CSI HELSINKI: SWLI IN FORENSIC SCIENCE: COMPARING TOOLMARKS OF DIAGONAL CUTTING PLIERS

P. Ahvenainen[1], I. Kassamakov[2], K. Hanhijärvi[1], J. Aaltonen[3],
S. Lehto[4], T. Reinikainen[4] and E. Hæggström[1]

[1] Department of Physics, P.O.B. 64, FIN-00014 University of Helsinki, Finland
[2] Department of Micro and Nanosciences, Helsinki University of Technology, P.O. Box 3500, FIN-02015 TKK, Finland
[3] Helsinki Institute of Physics, P.O.B. 64, FIN-00014 University of Helsinki, Finland
[4] National Bureau of Investigation, Forensic Laboratory, Vantaa, Finland

ABSTRACT. Scanning White Light Interferometry provides sub-micron depth resolution and is therefore an ideal data acquisition method for forensic toolmark comparison in which such resolution is required. We imaged toolmarks made on ten copper wires with a preselected part of the jaws of a pair of diagonal cutting pliers. The common pattern found in the surface depth profiles comparison indicated a common source. The application of white light interferometry provides a quantitative method for forensic toolmark study through high-resolution 3D profiles.

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INTRODUCTION

New forensic technologies and techniques make it harder to commit crimes without getting caught. Evidence that was unavailable in the past due to its microscopic size and lack of proper analyzing equipment can now be used to connect a suspect to a crime scene. Large databases of fingerprints, DNA markers and bullet surfaces have made it possible to connect a gun or a person to a past crime scene. Cutting tools leave marks that can connect a set of toolmarks to an individual tool [1,2].

Traditional toolmark comparison is done with optical comparison microscopes. They have been used in forensic laboratories by forensic experts who compare two dimensional (2D) images qualitatively. Nowadays scanning electron microscopy offers high magnification and techniques such as confocal microscopy and Scanning White Light Interferometry (SWLI) allow three dimensional (3D) imaging.

Confocal microscopes are slow and employ high-power coherent light sources that may damage sensitive samples [3]. Scanning electron microscopes on the other hand require special sample preparation [4].

TABLE 1. Minimum numbers of Consecutive Matching Striae (CMS) in the best matching position required to find an agreement between an evidence toolmark and a test toolmark, "the conservative quantitative criteria for identification" (mostly based on bullet comparisons) [10].

Minimum number of CMS required for an agreement between two toolmarks	One group of CMS	Two groups of CMS
Two-dimensional image	8 striations	5 striations
Three-dimensional image	6 striations	3 striations

SWLI [5] solves these problems by enabling quantitative and rapid nondestructive 3D surface profiling relevant to forensic science. It delivers nanometer scale precision, which is sufficient when measuring impressions on bullet surfaces [6]. The depth resolution of SWLI is superior to that of conventional imaging methods where the resolution depends on the aperture [7]. SWLI is similar to optical coherence tomography (OCT) [8], frequently used in medical science. Both methods are based on low-coherence interferometry. The principal difference is that OCT is typically used in point measurement mode to construct cross-sections of semi-transparent materials, while SWLI is applied in full field 3D imaging of highly reflecting surfaces.

Traditional forensic toolmark comparison is based either on surface pattern comparison [9] or on Consecutive Matching Striae (CMS) [10]. Both these techniques rely on the expertise of the examiner making them expensive and resource-demanding. SWLI helps forensic examiners by offering surface profiles as a possible screening tool.

In statistical studies [11-13] no known non-match of two toolmarks has ever met the conservative quantitative criteria for identification (Table 1, no false positives). Such quantitative criteria can be applied to bullets, but not necessarily for other kind of toolmarks.

One should also note that since 3D imaging offers more information than 2D imaging fewer striations are required to find a match (Table 1) using the conservative quantitative criteria for identification. When the toolmark is very small a 2D image may not offer enough characteristics for a forensic examiner to make a positive identification. In this case 3D imaging may provide enough matching.

