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Investigating the Possibility of Determining the Sequence Intersecting Lines between LaserJet Printing and Handwriting in Document Examination using Color Measurement Technique

Atefeh Tajik Esmaeili and Mahdi Safi
Department of Color Imaging and Color Image Processing, Institute for Color Science and Technology, Tehran, Iran
E-mail: mahdisafi@icrc.ac.ir

Maryam Ataeefard
Department of Printing Science and Technology, Institute for Color Science and Technology, Tehran, Iran

Alireza Mahmoudi Nahavandi
Department of Color Imaging and Color Image Processing, Institute for Color Science and Technology, Tehran, Iran

Abstract. *In Questioned Documents Examination, the sequence of crossing lines in the intersection of handwriting and printed area can be important clues for detecting tampered documents. Recognition of such documents is a arduous task and requires people with experience and expertise. In the present work, we investigated the possibility of determining the sequence of intersecting lines between LaserJet printing and handwriting for a series of simulated laboratory specimens in the document examination using color measurement technique. The spectral reflectance curves and color coordinates of some points on and out of the cross lines were compared. Four different commercial ballpoint pens and a black toner LaserJet were used to prepare the specimens. The color change of the intersecting lines was subjectively considered through the captured images and a visual assessment process. It was also objectively determined by determining the color difference values from the colorimetric data in CIELAB and CIELCH color spaces in the visible range. The color change evaluation showed that the order in which printing or handwriting is applied alters colorimetric results. Moreover, the investigations showed small color difference values of less than 2 units between a point of printed area individually, and intersection could be applied as a tolerance limit for pass/fail judgments.* © *2022 Society for Imaging Science and Technology.*
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1. INTRODUCTION

Forensic science encompasses several sub-fields that consider various aspects of criminal investigations. One important branch is "Questioned Documents Examination". Document authentication is so essential for any commercial activity, border security, and law enforcement organizations utilize these examinations as a discrete division of forensic science [1–3].

Much effort has been made to prepare precise shreds of evidence for document forgery determination. Different sciences such as analytical chemistry, physics, and printing are used to answer questions concerning documents for forensic document examiners. The examination of forgery cases relating to handwriting and signatures is of great interest. Specifically, determining the sequence of intersecting lines of writing and print, especially in a document signed in blank, is of great interest in this regard [3–6]. Trusted personnels mostly do this type of fraud by adding some sentences to the original document using printers. Consequently, a sequence of overlapped lines between the writing and print at the intersection points may be recognizable [7].

Many destructive and non-destructive methods have been developed to determine the sequence of intersecting lines from writing and print, such as Raman Spectroscopy, Scanning Electron Microscopy, Optical Microscopy, Profilometry, Hyper-spectral, Camera-spectral Imaging, Fourier Transform Infrared Spectral Imaging and Near-infrared Analysis [6, 8–13]. Braz et al. showed that the Raman-based techniques have a great potential for chemical discrimination of ink signatures in questioned documents by its composition analysis [14]. Moreover, they applied the Raman imaging technique as a non-destructive surface analysis method to determine the sequence crossing of blue pen ink lines. Similar to the Raman technique, this method provides specifying chemical information of two intersection lines [15]. Mann et al. implemented another non-destructive technique with a confocal microscope. This optical technique's three-dimensional application for inks' homogeneous intersecting lines was associated with satisfactory results on average in 81% of samples [16]. Saini et al. showed that Illuminating angle and intersection magnification have an essential impact on detecting sequences' correct order. They also evaluated the sequence of intersecting lines descriptively by surface optical properties such as spectral reflection and sheen at the intersection point. The results showed an observation at the angle of 15° provides better recognition for

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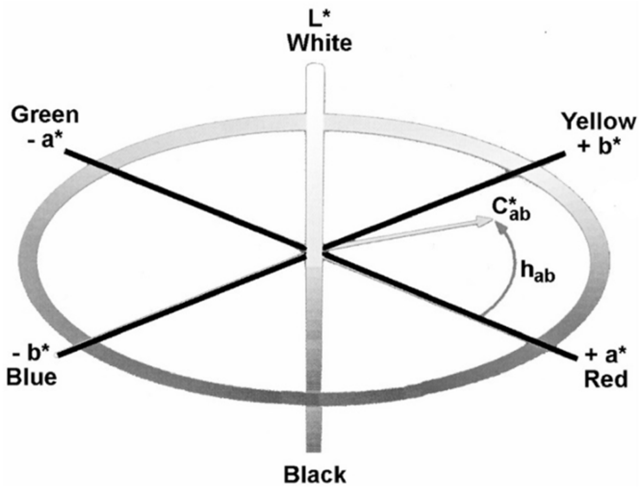

Figure 1. CIELAB and CIELCH color space [23].

