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Use of a scanning optical profilometer for toolmark characterization

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An optical profilometer has been used to obtain 3-dimensional data for use in two research projects concerning toolmark quantification and identification. In the first study quantitative comparisons between toolmarks made using data from the optical system proved superior to similar data obtained using a stylus profilometer. In the second study the ability of the instrument to obtain accurate data from two surfaces intersecting at a high angle (approximately 90 degrees) is demonstrated by obtaining measurements from the tip of a flat screwdriver. The data obtained was used to produce a computer generated "virtual tool," which was then employed to create "virtual tool marks." How these experiments were conducted and the results obtained will be presented and discussed.

Keywords

Materials Science and Engineering, Center for Nondestructive Evaluation, Statistics, Ames Lab

Disciplines

Applied Statistics | Computer-Aided Engineering and Design | Manufacturing

Comments

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Abstract

An optical profilometer has been used to obtain 3-dimensional data for use in two research projects concerning toolmark quantification and identification. In the first study quantitative comparisons between toolmarks made using data from the optical system proved superior to similar data obtained using a stylus profilometer. In the second study the ability of the instrument to obtain accurate data from two surfaces intersecting at a high angle (approximately 90 degrees) is demonstrated by obtaining measurements from the tip of a flat screwdriver. The data obtained was used to produce a computer generated "virtual tool," which was then employed to create "virtual tool marks." How these experiments were conducted and the results obtained will be presented and discussed.

Introduction

In light of the 1993 Daubert vs. State of Florida decision, forensic examiners are under increasing pressure to prove that the methods they routinely employ meet established criteria pertaining to a scientific investigation. It was asserted in this ruling that in order to qualify as 'scientific knowledge,' four criteria must be met: testability of scientific principle, known or potential error rate, peer review and publication, and general acceptance in a particular scientific community [1]. Thus, proving that basic inferences or assertions held by experts in the field of forensics have a sound scientific basis is a goal of law enforcement agencies and researchers around the country. In support of this goal, Iowa State University has been conducting research into the matching of toolmark striae using quantitative, objective measurements of the surface.

Initial results [2] indicated that simple statistics computed from the quantitative data produced by a surface profilometer, namely, maximized data correlations over short data segments, supported the empirical assertions of forensic examiners concerning comparisons of tool marks generated on lead plates by consecutively manufactured screwdriver tips. These results were substantiated in a later study [3] where a t-statistic index produced by a computer algorithm provided a more statistically meaningful comparison than maximized correlation. Experiments involving comparisons of samples obtained from a single tool to each other, and to samples produced from other similar sequentially manufactured tools, show that the analysis can fairly reliably separate sample pairs that are known matches from the same tool from pairs obtained from different tools. Additionally, the index provided a means of calculating estimates of error rates within the narrow and specific setting of the study.

One drawback to these studies is that the data analyzed was obtained by using a surface profilometer. In this method a balanced stylus is dragged across the surface of the sample to measure the relative heights of the sample. While this method is extremely accurate, it does slightly affect the

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surface of the sample, as is evident by the visible trace lines that appear as a result of the measurement scan.

This paper discusses the application of an optical scanning profilometer to obtain data from tool marked surfaces. This instrument provides a non-contact means of measuring the surface roughness of the toolmark, while maintaining the high quality of data required by the computer algorithm. The applicability of the instrument is such that reliable data can be obtained from steeply sided samples (e.g. the very edge of a screwdriver tip), which are difficult to measure by other means. This opens the possibility of making direct comparisons between tools and their resultant marks, as well as a means of characterizing a tool itself to deduce data concerning the nature of the toolmark it could be expected to produce. Results from initial experiments involving use of an optical profilometer will be presented as well as plans for additional research using this incredibly flexible instrument.

