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Sequencing of Intersecting Strokes of Printed Ink Lines with Writing Pen Inks Using Image Processing Software

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Abstract

Determining the sequence of intersecting strokes is a longstanding challenge in questioned document examination, particularly with the widespread use of computer printers and writing instruments in modern documents. This study aimed to establish the sequence of intersecting strokes between laser printer toner, inkjet printer inks, and ballpoint and gel pen inks using Adobe Photoshop CC 2021. A total of 2,880 intersecting stroke samples were prepared using laser and inkjet printers with ballpoint and gel pens on different paper substrates. The samples were analysed through image processing based on characteristics such as toner compression, toner expansion, and luminous appearance at the point of intersection. The proposed method successfully determined the sequence in 2,304 (80%) of the samples. Homogeneous combinations of red and blue inkjet printer inks with corresponding pen inks produced inconclusive results. The findings demonstrate that Adobe Photoshop provides a simple, objective, cost-effective, and non-destructive approach for sequence determination, offering a practical alternative for routine forensic document examination.

Keywords: Questioned documents, Intersecting lines, Writing inks, Image enhancement, Printers, Luminescence, Toner.

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Introduction

Questioned document examination plays a vital role in forensic science by authenticating disputed documents. One of its major challenges is determining the sequence of intersecting strokes, which establishes the order in which writing and printing materials were applied. This information is crucial in detecting document forgery, alterations, and tampering, particularly in legal and financial documents where additional text, signatures, or numerical entries may have been fraudulently added.[1-4]

The establishment of the sequence of crossing strokes is an extremely complex and challenging act since it depends upon the nature and colour of crossing ink strokes.[5,6] Many studies based on the sequencing of homogeneous and heterogeneous intersecting strokes have been reported over the decades. Traditional methods, such as optical microscopy, scanning electron microscopy (SEM), and Raman spectroscopy, have been employed to study the sequence of intersecting strokes. While these techniques are effective, they often require expensive equipment and highly skilled operators, making them less accessible for routine forensic examinations.[7,8] Advancements in techniques offer a non-invasive, cost-effective, and efficient alternative for determining the sequence of intersecting strokes. For example, image processing utilises computational algorithms to analyse visual data, enabling precise differentiation between ink layers based on their texture, colour, and spatial characteristics.[9] These techniques also allow for the digital enhancement of subtle features, such as boundary overlap and pressure effects, which are critical in stroke sequence analysis. However, challenges remain in standardising these methods for various ink types, substrates, and overlapping patterns. This paper aims to explore the application of image processing techniques to determine the sequence of intersecting strokes of printer inks and writing inks. By addressing these challenges, the study seeks to provide a reliable framework for forensic practitioners to enhance the objectivity and accuracy of document examinations.

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Materials & Methods

For this study, two brands of each laser printer, inkjet printer, gel pen and ballpoint pen were chosen. Intersecting stroke samples were prepared by using a laser printer (black colour ink), an inkjet printer (red, blue, black ink), a ballpoint pen and gel pen inks of each red, blue and black colour (Table 1). The intersections were prepared on three types of substrates, i.e., A3 stamp paper (215 x 297 mm), A4 JK copier paper, 75 GSM and A4 bond paper (JK paper excel bond), 100 GSM. Black laser-printed text was first printed on paper and intersected with red, blue, and black ballpoint pen strokes. Conversely, pen

Table 1: Writing instruments and printing devices utilised to create intersecting strokes.

S. No.	*Writing Instrument/Printer*	*Colour of ink/toner*	*Brand*
1	Gel pen	Red, blue, black	Rorito, Linc geltonic
2	Ballpoint pen	Red, blue, black	Butterflow, Linc Pentonic
3	Laser printer	Black	HP 1005 MFL, Brother DCP-L2520D
4	Inkjet printer	Red, blue, black	Epson L360, CanonPixma E470

strokes were prepared first, followed by laser printing to obtain both sequence combinations. Five intersections were selected for each colour combination. This procedure was repeated using two laser printer brands, two ballpoint pen brands, and three paper substrates, resulting in 360 laser printer–ballpoint pen intersections. The same protocol was followed for gel pens, producing an additional 360 intersections. Thus, a total of 720 laser printer intersections were prepared. Using the same experimental design, 2,160 inkjet printer intersections were generated. Overall, 2,880 intersecting stroke samples were prepared for analysis.