Figure 2. The visual assessment experiment.

the sequence of intersecting lines [17, 18]. Another study has shown that the use of fluorescence technique to determine the sequence of strokes works well except for the blending cases. Moreover, it has been pointed out that parameters such as color shade, aging of the strokes, pigment distribution, etc., influence the experiment results significantly [19].

In recent years, significant attention has been paid to developing a reliable solution or an effective technique to determine the sequence of printing and ink crossings. Despite obtaining good results, in some cases, the applied methods have been sophisticated or chemically destructive. Few of the proposed methods provided insufficient information, and the acquired results were uncertain and confounding for the examiners [2, 8]. Using combined techniques such as Raman spectroscopy in combination with nanotechnology, improved identification and detection was possible from even a tiny quantity of sample, a typical scenario in forensics [20]. In many research studies, color measuring was utilized to analyze the optical properties of materials. The colorimetric technique, a fast, simple, and non-destructive method, appears to be a good alternative to time-consuming and hard-laboring processes [3]. Vaid et al. showed that the sequence of intersecting lines could objectively be considered by studying measured reflectance data from the intersection points of two intersecting strokings; however, the obtained results were inconclusive or inapplicable in some cases [8].

The color appearance of an object could be evaluated by visual and instrumental measurements [21]. Visual assessments are influenced by physiological, experiential, and environmental factors. Consequently, it is difficult to achieve a definitive conclusion to determine the sequence of handwriting and printing in document forgery. Because of these diagnoses' qualitative nature, instrumental evaluations have been introduced as quantitative and objective methods to express numerical value for color and color difference. Thus, it is preferable to assign the tampering decision to an accurate algorithm.

A spectrophotometer measures the spectral data, the amount of incident light energy reflected from an object at 10 nm intervals along the visible spectrum, 400–700 nm. These measurements result in reflectance spectra, which are interpreted in a spectral curve's so-called fingerprint. Color is a three-dimensional property of a material that is arranged using three scales as h^0: hue angle, L^*: lightness, and C^*: chroma in the CIELCH color space and L^*: lightness, a^*: redness-greenness, b^*: yellowness-blueness in the CIELAB color space. In other words, the three-dimensional uniform color spaces CIELAB and CIELCH have been recommended by the International Commission on Illumination (CIE) to describe an object's color [22, 23]. Figure 1 depicts these two color spaces. For an ideal achromatic color like a gray, a^*, and b^* coordinates approach zero, and for more saturated or intense colors, it increases in magnitude.

The color of an object is determined by the tristimulus values X, Y, and Z. These quantities are determined through the modification of an illuminant's spectral power distribution, $\mathbf{E}_\lambda$ by the reflectance factor of the object, $\mathbf{r}_\lambda$ achieved through a specific color measurement geometry. The resultant projection on the color vision of a standard observer with color-matching functions given as $\bar{\mathbf{x}}_\lambda$, $\bar{\mathbf{y}}_\lambda$ and $\bar{\mathbf{z}}_\lambda$ and wavelength between 400 and 700 nm is integrated to calculate the object's color (Eqs. (1)–(3)).

$$X = k \sum_{400}^{700} E_\lambda r_\lambda \bar{x}_\lambda \tag{1}$$

$$Y = k \sum_{400}^{700} E_\lambda r_\lambda \bar{y}_\lambda \tag{2}$$

$$Z = k \sum_{400}^{700} E_\lambda r_\lambda \bar{z}_\lambda \tag{3}$$

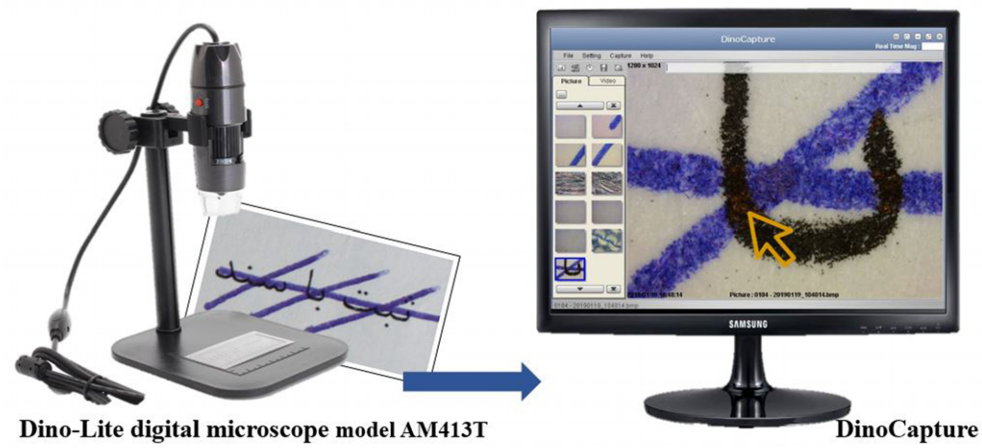

Figure 3. A scheme to represent the captured images.