Experimental Procedure

The test set for this study involved 50 screwdriver tips obtained from Omega Company and manufactured sequentially so to be as nearly identical as possible. Test marks for study were produced in lead by dragging the tip across a small sample plate at fixed angles of 30˚, 60˚, and 85˚. Details of sample production are described in [2]. The surface roughness of the samples had already been characterized using a surface profilometer [2,3] for earlier studies. In the present study a smaller subset of samples were re-examined using an Alicona Infinite Focus optical profilometer, Figure 1. This instrument capable of scanning with a resolution of up to 800 nm in the z axis at 5x magnification, and up to a resolution of 10 nm in the z axis at 100x magnification, over an extended x-y range of 100 mm by 76 mm respectively at 5x magnification, and 5 mm by 4 mm respectively at 100x magnification. Rough surfaces can be easily quantified with accurate measurement of Ra, Rq and Rz wher Ra is the arithmetical mean roughness of a measured surface, Rq is the root mean square roughness, and Rz is a result of ISO 9000 standards and specifically is measured over 5 peaks and valleys at 10 points on the part. Measurement of roughness, waviness and contour all conform to recognized international ISO standards. This instrument also allows for the accurate measurement of surfaces at steep angles of up to 80 degrees from the x- y plane.

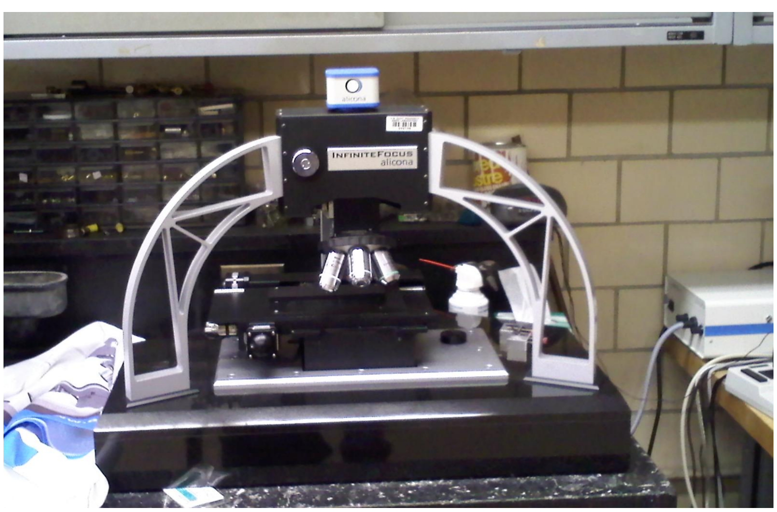


Figure 1: Alicona Infinite Focus Instrument.

The samples chosen to be re-evaluated were those examined by practicing forensic examiners at the 2008 Asssociation of Firearms and Toolmark Examiners (AFTE) convention. The resultant data were analyzed using the same computer algorithm employed in [3], and the T-statistic indexes determined. The samples examined fall into four distinct classes: True match samples were the algorithm returned a high T1 value; true Match samples where the algorithm returned a low T1 (indicative of a nonmatch); true nonmatch samples where the algorithm returned a low T1; true nonmatch samples where the algorithm returned a high T1 (indicative of a match).

The Infinite Focus Microscope (IFM) was also used to obtain quantitative information from the end of one screwdriver tip selected at random from the pool of 50 possible tips. In order to characterize the tip scans one scan is not sufficient to obtain the necessary information from the neighboring surfaces due to the high angle of incidence they make with the tip of the tool. For this proof of concept study a single scan made at an angle 45 degrees was used.

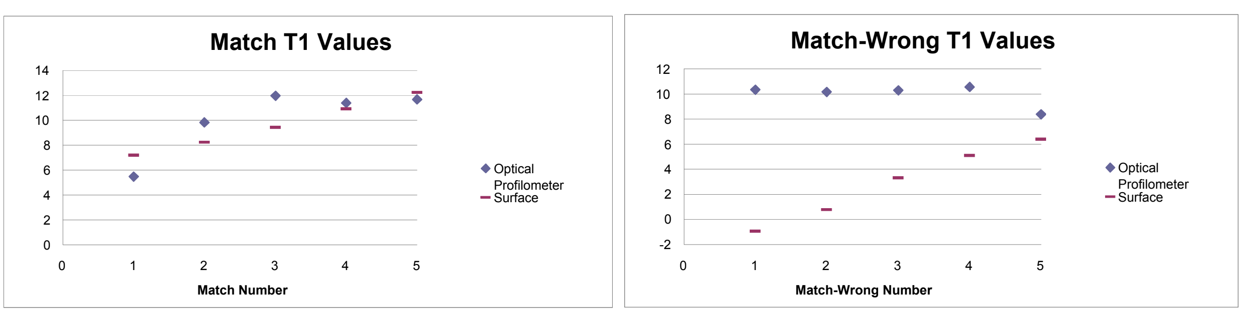
Scanning two surfaces at a high angle with respect to each other where the vertical distance changes substantially results in a considerable amount of noise. Since the software provided by Alicona requires an extremely time-consuming procedure to clean up the noise, an automatic approach to process the data was developed to speed this process [4]. By approximating polynomials line-by-line horizontally and vertically, the invalid measurement points are detected and fixed automatically.

