TECHNICAL NOTE

Is Atomic Force Microscope a Suitable Tool for Studying Crossing Lines?

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This work is a preliminary inquiry into the usefulness of atomic force microscope (AFM) to determine the sequence of crossing lines. Intersecting lines were prepared using different types of pens and printers and studied with AFM to discover whether any diagnostic feature could be found that would reliably indicate which line lay on top. The effect of the age of the ink/printer lines was also studied. Specimens were created with elapsed times between the applications of the 1st line and the 2nd line in seconds, days, weeks, and months in order to study whether the period of time elapsed between the entries, with possible hardening of resin components of certain inks, affected observations.

Introduction

The determination of the sequence of line crossings is a common problem for forensic document examiners. These crossings can be homogenous, when both lines were made with the same tool, or heterogeneous, when the lines were made with different media.

This investigation is a preliminary study on the validity of the AFM as a new tool in the study of heterogeneous line crossings and, in particular, of crossings between texts printed with inkjet and laser printers on the 1 hand and different writing pens on the other. Ballpoint, roller-ball, and gel-ink pens are common types of writing instruments encountered in such cases.

Several studies have been published on the use of the scanning electron microscope (SEM) on line-crossing problems (1-9). In order to use the SEM, the surface to be analyzed must be rendered conductive, usually by vacuum coating the sample with metal or carbon. There has been only 1 known case of the use of an AFM for establishing the sequence of line crossings, and that study was limited to a dot matrix printer and only 1 ballpoint pen [10]. The AFM has the advantage over the SEM in that it can be used on nonconductive surfaces, thus avoiding destructive sample preparation.

The study was based on the microscopic differences observed on the surface of a paper when an ink crossing was deposited with the various writing instruments as well as inkjet and laser printing.

The mechanical characteristics of the different writing instruments, as well as the composition of the inks that, in turn, offer differences in the viscosity of the lines, the adhesion of the ink to the paper, etc., suggest that a detailed study of these surfaces with an AFM may allow determination of order of deposition.

A ballpoint pen produces an indentation on the paper fibers as the tip advances over it to create a stroke. The hydrophobic composition of the ink prevents it from being absorbed by the tiny cellulose fibers of the paper. In roller-ball pens (wet ink), the indentation on the paper is lighter, and bleeding of the ink over the line can be observed. Roller-ball ink is less viscous than ballpoint ink, and the deposited ink layer will present different characteristics. An ink-gel pen, with ink more similar to paint, has much more saturated coverage. The mechanism of an inkjet printer is to sputter tiny droplets of ink onto the paper without any contact between the print head and the paper. A laser printer creates a layer of toner on the surface of the paper, which is then heat fused to the surface. It is reasonable to assume that the surface of the inked paper will be different depending on the medium used and on the way it is deposited on the paper.

The 1st step of the investigation was to determine whether an AFM could distinguish between image and non-image areas on paper. Since that proved to be the case, further testing was conducted.

The 2nd part of the research was to determine whether diagnostic features could be discovered

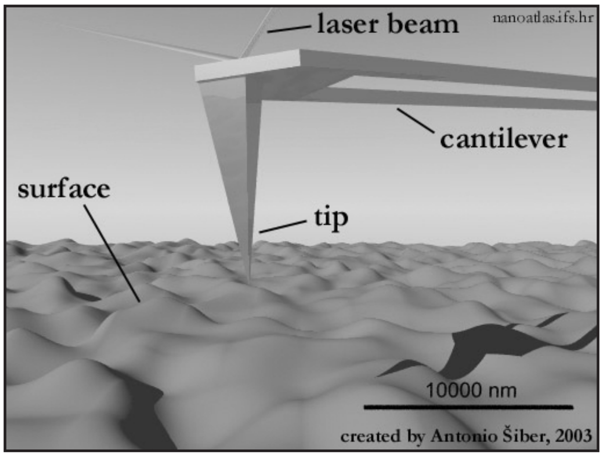

Figure 1. Level view from the surface of the sample shows the schematic operation of the AFM. (Image created and ceded by Antonio Siber)

