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Virtual and simulated striated toolmarks for forensic applications

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ABSTRACT

Large numbers of experimental toolmarks of screwdrivers are often required in casework of toolmark examiners and in research environments alike, to be able to recover the angle of attack of a crime scene mark and to determine statistically meaningful properties of toolmarks respectively. However, in practice the number of marks is limited by the time needed to create them.

In this article, we present an approach to predict how a striated mark of a particular tool would look like, using 3D surface datasets of screwdrivers. We compare these virtual toolmarks qualitatively and quantitatively with real experimental marks in wax and show that they are very similar. In addition we study toolmark similarity, dependent on the angle of attack, with a very high angular resolution of 1°. The results show that for the tested type of screwdriver, our toolmark comparison framework yields known match similarity scores that are above the mean known non-match similarity scores, even for known match differences in angle of attack of up to 40°. In addition we demonstrate an approach to automatically recover the angle of attack of an experimental toolmark and experiments yield high accuracy and precision of $0.618 \pm 4.179°$. Furthermore, we present a strategy to study the structural elements of striated toolmarks using wavelet analysis, and show how to use the results to simulate realistic toolmarks.

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1. Introduction

Tools like screwdrivers and crowbars are often used during the commission of a crime and therefore striated toolmarks can regularly be found at a crime scene. In case a tool can be seized from a suspect afterwards the question arises, whether the marks were created with that particular tool. To tackle this question forensic toolmark examiners generate experimental test marks with the suspect tool in the laboratory and subsequently compare them to the questioned marks found at the crime scene.

The traditional method to compare questioned and test marks is to use 2D microscopy. The examiner puts both marks under a comparison microscope and manually illuminates the toolmarks with oblique light, such that the striations become visible as a light(ridges)-shadow(furrows) pattern. Subsequently, the examiner has to assess the possibility of (dis-)similarities between the marks, assuming that they are made with the same tool vs. assuming that they are made with different tools.

The traditional approach of toolmark examination relies on manual illumination and comparison of the marks and therefore includes subjective judgments. Therefore a report of the US National Academy of Sciences [2] asks for more objective ways to assess toolmark evidence and in recent years, the interest in the use of surface metrology for objective data acquisition and automated approaches for objective data analysis and comparison has been growing [1,3–12]. For quantitative toolmark comparison however, the statistical properties of toolmarks have to be known. Several parameters including the angle of attack, the substrate material, the axial tool rotation and the toolmark depth influence the toolmark formation process and the degree of similarity between toolmarks (Fig. 1, left). For objective toolmark comparison, it is important to determine the influence of the various parameters statistically. This can be done by creating experimental toolmarks and varying one particular parameter like the angle of

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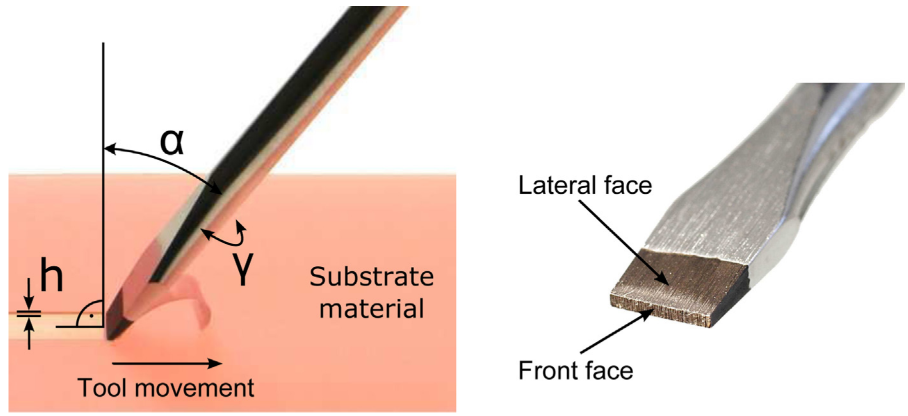

Fig. 1. Important parameters that play a role during toolmark creation with a screwdriver are the angle of attack α, axial rotation γ, depth h and the substrate material (left). The type of screwdriver used for creating the 3D surface datasets of the screwdriver blade (right). Figure adapted from [1].

