4 Databases of Cartridge Cases

Based on:

Abstract

Databases of cartridge cases have been used in forensic laboratories extensively. In these databases image-matching methods have been implemented that are proprietary. For quality assurance, it is necessary to understand the background of the matching algorithms, and to improve the results by implementing other algorithms.

In this study, three methods for matching of breech face marks have been compared: standard deviation of the difference, log polar, and KLT. These methods have been tested with the following pre-processing methods: histogram equalization and filtering with one of the first four scales of the à trous wavelet transform.

For testing we mixed 49 known matching cartridge cases with 4900 images of breech face marks in a database. The standard deviation of the difference of histogram-equalized images of the breech faces resulted in first matching ranks in the database if they are acquired under strict standards for lighting and positioning. A brute force approach by shifting and rotating the cartridge case was not feasible, since too much computing power was required.

Log Polar matching of the third scale from the à trous wavelet transform worked well. With this method, all images were retrieved in the first position of the ranking. KLT in combination with the third scale of a trous worked for 11 breech face marks, as the relevant images were retrieved in the first position. The KLT-method is computationally efficient, and could be used as pre-selection, since all relevant
images were retrieved in the first five percent of the database. On this pre-selection the log polar method could next be used to this selection to retrieve the matching shapes.

For further evaluation of these algorithms, it is necessary to test them in the databases of cartridge cases with a wider variety of casework.

4.1 Introduction

This chapter describes a comparative study of automated matching algorithms of breech face marks on cartridge cases. This study is a part of an evaluation of the different systems on the market for handling databases of cartridge cases and bullets.

In this chapter, first an overview is given of forensic investigation of firearms and cartridge cases, including a survey of commercial systems. Then, a selection of matching algorithms is discussed, in which the most promising are evaluated in experiments with a complete database.

The reason to compare the different methods of image matching is that the methods are proprietary. For quality assurance in a forensic laboratory, it is important to understand why a certain image is not found in the matching list and to have more background on the image-matching engine. Another reason for this research is to improve the results of image matching.

Figure 4-1: Image of breech face in the primer area with sidelight (left frame) image of firing pin with ring light (right frame)
4.1.1 Forensic Examination

When a firearm is loaded and fired the mechanisms that are exposed to the cartridge case cause impressions and striations that can be characteristic for the firearm being used. The striation marks on bullets are caused by the irregularities in the firearm barrel.

Often the cartridge case is the most important forensic specimen in the identification of weapons, as bullets are commonly deformed by the impact. The examiner can also determine, using class characteristics, what kind of firearm (often make and model) has been used.

The cartridge case ejected shows marks at the primer (Figure 4-1) that are caused by the firing pin and the breech face as the cartridge is repelled back in the breach by the force of rifling. The feeding, extraction and ejection mechanisms of the firearm will also leave characteristic marks.

For forensic comparison, a number of test fires are made with the firearm. In forensic laboratories the marks on cartridge cases and bullets are compared with the test fired ones. By comparing the marks, it is possible for the qualified examiner to conclude that a certain bullet or cartridge case has been fired with a certain firearm.

4.1.2 Ballistic Imaging Systems

DRUGFIRE and IBIS are databases for acquiring, storing and analyzing images of bullets and cartridge cases. These two systems have been evaluated at our laboratory.

Both systems capture video images of bullet striations and of the markings left on cartridge cases. These images are used to produce a digital signature that is stored in a database. The system then compares a signature to that of another fired bullet - or cartridge case - or to an entire database of fired bullets and cartridge cases. The user enters the cartridge case in the database for comparison, and can limit the search to using specific characteristics (e.g., caliber, date limit). Then, the system produces a hit list that shows a ranking of all cartridge cases based on the similarity, as measured by the system, between the cartridge under investigation and the cartridges in the database. The system functions properly if all relevant matches are in the top of the hit list.
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The methods of image matching applied in these systems are not known. However patents\textsuperscript{60,61,62} applied by IBIS mentions that state-of-the-art image matching methods are used. The system of IBIS is now used most often, and since the images are acquired in a reproducible way by a special kind of lighting, the ring light, it is expected that this system will give the best matching results.