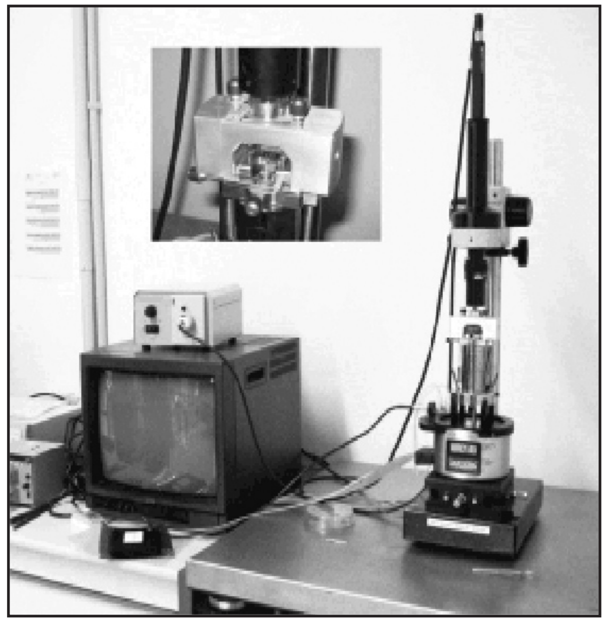

Figure 2: AFM equipment used for this study placed in the nanotechnology service of the Basque Country University.

that could reliably indicate the order of application of intersecting lines.

The 3rd part of the study was to determine whether various time intervals between the applications of ink lines affected results.

The effect of differing time intervals between deposition of the 1st and 2nd lines was considered. This point is especially important with this technique because the hardening of the surface can alter the images obtained by scanning. In case work, a common allegation is that a signature was signed on a blank paper and some time later a document created with a printer on that previously signed sheet. Therefore, it was considered important to determine whether time intervals between depositions of crossing lines affected observations made with AFM.

Atomic Force Microscope – AFM

A solid surface may be characterized by spectroscopic and microscopic means. The AFM, invented in 1986, along with the scanning tunneling effect, comprise the scanning probe microscopes (SPM) used to examine the topography of surfaces. These types of microscopes give details in 3 dimensions, x, y, and z, with approximate resolutions of 2Å. The AFM operates by scanning the surface of the sample with a very sharp tip which moves, as it sweeps the surface, up and down along the z-axis, measuring the topographic changes of the surface (Figure 1). While sweeping the surface, attractive and repulsive forces are produced between the tip on 1 end of the cantilever and the surface of the sample causing small deviations of the cantilever. These deviations are detected and measured optically and translated into a topographic image of the surface by a computer. The great advantage of this microscope is that it allows for the resolution of both conductive surfaces and nonconductive surfaces, thus avoiding destructive sample preparation necessary for examination by SEM.

One of the work modes the AFM possesses consists of oscillating contact (tapping) that solves the problem of excessive contact of the tip with the sample surface and the possible deterioration of the sample. Since there is physical contact between the probe and the sample, it is possible for the probe to alter the sample and produce a distorted image. The tapping mode, consisting of the cantilever being in contact with the surface intermittently during the scan, reduces this possibility.

Methods and Materials

Materials

Multimode Atomic Force Microscope from Veeco - Digital Media with Nanoscope IIIa controller Software v530r3 - Scanner-J (allows greater field) (Figure 2).

