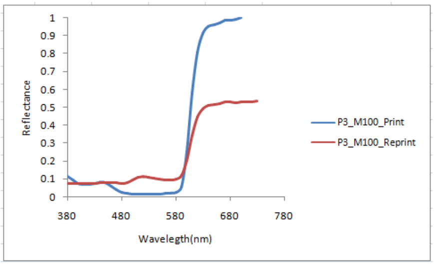


Fig7: Reflectance Spectrum of Solid Magenta for Printer3 (P3)

These spectrums were measured from different printed foil papers and four different positions per foil paper for the same magenta patch. It was observed that the spectrums were similar in nature only for printer P1. Meanwhile, for the two other printers (P2 & P3), in the red region, the intensity value of the magenta color for print is higher than for the reprint. Even if this spectrum shift can be modeled, none color post-processing can be applied after the scanning process to compensate it properly. Our assumption is that while grabbing the magenta patch through the image acquisition device, its color changed (shifted a little bit). These deviations could be used as a second indicator whether a print is original or not and might be used to identify the original printer used to print the reference sample.

c) Comparison of reflectance spectrums of Solid Yellow for Printer1, Printer2 & Printer3 (Figures 8 to 10).

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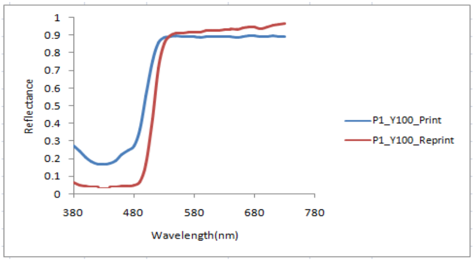


Fig8: Reflectance Spectrum of Solid Yellow for Printer1 (P1)

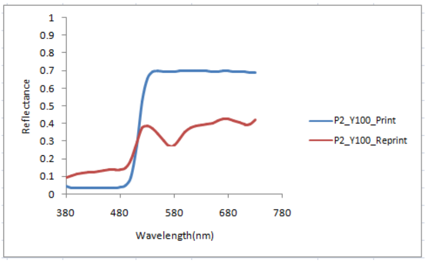


Fig9: Reflectance Spectrum of Solid Yellow for Printer2 (P2)

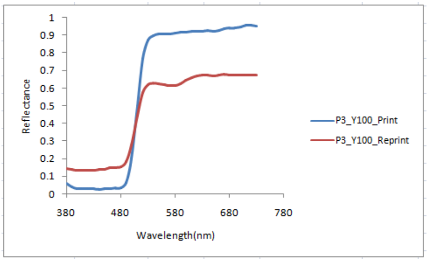


Fig10: Reflectance Spectrum of Solid Yellow for Printer3 (P3)

Once again these spectrums were measured from different printed foil papers and four different positions per foil paper for the same yellow patch. It was observed that for printers P1 & P3, the overall shape of the spectral curve for print and reprint yellow samples is similar, meanwhile for printer P2 the curves are rather dissimilar. On the other hand, for printers P2 & P3, in the green region, the intensity value of the yellow color of the print is higher than for the reprint. One again this cannot be compensated by any color post processing. These deviations could be used as a third indicator whether a print is original or not and might be used to identify the original printer used to print the reference sample.

d) Comparison of reflectance spectrums of Solid Black for Printer1, Printer2 & Printer3 (Figures 11 to 13).

