COMPUTER-ASSISTED ANALYSIS OF STRIATED TOOLMARKS AND IMPRESSIONS

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ABSTRACT: An image database system is presented, storing images and other data related to forensic toolmarks. The system facilitates handling and matching of toolmarks found on the crime scene or made in the forensic laboratory using suspected crime tools. For striated toolmarks, automatic search for probable matches is provided, subject to verification by human expert. A number of comparison criteria is presented. Toolmarks can also be matched manually on screen, using a virtual comparison microscope interfaced to the database. For the purpose of further development and verification of comparison algorithms, a large corpus of image fragments has been cross-compared by hand, and the resulting data is available in the public domain. The system intends to fill the gap in the forensic expert's array of computerised tools, where similar systems for fingerprint and firearms investigation have long been taken for granted.

KEY WORDS: Toolmarks; Striations; Impressions; Automated matching; Forensic databases.

Problems of Forensic Sciences, vol. XLVII, 2001, 291–299
Received 28 November 2000; accepted 15 September 2001

INTRODUCTION

Computer-assisted, if not fully automatic, image matching systems are already widespread in fingerprint analysis and ballistics. Toolmarks analysis, on the other hand, is still largely manual labour. The purpose of our work has been to create an image database with automatic matching criteria which will, for a given image, screen through the stored images and provide the human expert with ashort list of likely matches. This should reduce the work load and improve the throughput of the forensic lab, while leaving the final decision, and the legal responsibility, with the human.

TYPES OF TOOLMARKS CONSIDERED IN THE PROJECT

The project focused on two types of toolmarks:

1. Compression toolmarks (made by pressing or hitting, such as the trace of a seal in wax) are difficult to represent by standardised attributes. The project therefore limited itself to developing a virtual comparison microscope (the SOMIC, as described below).
2. Sliding toolmarks (also known as striated toolmarks, "stria" meaning a narrow stripe) are made when a tool slides over a surface or creates a surface by cutting through a material. A good model is slicing butter with a toothed knife. We chose to regard these marks as "smudged" two-dimensional extensions of one-dimensional grey-level profiles, which in turn represent the physical profile of the tool edge. Consequently, software instruments were developed to project the image back into a 1D domain and to compare such 1D profiles.

OVERALL STRUCTURE OF THE SYSTEM

The system comprises five principal elements:

1. The VIDOCQ toolmark database (Visual Documentation for Crime Queries) is at the core of the system. It stores the toolmarks and uses the Comparison Criteria (see below) to identify possible matches.
2. SOMIC – the Software Comparison Microscope is a program which allows two images to be displayed together and moved around, by hand, for visual comparison. It is used as the display module for Vidocq, as well as a standalone dual image handling tool.
3. The Comparison Criteria take the projected grey level profiles of two striated toolmark images and slide one of them along the other to find the position where their striae coincide most closely. This position, and a measure of the similarity obtained, is then used to provide the human expert with a short list of possible matches.
4. Strips – the Toolmark Expert Interviewer – was developed to obtain a corpus of expert judgements on local stria similarities. It shows the expert two small fragments of striated images (so small as to contain, ideally, just one isolated stripe each). The expert is then asked to decide if these two small fragments match.
5. MARPLE (Matching Accuracy Rated Pointwise by Lenient Expert) is a large set of pairs of image fragments, compared by an expert under Strips.

We shall now describe each of them in more detail.

THE VIDOCQ DATABASE

The prototype application was developed using Visual C++ with Microsoft Foundation Classes (MFC). Directional projection and top-hat techniques for maxima detection [2] were developed to extract essential 1D information from 2D images of dynamic toolmarks. To compare them, criteria were formulated based on correlation or probabilistic considerations. A neural-network approach was also proposed, but its development did not get past the early experimental stage and the technique was not incorporated in the prototype forensic workstation.

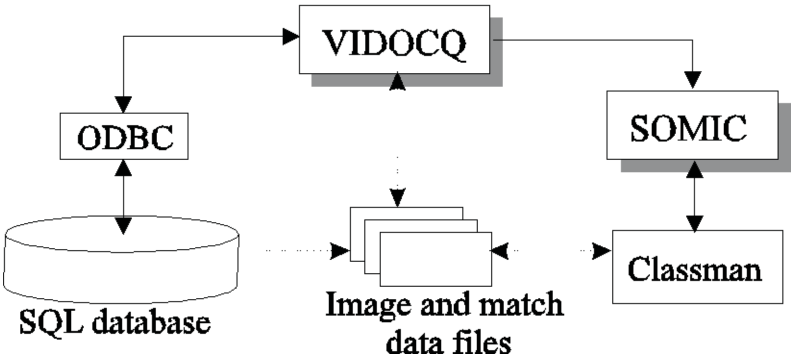

Fig. 1. Overall structure of the system.