Blind Study

Five known samples from each type of intersecting stroke of laser printer stroke (black), inkjet printer strokes (red, blue and black) with ballpoint pen and gel pen ink strokes (red, blue, black) were prepared for the blind study. Every blind sample has been examined under each technique. The key for samples was kept aside to be used later on examination for verification.

Image Processing Technique

Introduction to Adobe Photoshop

Adobe Photoshop is an image editing software that was previously used by researchers to differentiate different colours of ink strokes and to examine manipulations in digital documents.[10,11] For the examination of samples of intersecting strokes, the various settings of Adobe Photoshop have been used. The samples of intersecting strokes were examined using Adobe Photoshop CC 2021.

Operating procedure to examine a sample of crossing lines using Adobe Photoshop CC 2021

The samples of intersecting strokes were first photographed and then transferred to a computer system with the Adobe Photoshop cc 2021 software. The photographs of samples were then uploaded into the software. Ctrl +J keys were first applied to form the layer of the sample. The layered sample

Table 2: Laser printer text with gel and ballpoint pen ink lines using Adobe Photoshop

Laser Printer text	*Ballpoint pen ink lines*					
	Red		*Blue*		*Black*	
	Above	*Below*	*Above*	*Below*	*Above*	*Below*
Black	Compression of laser toner Expansion of laser toner Luminous appearance in pen ink	No Compression of laser toner No Expansion of laser toner No Luminous appearance in pen ink	Compression of laser toner Expansion of laser toner Luminous appearance in pen ink	No Compression of laser toner No Expansion of laser toner No Luminous appearance in pen ink	Compression of laser toner Expansion of laser toner Luminous appearance in pen ink	No Compression of laser toner No Expansion of laser toner No Luminous appearance in pen ink
Laser Printer Text	*Gel pen ink lines*					
	Red		*Blue*		*Black*	
	Above	*Below*	*Above*	*Below*	*Above*	*Below*
Black	Compression of laser toner Expansion of laser toner Luminous appearance in pen ink	No Compression of laser toner No Expansion of laser toner No Luminous appearance in pen ink	Compression of laser toner Expansion of laser toner Luminous appearance in pen ink	No Compression of laser toner No Expansion of laser toner No Luminous appearance in pen ink	Compression of laser toner Expansion of laser toner Luminous appearance in pen ink	No Compression of laser toner No Expansion of laser toner No Luminous appearance in pen ink

Table 3: Inkjet printed text with gel and ballpoint pen ink lines using Adobe Photoshop

Inkjet Printer text	*Ballpoint pen ink lines*					
	Red		*Blue*		*Black*	
	Above	*Below*	*Above*	*Below*	*Above*	*Below*
Black	Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink
Red	No Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink
Blue	Luminous appearance in the pen ink	No Luminous appearance in the pen ink	No Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink
Inkjet Printer Text	*Gel pen ink lines*					
	Red		*Blue*		*Black*	
	Above	*Below*	*Above*	*Below*	*Above*	*Below*
Black	Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink
Red	No Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink
Blue	Luminous appearance in the pen ink	No Luminous appearance in the pen ink line	No Luminous appearance in the pen ink	No Luminous appearance in the pen ink	Luminous appearance in the pen ink	No Luminous appearance in the pen ink

was then converted into a smart object. The purpose behind the conversion of a sample image into a smart object was that, upon applying specific tools and functions, the pixel quality of the image would not be affected. After this, by using the Ctrl + I key, the smart image was changed to a negative form. Up to this point, the steps are common for every type of sequence of intersecting strokes of laser-printed text with ballpoint ink of a different colour.

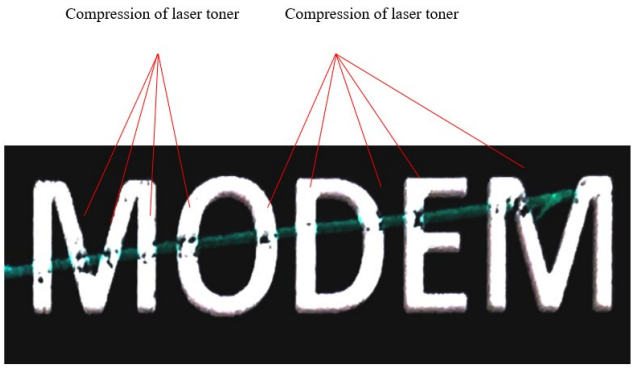

Figure 1: Showing compression of laser toner at an intersection point when red ballpoint pen ink line intersected black laser printed on A4 office paper using Adobe Photoshop

Features examined using Adobe Photoshop

The following features were observed at the area of intersection using Adobe Photoshop

- *Luminous appearance*

Glow observed in the pen ink when it overlies the printed stroke.

