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Original Research Paper

Influence of the axial rotation angle on tool mark striations

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ABSTRACT

A tool's axial rotation influences the geometric properties of a tool mark. The larger the axial rotation angle, the larger the compression of structural details like striations. This complicates comparing tool marks at different axial rotations.

Using chisels, tool marks were made from 0° to 75° axial rotation and compared using an automated approach Baiker et al. [10]. In addition, a 3D topographic surface of a chisel was obtained to generate virtual tool marks and to test whether the axial rotation angle of a mark could be predicted.

After examination of the tool mark and chisel data-sets it was observed that marks lose information with increasing rotation due to the change in relative distance between geometrical details on the tool and the disappearance of smaller details.

The similarity and repeatability were high for comparisons between marks with no difference in axial rotation, but decreasing with increased rotation angle from 0° to 75°. With an increasing difference in the rotation angles, the tool marks had to be corrected to account for the different compression factors between them. For compression up to 7.5%, this was obtained automatically by the tool mark alignment method. For larger compression, manually re-sizing the marks to the uncompressed widths at 0° rotation before the alignment was found suitable for successfully comparing even large differences in axial rotation. The similarity and repeatability were decreasing however, with increasing degree of re-sizing.

The quality was assessed by determining the similarity at different detail levels within a tool mark. With an axial rotation up to 75°, tool marks were found to reliably represent structural details down to 100 μm. The similarity of structural details below 100 μm was dependent on the angle, with the highest similarity at small rotation angles and the lowest similarity at large rotation angles. Filtering to remove the details below 100 μm lead to consistently higher similarity between tool marks at all angles and allowed for a comparison of marks up to 75° axial rotation.

Finally, generated virtual tool mark profiles with an axial rotation were compared to experimental tool marks. The similarity between virtual and experimental tool marks remained high up to 60° rotation after which it decreased due to the loss in quality in both marks. Predicting the rotation angle is possible under certain conditions up to 45° rotation with an accuracy of 2.667 ± 0.577° rotation.

1. Introduction

During crimes, such as burglaries, tools (e.g. screwdrivers, chisels and crowbars) are used by the perpetrator to remove or open obstacles including windows and doors. Actions that forcefully move a tool across the surface leave behind striated tool marks on these obstacles. These marks can be secured for comparison with other tool marks or experimental tool marks made using a (suspected) tool. Tool mark examiners determine if there is a similarity between these marks and draw a conclusion based on their findings [1]. Such a comparison is based on certain characteristics or details from the tool that cause the striations present within a tool mark [2,3]:

- Class characteristics: general properties of the tool type, i.e. the overall geometric tool shape.
- Sub-class characteristics: define a tool subset from the same class based on manufacturing changes.
- Randomly-acquired characteristics: produced by the final manufacturing steps and tool use.

Traditionally, comparing two tool marks involves the use of a comparison microscope [1]. The striations present are illuminated to create a light-shadow pattern based on the striation heights and to visualize the striations when viewed from above. Tool mark

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examiners visually compare these to assess their degree of (dis-) similarity [3,4].

The traditional method of tool mark comparison has recently been criticized as being subjective in nature due to the dependence on the human examiner making the comparison. The National Academy of Sciences mentioned in their 2009 report that forensic laboratories need to " . . . *make . . . investigations as objective as possible* . . . " [5]. Furthermore, the need for more objective approaches in the several forensic fields, including tool marks, has recently been recommended in a PCAST report [6].

This has led to several approaches with the aim to objectify the comparison of tool marks being described in literature. For striated tool marks this started with the use of Consecutive Matching Striations introduced by Biasotti around 1959 [7] and more recent 2D and 3D analytic approaches [8,9], a more extensive overview can found in [10]. Most of the approaches described are " . . . *based on reducing the tool mark to a 1D profile, which is subsequently used for comparison with another striated tool mark*" [10].

Characterizing the influences on the 1D tool mark profiles is the basis of a sound comparison method. The profile extracted from the striation pattern created by a tool is influenced by several parameters [10,11]. Firstly, the surface or substrate material has properties which determines the quality and detail of the striations a tool leaves. Secondly, the tool orientation with respect to the substrate, i.e. the tool angle of attack, that determines the part of the tool that comes into contact with the substrate. Finally, the tool depth in the substrate and the direction of motion determine how and which characteristics will contribute to the tool mark. Fig. 1 shows an overview of these parameters.