Recently a commercial 3D comparison system (BulletTRAX-3D™) based on confocal microscopy and a 2D based comparison system (IBIS) were compared [14] using copper and lead bullets. With copper bullets both systems performed well. However, with lead bullets, the IBIS system ranked 70% of the reference samples outside a top-20 position to their known match (many false negatives) whereas BulletTRAX-3D matched them all in the top 10 positions. This means that the use of the 2D comparison system could miss a match (false negative). This is why a 3D comparison system for toolmarks is vital in modern crime scene investigation.

METHODS

Sample Preparation

We soldered ten copper wires (diameter 2.10±0.10 mm) onto a sample plate made of two pieces of test Printed Circuit Board (PCB), (Fig. 1a-1c). This sample preparation limited the number of variables involved in the imaging.

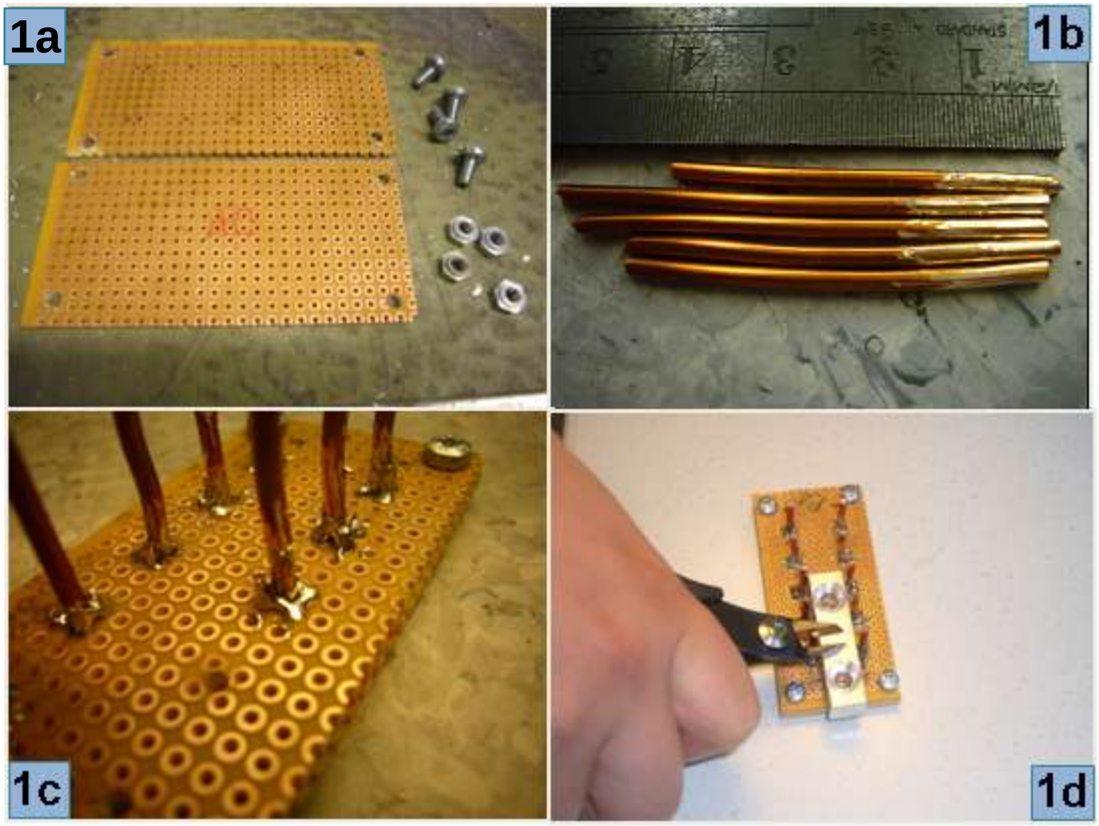

FIGURE 1. a) Sample plate material: two test PCB plates (71 mm times 33 mm) with a 2.9 mm hole in each corner, four Phillips-head 3x6 steel bolts (3.0 mm diameter and 6.0 mm thread length) and four matching nuts. **b)** Five of the ten copper wires with one head stripped of isolating material **c)** Close-up of sample after eight of the ten wires have been soldered. **d)** The sample wires were cut with Pro's Kit Micro Nippers, model 1PK-30-E

