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PAPER

QUESTIONED DOCUMENTS

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Examination of Heterogeneous Crossing Sequences Between Toner and Rollerball Pen Strokes by Digital Microscopy and 3-D Laser Profilometry

ABSTRACT: The determination of line crossing sequences between rollerball pens and laser printers presents difficulties that may not be overcome using traditional techniques. This research aimed to study the potential of digital microscopy and 3-D laser profilometry to determine line crossing sequences between a toner and an aqueous ink line. Different paper types, rollerball pens, and writing pressure were tested. Correct opinions of the sequence were given for all case scenarios, using both techniques. When the toner was printed before the ink, a light reflection was observed in all crossing specimens, while this was never observed in the other sequence types. The 3-D laser profilometry, more time-consuming, presented the main advantage of providing quantitative results. The findings confirm the potential of the 3-D laser profilometry and demonstrate the efficiency of digital microscopy as a new technique for determining the sequence of line crossings involving rollerball pen ink and toner.

KEYWORDS: forensic science, questioned documents, laser profilometry, digital microscopy, rollerball pens, toner printing, crossing sequences, line crossings

With the mass marketing of laser printers and the popularity of rollerball pens, the determination of line crossing sequences between such instruments is encountered by forensic document examiners. This type of crossing presents difficulties with optical microscopic line crossing techniques involving ballpoint pens or gel pens and toner (1–4). Indeed, the rollerball's aqueous ink penetrates through the toner and is absorbed by the fibers of the paper, leaving the examiner with the impression that the toner is above the ink even when it is not (5). Novotny and Westwood (3) investigated the possibility of determining aqueous ink and toner crossing sequences by microscopic observation of the intersection before and after toner removal. A major disadvantage of their study resides in destruction of the sample by scraping off the toner line to see what was underneath. The aim of this research was to investigate the ways to overcome these difficulties through digital microscopy and three-dimensional (3-D) laser profilometry. The former was used as a technique for the determination of sequences between gel pen and toner printing strokes, but provided less conclusive results than that of an optical stereomicroscope (4). 3-D laser profilometry, which allows one to observe and measure the topography of a surface, has been the subject of a number of recent studies in this area. Berx and De Kinder (6) and Schirripa Spagnolo (7,8) have tested the application of laser profilometry to determine the sequence of intersections of several lines. The results obtained in these studies overcome disadvantages of other methods applied in this area, such as scanning electron microscope or the atomic force microscope. The main advantages of 3-D laser profilometry include the ease of implementation of the technique and its nondestructive nature, which does not require sample preparation (8–10). Moreover, the technique is reproducible and presents a high degree of freedom in the vertical axes (up to 1000 μm). However, when the paper surface presents a given roughness, if the pen impressions alter the paper with a depth similar to the roughness of medium, the results are not always conclusive (8). It becomes difficult in this case to distinguish which characteristics can be imputed to the pen impressions or the quality of the paper surface. This important limitation is assessed by testing different types of paper of variable quality (of different grammage and finishing) and the writing pressure. The authors will therefore assess the limits of 3-D laser profilometry technique and determine whether the method can overcome such constraints. Second, the authors will investigate the use of digital microscopy because it presents a number of advantages: it is efficient, user-friendly, and provides an objective evaluation and interpretation.

Material and Methods

Digital Microscopy

The specimens were observed and photographed with a Keyence VHX-600 digital microscope mounted with a VH-Z20R (20–200×) objective (Keyence Corporation, Osaka, Japan). The lighting consisted of a partial illumination in one direction (only one-fourth of the annular light source located on the tip of the objective). The objective was placed perpendicularly to the sheet of paper

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containing the crossings. This type of illumination enhances shadows created by projections and depressions. The light beam was always placed perpendicularly to the direction of the rollerball line.

