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Similarity Measurement of Striation Marks Based Upon the Longest Common Subsequence Method

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Abstract

Similarity comparison of striation marks plays an important role in striation mark analysis. The cross-correlation technique is used to measure the similarity of two striation tool marks. But this method is time-consuming and scale-dependent. In this paper, a striation mark manufactured by a screwdriver can be converted into a pattern of alternative bright and dark lines ("similar" to a barcode). We build a striation pattern feature based upon the distance of adjacent bright lines, and denote the feature by a sequence. We use the longest common subsequence (LCS) method to compare the similarity of sequences of striation marks. The LCS method provides a good way for measuring the similarity between sequences. The advantage of making use of the LCS method is easy and efficient. The 1-D strings can also reduce the storage space of database. From the experimental results, the LCS method provides feasibility to describe the similarity between two striation marks.

Keywords: striation marks, lCS, classification, similarity, screwdriver, tool-mark

Introduction

Tool mark analysis plays an important role in forensic science [1][2]. Dr. R. Kockel at University of Leipzig first identified the use of striation matching in 1800's. The practice of using a comparison microscope to study striae was found dating to April 1925 [3].

The marks caused from tools are generally called tool marks. They are usually left on a soft surface by forms of impressions or striations. Tool marks are often found in cases of burglaries, and sometimes at crime scenes, such as housebreaking for sex-violation or the coffer breaking [3]. The patterns of tool marks may appear in various types according to the contact surface of materials, the force and the angles of using the tools. By analyzing patterns of tool marks, such as sizes and shapes, we may discriminate them from kinds of tools [4].

When tools (such as screwdrivers, chisels and pliers) are manufactured, the manufacturing process may leave certain obvious patterns on the tools' surfaces [5]. When criminals use them to commit crimes, such as jimmying a door to intrude into a house or building, the surface patterns of tools are often transferred to objects at crime scenes. We may use these patterns found on the material surface to analyze the tools that criminals used. The basic concept in tool mark comparison is the reproduction of similar marks with the suspected tool and simulating the possible conditions with the original marks [6]. Investigators have been able to help the courts convict criminals by visually matching the marks on tools to crime scenes [7]. Traditionally, the examination of tool marks is visual processed by experts. Forensic experts use particular microscopes (such as stereomicroscopes, comparison microscopes, and scanning electron microscopes) to analyze those tool marks [7][8].

Marks left by various tools have been studied in past literatures, including screwdrivers, chisels, wire-cutters, hammers, axes, and knives [9]. Screwdrivers

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are the most useful common hand-tools at home, and most families have more than one screwdriver [10]. Therefore, screwdrivers are so popular and carried easily. There are many kinds of screwdrivers, and the most common screwdrivers are slotted (flat-tip) screwdrivers and phillips (cross-head) screwdrivers (see Figure 1). A slotted screwdriver comprises two parts: one is the handle and the other is the blade with a flat end (see Figure 2). The raw materials of blade and handle are steel and plastic individually. The steel is processed by annealing (heat-treating), straightening, and cold-forming to form a proper shape. Finally, the blade is nickel-plated to protect its surface, see Figure 3. The plastic (cellulose acetate and plasticizer) is processed by shaping, drilling and cleaning, see Figure 4. Then both of them are assembled together [11].

Because the slotted screwdriver provides with the flat-tip, criminals usually use these kinds of tools to jimmy doors, windows or strongboxes in cases of burglaries. Slotted screwdrivers often leave grooves on the materials surface. These grooves are generally called striation marks. If we can identify the striation marks made by screwdrivers, it will be useful for police to trace relative evidences or cues.

Striation marks provide valuable evidence in forensic science. These striations formed by tools may be considered as fingerprints of tools at crime scenes. Tool marks in criminal cases do not only appear at crime scenes, but also on the machine tools (e.g., lathes) at suspect's home [3]. Through striation marks examination, we have a chance to connect a criminal tool to a manufacturing machine.

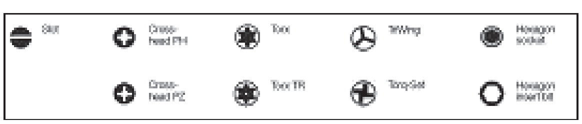


Fig.1 The illustration for different kinds of screwdrivers.

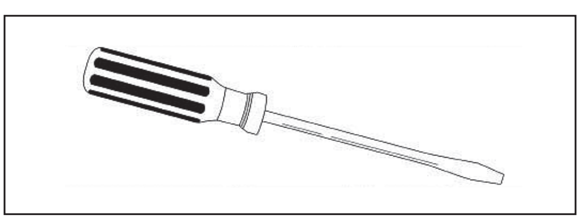


Fig.2 A slotted screwdriver.

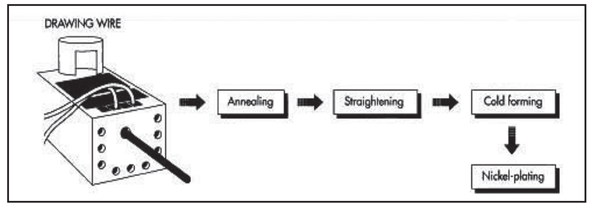


Fig.3 A blade manufacturing flowchart.

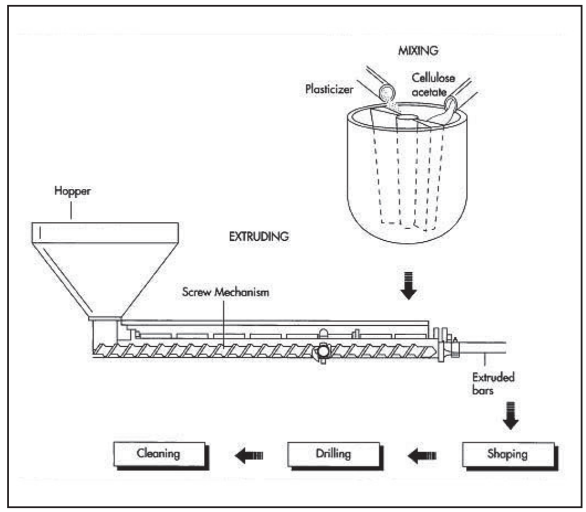


Fig.4 A handle manufacturing flowchart.

Image retrieval generally can be accomplished by text-based or/and content-based retrieval methods. The text-based retrieval methods use keywords to search images, such as Google Image Search and Yahoo! Image Search system. The content-based image retrieval method uses features to search images. These features are extracted from color, shape, size, texture [12][13][25], etc.

Similarity comparison of striation marks plays an important role in striation marks classification. Cross-correlation technique is a traditional approach to measure the similarity of two signals, and it is applied to identify tool marks [40]. Each tool mark is presented by a pair of signatures with left and right illumination. Therefore, a comparison of two marks comprises four correlations [16].

Cross-correlation function includes two important results: the maximum value indicates the degree of similarity between two signals, and the location of the maximum value indicates the shift leading to the best possible similarity between both signals [14][15][34]. But this method is time-consuming and scale-dependent. It is not suitable for database with large data [35].

Longest common subsequence (LCS) matching is a commonly technique [17][18] which can measure the similarity between DNA sequences in molecular biology studies [19]. It is also applied to text-based databases [20]; e.g., comparison of personal name Matching [21], English/Chinese information retrieval [22] and melody retrieval [23].

In order to improve the time-consuming problem and provide objective examination results, automated approaches for the evaluation of marks are essential.

The LCS searching method is the mostly used in string-based image databases [25]. By using the string-based representation, image retrieval can be converted to be a string matching problem; i.e., finding the longest common subsequence (abbreviated LCS) between two images [20]. The LCS method also makes use of similarity matching of sequences with different lengths [26]. It supports elastic and imprecise matches for finding the longest common subsequence of two or more sequences [24]. The advantage to make use of the LCS method is easy and efficient, and can reduce the storage space of database.

In this paper, we use the LCS method to measure the similarity of striation marks. The main purpose of this study is to develop a useful feature extraction method for classifying striation patterns formed by slotted screwdrivers. A striation mark manufactured by a screwdriver can be converted into a pattern of alternative bright and dark lines, as a bar code. First, we build a striation pattern feature based upon the distance of adjacent bright lines, and denote the feature by a sequence. Then, the striation mark matching will be represented as a 1-D string matching. Second, we consider the influence of striation mark's width and combine the ratio of width with the LCS method to compute the similarity. According to the computing similarity, we can rank the sequence of striation marks to be the reference of comparison and query similar striation marks.