Other systems for analyzing cartridge cases are the systems Fireball\textsuperscript{64}, CIBLE and TAIS. These systems also use image-matching techniques, however they were not available for investigation at our laboratory.

Three-dimensional measurement of the striation marks by laser triangulation\textsuperscript{65} or by fusing the images with different angles of coincidence are described in the literature\textsuperscript{66}. Since the firearm examiner is used to compare side light images rather than three-dimensional images, development and acceptance of 3D-image matching methods progresses slowly. Accordingly, this study is focused on the matching of side light and ring light images.

4.2 Image matching

In order to carry out the comparison of matching methods, we tested various techniques, which are available from the literature\textsuperscript{67}. Recently, the interest in content-based searching of image databases has increased considerably; image matching is a crucial step in content-based retrieval. Several commercial and research systems as QBIC, Virage and Photobook\textsuperscript{68,69} search similar images in the databases based on the contents of the images. They generally take features from the images, and index these features as descriptors that are easily searchable. The results of searching are generally influenced by the following factors:

- Noise in the image due to the acquisition process
- Rotation and shift
- Difference in light source

Further differences that are typical for databases of cartridge cases:

- Difference in cartridge case metal (material, type, brand)
- Wear of firearm
• Wear of cartridge case

• Marks between two shots can be different for statistical reasons in the shooting process; this means that sometimes parts of striation and impression marks are visible that are not visible with the next shot

In present-day forensic investigations, the firearm examiner determines which marks on cartridge cases are similar. The approach examined in this chapter involves automatic comparison, by using the shape of the firing pin and the texture of the impression marks. Since the light conditions and the images of the marks do change depending on the marks, methods have been developed that compare the features of gray-scale images. In practice, it turned out to be important to have an appropriate preprocessing image step to compensate for the variation of light. In the optimal situation, the algorithm should only compare the marks caused by the firearm, and not any other features of the cartridge case, as damage and symbols.

In this research, approaches are described that are either pixel based or feature based. The reason to use feature-based methods is to improve the calculating speed and to keep the selection restricted to marks.

4.3 Test database

For our evaluation of image matching algorithms, we studied two kinds of images (Figure 4-1)

• Images of breech faces which are illuminated with side light

• Images of firing pins which are illuminated with ring light

We used a database of 4900 images, which were acquired by different firearm examiners from different institutes around the world using the Drugfire system under different circumstances (light sources and a number of views of the cartridge case). Table 5 shows the different calibers and the kind of images (side or ring light images). We tested the algorithms on all images (without prior knowledge).

For testing, we added 49 images from a test set to the database. The test set consists of side light images of 49 different cartridge cases that have a known match. They are consistent in light conditions. These cartridge cases are fired from 19 different firearms of caliber’s 9 mm Parabellum (15), .45 automatic (3) and .32 (1).
Depending on the case, there were 2-5 matching cartridge cases (Table 6). Some of these cartridge cases are from different test shots. The marks of the cartridge cases and the shapes of the firing pin were visually similar between the matches. Five cartridge cases had a rotation of more than 10 degrees to each other. The 49 cartridge cases were also available as ring light images of the firing pin. There were marks in all ring light images of the firing pin that could be distinguished from each other visually.

The images are acquired by using a protocol. The firearms examiner determines in the 12-o’clock point of the cartridge case by examining the marks and positions the cartridge case at the 3-o’clock position. Often the striation lines in the breech face of the firearm are parallel. The image is rotated in such a way that the striation marks are most visible by using side light.