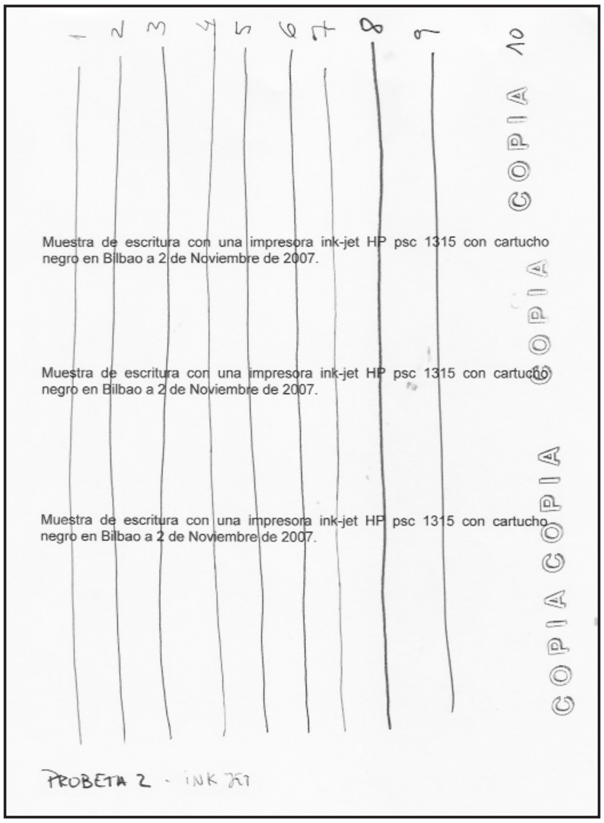

Figure 3: Test Sample

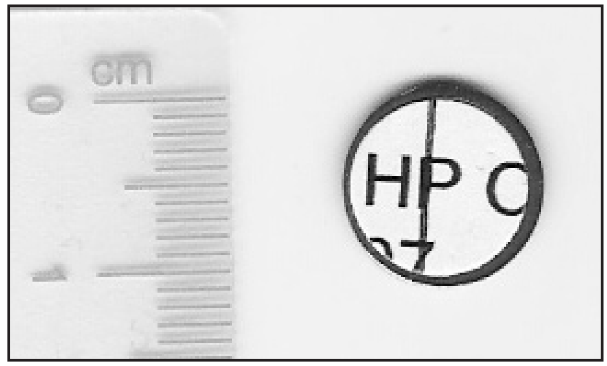

Figure 4a. The crossing extracted from the test sample and glued on the metallic surface of the AFM with double-layer tape. The intersection shown is of the HP Office 56120 over Stypen Gel Grip 0.8 (test sample 4).

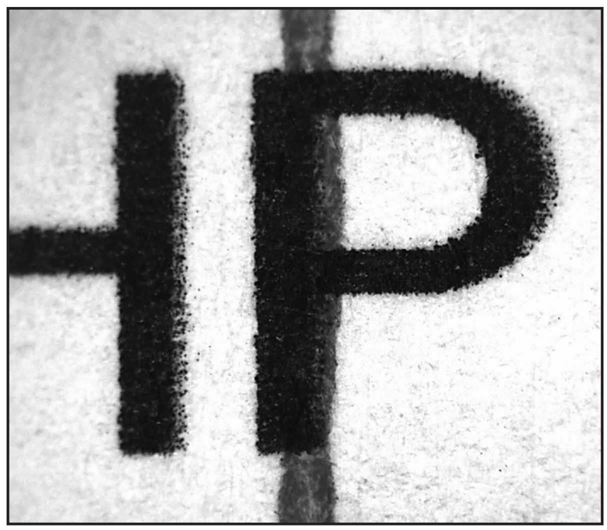

Figure 4b. Same crossing as Figure 4a magnified at 40x.

Specifications:
Phosphorous (n) doped Si
Length of cantilever: 115-135 microns
Nominal spring constant: 20-80 N/m.

Experimental Procedures and Work Plan

The 1st part of this study was to determine whether AFM could differentiate between image and non-image areas of samples. To achieve this, small portions of inked paper were extracted and images taken.

The 2nd part of the work centered on the study of the crossings between the strokes of different writing media with texts printed using different printers. For this, 18 test samples (Figure 3) were created using normal white 80g paper for photocopiers. In the odd-numbered test samples, texts were printed with the different printers listed above, and later these texts were marked with intersecting lines using the 7 writing instruments described above. For ink-jet printers, 2 samples for each printer (HP PSC 1315) were taken, 1 when the ink cartridge was completely full and another when the printer warned that it needed the cartridge changed. The purpose was to eliminate the possibility that the amount of ink in the cartridge could affect results. The even test samples were 1st marked using the 7 writing media, and then they were put through the printers as described above. A total of 14 different types of crossings with each printer were created, 7 with the printer below and 7 with the printer above. For each pair of media/printers, there were 2 test samples; in 1 the text from the printer was underneath the instrument stroke, whereas in the other the instrument stroke was under the printed text.

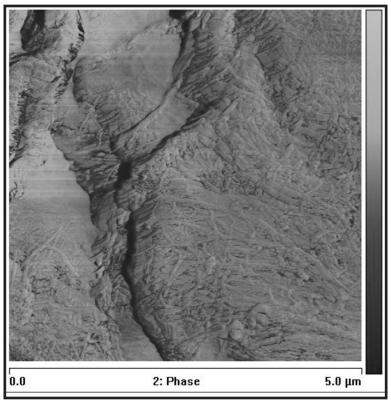

Figure 5. Phase image of a blank paper.