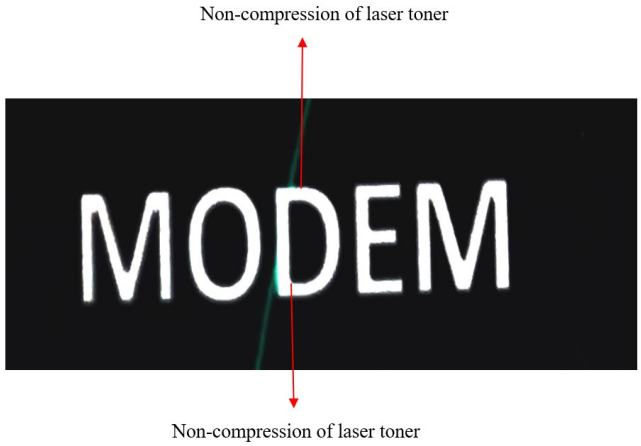

Figure 4: Non-compression of laser toner at an intersection point when black inkjet printed text intersected red ballpoint pen ink line on A4 office paper using Adobe Photoshop.

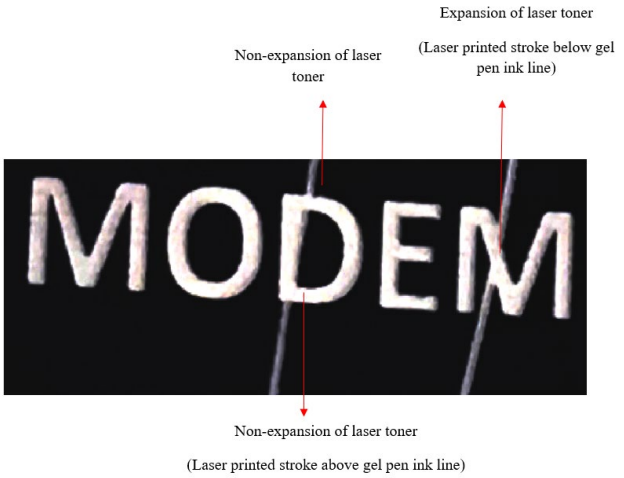

Figure 2: showing expansion and non-expansion of laser at an intersection point when black gel pen ink line intersects or intersected by black laser printed text on bond paper using Adobe Photoshop

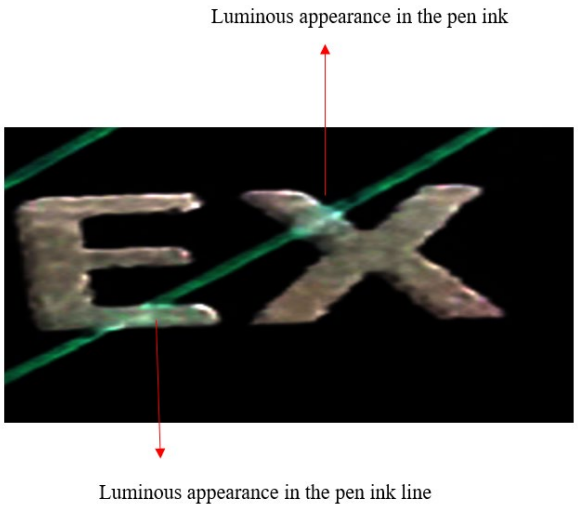

Figure 3: Luminous appearance in the pen ink at an intersection point when a red gel pen ink line intersected black laser-printed text on stamp paper using Adobe Photoshop.