Three-Dimensional Laser Profilometry

The topography of the surface of the specimens was recorded by means of a 3-D laser profilometer (μscan®; Nanofocus AG, Oberhausen, Germany). A conoscopic detector was used, which is suitable for small variations of the profile, such as the case for paper surfaces. The conoscopic detector has a maximum scanning resolution of 1 μm along the *x*- and *y*-axes. The resolution along the *z*-axis (vertical) is 0.02 μm for the conoscopic sensor. The maximum amplitude that can be measured by the vertical axes is 1000 μm. The scanning speed was set at 1000 points per millimeter, corresponding to a laser resolution of 1 μm for both the *x*- and *y*-axes resulting in an acquisition time of approximately 160 min for a 2.5×2.5 μm square zone (6.25 μm^2). During the measurement process, the conoscopic detector remains immobile, while the table with the sample moves. There is no contact between the sample and the detector. Two types of representations of the results were used to determine the stroke sequence. The first consists of a 3-D image that can be rotated in any direction for dynamic observations. The incident angle and intensity of the virtual light source can also be adjusted. The second representation of the results is the topographic profile along each of the toner and rollerball pen lines that form the intersection.

Sample 1: Preliminary Assessment

Three types of satin finish or high-quality wove papers were used during this study: 100 g/m^2 white satin finish paper (Elco "James" model, A4 format; Seetal Elco, Brugg, Switzerland); 90 g/m^2 white satin finish paper (Clairefontaine "Trophée" model, A4 format; Etival-Clairefontaine, France); and 80 g/m^2 white wove finish paper (Elco "Prestige" model, A4 format). All of the sheets of the same type used throughout the study came from the same pack of paper.

The surface of the paper can have a significant influence on the outcome of the 3-D profilometry results. Indeed, the rougher the paper surface, the higher amount of background noise will be observed, which can hinder the line crossing evaluation.

The line strokes were created by applying different pressures on the rollerball pen. The authors focused on the influence of normal and high pressures. The values chosen for such pressures were determined by calculating an average pressure exerted by the pen point from 10 freehand signatures signed on a Wacom Intuos 3 (Wacom Co. Ltd., Kazo-Shi, Saitama, Japan) tablet by 150 different people. This tablet records the variable pressure applied on the ball throughout the writing process. The signatures were carried out with a ballpoint pen on a 10-layer paper substrate. The calculated mean values for normal and high pressures are, respectively, 246 and 354 g. These two values were adjusted to 250 and 350 g for the acquisition stage of this study to represent natural writing pressure. These values are assumed to represent normal writing pressures, independently of the writing instrument used. An experimental apparatus (Fig. 1) was fashioned to deposit the rollerball pen lines with a constant and reproducible pressure. The apparatus was designed to best reproduce the writing conditions, including the angle of the pen, while maintaining the desired pressure. The rollerball pen was fastened in the metal brace, and lead weights were placed on the adjacent axis to fix and control the desired pressure. The heterogeneous line crossings were all carried out with a 90° angle. The substrate consisted of 10 pages of 80 g/m^2 printing paper placed under the sample page during the rollerball pen apposition process. The same rollerball pen (Lamy M66; Heidelberg, Germany) and laser printer (Canon IR 2270 equipped with Canon C-EXVII toner; Tokyo, Japan) were used to create all of the samples in the study. The under stroke and the upper stroke of each crossing were affixed within *c.* 30–60 min. All specimens were preserved for at least 1 month in the dark before analysis.

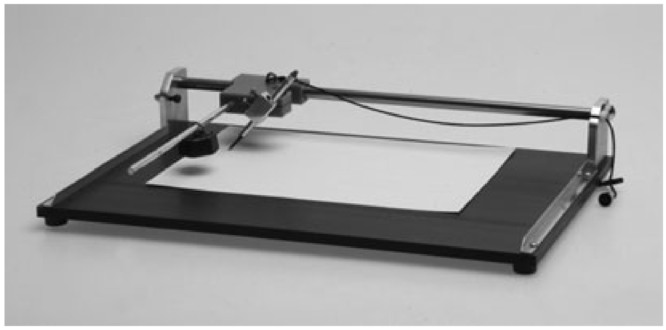

FIG. 1—*Apparatus used to obtain rollerball pen lines of uniform and known pressure. The pressure is adjustable by moving the weight on the metallic bar at given predefined positions. The sheet of paper is size A4.*

Samples were prepared under the aforementioned variables for every line crossing combination on an A4 size paper in a grid-type pattern. The vertical lines correspond to those carried out with the rollerball pen and the horizontal lines to the toner lines (of a thickness of 1.25 pts). Three samples were then arbitrarily chosen from 16 prepared samples. Three replicates were thus analyzed for every possible combination to test the reproducibility of both of the tested methods, giving a total of 36 specimens (3 types of paper × 2 pressures × 2 sequences (ink-toner and toner-ink) × 3 replicates).