Methods

The flowchart of image processing for striation marks classification is shown in Figure 5. There are three major parts in this section: image scale, width measure, and the LCS method. In the part of image scale, the image size is first normalized. In width measure, we discuss the blade size of screwdrivers. In the LCS method, we encode the pattern of striation and use the LCS method to achieve the goal of classification of striation marks.

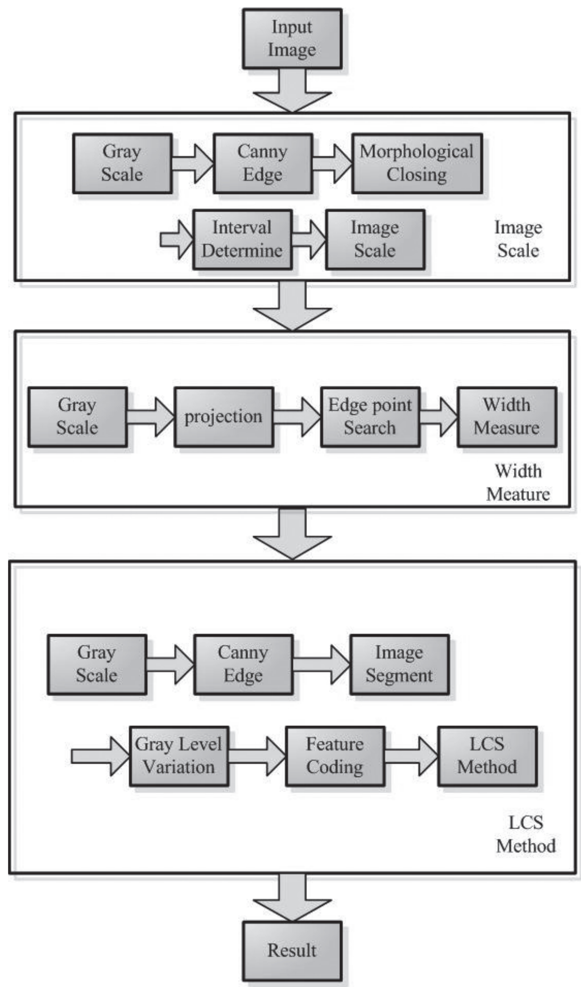


Fig.5 The flowchart of image processing for striation marks classification.

Canny edge detection

Edge points indicate the object boundary and area with strong intensity contrasts. Edge detection plays an important role in image processing. The Canny edge detector is widely used in computer vision to locate sharp intensity changes. We can remove the influence of background on features extraction by canny edge detection, see Figure 6

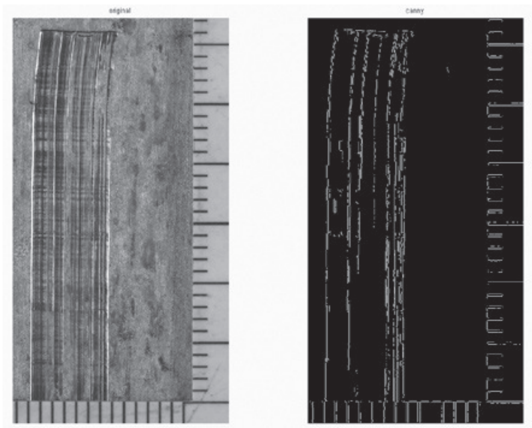


Fig.6 (a) the original gray image. (b) the Canny image.

The Canny edge detection [42] includes four steps:

Step1. Smooth the image with a Gaussian filter.

$$S[i,j] = G[i,j,\sigma] * I[i,j], \tag{1}$$

$$G[i,j] = \exp\left(\frac{i^2 + j^2}{2\sigma^2}\right), \tag{2}$$

where * denotes convolution operation, and $I[i,j]$ is the processed image, $G[i,j,\sigma]$ is the Gaussian smoothing filter with standard deviation σ.

Setp2. Compute the gradient magnitude and orientation.

$$|G| = |Gx| + |Gy|, \tag{3}$$

where |G| is the magnitude which is obtained by edge detection operators (for example, Roberts, Prewitt, Sobel [40]).

$$E_O = \tan^{-1}\left(\frac{Gy}{Gx}\right), \tag{4}$$

where E_O is the orientation of an edge point.

Step3. Apply non-maxima suppression to the Gradient magnitude.

Step4. Use double threshold algorithm to detect edge points.

Morphological Closing

Morphology is a useful image processing tool for extracting image components such as boundaries and skeletons. The erosion and dilation are two basic operators in morphological image processing.

Dilation

First, let A and B be the reference and structure images, respectively. The dilation operator is defined as [39]:

$$A \oplus B = \left\{ z \mid \left[(\hat{B})_Z \cap A \right] \subseteq A \right\}, \tag{5}$$

where $(\hat{B})_Z$ is the reflection of B rotated about the origin, and shifted the reflection by z.

Erosion

The dilation operator is defined as [39]:

$$A \Theta B = \left\{ z \mid (B)_Z \subseteq A \right\}, \tag{6}$$

The closing operator is defined as:

$$A \bullet B = (A \oplus B) \Theta B .$$

Fig. 7 is the Fig.6(b) image processed by using the closing operator.

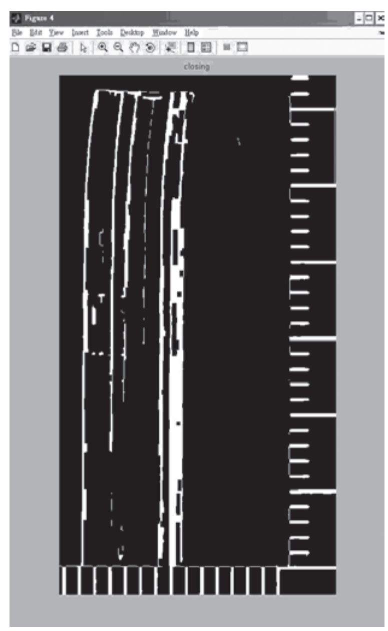
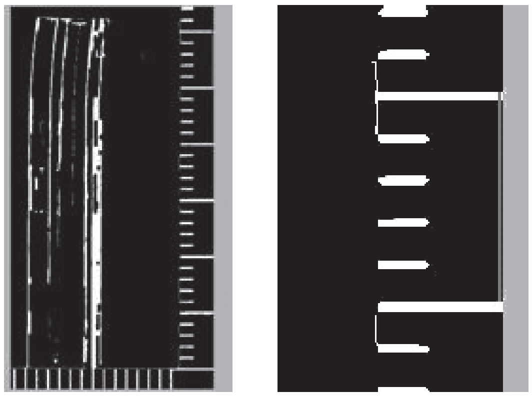


Fig.7 The result of Fig.6(b) processed by using the closing operator.

Interval Determine

Through the reference of a ruler, we can estimate the real length of an object in an image by counting pixel number, see Figure 8.



(a) (b)

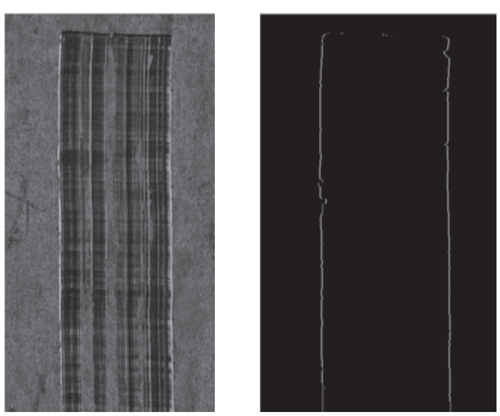
Fig.8 (a) an image with a ruler. (b) the enlarged ruler image.