K is a normalizing constant given by Eq. (4):

$$k = \frac{100}{\sum_{400}^{700} E_\lambda \bar{y}_\lambda}. \tag{4}$$

For better uniformity, the tristimulus values have been developed to the CIELAB and next the CIELCH color coordinates represented by the following Equations:

$$L^* = 116(Y/Y_n)^{1/3} - 16 \tag{5}$$
$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}] \tag{6}$$
$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}] \tag{7}$$
$$C^* = (a^{*2} + b^{*2})^{1/2} \tag{8}$$
$$h^0 = \mathrm{Arctan}(b^*/a^*), \tag{9}$$

where, X, Y and Z are the CIEXYZ tristimulus values of object and X_n, Y_n and Z_n indicate those of the perfect reflecting diffuser, i.e., the illuminant. It should be noted that here in Eqs. (5)–(7), the values of X/X_n, Y/Y_n, and Z/Z_n are greater than 0.00855 [24]. Additionally, other important one-dimensional indexes such as color difference formulas are used to measure the objects' color difference as a Euclidean distance between two colors in a color space. The CIE has recommended different industrial color difference formulas. The CIELAB 1976 (ΔE^*_{ab}) formula ((Eq. (10)) that estimates the visually perceptible color difference is calculated from ΔL^*, Δa^*, and Δb^*. Δ is the difference between a sample minus its reference. Further improved color difference formulas are being investigated by CIE [25].

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}. \tag{10}$$

Despite much research on forgery detection, to the authors' knowledge, very little attention has been paid to investigating the application of colorimetric data to evaluate a document forgery [26, 27]. Colorimetry techniques provide solutions that determine the object's color by measuring the reflected or transmitted light. The colorimetric numerical values correlate to the human visual system. This study aimed to investigate the possibility of determining the sequence of the simulated laboratory strokes of handwriting and printing on a document examination through the color measurement technique. The fundamental premise is that the order in which printing or writing is applied alters colorimetric results.

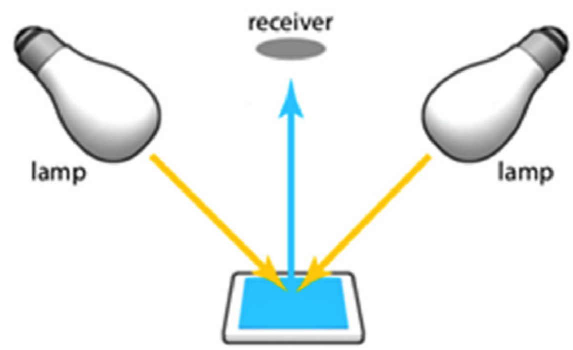

Figure 4. Set up of the 45° a:0° geometry of the illuminant and observation for measuring the reflectance data.

2. MATERIALS AND METHODS

2.1 *Specimen Preparation*

A commercial ballpoint pen from the Bic brand in four colors of blue, black, green, and red as well as from a domestic maker and a toner LaserJet printer model HP 1320 series were used in this study. A set consisting of 50 specimens simulating document forgeries of crossing lines between handwriting and printing was prepared on an A4-size white sheet of uncoated paper. They were categorized into four series and coded as shown in Table I. The points' color components on and out of the intersection were compared in each series, and the color difference values were calculated. For instance, the P/POI code points to the printing area (P) individually and a part of printing on the handwriting zone (POI). The duration