Sample 2: Blind Test

Every type of line crossing combination was reproduced by a third party for blind testing, in the same manner as the previous samples. The following parameters were varied to produce the different crossing combinations:

- Three different types of paper: 100 g/m^2 white satin finish paper (Elco "James" model, A4 format), 90 g/m^2 white satin finish paper (Clairefontaine "Trophée" model, A4 format), 80 g/m^2 white wove finish paper (Elco "Prestige" model, A4 format);
- Three different types of rollerball pens: Lamy M66, Pilot Hi Tecpoint V7 (Tokyo, Japan), Bic Metal Point (Clichy, France);
- Two different writing pressures: 250 and 350 g.

The surface substrate (soft, 10 sheets of 80 g/m^2 printing paper) as well as the laser printer was the same as for the known experimental samples. Each type of combination was fashioned once and given in a random order to the examiner (who was unaware of the number of each type of combination), resulting in a total of 36 specimens (3 papers × 3 rollerball pens × 2 pressures × 2 replicates) that were analyzed in the same fashion as sample 1. The examiners did not obtain any information concerning the types and number of paper, the number of rollerball pens, and the writing pressure. The examiners did not know that the results were to be published. They were asked to examine the crossings with the same attention as they would for normal casework. The examiners had, respectively, 22

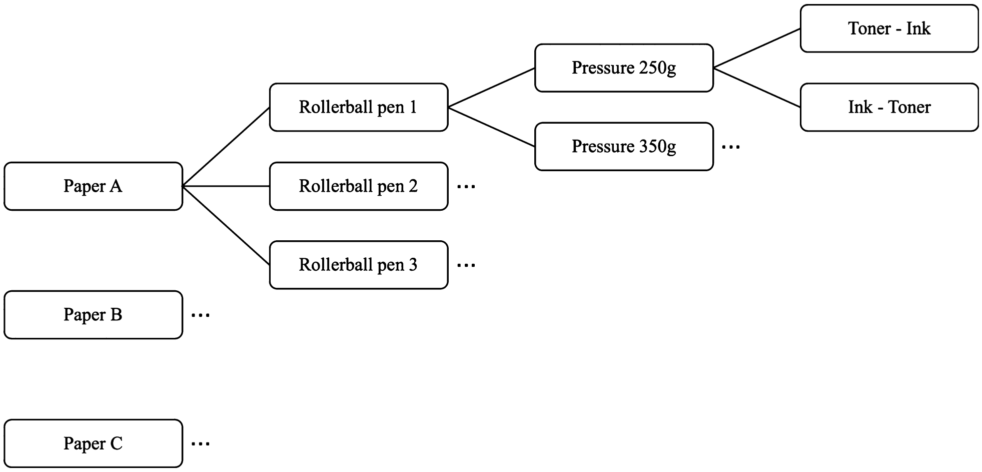

FIG. 2—*Graphical representation of the sampling specimens of sample 2. For sample 1, the specimens were established only with rollerball pen 1. Paper A: Elco "James," Paper B: Clairefontaine "Trophée," Paper C: Elco "Prestige," Rollerball pen 1: Lamy M66, Rollerball pen 2: Pilot Hi Tecpoint V7, and Rollerball pen 3: Bic Metal Point.*

and 7 years of experience in document examination. A summary of tested crossing combinations is presented in Fig. 2.

Sample 3: Blind Test with Freehand Signatures

An analysis of line crossings was then carried out on sequences of toner lines and freehand signatures affixed with a rollerball pen. This step was to assess the results of digital microscopy and laser profilometry that are typically observed in real-life cases, where the pressure and angle between the crossing lines are variable and unknown. For this step, the following parameters were varied:

- Two types of paper: 90 g/m^2 white satin finish paper (Clairefontaine "Trophée" model, A4 format) and 80 g/m^2 white wove finish paper (Elco "Prestige" model, A4 format);
- Two pens: Lamy M66 and Pilot Hi Tecpoint V7;
- Two writing substrates: 10 sheets or no sheet.