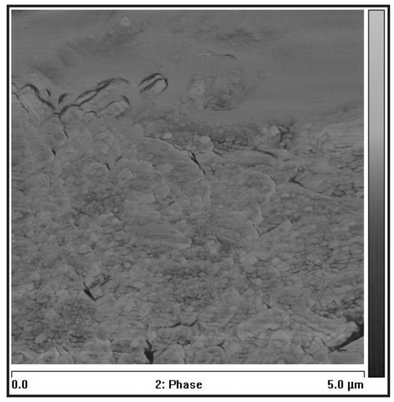

Figure 6. Phase image of an ink stroke made by a ballpoint pen: Bic Cristal, made in Mexico.

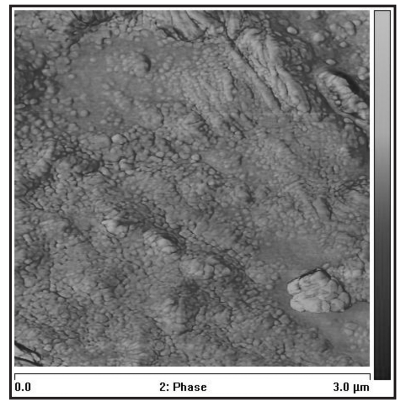

Figure 7. Phase image of an ink stroke made by a roller-ball pen: Hi-Techpoint Extra V5 fine.

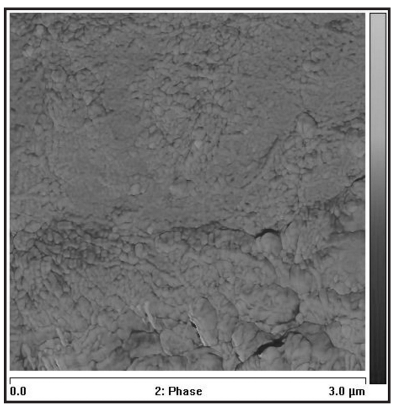

Figure 8. Phase image of the surface of the ink made by a gel-ink instrument: Stypen Gel Grip 0.8.

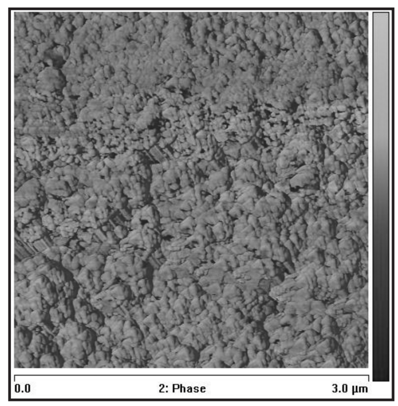

Figure 9. Phase image of an ink entry made by an HP 1315 inkjet printer.

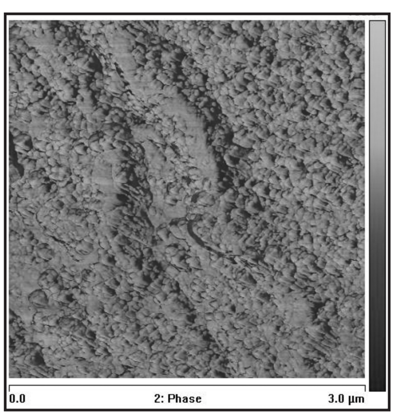

Figure 10a. Phase image of an ink entry made by an HP 1315 inkjet printer with a full cartridge.

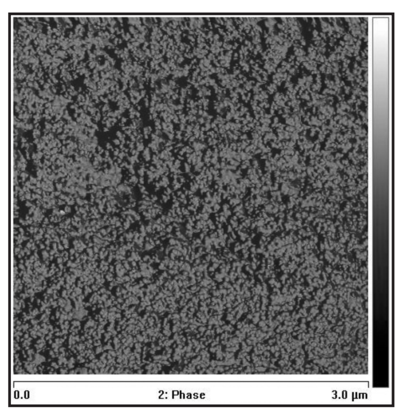

Figure 10b. Phase image of an ink entry made by an HP 1315 inkjet printer with a nearly empty cartridge.

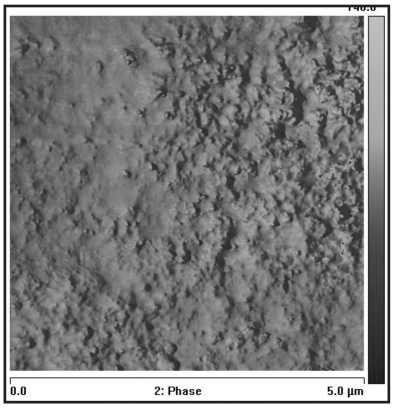

Figure 11a. Bic Cristal (ballpoint pen) over HP 1315 inkjet printer.