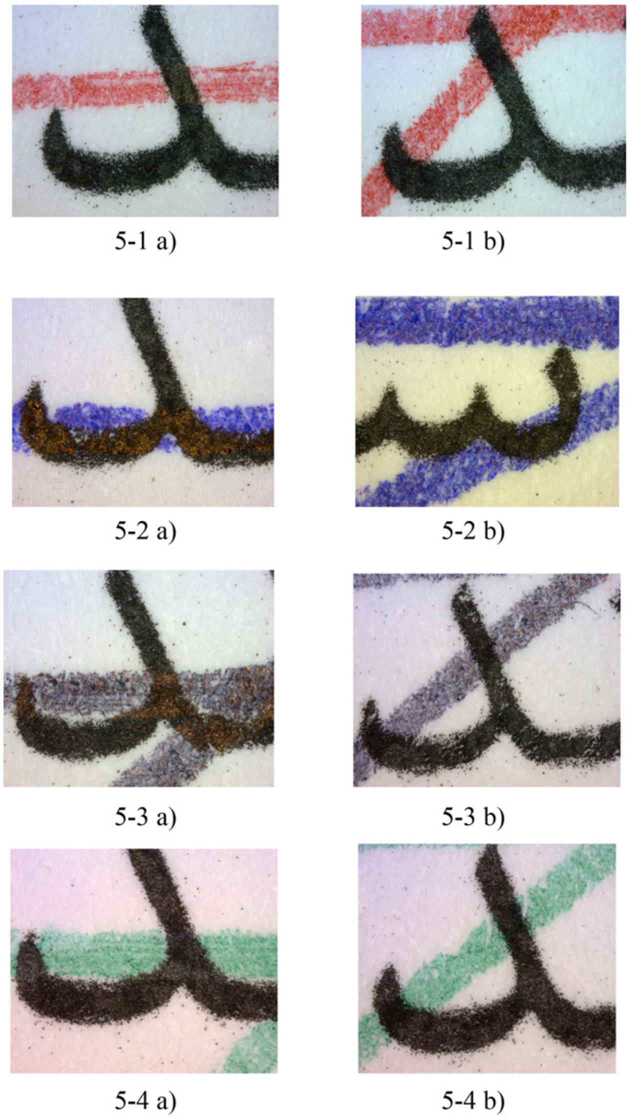

Figure 5. The captured images from the different colors' intersecting lines. 5-1(a) red ink - handwriting on print (IOP). 5-1(b) red ink - print on handwriting (POI). 5-2(a) blue ink - handwriting on print (IOP). 5-2(b) blue ink - print on handwriting (POI). 5-3(a) black ink - handwriting on print (IOP). 5-3(b) black ink - print on handwriting (POI). 5-4(a) green ink - handwriting on print (IOP). 5-4(b) green ink - print on handwriting (POI).

Table I. Coding and definition of specimens (experimental conditions).

No.	Condition	Code
1	Printing individually / printing on handwriting	(P/POI)
2	Printing individually / handwriting on printing	(P/IOP)
3	Handwriting individually / handwriting on printing	(I/IOP)
4	Handwriting individually / printing on handwriting	(I/POI)

of specimen preparation and drying was empirically set to one hour. Moreover, the handwriting pressure was kept constant during the preparation steps.

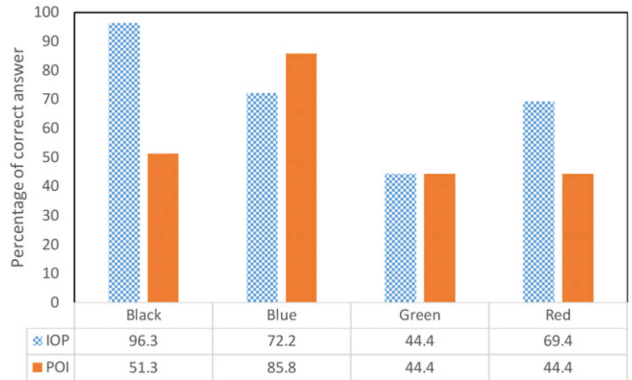

Figure 6. Visual assessment results.

2.2 *Visual Assessment*

This study investigated an alternative quantitative method for determining intersecting strokes of handwriting and printing on a document examination. Commonly, signature verification and forged/false documents recognition for police are done by forgery experts through visual and intuitive evaluations as primary methods. Consequently, to evaluate the accuracy of visual and qualitative assessment, a visual assessment experiment was designed (Figure 2).

Ten trained participants aged 30–40 were selected and tested for normal color vision using the Ishihara test before participating in the visual assessment experiment. A SAMSUNG SyncMaster T1900 21-inch. monitor was used to display the captured images. The visual experiments included 30 captured images displayed on a CRT monitor one by one under constant and controlled illumination. The participants were asked to judge and compare the images of intersecting lines to determine the sequence of handwriting and printing. The verbal responses were consolidated to determine the percentage of correct answers.

An internally white LED light-equipped AM413T Dino-Lite digital microscope as shown in Figure 3 captured the images with 200× magnification in the visible region of the electromagnetic spectrum.

The black level and peak luminance levels were measured at 0.27 and 174.86 cd/m^2, respectively. The white point of the used monitor was set close to D65, 10° observer with the chromaticity $x = 0.314$ and $y = 0.331$. To avoid the ambient light's effect, a completely dark room was selected for the visual assessment process. The warming up of the monitor was at least 30 min.

