Pilot investigation of automatic comparison of striation marks with structured light

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ABSTRACT

We have developed and tested an algorithm that can compare striation marks that are acquired with a standard camera and sidelight as well as 3D- information acquired with structured light.

With six different screwdrivers test marks have been made with an angle of 45 degrees to the surface. These striation marks are moulded with gray silicon casting material. Then these marks are digitized with the structured light approach and with side light. For the structured light approach, it appeared that there are artifacts and variations in the image due to the number of stripes in the LCD projections and the camera resolution. We have compensated for these variations by averaging the lines over an area that is selected by the user. In the method that has been used for averaging, the slopes of the striae are followed. This method is also used for side light images to compensate for variations in the striation mark.

In this research, signatures of the tool marks are calculated then compared with a database of signatures by calculating the standard deviation of the difference. For the limited test set of six striation marks made with six different screwdrivers, the algorithm was able to distinguish the global shape of the screwdriver and the depth information itself. Since the images acquired with structured light contain more information on the toolmark itself, the correlation results were better than with side light images.

Keywords: Structured light, correlation algorithms, 3D, tool marks, forensic

1. INTRODUCTION

Tool marks are often found at the scene of crime. They can appear in a wide variety of shapes depending on the tool and the surfaces where the tool mark is formed. Often pliers, screwdrivers or crowbars are used for entering a building for a burglary. These tools will cause tool marks that appear in different shapes: striation marks and impression marks. In several police regions in the Netherlands the images of the tool marks that are found at the scene of crime are stored in a database, and when a suspect has been found with tools, test marks are made with these tools and compared with the database. In figure 1 an example is shown of a striation and impression mark in a police database.

The tool marks in the database are created by a procedure. A casting is made with a gray silicon casting material, and subsequently these images are stored in the database. The database is used for pre-selection, and subsequently the real toolmark is compared with a test mark of the tool on a comparison microscope by a qualified examiner.

In this research we focus on striation marks, since they are most time-consuming for an examiner making a comparison. The tool can have many different angles to the surface, and for each angle a different striation mark is formed. For this reason the examiner has to make several test striation marks with different angles of the tool. In the case of a screwdriver, the examiner will make at least four test striation marks under different angles for each side of the screwdriver. All of these test marks have to be compared with the striation marks.

Striation marks are caused by irregularities in the upper part of the blade of the screwdriver when scraping off material of a surface that is softer than the tool itself. If the irregularities in the upper part of the blade of the screwdriver are damaged or have grinding marks these can be characteristics of the tool that has been used. Depending on these damages and grinding marks, and the quality of the toolmark itself, a qualified examiner can conclude that the blade of the screwdriver has caused the striation mark.

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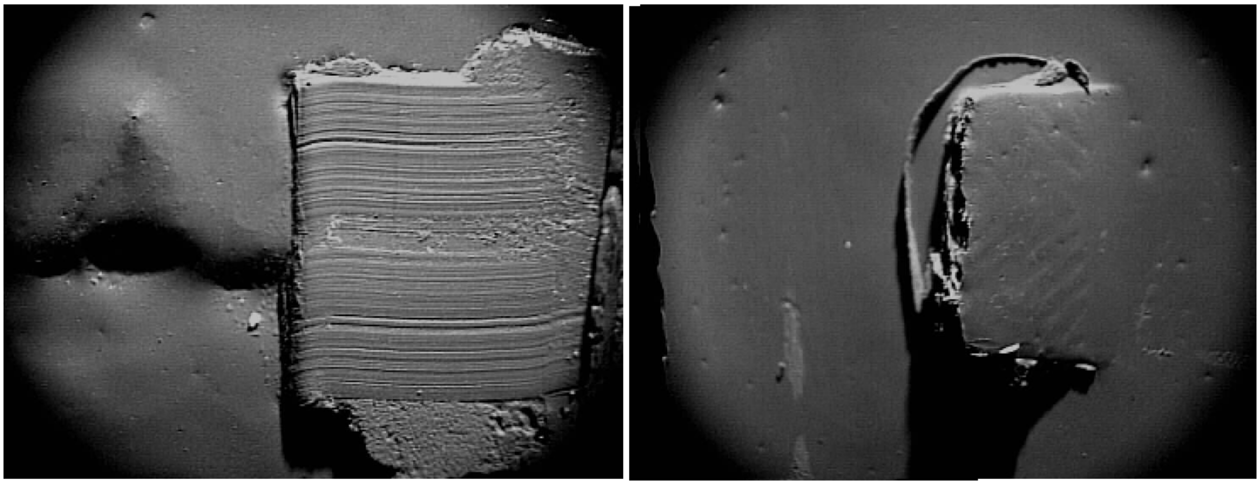

Figure 1: Tool marks in database. Left: striation mark; right: impression mark.