<table>
<thead>
<tr>
<th>Caliber</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 mm Parabellum</td>
<td>2402</td>
</tr>
<tr>
<td>.32 automatic</td>
<td>893</td>
</tr>
<tr>
<td>.25 automatic</td>
<td>393</td>
</tr>
<tr>
<td>.380 automatic</td>
<td>326</td>
</tr>
<tr>
<td>.45 automatic</td>
<td>236</td>
</tr>
<tr>
<td>9 mm short</td>
<td>230</td>
</tr>
<tr>
<td>.40 S&amp;W</td>
<td>118</td>
</tr>
<tr>
<td>.22 long rifle</td>
<td>109</td>
</tr>
<tr>
<td>Others</td>
<td>193</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4900</strong></td>
</tr>
</tbody>
</table>
Table 6: Number of matching cartridge cases in the test set vs. caliber

<table>
<thead>
<tr>
<th>Number of matching cartridge cases</th>
<th>9 mm Parabellum</th>
<th>.45au</th>
<th>.32au</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>3</td>
<td>1</td>
<td>49</td>
</tr>
</tbody>
</table>

The evaluation of methods consists of mixing the 49 images with the complete database, and evaluating how often the images will be placed on the top positions of the hit list. However in cases were calculation time is a problem, the 49 images are compared to each other. For validation of the algorithm itself, the cartridge case is also compared to itself. The experiments are based on practical cases, and this can also influence the correlation results.

4.4 Methods and results

The methods that are used have been evaluated in a time frame of four years of research. In first instance we started with the most precise method that is pixel-based comparison. Observing the need for improvement for calculation time, faster methods were used. In this chapter the methods are explained and results are presented.

4.4.1 Pre-processing

For pre-processing of the cartridge cases two different methods have been tested:

- histogram equalization and masking
- wavelets

Pre-processing is used to compensate for differences in lighting and for enhancing the marks that have to be matched.
4. Databases of Cartridge Cases

4.4.1.1 Histogram Equalization and masking

On the images in the database and the test set, histogram equalization\(^7\) is used in an effort to compensate for differences in lighting conditions and visualize the marks. Since we would like to compare just the inner circle of the image (where most impression marks are), we select the circle manually and all pixels outside of this circle will get a zero gray value (Figure 4-2) This pre-processing has been carried out to all images that are in our databases.

4.4.1.2 Wavelets

There are a huge number of articles\(^7\) on pattern recognition based on wavelet transforms. A wavelet transform is a localized function of mean zero. Wavelet functions are often wave-like but clipped to a finite domain. Wavelet transforms are computationally efficient and they allow exact reconstruction of the original data. The reason for choosing a wavelet transform is that wavelets are suitable of filtering properties at different scales (from coarse to fine) in the image. The challenge is to choose a wavelet scale and type that are optimal for the breech face marks (fine striation and impression marks).

We have chosen a wavelet transform that works on discrete data known as à trous (with holes) algorithm\(^7\). In this wavelet, the image is sampled by means of a
smoothing function, the B3 spline. The different scales of à trous that are calculated can be added to each other and the result will be the original image.

Scale 1 of the à trous algorithm will give the finest details and the noise in the image. The higher scales will give the coarse variation of lighting in the image. In Figure 4-3 an example is given of four scales of a cartridge case computed with the à trous algorithm. Most information on the marks is visible in the third scale, however in the experiments all scales have been tested.

4.4.2 Matching Results

In this section, we discuss the results of the different image matching methods (standard deviation of the difference, log polar and KLT) that we have considered for this database. We have compared the test set of 49 images with the complete database of 4900 side light images based on these methods. We have tested the method based on five situations:

- the histogram equalized images
- the four scales of the à trous wavelet scales

4.4.2.1 Standard Deviation of the difference

For a computationally simple kind of matching procedure, we take the variance of the difference in gray values between two images (which was also used in previous research\textsuperscript{73}).

The hit list is created by sorting the variance from small values for the best matching to high values for images that do not match well.

The user of the database has to position the cartridge cases according to standard procedure; a relatively rare error is that the position is 180 degrees rotated. This can happen when the examiner finds the wrong position of the cartridge case in the firearm based on the marks.