2.2.1 *Color Measurement*

A Konica Minolta CS-2000 spectroradiometer was used to measure the spectral reflectance data with a configuration of 45° a:0° geometry of the illuminant and observation (Figure 4) between 400 and 700 nm at 10-nm intervals. A 45° a:0° geometry indicates that an object has been illuminated at 45° and viewed directly at 0°. The CIELAB and CIELCH color spaces were chosen to present the specimens' color coordinates under D65/10° (the D65

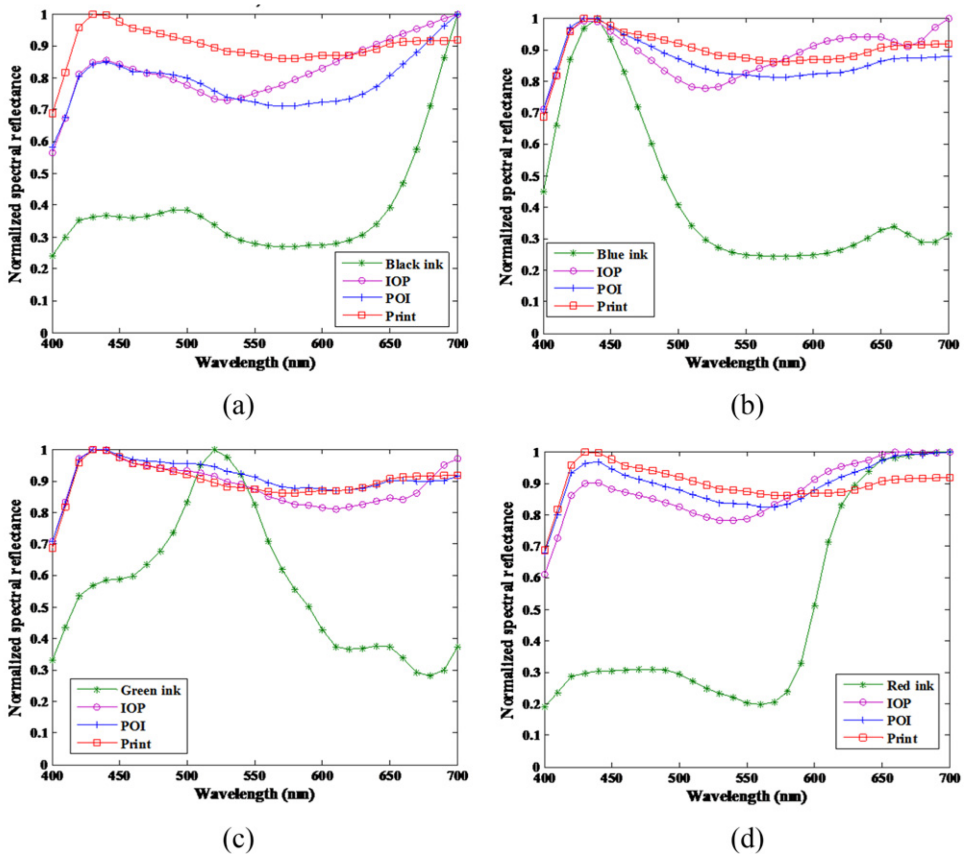

Figure 7. The normalized spectral reflectance curves for the different color strokes intersect with the printing in both POI and IOP statuses.

illuminant and the CIE 1964 (10°) degree standard observer). The color difference values between two-point at Table I. were calculated using the CIELAB 1976 color difference formula ((Eq. (10)) as a standard and widely used equation.

3. RESULTS AND DISCUSSION

Figure 5 displays the captured images for a specimen of printing line on handwriting (POI) and vice versa, a handwriting stroke on printing (IOP) in four colors: red, blue, black, and green. In Fig. 5-1(a), 5-2(a), 5-3(a), and 5-4(a), the handwriting stroke is above the printed text. Conversely, Fig. 5-1(b), 5-2(b), 5-3(b), and 5-4(b) show that the printed text is above the handwriting stroke.

For instance, comparing Fig. 5-1(a) and 5-1(b) shows when the handwriting stroke is above, the intersection's appearance has a specific brightness with a highlight reddish effect. This effect can be observed more or less in other cases. This result is, to some extent, caused by the specular reflection from the surface and the mechanism of print processing. Moreover, most inks' formulations are composed of more than one colorant. Consequently, for a shade like reddish-blue (a regular blue pen), at the intersection point where handwriting stroke is on the black printing, the high adsorption of black makes a red color change in the handwriting ink.

As mentioned above, 30 captured images were displayed on the monitor under constant and controlled illumination during the visual experiments. The participants were asked to compare the images of intersecting lines to determine the sequence of handwriting and printing. The preliminary evaluation of the participants as a percentage of correct answers was analyzed and presented in Figure 6 for both statuses, handwriting on print (IOP) and vice versa (POI).

The results of Fig. 6 show that 96.3% of the answers were corrected for the black color in the IOP status. The minimum consistency was achieved for the green and red color specimens. No significant correlation and trend was observed between the different colors and both statuses, i.e., handwriting on print (IOP) and print on handwriting (POI). Moreover, it can be seen that responses to the different colors differ to a certain extent. One of the reasons is that the human eye's sensitivity and acuity vary from person to person across the spectrum's visible range, often causing different color decisions and discrepancies in the results.