Width measure

The width is an important feature that can be observed easily. First, we cut the metric scale from a calibrated image and keep the part of striation marks. We can get the width of striation by calculating the distance between right and left edge lines. For example in Figure 9(b), there are two edge lines of Figure 9(a). We can calculate the distance D between right and left edge lines by

$$D = \frac{1}{k}\sum_{i=1}^{k} dis(a_i, b_i) \tag{7}$$

where a_i and b_i are the pixels of left and right edge lines, respectively. $dis(a,b)$ is the Euclidean distance between two pixels.



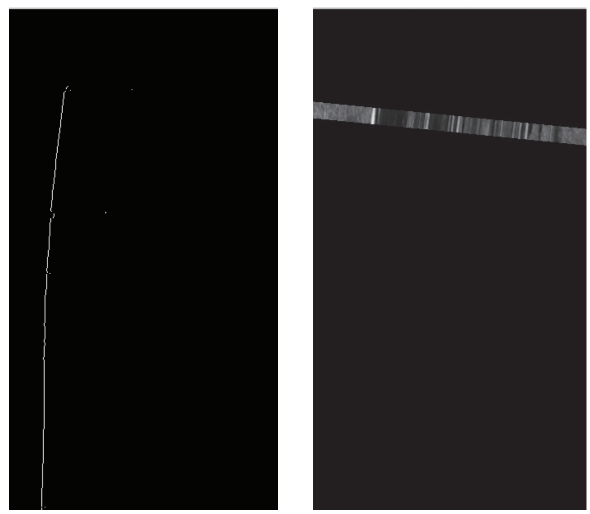
(a) (b)

Fig.9 The illustration of width measurement: (a). Original image. (b) Right and left edge lines.

The Longest Common Subsequence method (LCS)

Image segmentation

Since the striations made by slotted screwdrivers are usually curved, see Figure 6 (a). To get a "barcode" of tool marks, we need segment the striation. We make a division of the striation into 20 fragments along the normal direction of left edge line see Figure10 (a). The height of each fragment is 20 pixels, see Figure 10 (b).

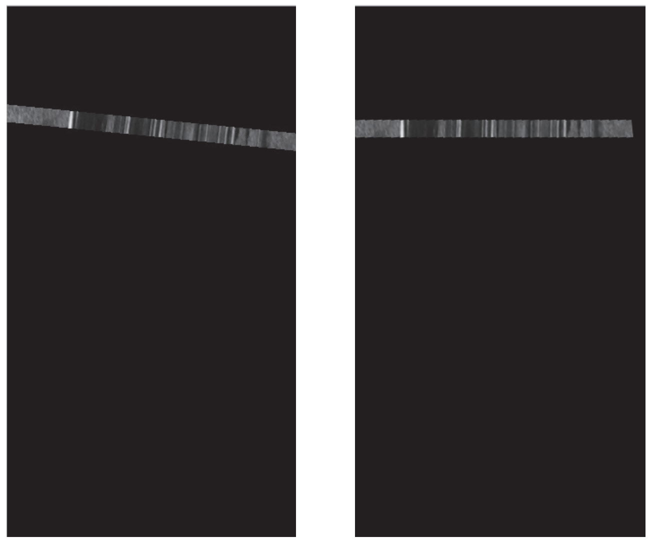


(a) (b)

Fig.10 (a) Left edge line. (b) One of the 20 fragments.

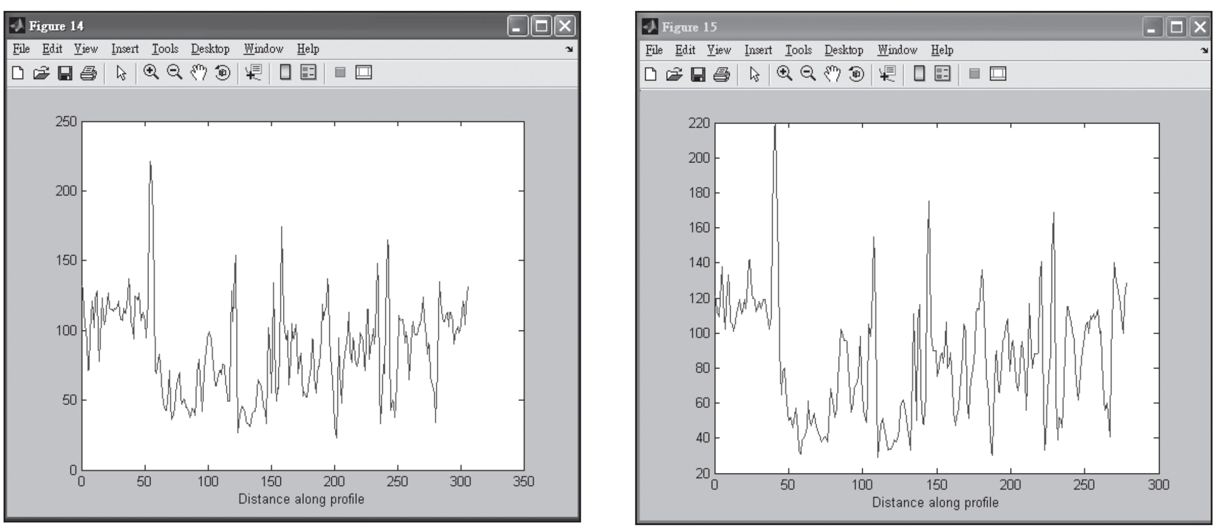
Gray level variation

Each fragment obtained from the normal direction of the left edge line in the image is not horizontal, see Figure 11 (a). We can get the angle between the parallel line and normal of the left edge line from normal slope. According to the angle of the fragment, the fragment is rotated and becomes horizontal, see Figure 11 (b). Along the horizontal direction (x-axis) of the fragment, we can extract the gray level variation of each pixel. Figure 12 (a) and Figure 12 (b) are the gray level variation before and after rotation, respectively. Figure 13 shows 20 fragments after image segmentation and rotation.



(a) (b)

Fig.11 (a) One of the 20 fragments. (b) Fragment after rotation.



(a) (b)

Fig.12 (a) Gray level variation before rotation. (b) Gray level variation after rotation.

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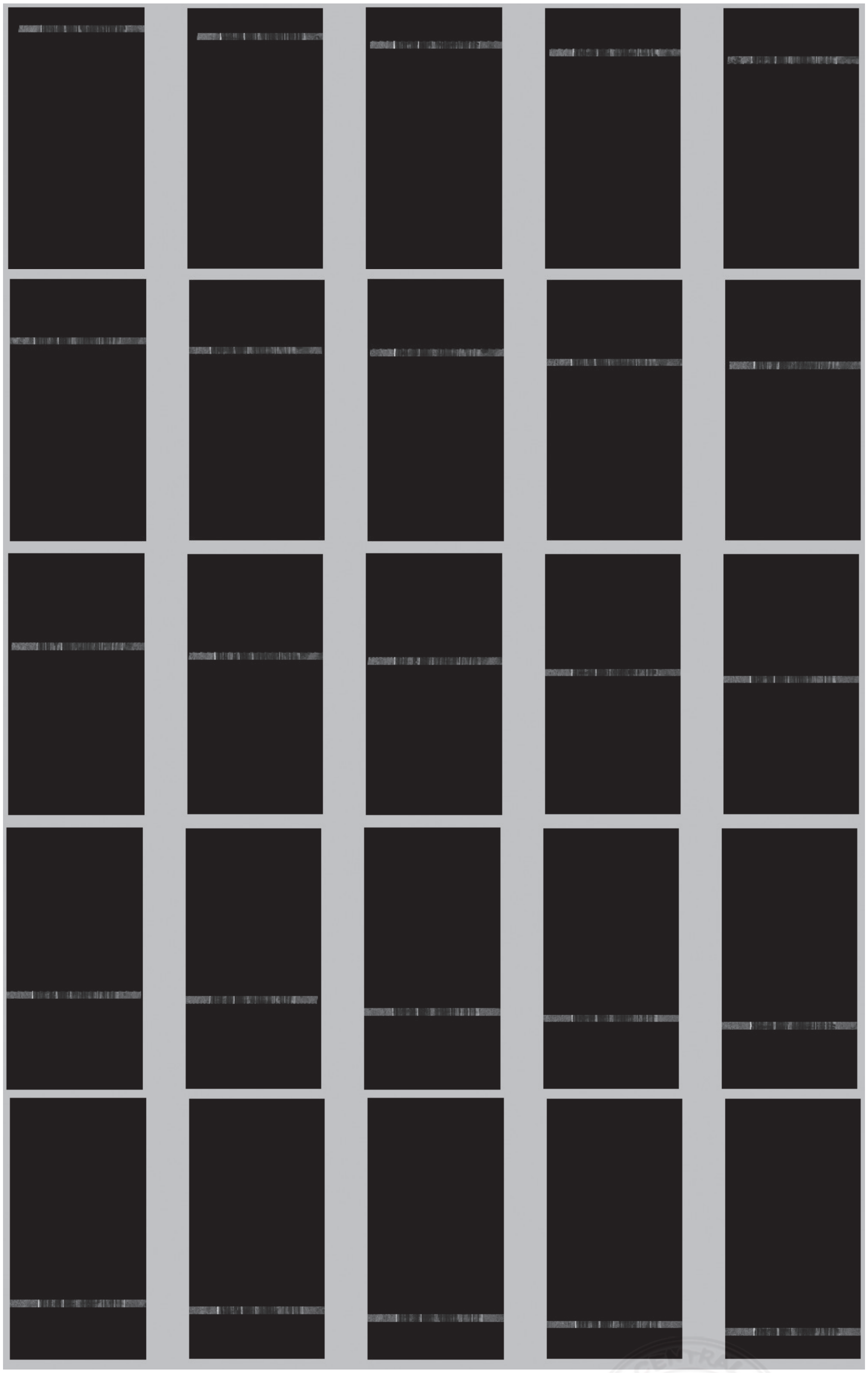