Since we did not know if the protocol was strictly applied for all images in our database, we decided to test the influence of small rotations on the matching results. It appeared that a rotation of a cartridge case up to five degrees did not affect its ranking.
The first test was done with histogram equalized images. We subtracted the images from the test set from each image in the database and compared the standard deviations of the resulting differences. It appeared that 21 out of the 49 images were in the top positions, fifteen were in the top 5 percent of the database. This means that the examiner should compare 250 cartridge cases in the database of 4900 images before knowing there is no match. This does not work well in practice, since it is a time consuming task. Five more cartridge cases were in the top 50 percent of the database. These five cartridge cases had a rotation of more than 10 degrees to each other, and this caused the difference. For this reason this approach is not effective, unless the cartridge cases are positioned within five degrees accuracy to each other. The results for the a trous wavelet transformed images, did not improve the results of the matching algorithm.

From examination of the images, it appeared that some of these primer areas of the cartridge cases were slightly rotated and translated to each other. We tried to compensate this influence by a “brute force” method of rotating and translating the images, and calculating the minimum of the standard deviation of the difference in gray values. With those compensations, all images were found in the top positions.

This approach worked both in the polar coordinates as well as in the raw images. The computation is done by rotating 360 degrees in steps of one degree and shifting 40 pixels in x and y-direction (which is the estimated maximum of shift) in steps of one pixel. The computation took more than one month on a Pentium-II PC 333 Mhz for 49 images; for this reason this “brute force” method has not been used with the complete database.

4.4.2.2 Log Polar Transform

A classical technique for registering two images with translation misalignment involves calculating the 2D cross-image matching function\(^74\). The maximum of this function yields the translation necessary to bring the images into alignment. This function has the disadvantage of being sensitive to rotation and scale change. Even small rotations of a few degrees can reduce the peak of the cross image matching function to the noise level.
By using invariant image descriptors in place of the original images, it is possible to avoid this problem. One such descriptor is the log-polar transform of the Fourier magnitude, which removes the effect of rotation, and uniform scaling into shifts in orthogonal directions\textsuperscript{75}.

We tested the log polar transform on histogram equalized images of the primer area. It appeared that five out of the 49 cartridge cases were ranked in the first position. All images were however in the first 6 percent (top 300) of the complete database. For this reason the method can be used as a faster selection method. The log polar transform took 7 days to calculate for the complete database of 4900 images.

Better results were found when applying the third scale of the à trous transform on the images of the primer area. By pre-processing the images this scale, all matching images were in the top positions.
4.4.2.3 KLT Method

There are extensive studies of image matching for tracking\textsuperscript{76} (following an object in a scene). Since tracking has many similarities with searching in a database of images\textsuperscript{77}, we have tested a tracking algorithm. Tracking algorithms are optimized for their speed. Determining whether a feature is of interest can be used for ranking it in a hit list. Tracking also has the problem of registration, since the camera might move, with image intensities that change in a complex way.

One of the methods that appears to work for a wide range of tracking problems, and that works fast, is the Kanade Lucas Tomasi (KLT) method\textsuperscript{78}. Prominent features, e.g., strong edges) are located by examining the minimum eigenvalue of each 2x 2-gradient matrix. The features are tracked using a Newton-Raphson method of minimizing the difference between the two images.

Based on the KLT method, the details in the images that are prominent are selected as points. From each image, these points are calculated by comparing two images of one shifted cartridge case. For the experiments, we have shifted the cartridge case five pixels, and have calculated the 100 most prominent points, which are stored in the database. The number of points that are matched between two cartridge cases, is a measure of similarity between two images.

For our test set of 49 images compared to the database of 4900 images, it appeared that the histogram equalized images did not work well, since no images were retrieved in the first positions, and some images were retrieved on the last positions of the matching list.

The third à trous wavelet scale gave the best results. Of the 49 images, 11 were retrieved in the first position out of the 4900 images. Furthermore, all images were retrieved in the first five percent of the database.

4.4.2.4 Overview of results

In Table 7 a comparison between the matching methods used in this chapter, is shown.