Images of toolmarks are stored as files, in such standards as GIF (both GIF-87 and GIF-89) image, RAW file or Windows bitmap (BMP).

The database contains:

- Image descriptions;
- Toolmark (comparison or crime scene) descriptions, with such attributes as: date of toolmark acquisition, case number (for crime scene), tool type and hardness of material, expert who entered crime scene toolmark into database, links to image and profile;
- Profiles (used for quick matching);
- Descriptions of match, with such attributes as: values of comparison criterion, Name of .mch file for SOMIC (generated by VIDOCQ or imported), links to toolmarks.

Access to database is ensured by the ODBC (Open DataBase Connector). The passwords regulating access to the VIDOCQ database are stored using the SHA (Secure Hash Algorithm). The SQL (System Query Language) is used for queries. Data may be stored in SQL database servers. VIDOCQ was tested with the MS Access and the IBM DB2 server. An overall logical structure of the database is shown in the following diagram:

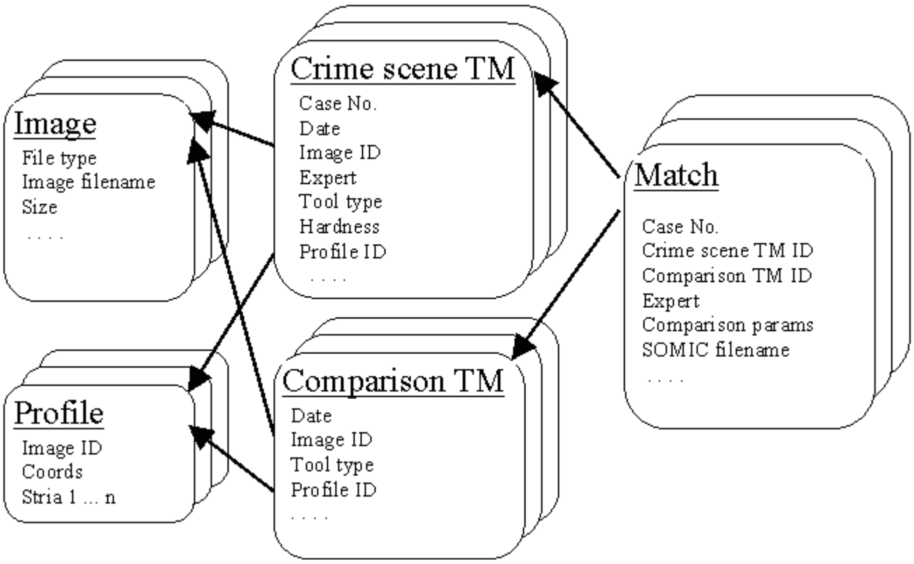

Fig. 2. Overall logical structure of the VIDOCQ database.

THE COMPARISON CRITERIA

In the database, each image of a striated toolmark is accompanied by a record describing the position and greylevel profile of the relevant zone (containing the actual striae, as opposed to the whole image which is larger). The zone is identified by the user at acquisition, and its profile is extracted by an aligned projection procedure described in [2].

The profiles are used by the comparison criteria applied when searching through the database for possible matches. The muster profile (the profile representing the search query) is compared to each profile in the scope of the search in all the possible relative positions of one profile alongside the other:

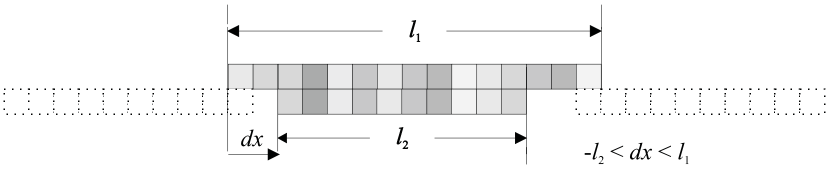

Fig. 3. Possible relative positions of two profiles.

In each position, the quality of the match is compared by the criterion that was chosen for the query. The following criteria are available:

1. Simple correlation. The greylevel correlation of the overlapping parts of the two profiles can be used as a straightforward similarity measure. Its advantage is that it is comprehensive, i.e. it uses all the information contained in the relevant segment of each profile. Its drawback is its sensitivity to difference in such circumstances as depth of toolmark or aspect of the material.
2. Combinatorial criterion. This is an approach proposed by Deinet [1], where the pixels of each profile are regarded as one-bit binary values. Logical "true" values represent pixels where a stripe was detected. The criterion consists in counting the "true" bits in one profile that meet (or "hit") those in the other (see Figure 4), and then evaluating the probability of creating such level of co-occurrence incidentally. If this probability is low, the marks are likely to have originated from the same tool.

$$P = \frac{\sum_{m=n}^{\min(k_1, k_2)} \binom{k_1}{m}\binom{l-k_1}{k_1-m}}{\binom{l}{k_2}} . \qquad \{1\}$$

The probability of incidentally creating a co-occurrence no worse than a given pattern is where: l is the length (in pixels) of the overlapping part of the two profiles; k_1, k_2 are the numbers of striae ("true" bits) in either profile, within the range of the overlap; n is the number of coinciding striae.