Fig.13 Twenty fragments after image segmentation and rotation.

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Distance between peaks (pixels)	Corresponding feature code	Distance between peaks (pixels)	Corresponding feature code
10-19	A	90-99	I
20-29	B		
30-39	C		
40-49	D	Others	N
50-59	E		
60-69	F		
70-79	G		
80-89	H	0-10	Z

Fig.14 Corresponding table of Feature code.

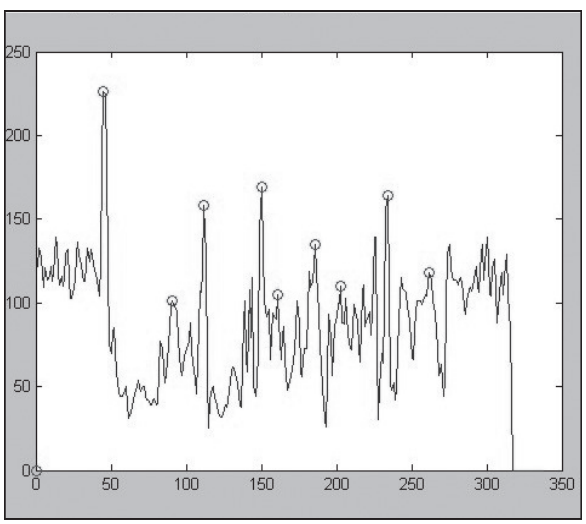


Fig.15 The peak locations are found by threshold selection.

56	122	160	196	236	244	285	293	303	307	310	315	323
0	66	38	36	40	8	41	8	10	4	3	5	8
Z	F	C	C	D	Z	D	Z	A	Z	Z	Z	Z

Fig.16 Feature code of a fragment.

Feature coding

The striation marks possess the feature of bright lines and dark line alternately, like bar code. We build a striation pattern feature upon distance between bright lines. The peak locations are found by threshold selection. The mean and double standard deviation of gray level value are set to be threshold ($T1$) to find the coordinate of left edge line. Similarly, the mean of background set to be second threshold (T2) to find the coordinate of bright line:

$$\begin{cases} F(i) = F(i) \text{,if } F(i) > T2 \text{ and } F(i) > F(i+1) \text{ ,} \\ F(i) = 0 \text{ , otherwise,} \end{cases}$$

where F(i) is the coordinate of bright line and n is the location of left edge line.

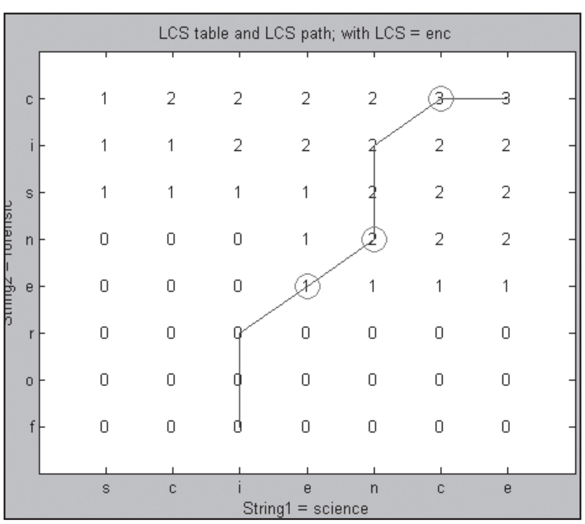
When we find the coordinate of bright line and calculate the distance between peaks we can encode them into sixteen different codes. Figure 14 shows their corresponding feature codes. Each fragment of the image has its corresponding code. For example in Figure 15, a 1-D string is used to represent the fragment: “Z F C C D Z D Z A Z Z Z Z”, see Figure 16.

The LCS method

The longest common subsequence method (LCS) is used to calculate the similarity between two 1-D strings. We assume there are two 1-D strings A's and B's. Each of them is formed by a sequence of simple English words; e.g., As={a1,a2,a3⋯,am}, where am is the mth word in A's, and B's is ={b1,b2,b3⋯,bn}, where bn is the nth word in B's. We call the string C's is the common subsequence of A's and B's if the elements of string C's belong to A's or B's. The LCS uses the recurrence relation of dynamic programming to calculate the length of two strings. The words in these subsequences just need to appear in the same order as they appear in the other string. Therefore the LCS is a common subsequence having the maximum length and allowed to be non-contiguous. For example, the length of LCS ("forensic" and "science") is 3 with the longest common subsequence is "enc", see Figure 17. Let $X=\{x_1,x_2,...,x_i\}$, $Y=\{y_1,y_2,...,y_j\}$ be sequences, and the LCS algorithm is described as follow:

$$len[i,j]=\begin{cases}0 & \text{if } i=0 \text{ or } j=0,\\ len[i-1,j-1]+1 & \text{if } i,j>0 \text{ and } x_i=y_j,\\ \max(len[i.j-1],len[i-1,j]) & \text{if } i,j>0 \text{ and } x_i\neq y_j.\end{cases}$$

, where len[i,j] is the length of an LCS of *Xi* and *Yj*.



(a)

Fig.17 (a) an example of dynamic program and the length of LCS is 3.

Similarity measure

Width similarity

Assuming there are the width of striation A and striation B, W_A and W_B respectively. We can define:

$$SW=\frac{\min(W_A,\ W_B)}{\max(W_A,\ W_B)}, \quad (8)$$

where $SW\in[0,1]$

String similarity

In string S_A and string S_B, $SM(S_A, S_B)$ and $SN(S_A, S_B)$ are Long and Short measurement of similarity, respectively. $SM(S_A, S_B)$ and $SN(S_A, S_B)$ can be defined as the following :

$$SM=\frac{LCS(S_A,\ S_B)}{\max(L_A,\ L_B)}, \quad (9)$$

$$SN=\frac{LCS(S_A,\ S_B)}{\min(L_A,\ L_B)}, \quad (10)$$

where L_A and L_B are the length of strings S_A and S_B, respectively.