These parameters gave a total of eight types of combinations. Three replicates of each type of combination were chosen, giving a total of 48 specimens (2 papers × 2 pens × 2 substrates × 2 combinations × 3 replicates). A replicate represents a signature and not a single line crossing. A summary of tested crossing combinations is presented in Fig. 3. Note that in average, each signature presented 12 crossings. All of these crossings were observed with the digital microscope. For each signature, two crossings corresponding to ascending and descending writing lines were further analyzed by 3-D laser profilometry.

Sample 4: Blind Test with Freehand Signatures on Plain Paper

Finally, eight independent crossings between toner and rollerball pen lines were observed with the digital microscope. These specimens were created in 2002 with unknown plain paper, an unknown rollerball pen, and an unknown laser printer. These crossings dated from internal studies carried out for casework. At that time, it was found that the sequences could not be determined with the techniques at hand.

Results and Discussion

Digital Microscopic Observations

The digital microscopic observations lead the authors to form a correct opinion regarding the sequence of line crossings in all of the observed specimens of sample 1. The determination of the line sequences was based on the presence of a shiny aspect of the crossing areas, because of reflected light, in the case where the rollerball line was affixed after the toner (Fig. 4*a*). On the contrary, when the toner preceded the rollerball line, no shininess or reflected light was observed at the crossing zone (Fig. 4*b*). No difference was observed between the three replicates of each sample. The conclusion regarding each sequence was categorical. Furthermore, all observations were independently confirmed by two forensic document examiners.

The examination of sample 2 (blind test) was carried out by a third forensic document examiner, to whom the analysis procedure

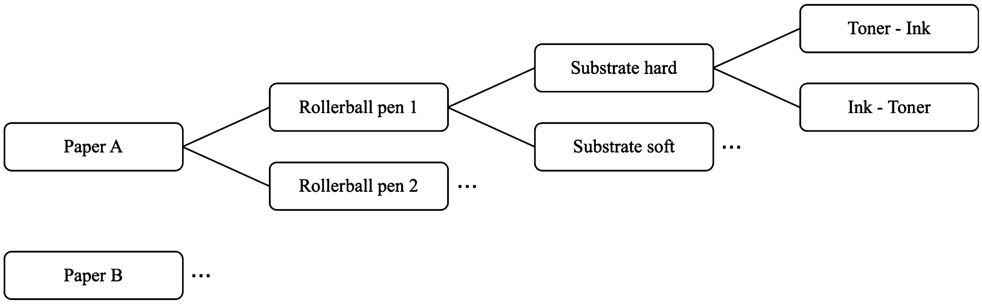

FIG. 3—*Graphical representation of the sampling specimens of sample 3. Paper A: Elco "Prestige," Paper B: Clairefontaine "Trophée," Rollerball pen 1: Lamy M66, and Rollerball pen 2: Pilot Hi Tecpoint V7.*

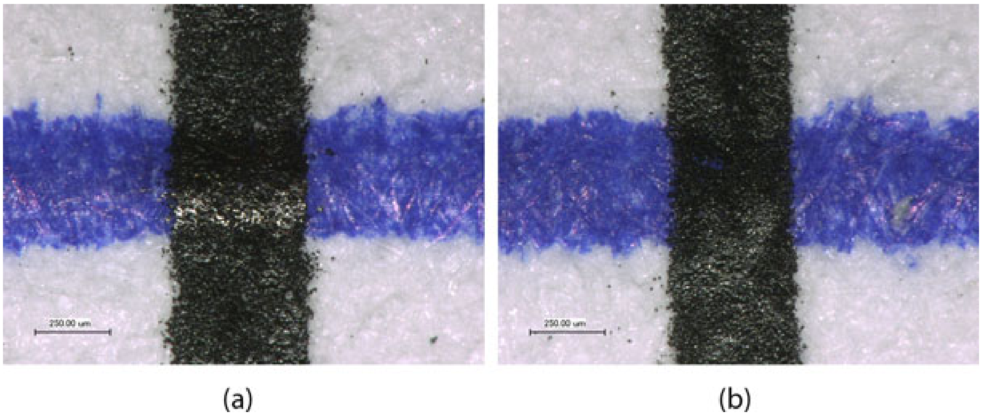

FIG. 4—*Digital microscopic observations on line crossings where (a) the ink is affixed after the toner and (b) the toner is printed after the ink. The writing pressure was of 250 g on both crossings.*