This study was part of an on-going project that aims to characterize and quantify how these parameters influence a tool mark, with the eventual goal of automating tool mark comparisons. An automated approach was developed that allows for "*...1) a tool mark alignment procedure that is robust with respect to large differences in angle of attack and moderate tool mark compression and 2) a comparison strategy that enables a separation of relevant and non-relevant structures in the data...*" [10].

Using this approach, the influence of varying angles of attack, the substrate material and the depth of a mark on the similarity between tool marks and their quality were assessed [11]. This study focuses on the influence of the axial rotation of a tool during the creation of a mark. The need to determine and quantify the influence of axial rotation on tool mark striations arises from the following factors: (1) it is easier for examiners to reliably create experimental tool marks with no rotation, (2) a decrease in tool mark width leaves less information for tool mark comparisons and, (3) the changes in the tool marks can be expected and accounted for when comparing tool marks with different rotations without a tool present.

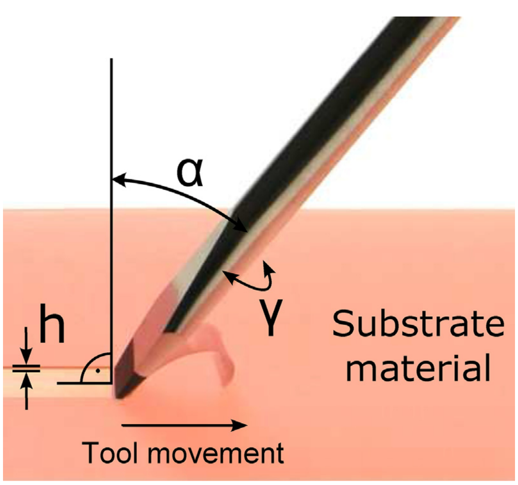

Fig. 1. An overview of tool mark parameters with the angle of attack (α), axial tool rotation (γ), tool mark depth (h), tool movement ($\longrightarrow$) and substrate material. Figure adapted from [10].

1.1. Axial rotation principle

Axial rotation, the γ parameter in Fig. 1, complicates tool mark comparison due to the compression of the tool mark width and relative distances between striations. With no axial rotation the tool characteristics that cause the striations are arranged alongside each other across the tool width, as shown in Fig. 2 with the 0° rotation tool mark. When the rotation increases, the available tool mark width for the characteristics decreases and changes the relative orientation of the characteristics to each other. As a result the distance between characteristics decreases as shown in Fig. 2 for γ = 15 to 75°.

Often this rotation is present within crime scene tool marks due to the tool orientation required to gain enough leverage or the force applied to remove obstacles. This complicates a one-to-one comparison between tool marks with different axial rotations. Both examiners and automated methods need to take the different compression factors into account.

However, the rotation angle can be estimated from a tool mark by comparing the compressed width (W_{comp}) with the original width (W_{orig}), this can be measured in the stopping moments (e.g. start, end) along the striations where the (full) width is impressed as the rotated width (W_{rot}). The amount of compression a tool mark is subjected to follows, in theory, a cosine function: $W_{comp} = \cos(\gamma) \times W_{orig}$. The compression factors ($\cos(\gamma)$) for axial rotation with 15° increments from $\gamma = 0°$ to 75° are as follows: 1.000, 0.966, 0.866, 0.707, 0.500 and, 0.258. This is visualized in Fig. 3; when W_{orig} is rotated the width is compressed to W_{comp} with the compression becoming more apparent with larger rotation angles.

1.2. Contributions

A literature search yielded a few publications addressing the angle of attack [1,12] and one describing a study regarding the combined effect of axial rotation and the angle of attack in tool mark examinations. Macziewski et al. [13] showed that tool comparisons based on experimental data resulted in high correlation values at identical axial rotational angles and a decreasing correlation with increasing angular difference. Angles up to 30° were examined. They concluded that "*...there is evidence demonstrating that tool marks can be identified if the variation in angle is within 10°*" [13].

This study addresses the problems associated with axial rotation by determining the quantitative effects and influences of axial rotation on the striations within a tool mark and, correcting these influences to allow for a comparison between rotated tool marks up to 75° rotation. Specifically, this study investigated the following aspects of tool mark striations when a tool is used at different axial rotational angles with respect to the substrate material:

1. The behavior of tool mark characteristics at an axial rotation and the resulting effect on comparisons.
2. The similarity and repeatability of tool marks made with an identical axial rotational angle.
3. Correcting the tool mark compression due to axial rotation by re-sizing the mark.
4. The separation between known matching and known non-matching tool marks with axial rotation.
5. The similarity and repeatability of tool marks made at different axial rotation angles.