Striation mark similarity

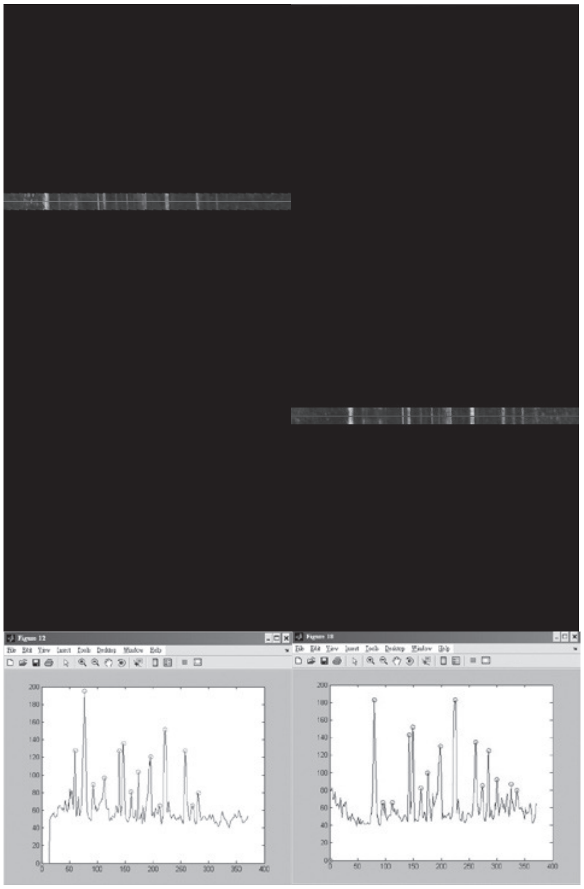
After defining the width similarity and the string similarity, we combine both of them to obtain the final similarity, S_{total}, which is defined as:

$$S_{total}=\frac{r1\cdot SM+r2\cdot SN+r3\cdot SW}{r1+r2+r3}, \quad (11)$$

where r1, r2, and r3 are the weights. $S_{total}\in[0,1]$. A larger *Stotal* means the strings are more similar to each other. There are some examples to show the result of similarity measure as follows, see Figure 18 and Figure 19.

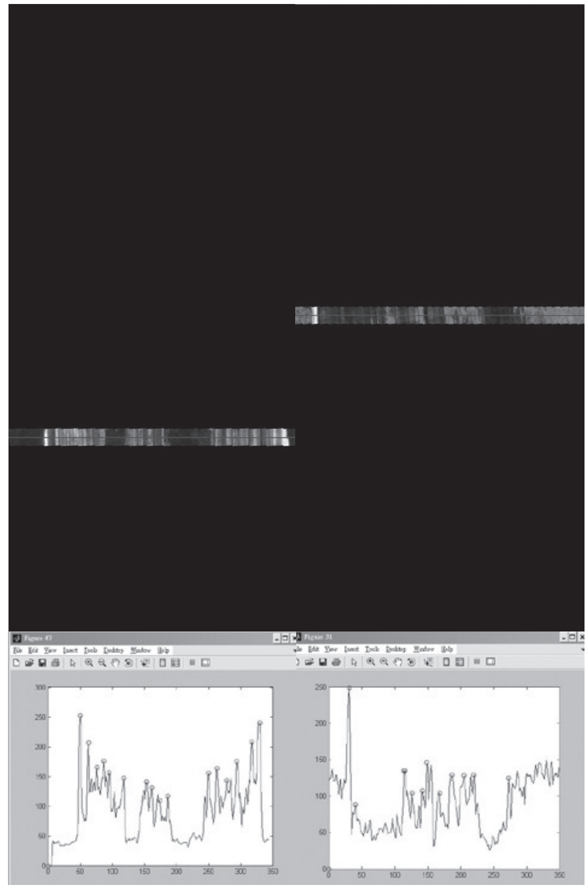
Experimental results

We collected 12 different slotted-screwdrivers and 2 chisels with different widths. Striation marks were produced by two different sides of the slotted screwdriver on lead sheets with "pull" way at 30^o~40^o angles. These striation marks were took pictures by DSLR at



1-D string: ZAABBZAABAACAA 1-D string: ZAACZAABBCAAABA
LCS=11，SM=11/15=0.7333

Fig.18 The 1-D signature string similarity measuring of two fragments in the same striation mark.



1-D string: ZAAAZBCZAAFAAABA 1-D string: ZAGZAAZAAAAE
LCS=9，SM=9/16=0.5625

Fig.19 The 1-D signature string similarity measuring of two fragments in the different striation mark.

the resolution of 180 dpi. We got 28 pictures of striation marks. Each image was segmented into 30 fragments with 20 pixel height. We selected 20 fragments from 30 ones to extract features. Consequently we acquired 560 fragments from the images of striation marks to be the experimental samples.

After the fragment features were coded, each image of striation mark had 20 1D-string signatures. We used the LCS method to compare their similarities. The parameters of the final similarity (S_{total}) were set $r1$=3, $r2$=1 and $r3$=1.

We tested the system on the PC with an Intel Core2 6300 1.86 GHz CPU and 2GB RAM, and the system was developed by using Matlab and executed under the operation system of Windows XP.

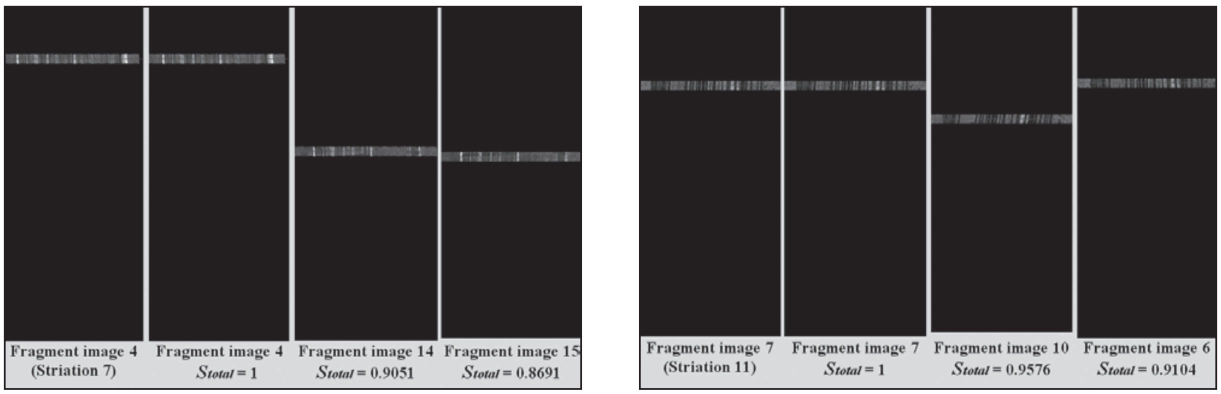
Comparison of selfsame striation mark by the same tool's one side

We compare the selfsame striation marks by the same tool and attempt to look for a representative signature that can indicate the striation itself. According to the feature coding, we can compare the similarity of each fragment in the selfsame striation mark. We choose two striations and compare 20 signatures with each other extracted from a striation mark to obtain 40 final similarities (S_{total}) and the average execution time is 1.42

seconds. One of the striation's range of *Stotal* is 0.91~0.49 except for S_{total} =1 and the three most similar results are shown in Figure 20 (a). Another striation's range of Stotal is 0.96~0.66 except for S_{total} =1 and the three most similar results are shown in Figure 20 (b).

Comparison of striation marks by the same tool's two sides

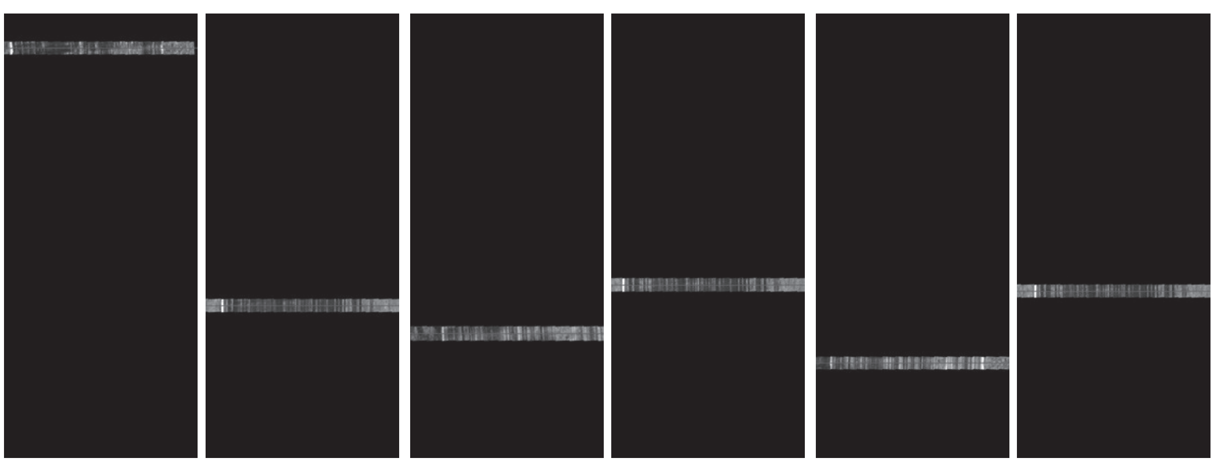
We compare two striation marks made by using the same tool (two sides). We choose three pairs of different striation marks and they are made by three different