Once all wires were soldered they were cut with the diagonal cutters, (Fig. 1d). A metal support was used during cutting to control the five degrees of freedom, Fig. 2a. One part of the blades was marked and this part was used to cut all sample wires. The finished test sample is pictured in Fig. 2b.

Scanning White Light Interferometry

3D images were obtained with a Scanning White Light Interferometer. The measurement instrument [15] used in this study was built at the University of Helsinki. A schematic of our forensic SWLI set-up is pictured in Figure 2c. In this study a total optical magnification of 2.5x was used.

The end surface of the sample has two sides created by different blades of the diagonal cutting pliers. The side generated by the left jaw was named 'A', whereas the other side was named 'B' (Fig. 3). First we closed the reference arm of the interferometer and took a snapshot with the CCD camera to get a microscope type image. The surfaces were then scanned in interferometric mode (the reference arm was in use). During scanning, frames were averaged (N=25) at each optical delay position in order to improve the signal-to-noise ratio. The scanning process took less than two minutes to complete.

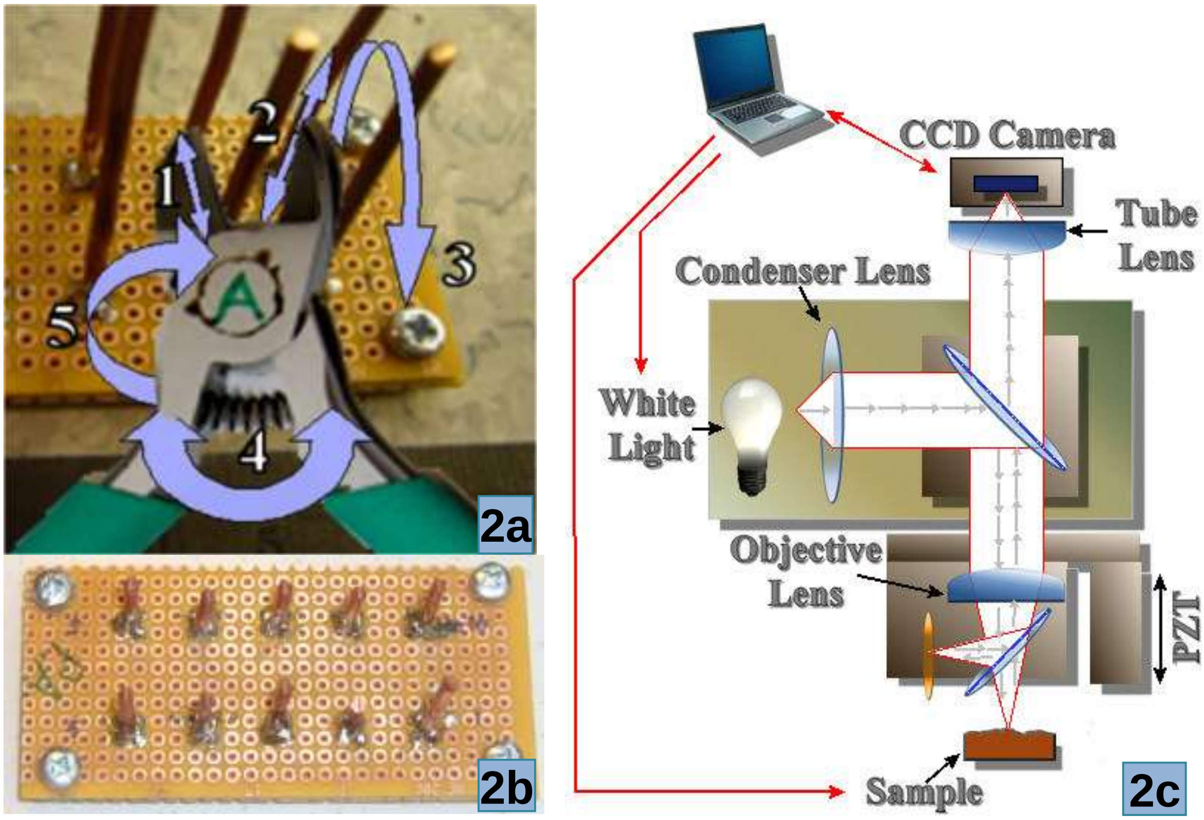

FIGURE 2. **a)** The five degrees of freedom shown here were constrained by the sample preparation. **b)** Toolmark comparison samples. **c)** Schematic of SWLI set-up used for forensic applications

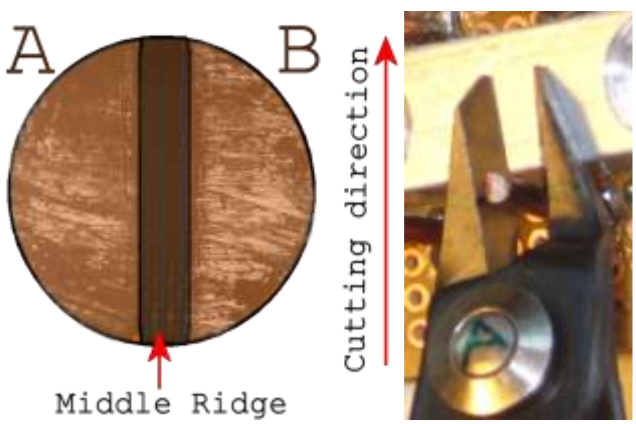

FIGURE 3. Wire topview and close-up photograph of the actual cutting procedure. A schematic of the cut surface of a wire cut with diagonal cutting pliers shows that the two blades leave toolmarks on different hemicircles of the surface. The middle ridge is the elevated part of the surface where the blades have met.

The acquired 3D image was tilted and filtered (median filter, 3x3 window and intensity thresholding) in software. This 3D data was exported from the device control software and processed in a numerical computing environment (Matlab). A surface profile was chosen close to the middle ridge (Fig. 3) that separates the two sides of the cut surface. This imaging process was repeated for all ten wires.