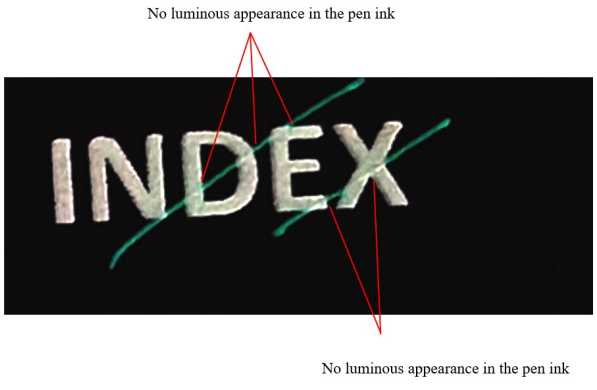

Figure 7: No luminous appearance in the pen ink at an intersection point when red ballpoint pen ink lines are intersected by black laser-printed text on bond paper using Adobe Photoshop.

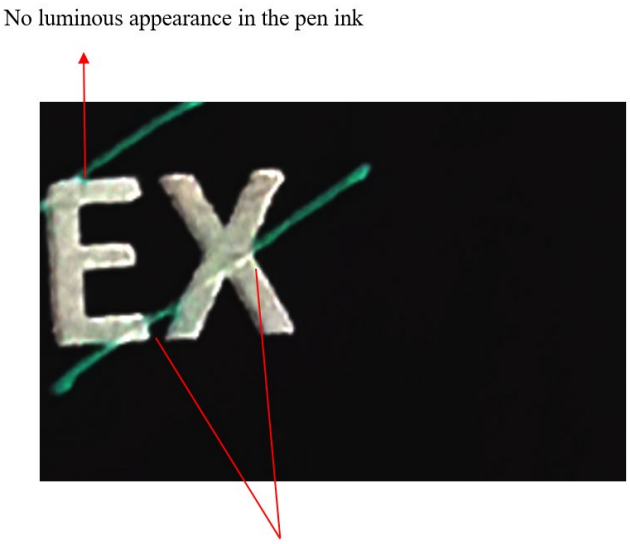

Figure 5: No luminous appearance in the pen ink line at an intersection point when black inkjet-printed text intersected red gel pen ink line on stamp paper using Adobe Photoshop.

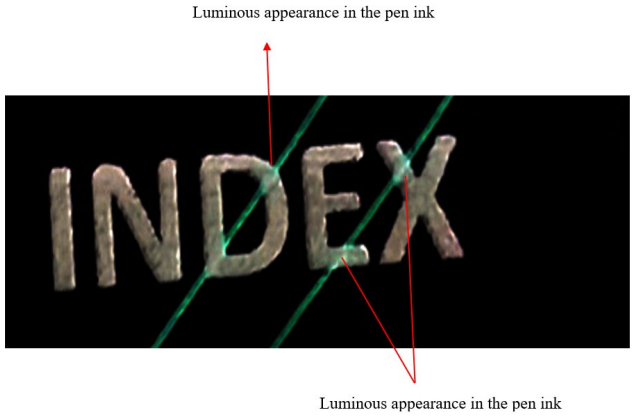

Figure 6: Luminous appearance in the pen ink at an intersection point when a red ballpoint pen ink line intersected black laser-printed text on bond paper using Adobe Photoshop

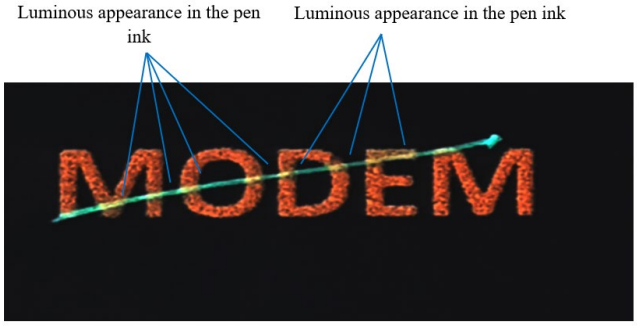

Figure 10: Luminous appearance at the intersection of red gel pen ink and blue inkjet-printed text on bond paper