(a) (b)

Fig.20 The results of experiment of selfsame striation mark of (set *r*1=3, *r*2=1, *r*3=1): (a) Striation 7; (b) Striation 11.

screwdrivers' two sides. We compare 20 signatures with each other extracted from each pair of striation marks to obtain 40 final similarities (S_{total}) and the average execution time is 1.31 seconds. One of the striation's range of S_{total} is 0.78~0.33 and the three most similar results are shown in Figure 21. Another striation's range of S_{total} is 0.86~0.55 and the three most similar results are shown in Figure 22. Third striation's range of *Stotal* is 0.79~0.34 and the three most similar results are shown in Figure 23.



Fragment image 2 (Striation 5) **Fragment image 20 (Striation 6)** **Fragment image 18 (Striation 5)** **Fragment image 19 (Striation 6)** **Fragment image 20 (Striation 5)** **Fragment image 19 (Striation 6)**

(a) (b) (c)

Fig.21 The S_{total} of experiment of Striation 5 and 6 (set *r*1=3, *r*2=1, *r*3=1): (a) 0.7801; (b) 0.7774; (c) 0.7521.

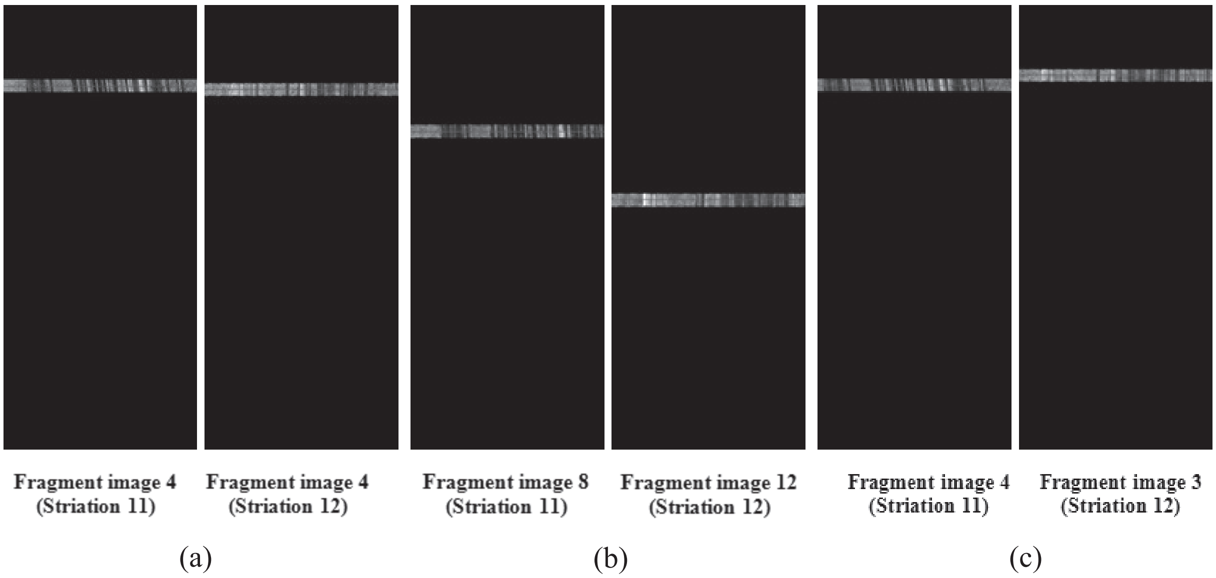


Fig.22 The S_{total} of Striation 11 and 12 (set $r1$=3, $r2$=1, $r3$=1): (a) 0.8578; (b) 0.8167; (c) 0.8150..

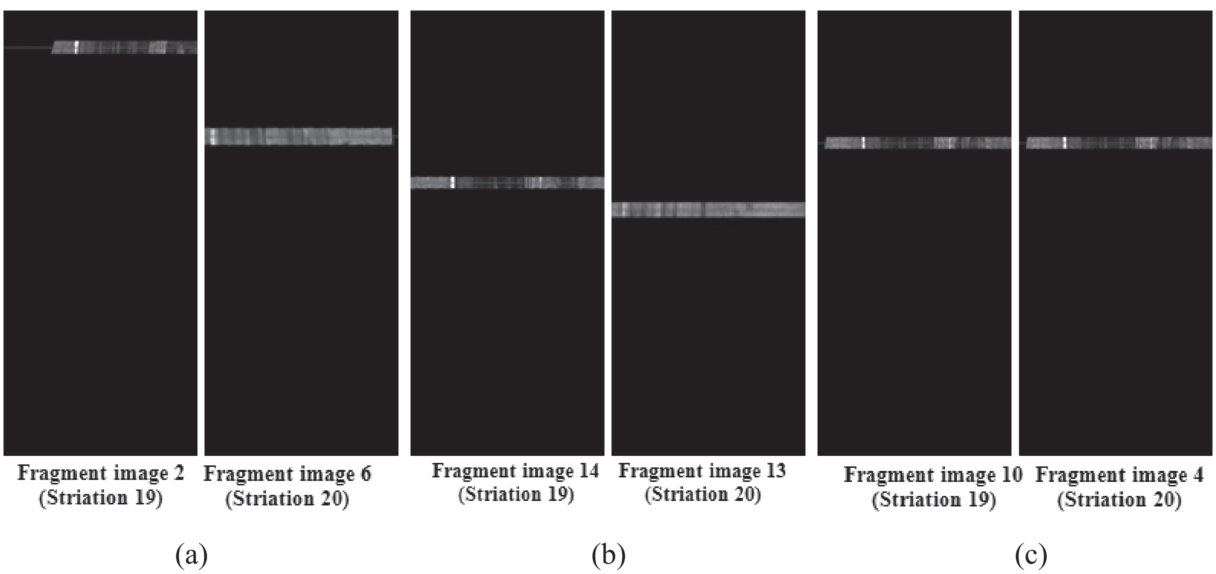


Fig.23 The S_{total} of experiment of Striation 19 and 20 (set $r1$=3, $r2$=1, $r3$=1): (a) 0.7943; (b) 0.7934; (c) 0.7772.

Comparison of different striation mark by different tool

We want to test different striation marks in the database randomly and verify if random one will match itself. We choose 3 striation marks randomly and compare these 3 striation marks with our database. In this experiment, each striation marks have 20 signatures and our database has 28×20 signatures; therefore, this process of comparison enforcement 20×28×20 iteration times. The experiment results list the five most similar striation marks from the database in Figure 24, Figure 25 and Figure 26; the average complete time is 20.29 seconds.