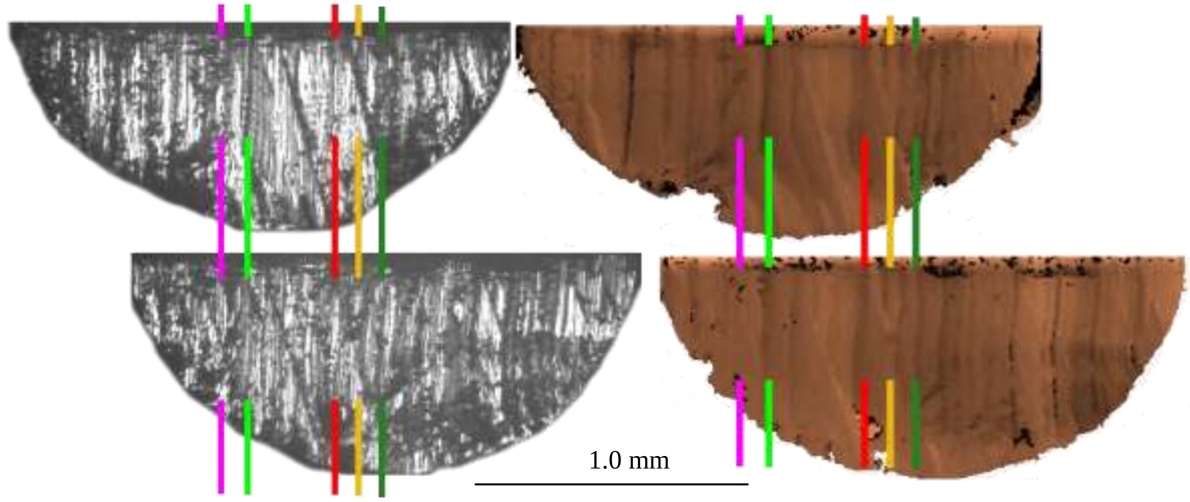

FIGURE 4. Microscopic CCD camera snapshots (left) and 2D surface plots based on interferometric data (right) of samples 1 (top) and 7 (bottom), both side B. For an untrained observer the common ridges and peaks are more visible in the interferometric image, compared to the microscopic photograph. Colored vertical lines indicate common lines for both sides.

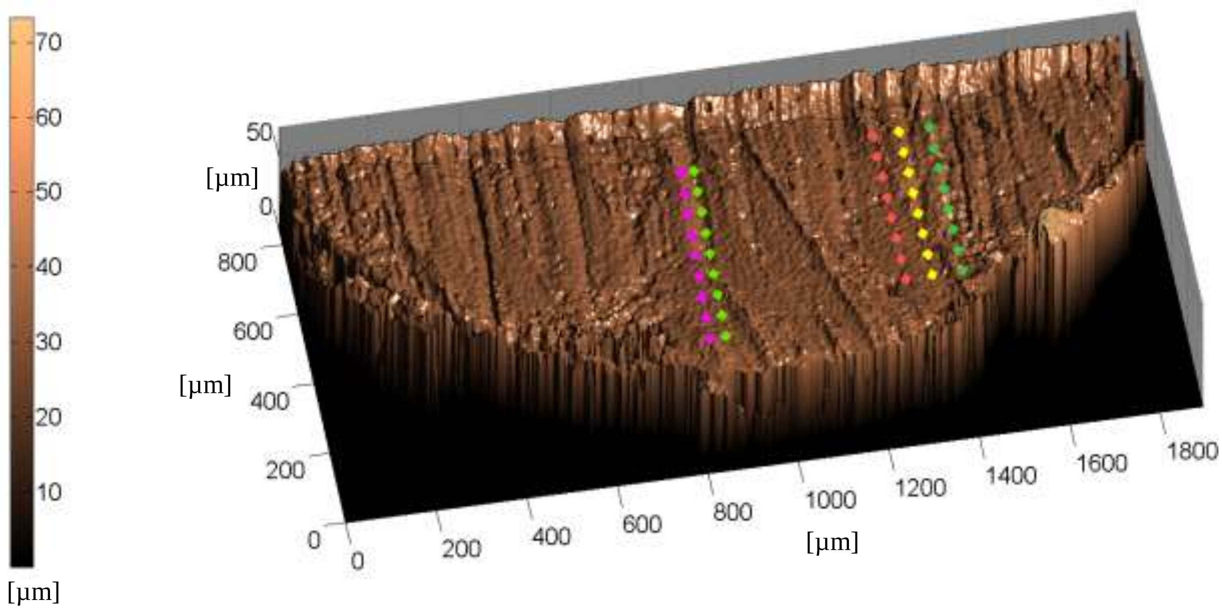

FIGURE 5. 3D plot of the side B of sample 1 (N.B. z axis scaled bigger than other axes for visual emphasis). The image illustrates the ease of feature recognition from interferometric data. Interferometric image color indicates surface height rather than reflection dependent contrast. The colored dotted lines are identical to those shown in Fig. 4.

RESULTS AND DISCUSSION

Figure 4 shows a microscopic snapshot of two toolmarks. It is hard for the untrained eye to find and match the peaks and ridges without adjusting lighting conditions. A 2D surface plot can be constructed from the interferometric data (Fig. 4). In such a plot it is easier to find these common striations (marked with vertical lines in Figs. 4 and 5). A 3D plot permits adjusting the illumination settings, similarly to what forensic experts do when using comparison microscopes.