Once 3-D data is acquired and the background noise removed, a full 3-D surface map can be generated and used to produce a reconstructed "virtual tool" that allows a user to manipulate the tool in whatever manner desired. This virtual tool (VT) could then be employed to construct "virtual marks" (VM) where all of the parameters required to generate the mark are known.

Experimental Results and Discussion

<u>Toolmark Comparisons</u>

The results of samples evaluated using the optical profilometer and analyzed using the algorithm are shown in Figure 2. Note that a high T1 value is indicative of a match, while values near to 0 indicate little similarity between the comparison scans.



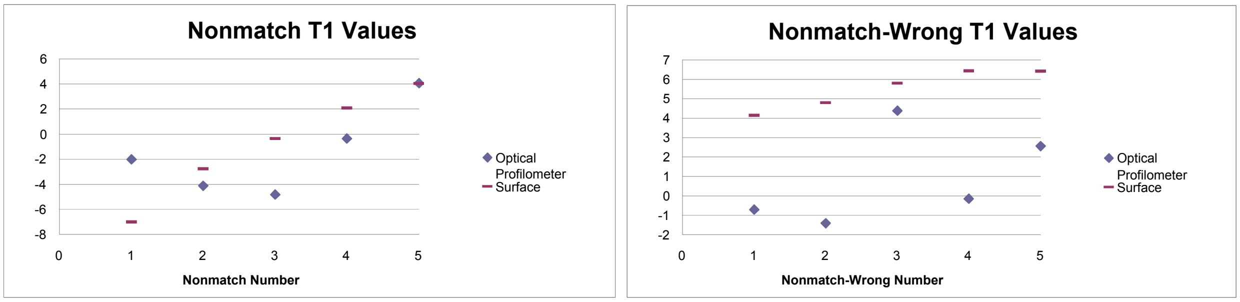


Figure 2: Comparison of T1 values for data obtained using a stylus profilometer vs. the optical IFM. comparison of a) true matches properly classify as such; b) true matches improperly classified as nonmatches; c) true nonmatches properly classified as such; d) true nonmatches improperly classified as matches.

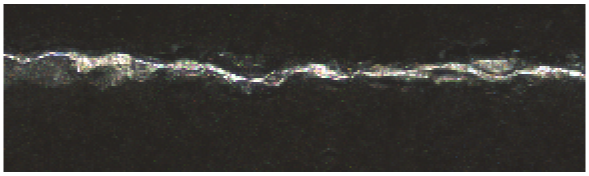
In almost all cases the T1 values obtained using the optical data are superior to those from the profilometer. For the correctly identified matches of Figure 1a the optical Ti values are similar to the stylus data, being only slightly higher on average. However, a dramatic change is seen when the data from the previously incorrectly analyzed match samples of Figure 2b is considered. All of these samples now clearly would be classified as matches. Similarly, the nonmatch samples correctly identified as nonmatches have similar values for the optical and stylus data (Fig. 2c); the nonmatches incorrected identified as matches using the stylus data correctly result in low T1 values in four out of five cases when the optical data is used (Fig. 2d).