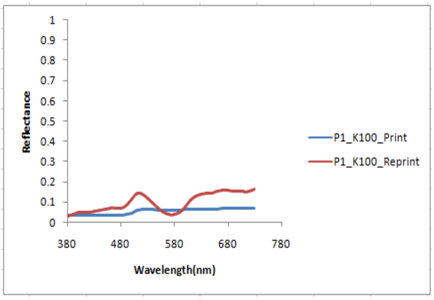


Fig11: Reflectance Spectrum of Solid Black for Printer1 (P1)

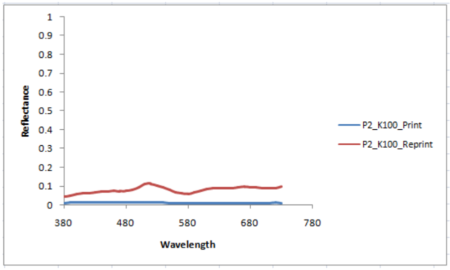


Fig12: Reflectance Spectrum of Solid Black for Printer2 (P2)

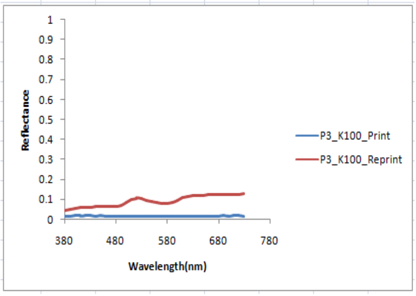


Fig13: Reflectance Spectrum of Solid Black for Printer3 (P3)

Once again these spectrums were measured from different printed foil papers and four different positions per foil paper for the same black patch. It was observed that for all printers, the shape of the spectral curve for print black samples is more homogeneous than for the reprint. Moreover, for all printers, in the red and blue regions, the intensity value of the black color of the print is a little bit higher than for the reprint. On the other hand, for printer P1, the curves are rather dissimilar. One again this cannot be compensated by any color post processing. These deviations could be used as a fourth indicator whether a print is original or not and might be used to identify the original printer used to print the reference sample.

From the spectral representations of C, M, Y and K inks, it was showed that the unique nature of spectrum of reference samples can be used to identify authentic printed samples

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and also help to recognize the original printer by which original samples were printed.

e) Comparison of $\Delta E_{00}$ values of Solid colors for Printer1, Printer2 & Printer3 (Table I).

Most of spectral differences observed in previous plots correspond to noticeable color differences for human observers (i.e. to a$\Delta E_{00}$>2), except for solid color Magenta for Printer 1, see corresponding spectral curves differences in Figure 5.

TableI: $\Delta E_{00}$(Color Difference) of reflectance spectrum of solid C, M, Y, Kinks (100% of surface coverage) for three different printers between print and reprint. Lowest significant $\Delta E_{00}$ are surrounded by cell.

| Color Difference | P1 | | | | P2 | | | | P3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Between Print & Reprint Samples | C 100 | M 100 | Y 100 | K 100 | C 100 | M 100 | Y 100 | K 100 | C 100 | M 100 | Y 100 | K 100 |
| $\Delta E_{00}$ | 2.84 | 1.12 | 8.61 | 7.76 | 9.57 | 19.52 | 21.22 | 18.49 | 11.84 | 10.66 | 9.76 | 18.45 |

f) Comparison of RMSE values of Solid colors for Printer1, Printer2 & Printer3 (Table II).

As report above, most of spectral differences observed in previous plots correspond to noticeable color differences. The main exception is for the Magenta color for Printer P1 for which the RMSE values are all lower than 0.045 in R, G and B regions. For the Black color and Printer 1, only two RMSE values are lower than 0.045 (for R and B regions), meanwhile the$\Delta E_{00}$ value is equal to 7.76, that means that the color difference corresponding to this spectral difference is visually noticeable. Likewise, for Magenta color and Printer 3, and for Black Printer 3, only one RMSE value is lower than 0.045 (for B region), meanwhile the$\Delta E_{00}$ value is equal to 10.66 and 18.45 respectively, that means that the color differences corresponding to these spectral differences are visually noticeable. The RMSE values reported in Table II (and in Figures 14 to 17 below) confirm the observations done in previous sections based on the analysis of reflectance spectrum curves.