For example, in the case shown in Figure 4, $l = 10, k_1 = k_2 = 3, n = 2$ and therefore $P = 18.3\%$

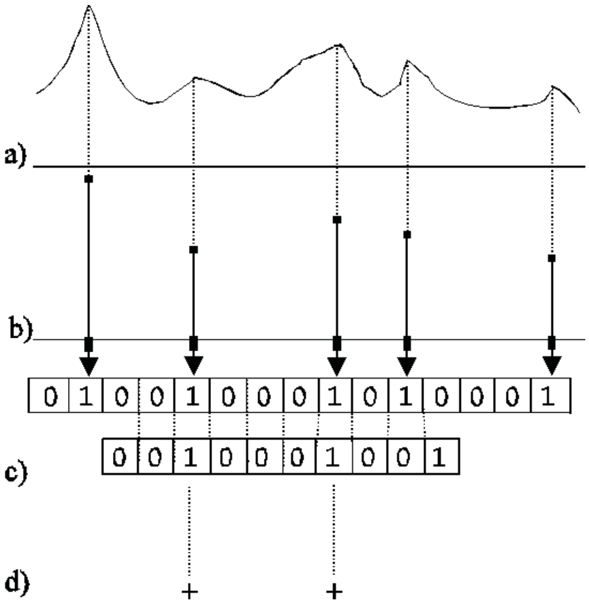

Fig. 4. Comparing binary profiles: a) greyscale profile, b) binary profile, c) binary striae vector, d) coinciding striae.

The combinatorial criterion is highly sensitive to longitudinal distortions of the profile, asonly direct “hits“ (pixel to pixel co-occurrences) of striae are counted.

3. Correlation of blurred binary profiles. The binary profiles described above are converted into strings of real values and blurred by replacing each logical “true” bit by a narrow Gaussian profile spanning a number of neighbouring pixels. These blurred profiles are then correlated as in the simple correlation criterion. The blurring allows small longitudinal distortions of the profiles to be tolerated.

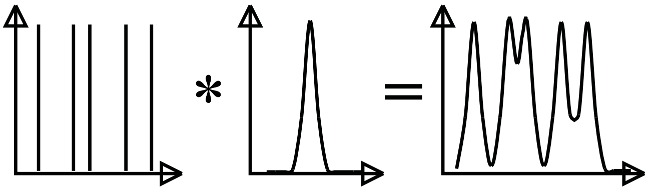

Fig. 5. Blurring a binary profile.

The blurred profiles are then matched using the simple correlation as described above.

No thresholds have been set for the comparison criteria. Their values are used to rank potential matches, and a fixed number of the best ones are submitted to the user for verification.

SOMIC – THE SOFTWARE COMPARISON MICROSCOPE

SOMIC [3] is an interactive program under Windows which allows two bitmap images to be placed side by side and patchworked together along an arbitrary broken line (as shown in the picture below). The user can move the images and edit the dividing line in search of an alignment which will allow him to ascertain a match.

Compared to an optical dual-stage microscope, a software implementation offers a number of advantages, such as: ease of handling, smaller hardware cost (only a standard single-stage microscope is required for image acquisition), and the flexibility of the dividing line (in the dual-stage microscope, it is constrained to avertical straight line).

The composite image can be stored as a single bitmap or in a specific format named*.cmp, preserving the component images, their relative position, and the shape of the dividing line.