attack. Ideally, the range of the varied parameter should be chosen as large as possible with as high resolution as possible to obtain robust statistical estimates of the toolmark variability. In practice however this requires producing a huge number of experimental toolmarks. This is very time consuming and therefore prior studies limited the amount of a tool's angle of attack to three [4,5,11] or five [3] angles. An alternative approach is to employ an approach that uses a 3D surface dataset of a particular tool, transforms, i.e. translates (shifts), rotates and scales, the dataset with a computer and subsequently predicts virtual marks that the tool would leave, depending on a given parameter. This offers the possibility to generate a large number of marks to study statistical properties of toolmarks theoretically. But also in daily practice, virtual toolmarks can play an important role. Typically, toolmark examiners have to create multiple test marks to compare with an unknown mark. However, even relatively soft substrate materials like lead may alter the state of a tool during toolmark creation [1]. If virtual toolmark generation software could predict, say, the angle of attack, with high accuracy (in case the suspect toolmark was indeed created with the suspect tool), a toolmark examiner would only have to create one experimental toolmark at that particular angle for comparison with the suspect mark.

Ekstrand et al. have developed a virtual toolmark generator [13] where a dataset of a tool's working surface is acquired using 3D microscopy (focus variation data was specifically reported, but the system can utilize data from any 3D microscopy). The geometry of the working surface is projected in the direction of tool travel. This identifies the highest points on that projection which scrape the deepest into the substrate material. A novel implementation scheme using graphical processing units (GPUs) was employed to significantly speed up the procedure. The technique developed by the Iowa group can simulate a toolmark at arbitrary twist of the tool, and angles of attack. An experiment showed that automated detection of the angle of attack of a tool during toolmark creation could be done with a precision of $\pm 5^\circ$ to 10°. Bachrach et al. have recently reported a an approach, which exploits wavelet analysis of bullet Land Engraved Area (LEA) signatures [14] to generate new signatures with similar properties, i.e. simulate LEA signatures. Long wavelength shape and 'brand' (class) characteristics are extracted through the wavelet coefficients. The software uses fractal analysis to include local 'randomness' components (i.e. surface roughness) into the simulated signatures. This allows the random portions of the signatures to be generated by predetermined parametric probability distributions. The system is also capable of producing 2D LEA images and 3D bullet surfaces.

1.1. Contributions

In the previously described approaches that have been published, either the influence of a particular toolmark formation parameter has been studied by generating virtual toolmarks with 3D surface datasets, or realistic toolmarks were simulated based on existing experimental, hence limited, data. In this paper we describe a methodology that can both, generate a large amount of virtual toolmarks for studying one particular parameter like the tool angle of attack or axial rotation angle and use this data to simulate realistic (but non-existing) toolmarks that can be created with the same tool. More specifically, we present an approach to acquire 3D surface datasets of tools and to use them to predict virtual toolmarks over a wide range of angles of attack and axial rotation angles. In addition we show a way to analyze the geometrical features of the virtual toolmarks using wavelet decomposition and subsequently simulate realistic toolmarks. To demonstrate the usefulness of our framework, we study the impact of the angle of attack on toolmark similarity with very high resolution, we recover the true angle of attack of known-matching (KM) toolmarks, we compare true and simulated toolmark variability and assess qualitatively simulated toolmark profiles and toolmarks.

2. Methodology

2.1. Tools

The tools for creating the surface datasets were new standard off-the-shelf slotted screwdrivers model Gedore 150 S-8-175 [15] with blade dimensions of about (8 mm$\times$1 mm). During manufacturing, all four sides and the front face of the blade have been ground manually, resulting in the grinding patterns visible in Fig. 1 (right).

2.2. Tool surface acquisition and pre-processing

The screwdrivers were put in a holder, in a position equivalent to 45° angle of attack α, and acquired using an Alicona Infinite Focus Microscope [16]. The working principle is based on focus variation, a non-contact, high resolution surface metrology approach. The acquisition parameters were set to $VR = 200$ nm (vertical resolution), $HR = 2$ μm (horizontal resolution) (with a sampling distance of $\approx$438 nm), and $M = 20\times$ (objective magnification). The surface data was provided on a regular grid (typically around $3k \times 20k$ pixels) with precision of 32 bit and was exported in the Alicona file format (al3d). For each tool, two datasets were

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