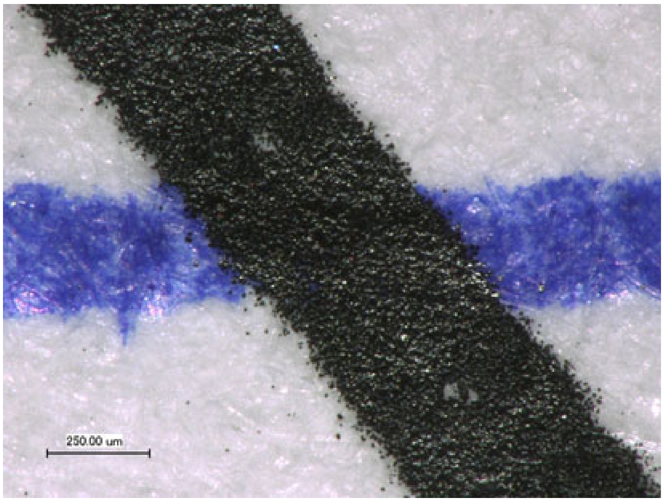

FIG. 5—*Digital microscopic observations on a line crossing where the rollerball pen line was affixed with a pressure of 250 g after the toner. The absence of the shiny aspect of the ink can lead an examiner to incorrectly conclude on the line sequence.*

was thoroughly explained and the expected results of both case figures were shown. All the sequences of the specimens of sample 2 were correctly assessed through the digital microscopic examinations.

Regarding sample 3 (blind test with freehand signatures), correct opinions were given for each signature by the third examiner. Nevertheless, when the writing pressure was low, especially in ascending strokes, the shiny aspect was sometimes too weak to allow the examiner to categorically conclude that the ink was deposited after the toner (see Fig. 5). However, a categorical conclusion could always be reached by the examiner by observing the descending writing strokes of the signatures.

Finally, the three crossings in sample 4, where the rollerball pen lines were affixed after the toner, were correctly assessed. In the five cases where the toner was printed after the rollerball pen lines, the absence of shininess supported the hypothesis of a roller–toner sequence, but could not be determined categorically. Indeed, because each crossing was observed independently, the experts could not confirm the results by combining the observations of several crossings of a same pen line. The authors noticed that a 180° rotation of the crossing helped to reach a conclusion. Indeed, the shiny aspect of the crossing was sometimes observed in only one direction.

In conclusion, in the case where no shiny aspect is observed at the intersection, the experts should not conclude categorically as a rollerball pen–toner line sequence. Indeed, a low writing pressure could be mistaken for laser printing on top of the rollerball pen line. To reach a conclusion, the authors recommend confirming the results with several other crossings to assess the pressure. Categorical conclusions could be rendered in every case where the shiny aspect is observed, that is, the toner is placed under the rollerball pen line.

Laser Profilometry Results

For sample 1, the 3-D laser profilometry analyses confirmed the results obtained with the digital microscope. The replicates of a sample provided the same results and were thus considered to be reproducible. Two different forensic document examiners reached the same conclusions.

On the 3-D reconstructions, the toner generally appears in relief and is above the base level that is defined as the surface of the paper, while the rollerball line, being affixed with a given pressure, causes a groove in the paper. In the case where the rollerball line was affixed after the toner, the crossing surface consisted of a smooth and homogenous groove over the toner line. Additionally, the topographic profile taken along the toner line was characterized by a "*U*" curve where the summits correspond to the borders of the inked line (see Fig. 6). The topographic profile taken along the rollerball pen stroke did not provide valuable information. No differences were observed between the different writing pressures, papers, and rollerball pens.

In cases where the toner was printed after the deposition of the rollerball pen line, the toner line in the crossing area was uninterrupted, independent of the rollerball pen line pressure. The toner line was always situated above the rollerball pen line and presented surface irregularities. In such situations, the topographic profile taken along the rollerball pen line showed an abrupt height increase because of the presence of the toner (see Fig. 7). The topographic profile taken along the toner line did not yield valuable information.