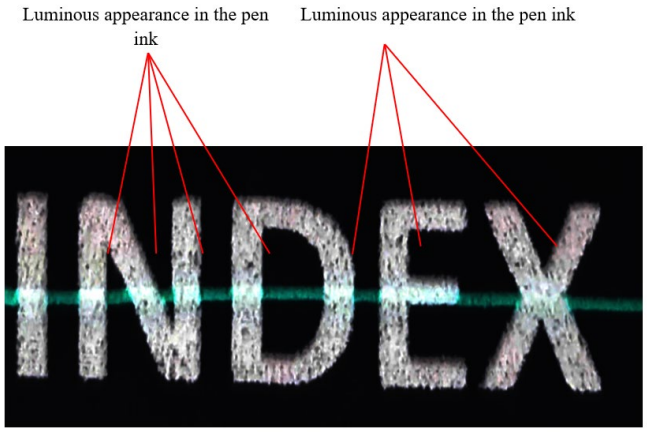

Figure 8: Luminous appearance in the pen ink at an intersection point when a red ballpoint pen ink line intersected black inkjet printed text on A4 office paper using Adobe Photoshop.

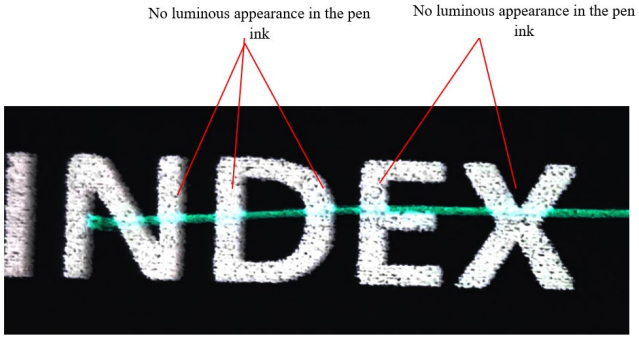

Figure 9: Luminous appearance in the pen ink at an intersection point when a red ballpoint pen ink line is intersected by inkjet-printed text on A4 office paper using Adobe Photoshop.

- *Laser toner expansion*

Outward spreading of laser toner at the intersection when crossed by another writing or printing medium.

- *Laser toner compression*

Partial deformation or breakdown of laser toner caused by pen pressure at the intersection.

Result & Discussion

Establishment of the sequence of intersecting strokes using Adobe Photoshop CC 2021.

Results

The results of sequence determination are summarised in Tables 1, 2, and 3.

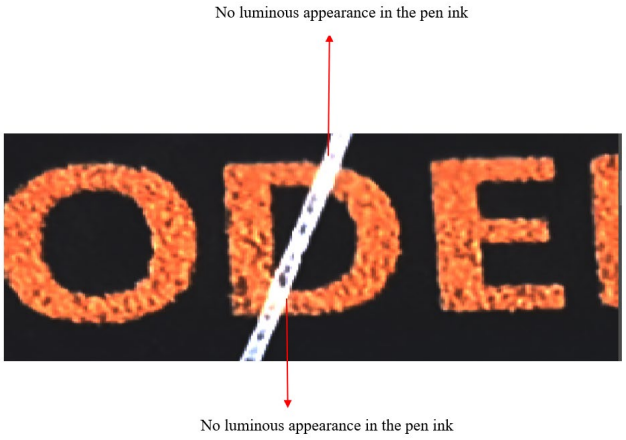

Figure 11: No luminous appearance at the intersection of black gel pen ink and blue inkjet-printed text on bond paper.

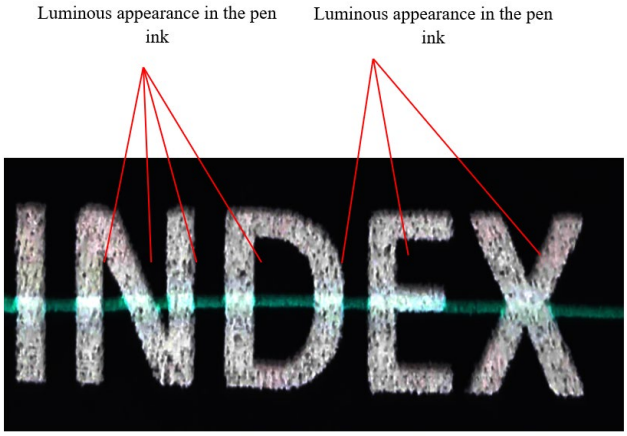

Figure 12: Luminous appearance in the red ballpoint pen ink at the intersection with black inkjet-printed text on A4 paper (Adobe Photoshop).