Additionally, factors such as image capture conditions and the digital camera's white balance setting that affect the decision, should be controlled. For instance, the camera's white balance is generally set to work automatically and it could change the overall color tone of images. Besides, the layers' properties of different ink formulations and print on each other affect the intersection point's perceived color. As

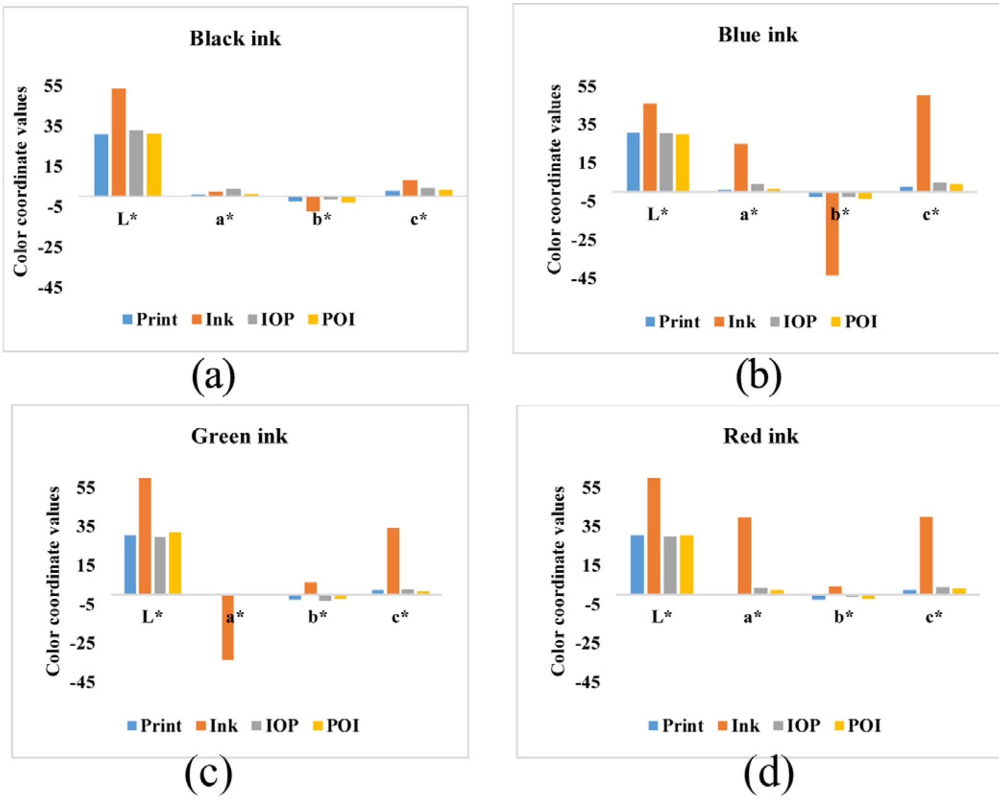

Figure 8. The color coordinates for the different specimens of Figure 7.

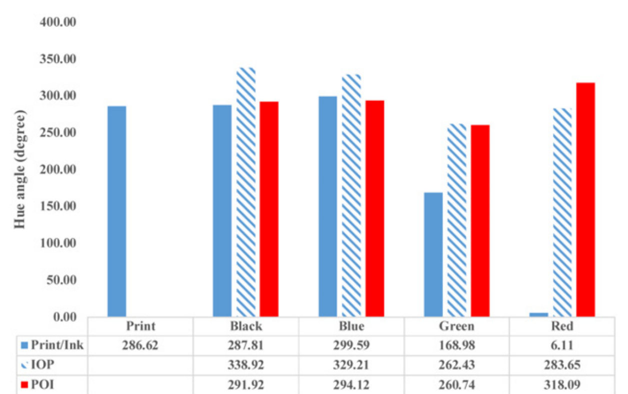

Figure 9. The hue angle values for the specimens of Fig. 7.

Table II. Color difference values for different statuses.

Status	Color difference value (ΔE^*_{ab})			
	Black	Blue	Green	Red
Printing/printing on handwriting (P-POI)	0.72	1.81	1.80	1.60
Printing/handwriting on Printing (P-IOP)	3.88	3.29	1.73	3.33
Handwriting/handwriting on printing (I-IOP)	21.38	48.47	56.43	50.46
Handwriting/printing on handwriting (I-POI)	22.97	48.87	54.40	50.83

a result, the penetration depth or ink and film thickness distribution change the perceived color of the surface.

Fig. 7 shows the normalized spectral reflectance curves for the black, red, blue, and green strokes individually and intersecting with the printing in both POI and IOP statues. The data are normalized when seeking the relations and transforming all data variables to a specific range and an equal scale. It makes it easier to compare the variations. The spectral reflectance curves are also presented in Appendix A (Figure A1).