The 3D surfaces (Fig. 5) are immediately digitized making initial comparison work faster and less resource-demanding. This allows future comparisons relying on larger databases, an approach that would be impossible in practice if an expert would have to manually compare all samples in the database using optical comparison microscopes.

The surface profiles of side B show a common microscopic striation pattern that is caused by the surface features on the right hand side blade of the diagonal cutting pliers (Fig. 3). Part of that pattern that comprises peaks and furrows is marked in Fig. 6 with dotted vertical lines.

The surface profiles of side A are shown in Fig. 7. As expected, a common microscopic pattern was found that corresponds to the left hand side of the jaws (Fig. 3). The profiles of different sides do not match which facilitates the identification of individual plier blades.

Note that only the part of the profiles that were common in all profiles is shown. Individual profiles were 1700±100 μm long. It has been mentioned in literature [16] that toolmarks that are less than 2 mm wide may exhibit insufficient characteristics to indicate correspondence, even if such exists. It should be noted that this reference deals with 2D comparison of matching lines. The 3D data obtainable by SWLI systems offer more information and makes comparison of smaller toolmarks easier and more reliable.

We would also like to point out that some samples either lacked some of the peaks and furrows or showed additional peaks and furrows. Sample #2 of side A (Fig. 7) lacked part of the common pattern of peaks and furrows. This lack of characteristics could result in sample #2 not being considered to have been cut with the same tool as the rest of the samples (false negative). Sample #10 of side B (Fig. 6) on the other hand shows more peaks and furrows than other samples (false negative).

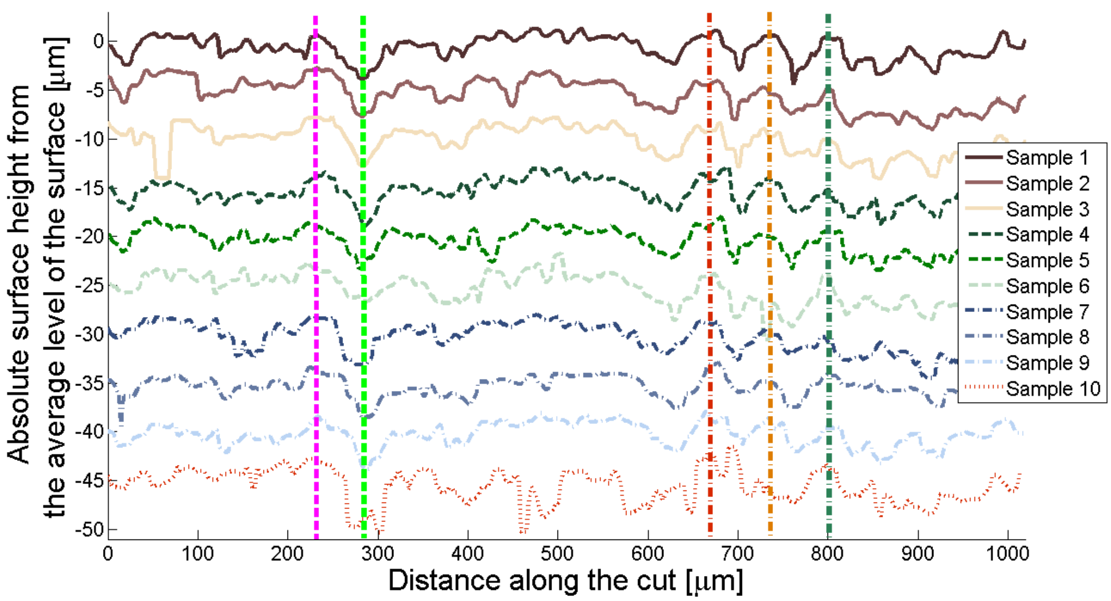

FIGURE 6. Depth profiles of samples #1 to #10, side B. Vertical lines show common characteristic points. Profiles are aligned by a computer program that chooses the horizontal alignment that results in least amount of total height difference between two profiles divided by their common length. This graph lets us correctly conclude that all wires were cut with the same tool.