While it is encouraging that the optical data out performs the stylus data, care should be taken in interpreting these results as being solely due to the application of the IFM. For the initial study using surface profilometer data, contextual information was not taken into account. In that study the algorithm was allowed to compare the linear marks without regard to which side of the mark corresponded to the left or right side of the screwdriver. As was discovered by the AFTE study, ensuring that this type of contextual information was used was one manner in which performance might be enhanced. This information was included for the comparisons of the optical data, and could be responsible for some of the improvement seen. However, it is clear that the optical data obtained using the IFM is of excellent quality.

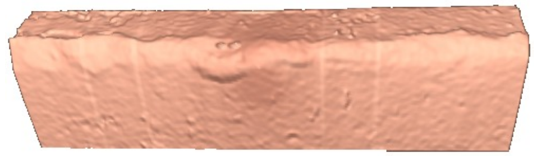
It should be noted that the consistent increase in T1 values for the stylus scans is merely a function of which samples were selected for the study. The large number of comparisons done in [6] gave a spread of values, from which the AFTE study samples were chosen. These were chosen to cover a range of T1 values, hence the apparent trend.

<u>Virtual Tool Generation</u>

Preliminary research to develop a virtual tool (VT) using the technique described in detail in [song 13] shows promising results. As a proof of the concept, a single scan taken at a 45-deg angle using the IFM was used to produce a VT edge. Figure 3 (a) shows the actual optical image of the edge in question; Figure 3 (b) shows the result of the IFM 3-D scanned data after noise reduction.



(a) 2-D photograph of the scanned tool.

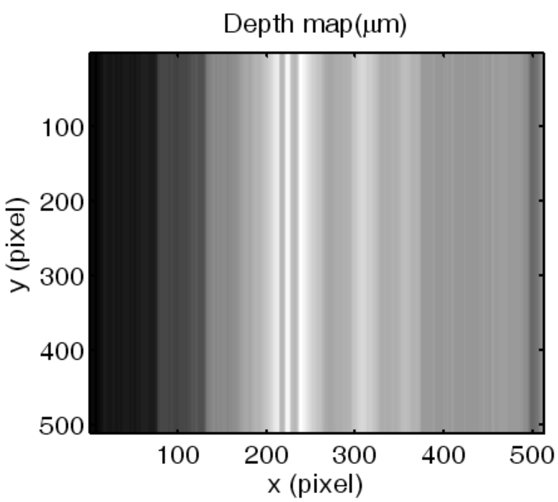


(b) 3-D data rendered in shaded mode.

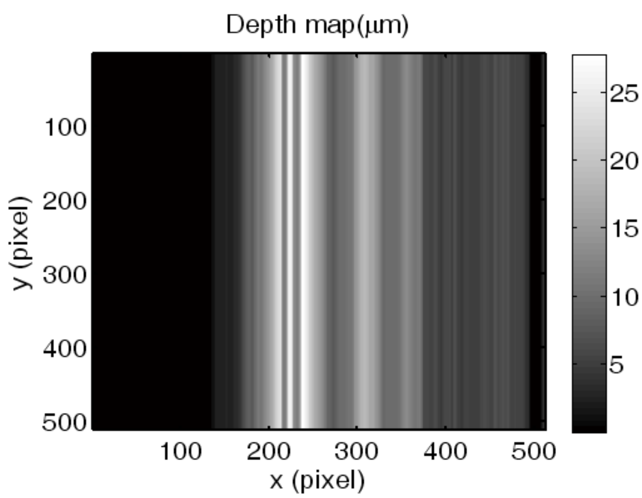
Figure 12: 3-D data scanned by the IFM after noise reduction.

Once the VT is obtained, generating a VM can be done by projection of the 3-D geometry onto a 2-D plane. For these initial tests it was assumed that the tool is always harder than the surface marked. This means the depth of the virtual mark is a function of the applied force and is simply transference of the surface roughness of the tool, with the angular dependence of the tool surface projections being taken into account. By changing the projection direction the effect of changing the angle of the VT on producing a different VM can be seen.