Suppose there was no intermixture at the intersection point of ink and print. In that case, that is to say, a physically simple overlapping, the resulting surface reflectance curve corresponds to and is similar to the top layer one, which may be a layer of ink or printing. It is evident from Fig. 7 that handwriting ink and printing have been modified each other's spectral behavior at the intersection point. In other words, the results show that the spectra at the intersection point do not match and are not similar to any of the applied ink or printing. However, it was expected the depicted reflectance graphs at the intersection point should be matched to those shown by either handwriting ink or printing individually. The amount of adsorption could be affected by parameters such as type of paper, ink formulation, and print processing that subsequently change the component's spectral behavior at the intersection point.

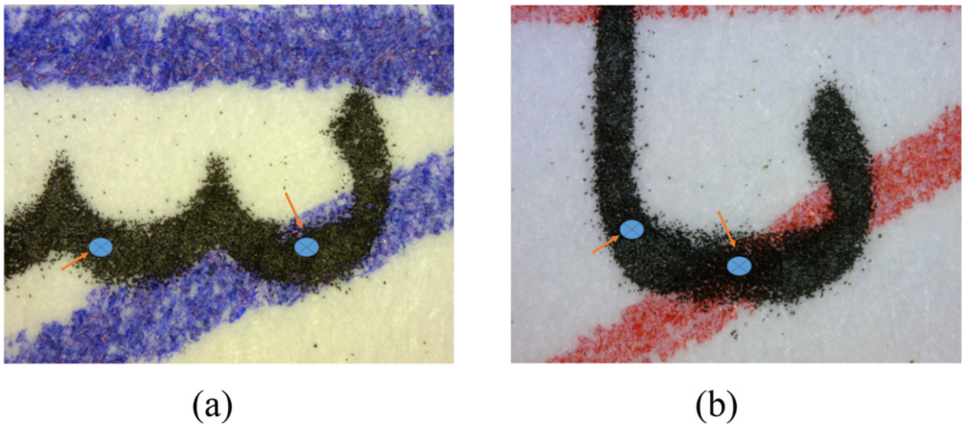

Figure 10. Proposed points to detect the sequence of handwriting and printing. (a) Red ink (handwriting on printing). (b) Blue ink (handwriting on printing).

Moreover, as shown in Fig. 7, the studied blue ink (as mentioned above in Fig. 5) showed a rise in the spectral reflectance on the red part of the spectrum. Although a black toner can be regarded as an opaque media provided that the printing layer is optically thick enough, it can be considered as a translucent material in practice. The peak about 430 nm in Fig. 7 corresponding to the legend "Print" confirms this. It shows the fluorescence emission of the paper, which the black toner layer has not fully absorbed. When the pen lines pass over the prints (IOP), the total reflectance comes down substantially. However, the chroma of the IOP, governed by the ratio of the long peak of the blue part to the small red peak (blue ink), decreases due to the synergistic absorption power of the black toner and the ink layer. In other words, the higher absorption power of the toner-ink layer causes lower excitation and consequently lower fluorescence emission in the IOP regions. This can highlight the role of the small red peak of the spectrum and shift the total color into a reddish effect, as observed in Fig. 5-2(a).

The same rationale could be used for the black ink as it also shows a rise in the long wavengths of the spectrum. It is confirmed by the reddish effect at IOP as can be seen in Fig. 5-3(a). As the small red peak does not exist for the green ink reflectance spectrum, the reddish tint will not be seen in IOP. This could be seen in Fig. 5-4(a). A small lighter appearance of the IOP region could be simply attributed to the surface reflection of the inks' resin. This phenomenon is also the case for the red ink IOP, as shown in Fig. 5-1(b). It should be noted that the resin may darken the appearance as is the case for the laminated color prints, however the surface reflection effect has overcome this. In Figures 8 and 9, the colorimetric data for the specimens of Fig. 7 was calculated. The depicted color coordinates were the averaged results of six repeated measurements.

It is evident from Figs. 8 and 9 that the color coordinates of the intersection point are different from each one of handwriting and printing. Moreover, the amount of color change significantly varies from the IOP to POI specimens in each color. The variation of a^* and C^* components is more sensible while the handwriting is located on the printing (IOP status). This is probably due to the minor long-wavelength peaks of the inks' reflectance spectra, as elucidated earlier. In the case of green color, no difference between the two statuses was noted, presumably due to the lack of a second minor peak in the green ink's reflectance. Here, a meaningful suggestion that could be made is official documents should not be signed in green ink. The color difference values of the above specimens are reported in Table II.

Table II indicates a specific significant difference in the value of ΔE^*_{ab} especially when a point of handwriting is compared with an intersection point of handwriting-printing in both cases, IOP and POI, clearly due to opacity of the printer toner. The obtained color difference value for the printed area compared with the intersection point of handwriting-printing (P-POI) is less than 2 units ΔE^*_{ab}. No specific discernment of the sequence was provided for the IOP case with the obtained significant color difference. It could be due to the ink film transparency that is usually more than the print layer.