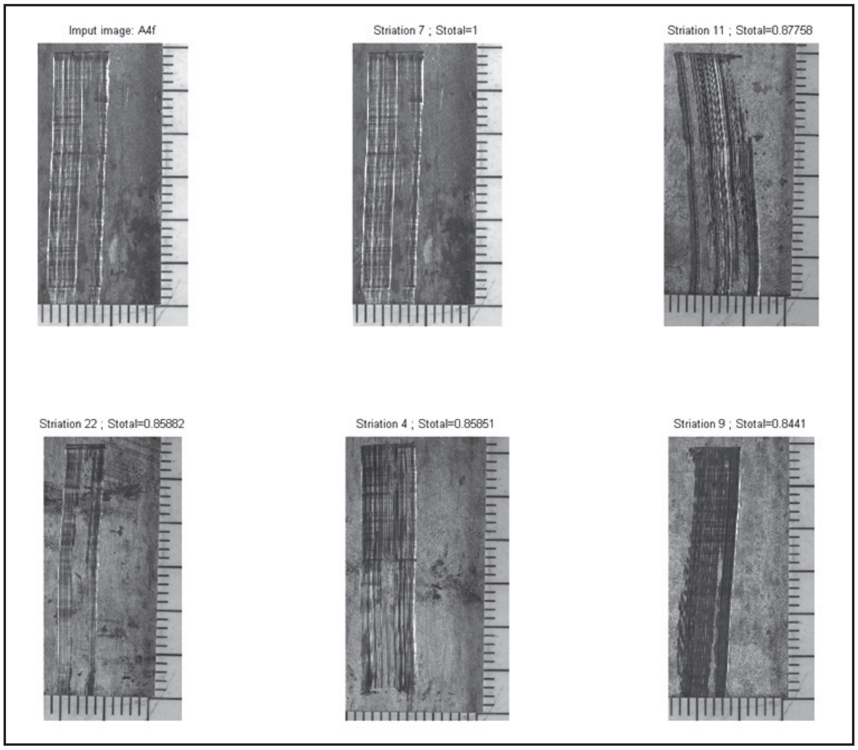


Fig.24 The query result of experiment of Striation 7 comparing with the database, and Striation 7 is the image A4f itself.

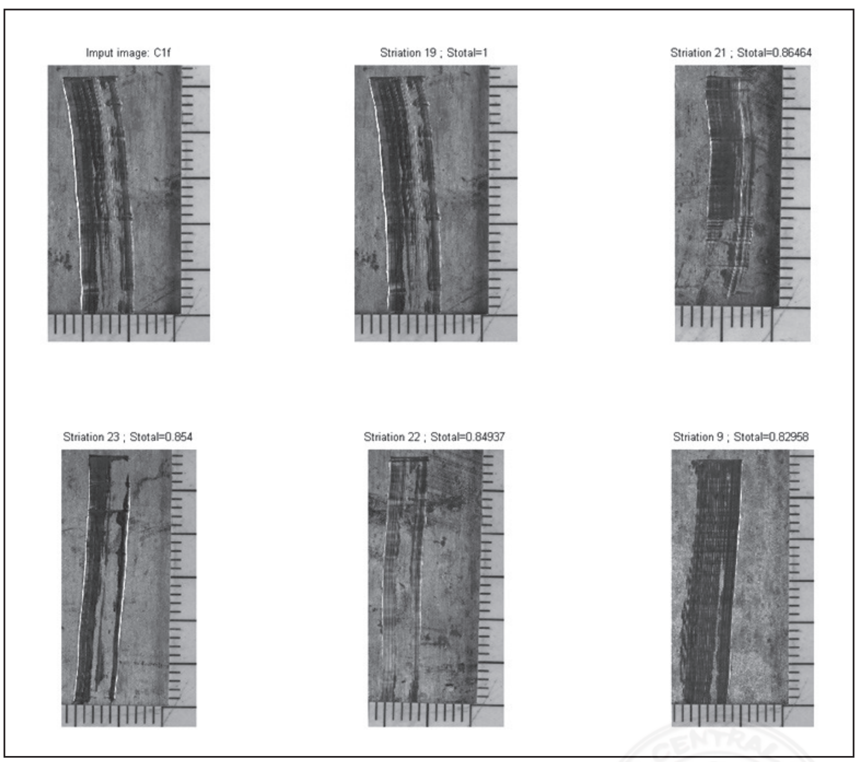


Fig.25 The query result of experiment of Striation 19, and Striation 19 is the image C1f itself.

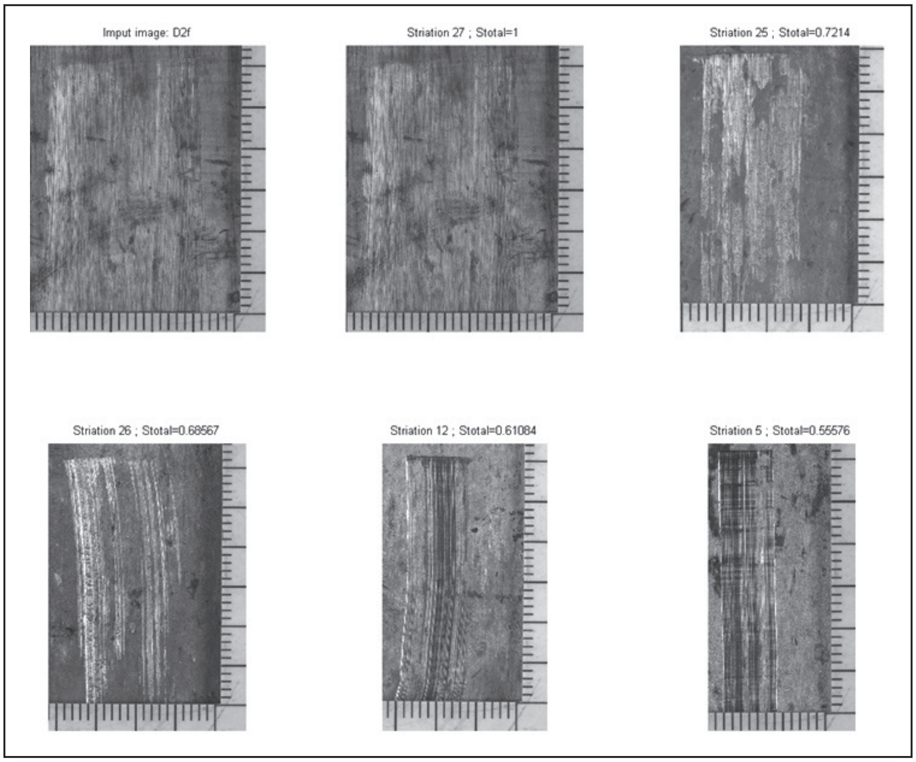


Fig.26 The query result of experiment of Striation 27 comparing with the database, and Striation 27 is the image D2f itself.

Comparison of different striation marks by the same tools

We test two different striation marks made by the same tool and confirm that if striation marks by selfsame tool will cause high similarity. We select 3 of 14 tools in this paper to make 3 striation marks and compare these 3 striation marks with our database. In this experiment, each striation marks have 20 signatures and our database has 28×20signatures therefore this process of comparison enforcement 20×28×20times. The experiment results list the five most similar striation marks from the database in Figure 27~29 and the average complete time is 18.27 seconds.

Image A2f1 and striation 3 are complete striation and most features are reserved. Striation 3 is ranked at 1st, and the result is shown in Figure 27. Image C3f1 and striation 23 are half complete striation and half empty. Striation 23 is ranked at 4th, and the result is shown in Figure 28. Image B2f1 and striation 13 are both imperfect striations and parts of features overlap. Striation 13 is ranked at 8th, and the result is shown in Figure 29.

Comparison of CCF and LCS method

The cross-correlation function (CCF) provides an approach to compare the similarity of one-dimensional signature of two marks. CCF is described as follows, where $\tilde{q}_1(\xi)$ and $\tilde{q}_2(\xi)$ are two signals:

$$k_{12}(\tau) := \tilde{q}_1(\xi) \otimes \tilde{q}_2(\xi) = \int_{-\infty}^{\infty} \tilde{q}_1(\xi) \cdot \tilde{q}_2(\xi + \tau) d\xi$$

where $\tilde{q}_1(\xi) := (q_1(\xi) - m_{q1})/S_{q1}$ and $\tilde{q}_2(\xi) := (q_2(\xi) - m_{q2})/S_{q2}$ denote the signals centered around their mean values m_{qi} and normalized by their standard deviation S_{qi}. The range of the $k_{12}(\tau)$ is limited to -1 and 1. The maximum value $\rho_{12} := \max\{k_{12}(\tau)\}$ indicates the degree of similarity of two signals. Because CCF belongs to the method of global comparison and must calculates the value of each location, it needs heavy computation.