Discussion

Laser printer text (black) with ballpoint and gel pen inks (red, blue, and black)

When the pen ink crossed the laser-printed text, compression and expansion of laser toner, along with a luminous appearance in the pen ink, were observed at the intersection (Figures 1–3). Toner compression was evident only in samples written with higher pen pressure, whereas luminous appearance was observed in samples with lighter pen pressure and served as a reliable indicator for sequence determination. In contrast, when the laser-printed text was deposited over the pen ink, no toner compression, expansion, or luminous appearance was observed because the pen ink was covered by the toner layer (Figures 4 and 5). Similar observations were obtained

for all pen brands and on all three paper substrates (Figures 6 and 7). These findings demonstrate that toner compression, toner expansion, and luminous appearance are reliable characteristics for determining the sequence of intersecting strokes between laser printer toner and writing pen inks.

Inkjet printer text (red, blue, and black) with ballpoint and gel pen inks (red, blue, and black)

Exposure, gamma correction, and offset settings in Adobe Photoshop were used to examine the intersecting strokes. A luminous appearance was observed when black inkjet-printed text was beneath the ballpoint and gel pen ink lines [Figure 8], whereas no luminescence was observed when the printed text was above the pen ink [Figure 9]. For red and blue inkjet-printed text, luminescence was observed in heterogeneous combinations (red printer with blue/black pen inks and blue printer with red/black pen inks) (Figure 10), while no luminescence was observed in the reverse sequences (Figure 11). These observations enabled reliable sequence determination for most heterogeneous intersections.

Inconclusive results were obtained for homogeneous combinations of blue inkjet-printed text with blue ballpoint and gel pen inks, and red inkjet-printed text with red ballpoint and gel pen inks [Figure 12]. Therefore, the sequence could not be established for these combinations. Similar results were observed across different pen brands and on all three paper substrates, demonstrating consistent performance of the method.

A blind study of the intersections has been carried out by examining five samples of each intersection of laser-printed text (black) and inkjet-printed text (red, blue, black) with ballpoint pen and gel pen ink lines (red, blue, black) through Adobe Photoshop. The analysis of five blind samples from the intersections of laser-printed text (black) and inkjet-printed text (red, blue, black) with ballpoint pen and gel pen ink lines (red, blue, black) was interpreted and gave results as obtained in the known samples (the same features have been observed) through Adobe Photoshop CC 2021. Apart from this, no blind study has been performed for the intersection samples of blue inkjet printed text with gel pen ink and ballpoint pen ink of blue colour, and also for the crossing lines of red inkjet printed text with gel pen and ballpoint pen ink lines of red colour and black, as inconclusive results were obtained in the known samples (Tables 2 and,3).

Adobe Photoshop CC 2021 successfully determined the sequence of most intersecting strokes between laser printer toner, inkjet printer inks, and ballpoint and gel pen inks using characteristic features such as toner compression, toner expansion, and luminescent appearance at the point of intersection. The method effectively established the sequence of heterogeneous intersections and homogeneous black inkjet–black pen combinations, whereas homogeneous red–red and blue–blue combinations remained inconclusive because of their similar optical characteristics. As a non-destructive and cost-effective approach, Adobe Photoshop preserves document integrity while providing an objective alternative for sequence determination.

Previous studies have primarily investigated intersecting strokes using optical microscopy, Raman spectroscopy, scanning electron microscopy, and hyperspectral imaging, with limited emphasis on the sequence determination of laser-printed and inkjet-printed text intersecting with ballpoint and gel pen inks using digital image processing techniques. Recent reviews have also highlighted the need for reliable, objective, and non-destructive methods for printer-generated and handwritten stroke sequencing in questioned document examination .[8–12] To the best of our knowledge, this is the first study to systematically evaluate Adobe Photoshop-based image processing for determining the sequence of intersecting strokes between laser printer toner, inkjet printer inks, and ballpoint and gel pen inks across multiple substrates. These findings demonstrate the potential of Adobe Photoshop as a practical tool for routine forensic document examination, particularly where access to sophisticated analytical instruments is limited.

Conclusion

Adobe Photoshop proved to be an objective and non-destructive tool for determining the sequence of intersecting strokes between laser printer toner, inkjet printer inks, and ballpoint and gel pen inks. The method successfully established the sequence for most heterogeneous intersections while preserving the integrity of the document. Future research should validate this approach using additional printer models, writing instruments, and variables such as writing speed, time intervals, and pen pressure to further improve its forensic applicability.

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