Table 7 : Number of relevant matches in top positions for the test set and percentage of database that has to be searched before all relevant images are retrieved.
4. Databases of Cartridge Cases

<table>
<thead>
<tr>
<th></th>
<th>Standard Deviation of Difference</th>
<th>&quot;Brute Force&quot; registration within test set</th>
<th>Log Polar</th>
<th>KLT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Histogram equalized image</td>
<td>21 / 50 %</td>
<td>49 / 0 %</td>
<td>5 / 6 %</td>
<td>0 / 45 %</td>
</tr>
<tr>
<td>Scale 1</td>
<td>5 / 78 %</td>
<td>-</td>
<td>3 / 15 %</td>
<td>2 / 34 %</td>
</tr>
<tr>
<td>Scale 2</td>
<td>7 / 79 %</td>
<td>-</td>
<td>21 / 4 %</td>
<td>3 / 15 %</td>
</tr>
<tr>
<td>Scale 3</td>
<td>21 / 53 %</td>
<td>49 / 0 %</td>
<td>49 / 0 %</td>
<td>11 / 5 %</td>
</tr>
<tr>
<td>Scale 4</td>
<td>4 / 82 %</td>
<td>-</td>
<td>2 / 45 %</td>
<td>3 / 45 %</td>
</tr>
</tbody>
</table>

4.5 Conclusions and Discussion

We tested three different image matching algorithms (standard deviation of the difference, log polar and KLT) for breech face marks on cartridge cases and two different pre-processing algorithms, were 49 cartridge cases from 19 different firearms with known matches were mixed with a database of 4900 cartridge cases.

In cases where the positioning, and the light conditions among the marks in the cartridge cases were reproducible, a simple computation of the standard deviation of the subtracted gray levels put the matching images on top of the hit list.

For images that were rotated and shifted, we have built a "brute force" way of image translation and rotation, and the minimum of the standard deviation of the difference is computed. For images that did not have the same light conditions and were rotated relatively to each other, all matches were found with the third scale of the à trous-wavelet computation. Since the method was very time consuming in computation, we have limited this experiment to the 49 cartridge cases, and compared them to each other.

For the log polar transform and KLT pre processing by the third scale of the à trous wavelet transform worked best. For log polar all relevant images were retrieved in the top position of the ranking. For KLT, eleven images were in the first position, and all 49 were in the first five percent of the database.
From our experiments, we conclude that if images are entered in the database using a standard protocol, a simple computation of the standard deviation of the difference of the image is feasible. If there are differences in positioning, the log polar transform of the third à trous wavelet scale works better. As a measure for pre-selection of images, the KLT method is an option. In Figure 4-4 the flowchart of the approach is shown.

The cartridge cases in our experiments, had clear breech face marks. In practice this is not always the situation, so for that reason other marks (firing pin, extractor marks) could also be used in the database. For further improvement, the user might select the areas that are relevant on the cartridge case for their marks. Sometimes the firearm examiner has information that marks on the cartridge cases are not caused by the firearm itself. Examples of this damage are text imprints in the firing pin.

For further evaluation of matching algorithms, it is necessary to test them in the databases of cartridge cases with a wide variety of casework.

The use of optical processors\textsuperscript{79, 80} or parallel processors implemented in hardware is an option to improve the speed of image matching of the brute force method. Implementations of faster matching algorithms should be considered for future research.

The cartridge case systems are widely used compared to tool marks databases. These systems have correlation engines, and modification to a 3D system will result in better correlation ranks. In The Netherlands, we use the system Drugfire, also used by many agencies in the United States. The company that produces this system is phasing out the software, since there appeared to be patent infringement problems with the other company, IBIS. In the United States, the IBIS system for cartridge cases will be the standard. This system has a more reproducible way of imaging the cartridge cases, and better results are possible with this system. In practice, the system results in "cold" hits. The systems for cartridge cases also help for statistical evaluation of forensic evidence. The identifying characteristics should be compared, and if the database is sufficiently filled, it is possible to make these kinds of comparisons.
Pre-processing
- Histogram Equalization
- or split in A trous scales

Extraction low level features
- Firing pin
- Breechface marks
- KLT

Textual descriptors
- firearm examiner determines which kind of firearm has been used based on class characteristics
- optional: user interaction to verify automatic feature selection

Indexing
- with KLT the indexes are stored

Retrieval:
- on textual descriptors
- and/or similarity measures of features
- standard deviation of the difference
- Log Polar
- KLT

Visualization

Figure 4-4: Flow chart of cartridge case visual information system