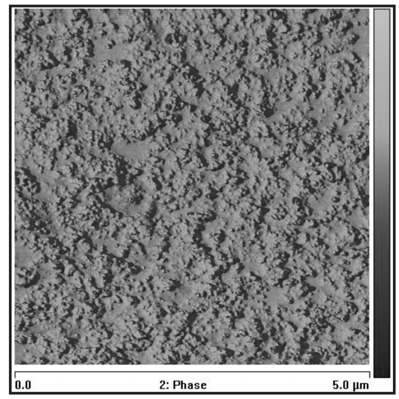

Figure 11b. HP 1315 inkjet printer over Bic Cristal (ballpoint pen).

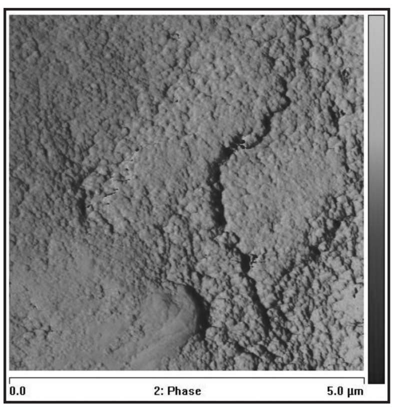

Figure 12a. Pilot Hi-Techpoint (roller-ball pen) over HP 5610 inkjet printer.

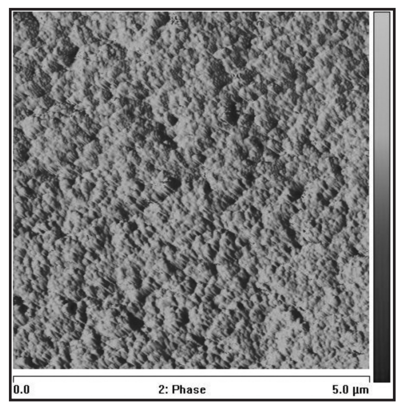

Figure 12b. HP 5610 inkjet printer. over Pilot Hi-Techpoint (roller-ball pen).

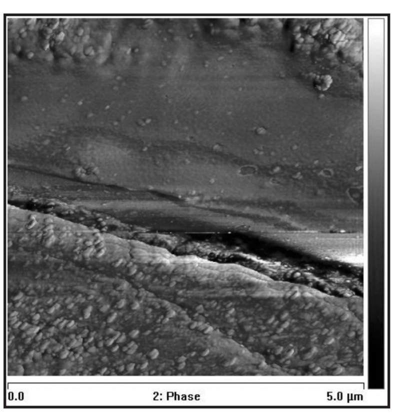

Figure 13a. Bic Cristal (ballpoint pen) over Epson Stylus inkjet printer.

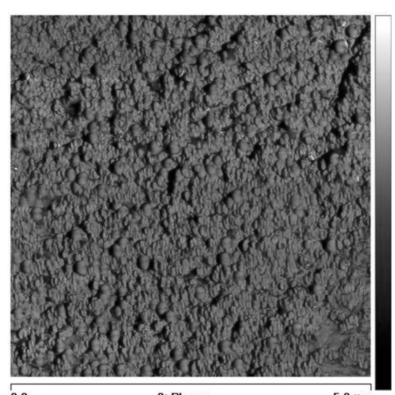

Figure 13b. Epson Stylus inkjet printer over Bic Cristal (ballpoint pen).

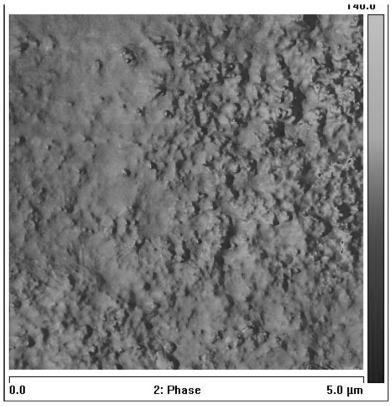

Figure 14. Bic Cristal (ballpoint pen) over HP 1315 inkjet printer (immediately).