A difficulty with forensic examination is that the toolmark found at the scene of crime might be partial. In this case the striation mark should be matched to the test striation mark. Furthermore the screwdriver could be damaged in the meantime because it has been used, and this will cause the striation marks to differ. Also the striation mark can be (partially) zoomed because of stretch or shrinkage of the material (e.g. elastic deformation) in which the tool mark has been formed. And finally the angle as shown in figure 2 might also give a gradient in the toolmark.

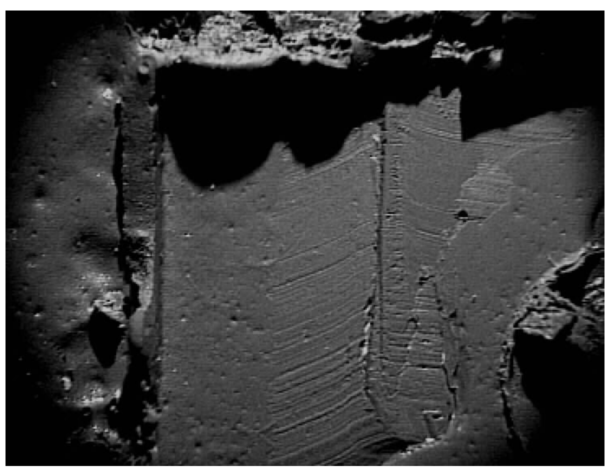

Figure 2: Example of angle of screwdriver and influence on the striation mark. Furthermore a partial striation mark is visible in this image.

In the past[1] we have developed a comparison algorithm that takes all these variations into account. In this research the method for taking a signature that has to be compared to the database is improved. Furthermore we focus on the structured light approach.

2. SIDE LIGHT

Dull surfaces, such as the gray casting material reflect light with the same intensity in all directions[2]. Diffuse reflection is sometimes also called Lambertian reflection because Lambert's is used to calculate the intensity of the reflected light. Lambert's law states that the intensity of the reflected light is proportional to the cosine of the angle θ between the light vector L and the surface normal N (figure 3).

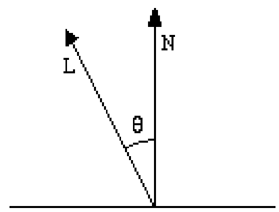

Figure 3 : Lambert's law; The angle θ between the light vector L and the normal N determines the intensity of the light reflected from the surface.

Lambert's law can be formulated as

$$I = I_p k_d \cos\theta \tag{1}$$

I_p is the color of the light source and k_d, the diffuse-reflection coefficient, is a material property varying between zero and one. The angle q must be between 0° and 90°. The surface will otherwise be directed from the light source and shadowed. The direction to the observer is irrelevant since the light is reflected equally in all directions from the surface.
If both N and L are normalized, the equation can be simplified by computing cos θ as the product of N and L:

$$I = I_p k_d N \bullet L \tag{2}$$

We can see that we very much depend on the light condition in this approach. For this reason under different light circumstances or light variations due to the surface itself, the striation mark might appear differently.
This is one of the reasons to choose for an approach using 3D images. The method that we used is the structured light approach. With this method it is possible to acquire a 3D-image in a few seconds. This method is faster than the implementations of laser triangulation methods[11] that scan a surface that we have tested in the past.

3. STRUCTURED LIGHT APPROACH

The structured light system is similar to the passive stereovision system with one camera replaced by a projector. A light source projects a vertical plane of light that creates narrow stripes on the scene. Since the intersection of an illumination plane of known position and a line of sight determines a point, the 3D-location of all points along that illuminated stripe that are visible by the camera can be obtained from a single image. For dense reconstruction the scene must be accurately scanned and many images should be taken.