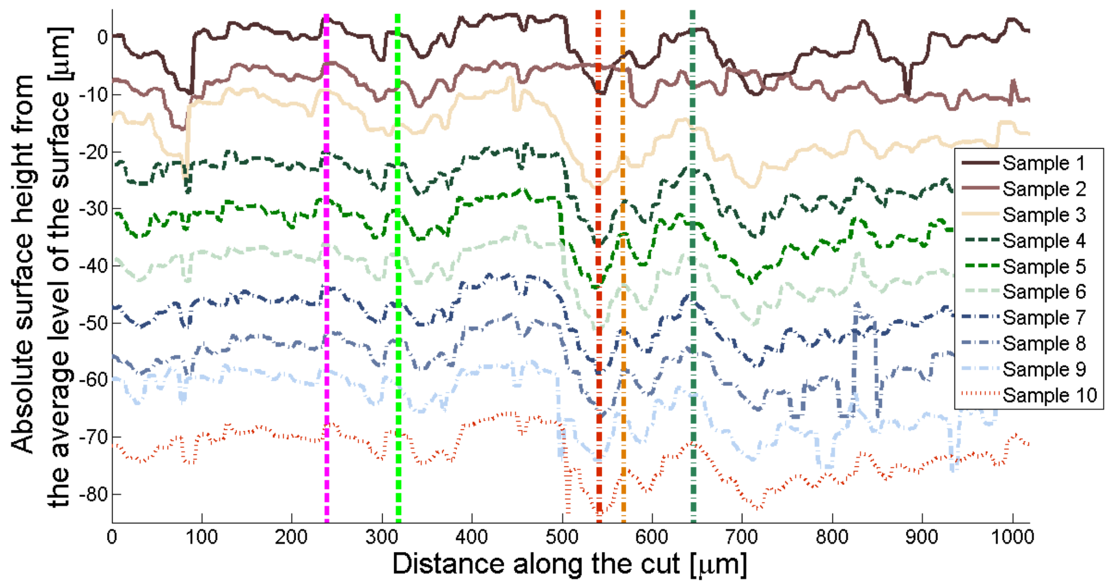

FIGURE 7. Depth profiles of samples #1 to #10, side A. The same program used in aligning side B was used in aligning side A as well. This graph lets us correctly conclude that all wires were cut with the same tool.

The cut surface is a striated toolmark and thus one can find a similar pattern of peaks and furrows even if the surface profiles are obtained at different distances from the center ridge. Further studies should be conducted on how much the profiles change depending on the distance from the center ridge (Fig. 3).

Normal tool use slowly alters its surface due to wear. Little quantitative data exist about such wear in the literature. However, studies have been conducted on how the bullet surface toolmarks change under normal gun use [17-20]. Unfortunately, those results may not be directly applicable to other types of toolmarks and tools. A further study should therefore be conducted on how the surface profile change over time, and how this change can be predicted.

Future work should also focus on developing a statistical approach to classifying toolmarks. By calculating bootstrap or jack-knife estimates [21] of mean profile heights, a certain toolmark could be linked to a previously known set of measurements.

CONCLUSIONS

A depth profile can be used to compare two sets of toolmarks. Since the profiles consist of numerical information the process of comparing profiles can be automated. The profiles can be used to limit the number of comparisons and as with IBIS [22] for bullets, and AFIS for fingerprints [23] to help forensic experts to find similarity easier.

SWLI data can also be used to archive 3D surfaces for future comparisons. Preliminary forensic comparison can be done with 3D models allowing long distance evaluation and centralized imaging facilities.

A SWLI set-up extends the data acquisition package of a forensic examiner by providing non-destructive, non-contact 3D imaging with sub-micron resolution.

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