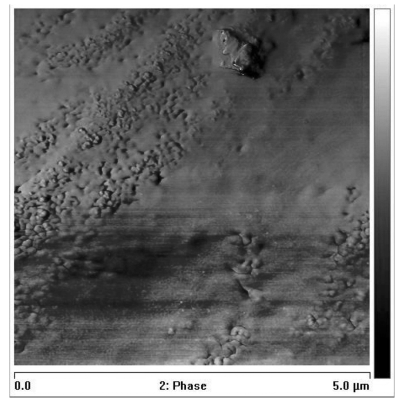

Figure 15. Bic Cristal (ballpoint pen) over HP 1315 inkjet printer (1 day).

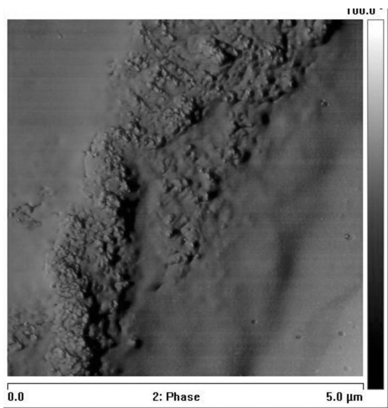

Figure 16. Bic Cristal (ballpoint pen) over HP 1315 inkjet printer (8 days).

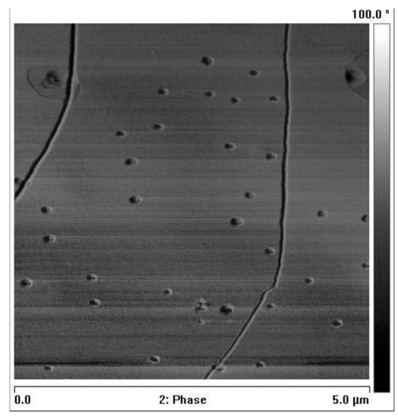

Figure 17. Bic Cristal (ballpoint pen) over HP 1315 inkjet printer (40 days).

In the 3rd part of the work, the elapsed time between strokes of the intersections was varied, with the purpose of determining whether the drying of the ink and the hardening of its resins influenced the results. For this test, an additional 8 test samples were created. Intersections using 3 ballpoint pens, 1 roller-ball, and 3 gel-ink pens with an HP Ink-jet PSC 1315 printer were made. The 1st set of these test samples was made with the intersecting lines applied contemporaneously; the 2nd set with a 1-day interval; the 3rd set with a 1-week interval; and the 4th set with a 1-month interval. Again, pairs of samples were made, one with the ink 1st and one with the printer 1st.

Each crossing was extracted from the test sample with a hole punch. For greater ease in handling, disks 1cm in diameter were excised (Figure 4a and 4b). These samples were affixed to the support of the microscope with 2-way tape. In actual case work, the sample can be reduced to a minimum of 3mm in diameter, thus minimizing damage to the document under study. If sample size were reduced any further the surface of the sample would be warped, negatively affecting the operation of the microscope. AFM needs the flattest possible surface to be most effective.

Results and Discussion

First Part: Study of the Pens and Printers

The 1st samples studied under the microscope were of the unmarked paper. The fibers that comprised the paper were readily imaged (Figure 5). In the next step, lines made with ballpoint, roller-ball, and gel-ink pens on the paper were imaged (Figures 6, 7, and 8). Next, text lines made with inkjet printers were imaged (Figure 9). Attempts to image laser printing were not successful.

As had been hypothesized, image areas on paper could readily be distinguished from non-image areas. The 4 different types of media that could be imaged could also be visually differentiated, though the 3 manually applied inks did show some similarities among themselves. All 3 showed complete coverage of the image area with small, rounded particles alternating with flat areas of various sizes. In contrast, the lines created with an inkjet printer presented a uniform, pebbly appearance (Figure 9). Samples made with a full cartridge could not be distinguished from those made with a nearly empty cartridge (Figure 10a and 10b). The amount of ink in an inkjet cartridge can be eliminated as influencing results obtained with AFM.

Results obtained from laser printers were variable. Adequate images could not be captured. An explanation may lie in the nature of laser printing, which consists of heat-fused toner sitting on the surface of the paper. AFM requires a smooth, flat sample surface in order to function properly. At this level of magnification, the build-up of toner on the surface of the image area may exceed the ability of the instrument to measure the "z" axis. These inconsistent results worsened when a study of line intersections was done. Therefore, the study of images made with laser printers was discontinued.