With reference to sample 2, the third examiner observed the results analyzed by 3-D laser profilometry. The examiner was given the aforementioned criteria to conclude on the line sequence and reached correct conclusions for every specimen, but reported that the examination of the results was more time-consuming than those obtained with the digital microscopy.

Correct opinions were given by the third examiner for every crossing involving freehand signatures (sample 3). In only one case,

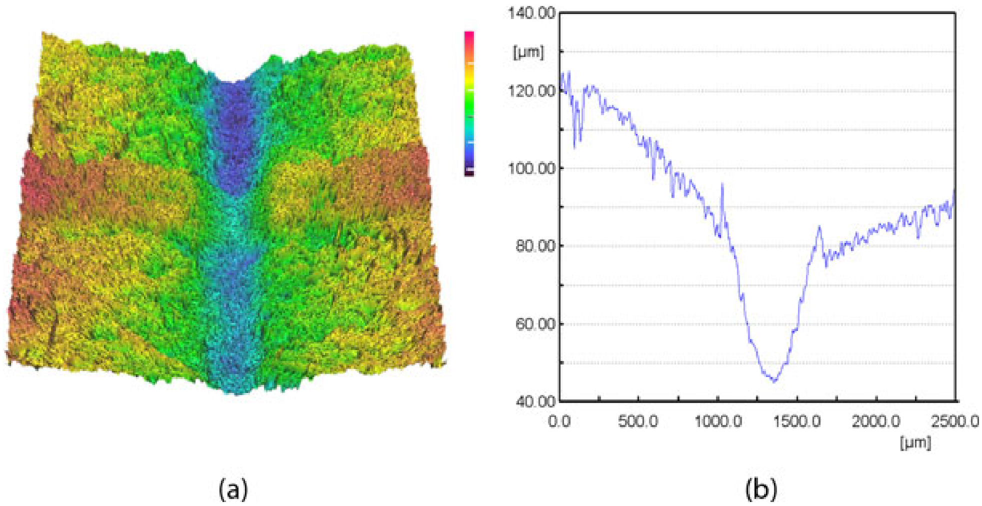

FIG. 6—*3-D laser profilometry results of a crossing where the rollerball pen line was affixed with a pressure of 250 g after the toner: (a) the 3-D reconstruction shows a smooth groove, and (b) the topographic profile taken along the toner line presents a U shape at the crossing zone.*

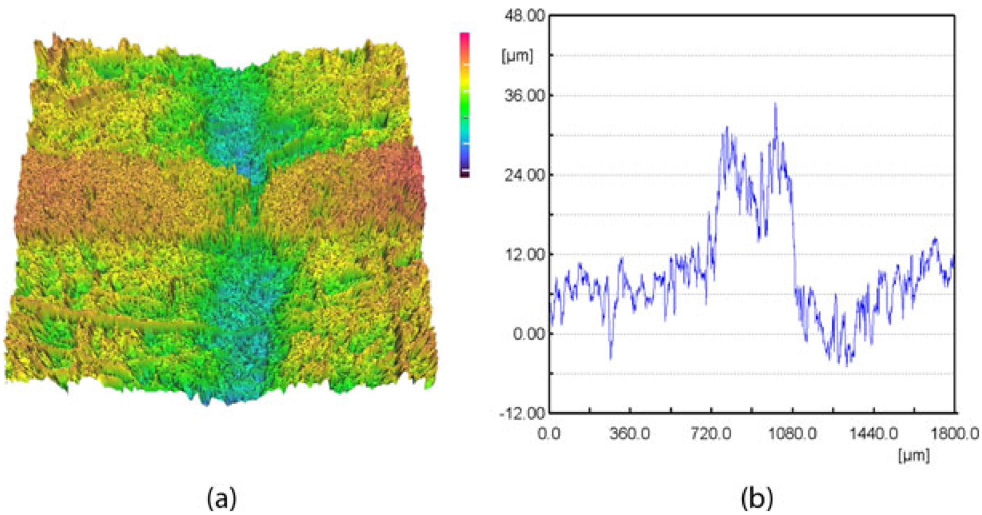

FIG. 7—*3-D laser profilometry results of a crossing where the toner was printed after the rollerball pen line (pressure 250 g): (a) the 3-D reconstruction shows irregularities of the toner surface, and (b) the topographic profile taken along the rollerball pen line shows a cliff representing the vertical borders of the toner.*

where the rollerball line was affixed after the toner line, an inconclusive opinion was reached. This was most likely because of the very low pressure of the writing line. For the 3-D reconstruction, the rollerball pen groove was neither visible on the paper, nor on the toner line (see Fig. 8). These results confirm those obtained with the digital microscopy. In the case of very low pressure writing lines, both of these techniques are limited, and categorical conclusions should not be rendered.