TableII: RMSE (Root Mean Square Error) of reflectance spectrum of solid C, M, Y, K inks (100% of surface coverage) for three different printers between print and reprint. Highest RMSE values are in bold. Lowest significant RMSE values (i.e. lower than 0.045) are surrounded by cell.

| RMSE | P1 | | | | P2 | | | | P3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spectrum Region | C 100 | M 100 | Y 100 | K 100 | C 100 | M 100 | Y 100 | K 100 | C 100 | M 100 | Y 100 | K 100 |
| Blue (380-490)nm | **0.128** | 0.013 | **0.186** | 0.027 | 0.067 | 0.065 | 0.089 | 0.055 | **0.275** | 0.029 | 0.108 | 0.043 |
| Green (500-610)nm | 0.082 | 0.006 | 0.159 | 0.046 | 0.068 | 0.073 | **0.317** | 0.075 | 0.163 | 0.081 | 0.248 | 0.075 |
| Red (620-730)nm | 0.075 | **0.045** | 0.050 | **0.080** | 0.062 | **0.395** | 0.293 | **0.081** | 0.140 | **0.439** | **0.264** | **0.104** |

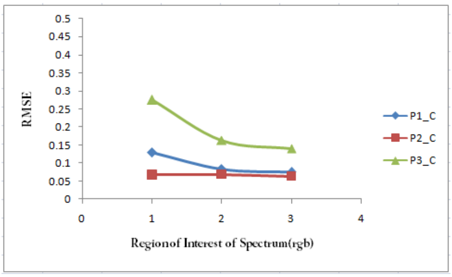


Fig14: RMSE values of Solid Cyan in R, G, B regions for printers P1, P2 and P3

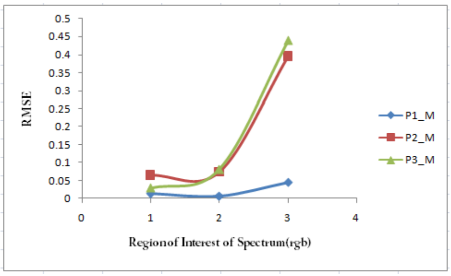


Fig15: RMSE values of Solid Magenta in R, G, B regions for printers P1, P2 and P3

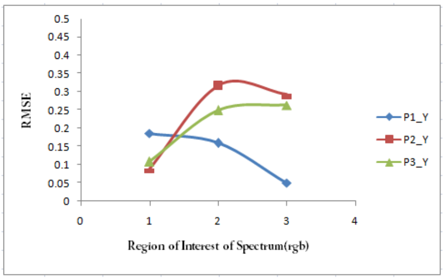


Fig16: RMSE values of Solid Yellow in R, G, B regions for printers P1, P2 and P3

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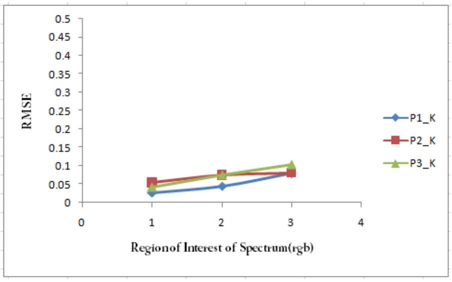


Fig17: RMSE values of Solid Black in R, G, B regions for printers P1, P2 and P3

All observations reported above can be also observed in Figures 18 to 21.These graphs summarize, for the three different printers used, the inequality of errors between reference (print) and test (reprint) samples for different color regions. For cyan ink printed on blister foil, RMSE values are higher at blue range (380nm to 490nm) than for green (500nm to 600nm) and red (610 to 730nm) ranges. For Magenta ink RMSE values are higher for red range for P1 and P2 printers than for the two other regions. No significant tendency can be drawn for Yellow and Black inks.