High reliability identification of light planes with minimal assumptions on the nature of the scene is achieved by sequentially projecting several patterns. A robust and widely applied structured light system is based on spatio-temporal modulation has been described by Kato[3]. Gray codes are used to label light planes, and each illumination pattern represents one of the bit planes of the Gray code labels.

In our approach we used the structured light system of OMECA[4] that is based on this research. In this system lines are projected on the surface by means of a micro mirror device that can be operated by the computer. The system consists of a CCD-camera, a frame grabber and a computer that will control the stripes that are projected, and calculate the depth of the surface. The advantage of the micro mirror projector compared to the LCD-projector is that we have a higher light intensity and that the pattern itself has more contrast. The method implemented will also cover problems with dark places of the object. In figure 4 the apparatus is shown as used in our laboratory. With this method it is possible to measure a striation pattern with a precision of several microns[5].

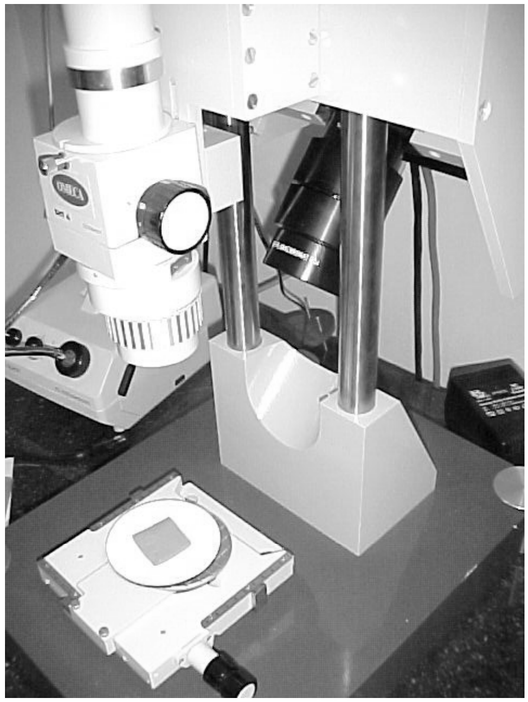

Figure 4: OMECA structured light equipment.

4. CORRELATION ALGORITHMS

For the correlation of tool marks several methods are described in literature[6 7 8 9]. In the past we have also examined if the output from a human examiner could be used in a neural network, however this method did not work for practical cases [10] other than in the database. The study of De Kinder[11] is focused on using 3D laser triangulation for bullets, since similar correlation algorithms can be used.

Commercial systems exist on the market for automatic toolmark comparison [12] and IBIS[13] for bullets. The system for bullets will extract a signature of the striation mark and compare these. For bullets, the bullet it is recommended they be the same composition, since otherwise differences in the striation marks might result depending on differences in hardness of the material. One advantage with bullets compared to tool marks with screwdrivers is that the striation marks are more reproducible, since most often the bullet can only leave the firearm in one direction. With tool striation marks it is often not known which angle is needed to reproduce the mark.

For the speed of the algorithm for the correlation of striation marks it is most optimal to have a short signature with which to compare the database. The advantages of this method are that we can combine the surface of a striation mark to a one-dimensional string of gray values or depth information. In this way artifacts of the surface can be averaged. For the explanation of the algorithm we will continue in gray values, however instead of gray values, one can also read depth-values.

Our improved algorithm will follow the striation lines, and then sample a signature of gray values with the following approach:

The user selects an area of the toolmark that should be sampled manually. The reason for user interaction is that the user can determine which part belongs to the striation mark, and which part belongs to damages or other artifacts.

We assume that the striation lines are horizontally placed in the image, however it is nearly impossible to place them exactly horizontal. For this reason we will follow the striation lines (or depth information), and calculate the signature from this.

The area that is selected should contain the visible striation mark. Furthermore the user should validate the final signature that is calculated by the algorithm.