One of the main advantages that can be cited for these techniques is that they are nondestructive. The digital microscopy provides an integrated photographic device that facilitates recording with high-quality and easily interpretable images. The recording process of the 3-D laser profilometry is based on a noncontact technique because the laser sweeps across the surface without touching, thus leaving the questioned document unaltered. The 3-D image from the analysis with the laser profilometry can easily be rotated in any direction with the delivered software, and the incident angle of the virtual light source can be modified at the user's discretion. The main limitation of the 3-D laser profilometry, as stated by Schirripa Spagnolo (8), is its inability to distinguish variations in the depth of pen traces if they are left on paper with surface depth variations. For this reason, a questioned crossing on satin finish paper is more likely to give results than a crossing on standard or low-quality wove finish paper. A high-resolution capture mode may help to overcome this problem, but inevitably also increases the analysis time. Furthermore, it cannot be excluded that the type of toner deposited, as well as the printing density, may affect the results.

Conclusions

This research demonstrates that the Keyence digital microscope can be recommended as a method of choice for the determination of the sequence of line crossings between toner and rollerball pen lines. This method had never before been used for determining the sequence of line crossings involving a rollerball pen and toner. With digital microscopy, categorical conclusions can be emitted when shininess is observed at the crossing (in the case of a rollerball pen line affixed after a printed toner line). However, the absence of shininess does not always support the alternative

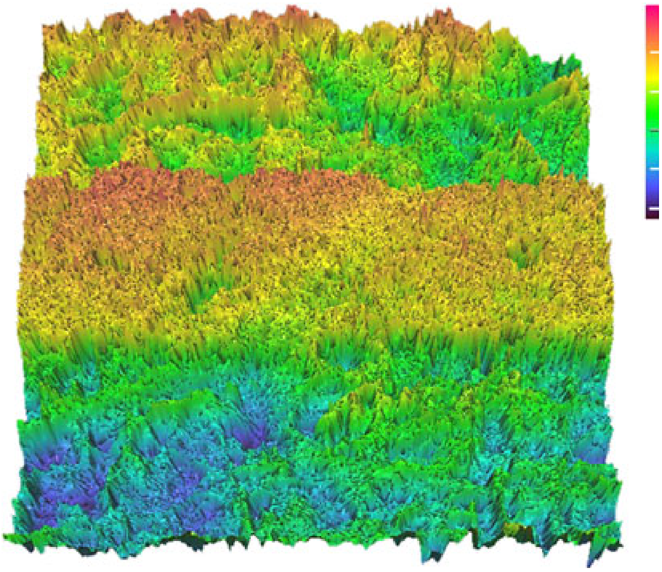

FIG. 8—*3-D laser profilometry reconstruction of a crossing where the rollerball pen line of a signature was affixed after the toner: the pen groove is not visible because of the low writing pressure (ascending writing line of the signature).*

crossing sequence, where the toner is printed after the rollerball pen line. The results in this case should be confirmed by the examination of several crossings.

The 3-D laser profilometry can also provide valuable information for determining the sequence of crossing strokes between toner printing and rollerball pen lines. The findings confirm the efficiency of the 3-D laser profilometry (8). The authors recommend observing the topographic profiles along both the toner and the rollerball pen strokes to determine the sequence of a particular crossing. However, the analysis time is far more time-consuming than digital microscopic observations, and the results of the 3-D laser profilometry did not provide additional information in cases where the digital microscope did not allow the experts to reach categorical conclusions. In this view, the only advantage of the 3-D laser profilometry resides in its ability to provide quantitative measurements concerning height differences in the profiles, which implies that the results are more objective.

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