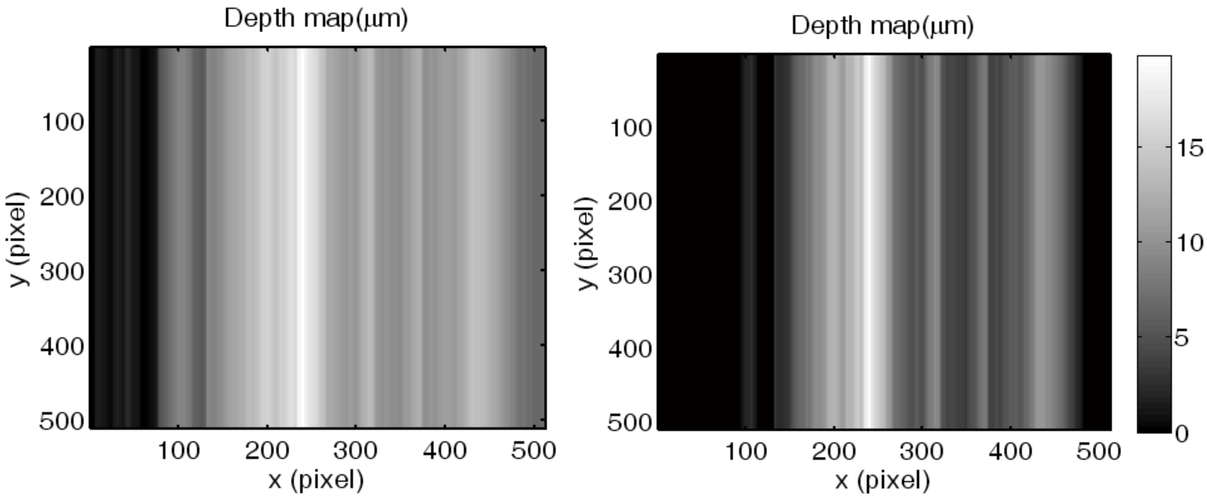
Figure 4 presents a comparison of four generated images of virtual marks, showing how the mark will change as a function of angle and applied force. Note that in these preliminary experiments material parameters have not been taken into account. Twist of the tool tip is also not accounted for, it is assumed that the entire width of the virtual tool marks the sample and the data of Figure 5 is taken perpendicular to the direction of the mark.



a.



b.



c. d.

Figure 4: Comparison of generated images of virtual marks from a) 30 degree angle, high applied force; b) 30 degree angle, low applied force; c) 45 degree angle, high applied force; d) 45 degree angle, low applied force.

Comparison of the images (Fig 4a to b and Fig. 4c to d) shows how reducing applied pressure not only causes a less than complete VM to be produced but also results in large roughness projections dominating the mark. While the scans at 30 degrees are similar to those at 45 it is clear that the change in angle is producing a variation in the pattern. This is in qualitative agreement with toolmark examiner experiential knowledge [5], which generally says that the angular difference between marks needs to be less than 10-15 degrees in order to positively declare a match.

The visual data of Figure 4 is quantified in Figure 5, where the physical measurements needed by the algorithm for conducting comparisons is shown. For these initial tests, changing the applied force simply reduces the amount of penetration of the VT into the virtual substrate, so the marks displayed as a function of applied force are essentially identical in regions where a VM is created. This will change, however, once physical properties of the substrate and tool are taken into account. For example, in real life when a low applied force is used, the yield strength of the substrate material may not be exceeded in many areas where tool roughness is low. In this case the deformation of the material may be entirely elastic, with no mark left on the surface.

The differences in the VMs made at the two different angles suggested in Figure 4 are even more apparent when one considers the height data of Figure 5. Changing the angle of incidence has cause some marks virtual striae to disappear entirely while creating new ones at other locations. This is entirely consistent with experiential knowledge.