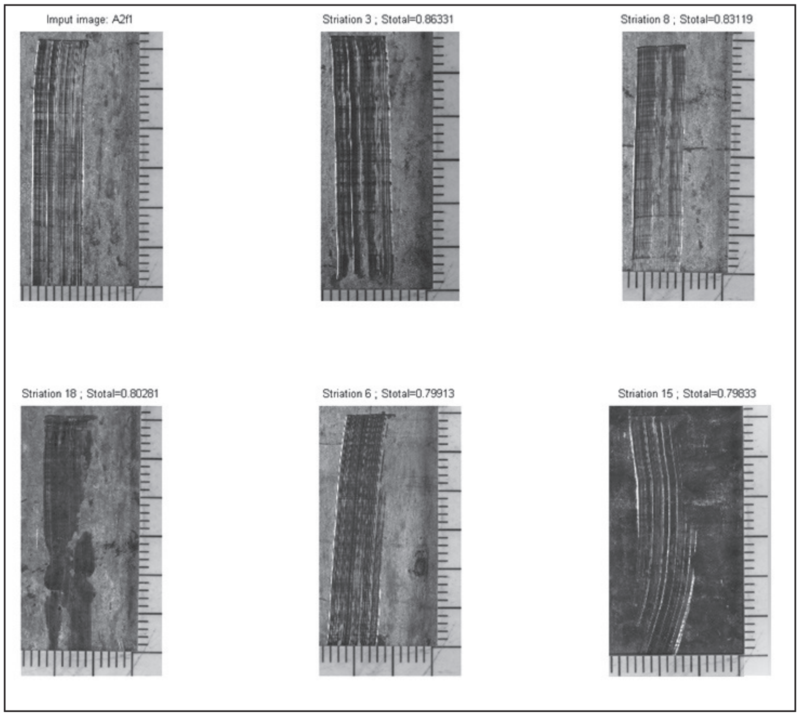


Fig.27 The query result of experiment of Striation 28 formed from screwdriver A2, and Image A2f1 and striation 3 are made by the same tool.

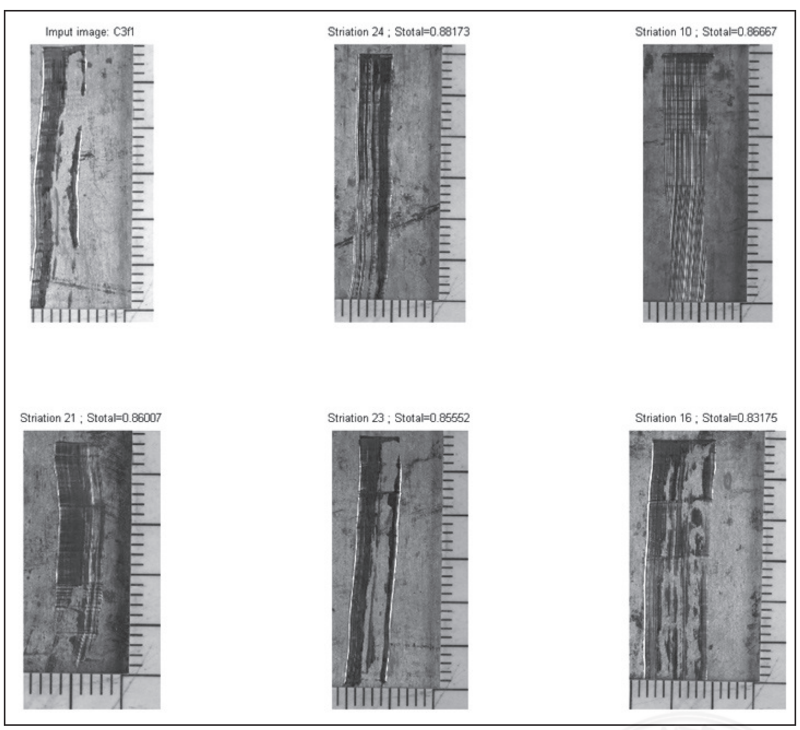


Fig.28 The result of experiment of Striation 29 formed from screwdriver C3, and Image C3f1 and s8triation 23 are made by the same tool.

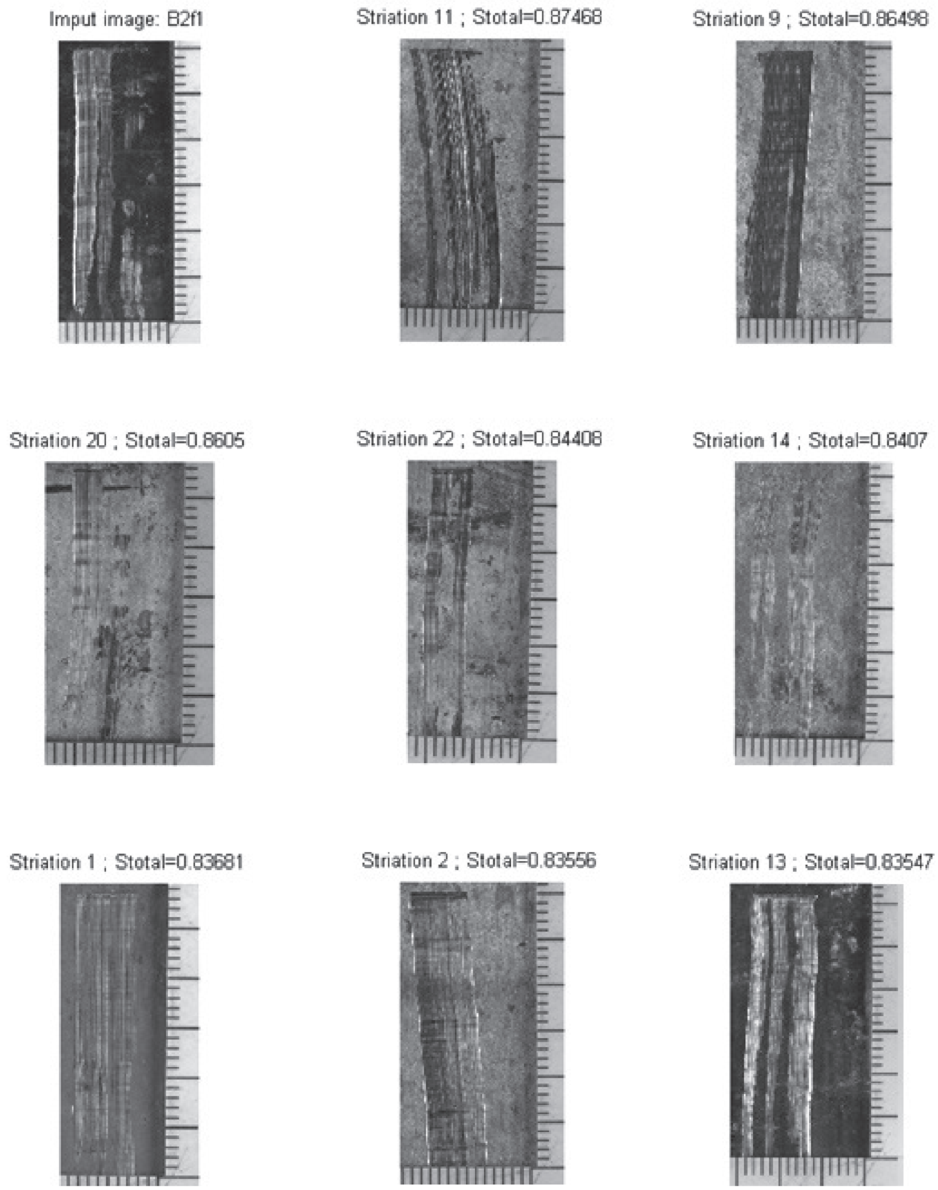


Fig.29 The result of experiment of Striation 30 formed from screwdriver B2. Image B2f1 and striation 13 are made by the same tool.

The LCS method provides a simple and efficient way for measuring the similarity between two sequences. By means of features coding, the striation mark matching will become a 1-D string matching. The LCS method can find the longest common subsequence, and a final similarity (*Stotal*) is considered of combination of the ratio of width.

The advantage to make use of the LCS method is easy and efficient. 1-D strings can reduce the storage space of database. The LCS method is faster than the CCF.

Conclusions

In this paper, we build a striation pattern feature based upon the distance of adjacent bright lines, and denote the feature by a sequence. We also use the longest common subsequence (LCS) method to compare the similarity of sequences of striation marks. From the experimental results, the LCS method provides feasibility to describe the similarity between two striation marks. We show the LCS method provides a potential tool for tool mark analysis.

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