In our previous approach we would just average all gray values. If we have an image g(x,y) were g(x,y) is the grey value of the image at position x,y, we can average the gray values for N vertical lines, we have a signature :

$$\bar{g}(y) = \frac{\sum_{x=0}^{x=N} g(x,y)}{N} \tag{3}$$

However the problem with this approach is that all striation lines should be horizontal. To compensate for this, we have developed a method that will follow the striation lines themselves.

This method will work on a basis of 2x3 pixel matrix. We take the line g(x) out of the image and compare it to g(x,y) by three pixels. We average the gray values of g(x,y) with g(x,y+1). Furthermore we make a second line that is shifted g(x+1, y+1/2). This is conducted by averaging g(x,y+1) with g(x, y):

$$g(x, y + \tfrac{1}{2}) = \frac{g(x,y) + g(x,y+1)}{2} \tag{4}$$

We also compare these gray values with each other, and calculate the same for g(x,y-1/2) and g(x,y-1).

In table 1 an example is given of comparing two lines.

Table 1: Example of comparing two lines with the adaptive zoom algorithm. The shift of –1/2 will result in the best result for this case for a gray value of 150 in line 1.

Line 1 g(x,y)	**Difference**	**Line 2 g(x+1,y)**	
50	75	75	G(x+1,y-1)
100	0	150	G(x+1,y-1/2)
150	-25	175	G(x+1,y)
200	-75	225	G(x+1,y+1/2)
250	-125	275	G(x+1,y+1)

Then we shift a pixel and do the same for g(x+1,y+1). If the difference between the pixels is better when shifting y-1/2, this

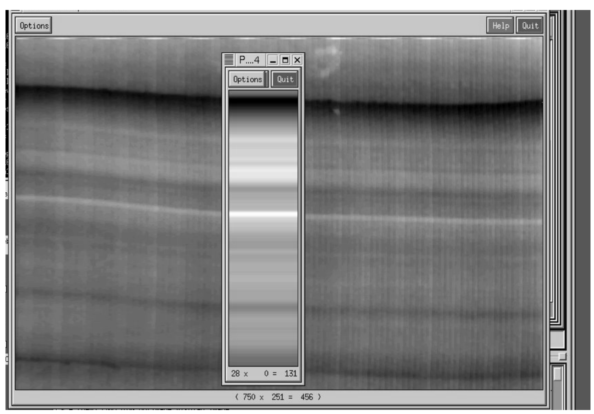

Figure 5: The result of sampling an area of a striation mark in a striation mark digitized with the OMECA.

will be done the second time that the values are approaching to each other. In this way this sampling method is repeated for all lines that were selected. Finally the average signature is displayed, and the user can validate to result. In figure 4 an example is shown using this algorithm for a 3D-profile that is displayed in gray values (figure 5). The user can check if the resulting signature is characteristic for the striation mark by checking the striation match.

A problem still remains for the 3D-case if there is a slope in the z-direction. In figure 6 an example is shown of an image with a slope in the z direction. Since this slope is linear (it is caused by the fact that the cast is not completely flat on the surface), the user can select the edges of the tool mark in both direction and then we compensate for the tilt by assuming the slope is linear, and subtracting the relative differences of the four points with a linear algorithm.

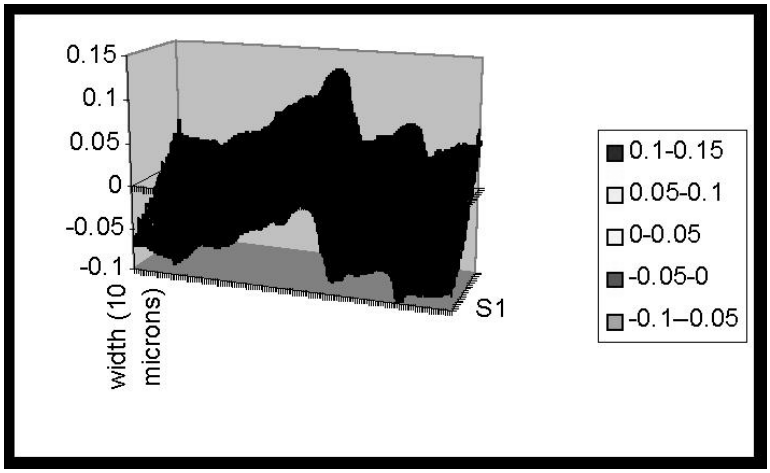

Figure 6: 3D-image of a toolmark with a slope in x and y-direction

By calculating the standard deviation of the difference and shifting the tool marks relatively to each other in the memory of the computer, we can compare the complete database. The results will be a list of matches based with the marks with the lowest standard deviation of the difference at the top of the list.