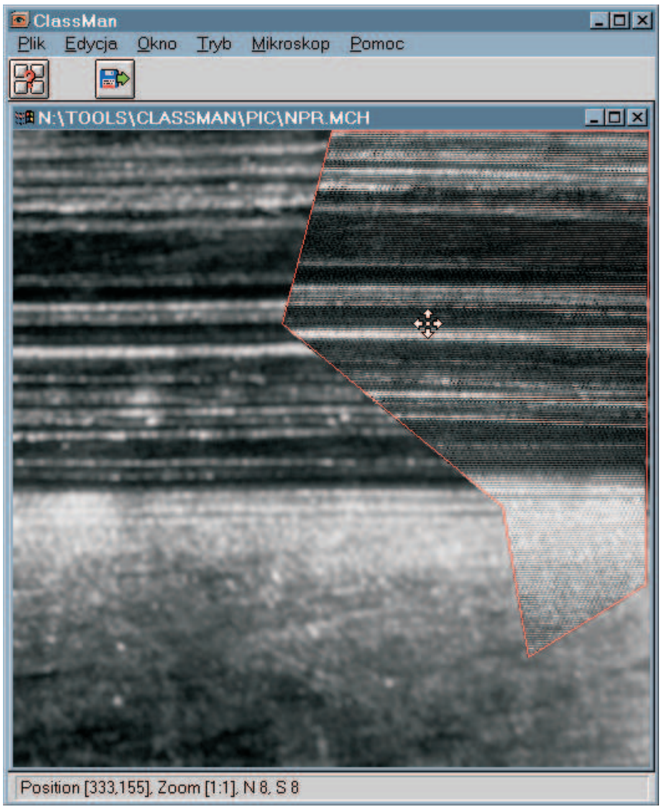

Fig. 6. SOMIC.

STRIPS – THE TOOLMARK EXPERT INTERVIEWER

Strips was developed to obtain a corpus of expert judgements on local stria similarities. It presents the expert with pairs of small fragments of striated images (so small as to contain, ideally, just one isolated stripe each). The expert is then asked to decide if these two small fragments match. See Figure 7 for an example of user interface.

MARPLE (MATCHING ACCURACY RATED POINTWISE BY LENIENT EXPERT)

This is a corpus of expert judgements acquired under Strips (see above). Its purpose is to help in the development of more sophisticated comparison criteria, especially based on soft computing techniques.

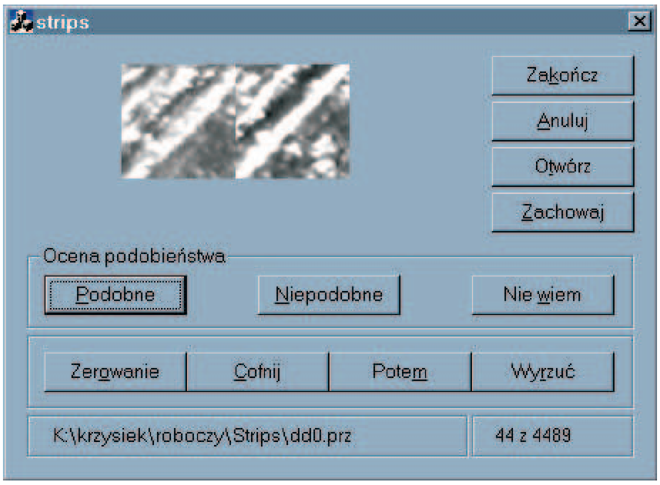

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Fig. 7. Dialog window of the Strips program.

Principle: A number of striated toolmarks were photographed, and a straight line was placed manually across the striae in each image. A program then projected a rectangular area around the line into a 1D domain, to obtain a crossection or profile of the toolmark.

Another algorithm analysed the profile to identify salient local maxima of its derivative. A 32×32 pixel square window around each such salient point was considered a feature.

All the features found in all toolmark images used in the study were compared to each other by a forensic expert, using the Strips interviewer program. The expert was presented two features at a time and asked to declare them similar, dissimilar, or undecidable. It was also possible to skip some of the feature pairs.

The expert was instructed to rate similarity based on local feature appearance only, and not to use extraneous information such as his own memory of the entire toolmarks.

Content. The database contains the following files:

- 20 files named *.pic, containing raw microscopic images;
- 3 text files named *.prz . These files define which fragments were submitted to the expert for comparison;
- 3 result files named *.out, containing expert's decisions. Every toolmark fragment was matched against every other one defined by the same *.prz file, and against itself for completeness, so the number of expert judgements in an .out file is N_2, where N is the total number of fragments defined by the *.prz file.

MARPLE has been placed in the public domain. It can be downloaded from the project web site (http://www.forensic.to/IITiS-MECH) as an archive or in separate files. Detailed format descriptions are available at the same site.

CONCLUSIONS

The project has proven the feasibility of computer-assisted toolmark identification. Prototype testing has confirmed the relevance of matching criteria and the utility of the SOMIC display module. Upgrading the prototype into a marketable product is being negotiated with a prospective industrial partner.

The project was financed as Workpackage # 14 of the European CRIT-2 programme (Cooperative Research in Information Technology).

Acknowledgments:
This research endeavour began thanks to the initiative of the late Professor Adam Mrozek, to whose memory this article is gratefully dedicated.

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