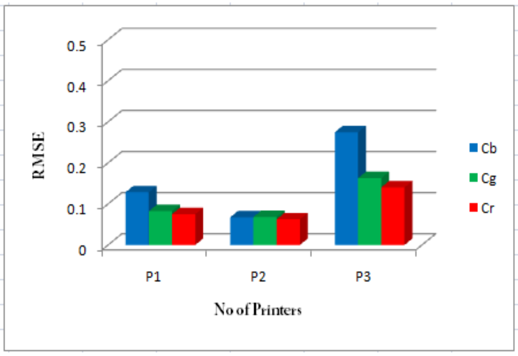


Fig18: RMSE values of Solid Cyan (between reference and test samples) for the three Printers

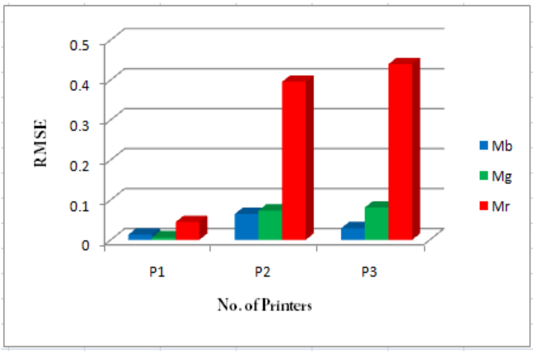


Fig19: RMSE values of Solid Magenta (between reference and test samples) for the three Printers

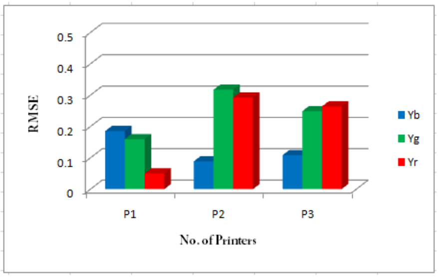


Fig20: RMSE values of Solid Yellow between reference and test samples) for the three Printers

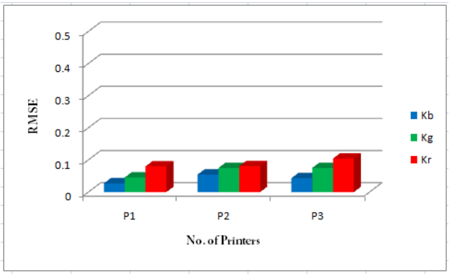


Fig21: RMSE values of Solid Black (between reference and test samples) for the three Printers

g) Comparison of GFC values of Solid colors for Printer1, Printer2 & Printer3 (Table 3).

In this study, we also studied and compared the Goodness-of-Fit Coefficient (GFC) values between print and reprint samples, for the blue, green and red regions of the visible domain, and for the three different printers used. The highest GFC values (higher than 0.995), for R, G and B regions, are for the solid color Magenta for Printer 1. As the corresponding color difference is acceptable for human observers, we could assume that GFC values higher than 0.995 correspond to non-significant spectral differences. Results shown in Table 3 are not all coherent with results report in Table 2, for example RMSE value for K color and Printer 3 is acceptable for B region but the opposite happens for GFC, inversely RMSE values for K color and Printer 3 are significant for G and B regions but the opposite happens for GFC. Likewise, results report in Table 3 is not all coherent with Figures 2 to 13. Therefore, to analyze print and reprint samples, RMSE values should be used preferably to GFC values.

TableIII: GFC (Goodness-of-Fit Coefficient) of reflectance spectrum of solid C, M, Y, Kinks (100% of surface coverage) for three different printers between print and reprint. Lowest GFC values (i.e. lower than 0.995) are in bold. Highes FC values (i.e. higher than 0.995, means good match between spectral curves) are surrounded by cell.