5. EXPERIMENTS

TESTSET

A small test has been prepared in which six screwdrivers are used. Of these six screwdrivers test marks were made with an angle of 45 degrees on wax. These striation marks were molded with gray silicon casting material. Then these marks were digitized with the structured light approach and with side light. It appeared that there are some artifacts and variations in the image due to: the largest number of stripes in the LCD projections, camera resolution and variations in the toolmark itself. Since the current setup of our OMECA-structured light apparatus is limited to 6 mm, a part of the striation mark has been scanned. For each striation mark we have chosen to scan one edge with lines.

RESULTS

The results of correlation with the standard deviation of the difference are shown in tables 1 and 2. From this experiment it appeared that all tool marks that were compared to each other, were retrieved well. If we compare the results of the gray value images with the 3D-images, the algorithm will distinguish the striation marks with, on average, a 30 percent higher correlation factor (in our approach this is the standard deviation of the difference).

Table 1 : Correlation factors for gray value comparisons of the six screwdrivers

	1	**2**	**3**	**4**	**5**	**6**
1	***17.3***	43.5	74.2	61.3	51.3	54.5
2	68.6	***27.7***	46.3	55.3	78.3	62.4
3	40.4	58.7	***15.4***	79.1	40.3	73.5
4	48.0	45.7	39.8	***20.2***	36.8	86.9
5	54.3	80.7	59.6	45.2	***23.2***	86.4
6	67.4	71.5	83.8	42.0	62.3	***20.6***

Table 2: Correlation factors for structured light comparison of the six screwdrivers

	1	2	3	4	5	6
1	***16.0***	47.7	81.2	114.4	44.4	107.0
2	55.8	***25.6***	71.8	113.7	82.1	110.8
3	81.3	47.4	***20.8***	66.8	47.3	104.5
4	101.8	103.4	56.4	***17.5***	70.2	70.2
5	91.2	90.4	100.0	89.3	***13.4***	97.5
6	92.8	88.3	113.7	83.0	97.3	***11.8***

6. CONCLUSIONS AND DISCUSSION

Based on this research it appears that the use of three-dimensional information of a striation mark is useful compared to the two-dimensional side light image because we have a measurement of the depth information and are less sensitive to the influence of lighting of the surface.

In future research this method should be tested on larger databases of striation marks. Comparing striation marks with the current set-up of the OMECA equipment is not recommended because the area of scanning is limited to 6 mm. The equipment should be modified before continuing with large-scale experiments.

A different approach that might reduce the time of examination is digitizing the shape of the blade of the screwdriver, and then comparing the striation marks with the toolmark. In this case we would not have to make test marks anymore, and less time is needed for making the comparison with the database (if a proper way of digitizing the blade is used). Another area of research is the impression marks and comparing them with the 3D data of the tool itself.

In figure 7 is shown that the shape of the blade of the screwdriver might also be used for distinguishing the toolmark easily. In this way a fast pre-selection is possible based on a small signature of the shape of the blade.

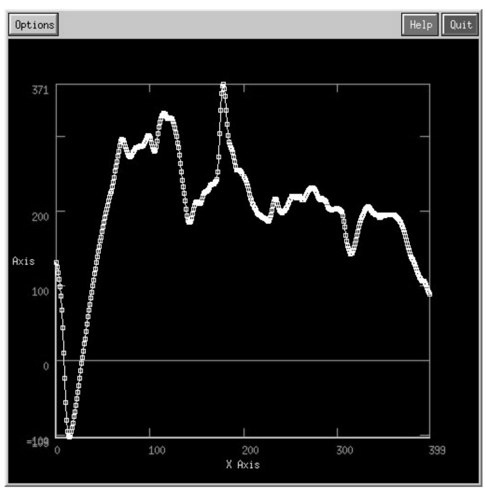

Figure 7: Shape of the upper part of the blade of the screwdriver visualized in 3D-information

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