Second Part: Study of the Crossings

Below are the results of several heterogeneous crossing studies: The images appear in pairs corresponding to the same printer. The 1st image (a) of each pair corresponds to the surface of an ink stroke from a printer over which a different ink has been deposited with a writing pen. The 2nd image (b) corresponds to the surface of a line drawn with a writing instrument that has been later covered by the ink of text printed with the printer.

A common feature exists among all the image pairs presented. Similarities can be seen between the images taken from the surface of the ink of the printer deposited directly on the paper and those on which the ink from the printer is deposited over the ink strokes made by the different pens (Figures 11b, 12b, and 13b). In all of these images, a rough surface is observed, with small protrusions, most likely due to the shape and speed in which the ink drop is deposited on the paper. The pebbled appearance and the lack of smooth surface areas indicate that the ink from the printer has been positioned over the ink stroke of the manual writing instrument.

When the manual writing instrument stroke is deposited over the inkjet line, wide, smooth areas can be observed. These areas can be observed occupying a greater or smaller amount of surface in all the images (Figures 11a, 12a, and 13a). The appearance of these smooth areas is consistent with the ink of the writing instrument having been deposited over the text printed by the machine.

Third Part: The Variable of Time

One of the characteristics of inks is the process of their drying on paper. Inks contain resins. These resins are in a liquid state while inside the ink reservoir but start their drying and aging as soon as they are left on the paper, and the polymerization process begins. The drying/hardening of inks over different time intervals must be considered as an influencing factor on observations of line intersections with AFM.

In order to evaluate this possibility, 4 test sample pairs were prepared. The 1st pair was prepared essentially contemporaneously (Figure 14); for the 2nd pair, there was a 1-day interval (Fig. 15); for the 3rd pair, 8 days elapsed (Figure 16); and in the last pair of samples, there was a 40-day interlude between deposits of ink (Figure 17).

It is apparent from the photographs that as the time interval between the inkjet deposit and the handwritten pen stoke increased, the pen stroke became flatter.

Elements of Distortion

Among the factors that could produce distortion in the surface images is the handling that the paper has received. A fingerprint of a subject that handled the paper deposited on a line intersection could distort an AFM image.

During this study, instead of handling the paper with gloves as in proper laboratory methodology, the papers were handled with bare hands in accordance with normal office practices. The samples were stored and carried in cardboard folders and plastic bags, as would be done in an office.

Ambiguous results could be due to previous handling or other extraneous factors. In such cases, repeated images should be made, either of the same or another intersection, if available. The area of a line intersection imaged by AFM is so tiny that a repeated examination of the same intersection would most likely be of a different location and might produce more definitive results.

Advantages and Disadvantages of the Use of AFM

The fundamental advantage of the AFM over the SEM is that there is no need to render the sample surface conductive in order to introduce it into the microscope.

A disadvantage of AFM is that it is a destructive technique in that a disk at least 3mm in diameter must be excised from the paper at a line intersection. The destructive nature of AFM is somewhat mitigated in that the sample, though excised from the paper, is not itself damaged. The sample is available for repeated examinations.

Another consideration in using AFM is operator experience. It must be emphasized that this is a qualitative technique subject to the knowledge of the expert who interprets the images. The interpretation of the images obtained by the AFM must necessarily be made by an expert familiar with this type of image

Conclusions

1. AFM can be used to differentiate image areas from non-image areas on paper and indicate the type of writing instrument/printer used to create a line.
2. The surface of texts with laser printers is not suitable for study with an AFM.
3. The images obtained from the ink-jet printers with a full cartridge and with an almost empty cartridge did not present significant differences. The amount of ink in the cartridge is not a factor to consider.
4. AFM can resolve sequence of some line intersections. When the printer ink is on top, the image is similar to the image of the printer ink outside of the crossing; when the printer ink is underneath and the stroke of the instrument is above, the surface of the line intersection is observed to be flatter and smoother.
5. Time between the deposition of the 1st line and the intersecting line is a factor that benefits discrimination with AFM when the handwritten line is on top. The longer the interval between printing and writing, the smoother the surface at the intersection appears.

Note 1: It is critically important to take images of both types of writing lines 1st before undertaking a study of their intersections. The operator must be familiar with the characteristics of both types of graphic media before attempting to understand how they will interact.

Note 2: This study dealt only with heterogeneous line intersections. Some initial testing with homogeneous line intersection did not yield encouraging results, and the effort was abandoned.

Acknowledgements

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