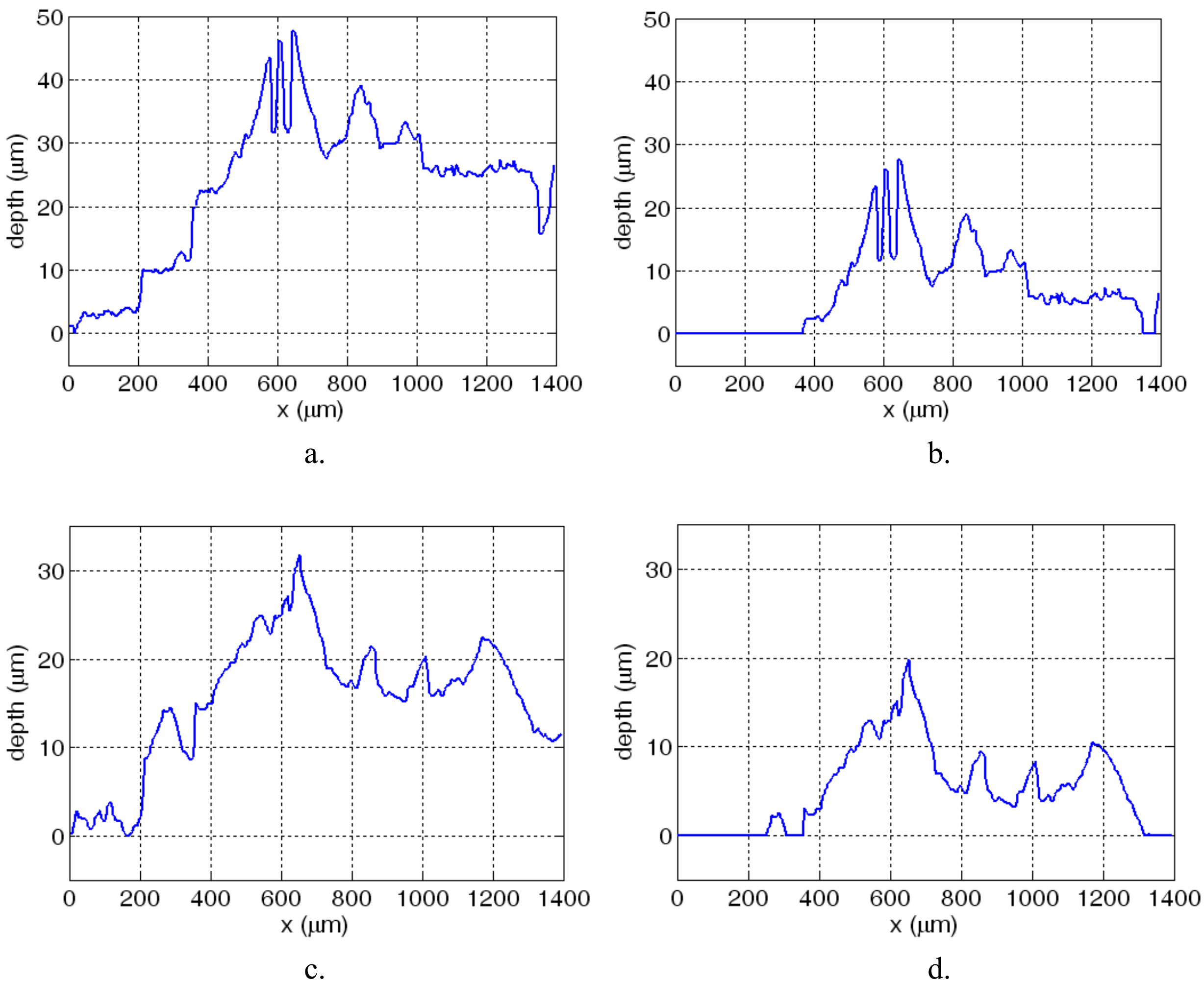


Figure 5: Comparison of generated height differences of virtual marks from a) 30 degree angle, high applied force; b) 30 degree angle, low applied force; c) 45 degree angle, high applied force; d) 45 degree angle, low applied force.

Summary and Conclusions

The preliminary experiments conducted thus far have shown the ability of an optical profilometer to produce high quality data similar to that obtained by a stylus profilometer, yet without affecting the surface in any way. Although the instrument is flexible, background subtraction and reduction of the data into a useable form is less than straightforward, and can be extremely time-consuming when relying on the company provided software. However, the ability of the instrument to obtain information from surfaces intersecting at angles approaching 90 degrees, when coupled with suitable background subtraction and data reduction and analysis algorithms, opens up numerous opportunities for employing the instrument in areas of forensic research.

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