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| Red (620-730)nm | Green (500-610)nm | Blue (380-490)nm | Spectrum Region | SAM |
|---|---|---|---|---|
| 0.0075 | 0.257 | 0.278 | **C100** | *P1* |
| 0.015 | 0.049 | 0.081 | **M100** | |
| 0.011 | 0.179 | 0.101 | **Y100** | |
| 0.075 | **0.438** | 0.238 | **K100** | |
| 0.153 | 0.314 | 0.183 | **C100** | *P2* |
| 0.038 | **0.857** | **0.406** | **M100** | |
| 0.033 | 0.247 | 0.166 | **Y100** | |
| 0.055 | 0.199 | 0.144 | **K100** | |
| 0.119 | **0.451** | 0.201 | **C100** | *P3* |
| 0.012 | **0.583** | **0.394** | **M100** | |
| 0.013 | 0.085 | 0.260 | **Y100** | |
| 0.063 | 0.100 | 0.137 | **K100** | |

| Red (620-730)nm | Green (500-610)nm | Blue (380-490) | Spectrum Region | GFC |
|---|---|---|---|---|
| 0.9966 | 0.9706 | 0.9617 | **C100** | *P1* |
| 0.9999 | 0.9961 | 0.9967 | **M100** | |
| 0.9999 | 0.9826 | 0.9949 | **Y100** | |
| 0.9972 | **0.9057** | 0.9717 | **K100** | |
| 0.9888 | 0.9537 | 0.9832 | **C100** | *P2* |
| 0.9977 | **0.7073** | **0.9187** | **M100** | |
| 0.9993 | 0.9659 | 0.9863 | **Y100** | |
| 0.9985 | 0.9802 | 0.9896 | **K 100** | |
| 0.9929 | **0.9168** | 0.9799 | **C100** | *P3* |
| 0.9998 | **0.7219** | **0.9234** | **M100** | |
| 0.9999 | 0.9959 | 0.9664 | **Y100** | |
| 0.9979 | 0.9950 | 0.9907 | **K100** | |

h) Comparison of SAM values of Solid colors for Printer1, Printer2 & Printer3 (TableIV).

In this study, we also studied and compared the Spectral Angle Mapper (SAM) values between print and reprint samples, for the blue, green and red regions of the visible domain, and for the three different printers used. The lowest SAM values (lower than 0.1), for R, G and B regions, are for the solid color Magenta for Printer 1. As the corresponding color difference is acceptable for human observers, we could assume that SAM values lower than 0.1 correspond to non-significant spectral differences. Results shown in Table IV are not all coherent with results report in Table II, for example RMSE value for K color and Printer 3 is acceptable for B region but the opposite happens for SAM, inversely RMSE values for K color and Printer 3 are significant for G and B regions but the opposite happens for SAM. Likewise, results report in Table IV is not all coherent with Figures 2 to 13. Therefore, to analyze print and reprint samples, RMSE values should be used preferably to SAM values.

TableIV: SAM (Spectral Angle Mapper) of reflectance spectrum of solid C, M, Y, Kinks (100% of surface coverage) for three different printers between print and reprint. Highest SAM values (i.e. lower than 0.1) are surrounded by cell.

## CONCLUSION

By using the spectral curves of CMYK colors, it has been shown that the spectral curves of cyan, magenta, yellow and black inks printed and reprinted on blister foils are different for different printers. When a printed sample is scanned and reprinted by same output device, the spectral signature of the reprint differs from the original print. This property has been used to identify the original printer. In this study, the shape of spectral curves of few color inks printed and reprinted by different printers has been studied. The shape of spectral curves of few color inks printed and reprinted with same printer has been also studied. We assume that the shape of each spectral curve is unique for each specific ink/substrate combination. Hence if a print is scanned and reprinted, it can easily demonstrate whether it was printed by an original printer or not. It has been also shown that between print and reprinted samples, the RMSE (Root mean square error) values are different for different printers, especially in the red (380nm-490nm), green (500nm-600nm) and blue (610nm-730nm) regions of the visible domain. Hence, RMSE (Root mean square error) between print and reprinted samples can be used to authenticate the printer used among different printers. Other spectral or color difference metrics could be also used additionally to the RMSE metric used, but for this preliminary study RMSE of spectral differences was sufficient to identify the original printer.

Future work is required to test the robustness of the proposed threshold values from more print and reprint samples, and to develop an accurate model to identify authentic devices among other devices used to create counterfeited samples.

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