As a result of color measurement application to determine the sequence of intersecting handwriting and printing lines in a document forgery, it is suggested that a point of print area individually is compared to a point or an area of intersection. This issue is graphically illustrated in Figure 10 for two colors, red and blue. A small and acceptable color difference value between the printed area and intersection point confirms that the printing layer is located on the top.

Furthermore, an instrumental color tolerance from the acquired instrumental and visual data could be set for pass-fail acceptability judgments. The specimen pairs with color differences less than or equal to the tolerance limit are acceptable. On the other hand, specimens with color differences beyond the tolerance limit are unacceptable. This issue is under consideration.

4. CONCLUSION

At the present work, we attempted to investigate the application of colorimetric data to determine the sequence of intersecting lines by comparing the color components of the points on and out of the handwriting and printing intersection. Although visual assessment is a prevalent and reliable method of identification, they are subjective, and in some cases, the results are influenced by individual and environmental factors. Consequently, it is difficult to achieve a logical conclusion to determine the sequence of handwriting and printing in document forgery. The obtained results considered four commercial inks and a toner printed text and showed that handwriting (pen line) on the printed area is accompanied by a sensible brightness and a color-shifting effect in the spectrum's red part.

As a result of the colorimetric analysis, it is suggested that a point of the printed text area individually should be compared to the point of intersection of used printing and handwriting. An instrumental color tolerance for pass-fail acceptability judgment is also suggested and defined.

The non-destructive technique of colorimetry in combination with other available methods is recommended for efficiency in identifying forensic documents more precisely. It can easily be demonstrated in a court of law to help the judiciary improve the conviction rate. The only shortcoming in using the color measurement technique is that the best results are obtained in the homogeneous crossings.

APPENDIX A

The spectral reflectance curves for the Fig. 7 are presented below. The second vertical axis of reflectance on the right belongs to the printing.

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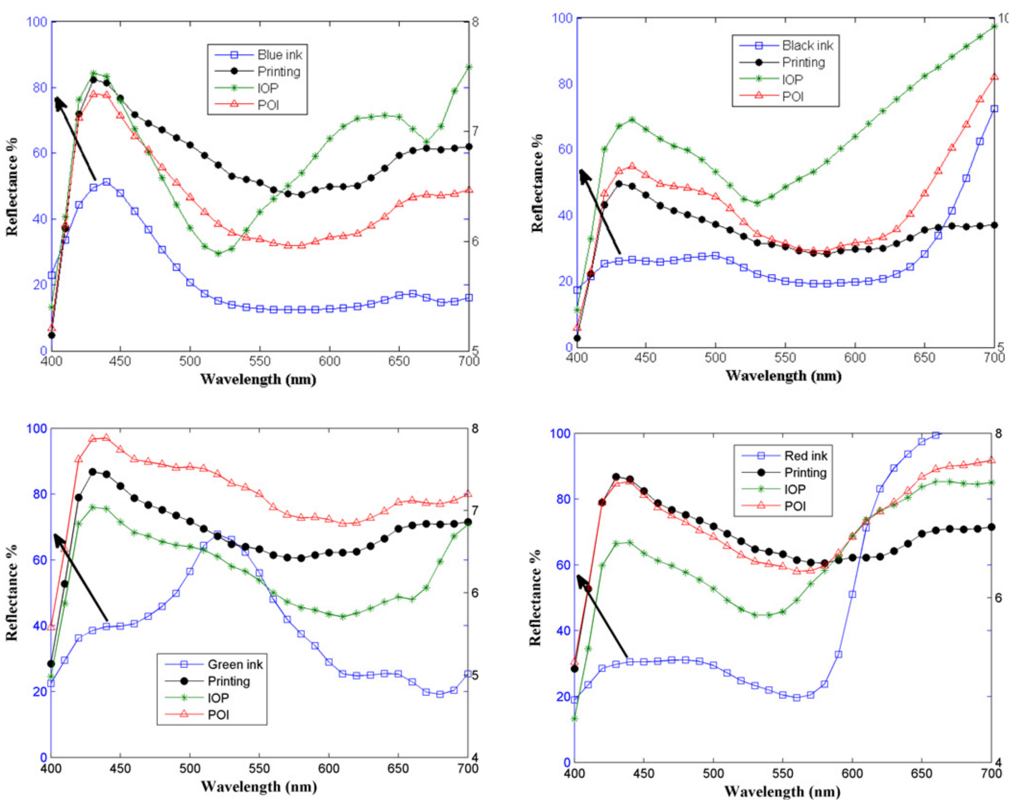

Figure A1. Spectral reflectance curves for the different color strokes intersect with the printing in both POI and IOP statuses

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