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Correlation of firing pin impressions based on congruent matching cross-sections (CMX) method

Hao Zhang [a,b,*], John Song [b], Mingsi Tong [b,c], Wei Chu [b]

[a] College of Mechanical and Electronic Engineering, Nanjing Forestry University (NJFU), Nanjing 210037, China
[b] Physical Measurement Laboratory, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899, USA
[c] School of Mechatronics Engineering, Harbin Institute of Technology (HIT), Harbin, 150001, China

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ABSTRACT

Comparison of firing pin impressions of cartridge cases is an important part of firearms evidence identification. However, compared with breach face impressions, there is only a limited surface area over which firing pin impressions can be compared. Furthermore, the curvature of firing pin impressions makes it difficult to perform automatic correlations of the surfaces. In this study, a new method and related algorithm named congruent matching cross-sections (CMX) are proposed. Each firing pin impression is sliced into layers and the resulting circular cross-sections are converted to two dimensional linear profiles by a polar coordinate transformation. The differential profile extraction method is used for extracting the high frequency micro-features, or the individual characteristics, for accurate correlation. Three parameters are proposed for determining whether these pairwise firing pin impressions are fired from the same firearm. The cross-correlation function (CCF) is used for quantifying similarity of the pairwise profiles which represent the two correlated firing pin images. If the correlated cartridge pair is fired from the same firearm, the maximum CCF value between each of the profile pairs from the reference and the correlated firing pin impressions will be high. The other two parameters relate to the horizontal (or angular) and vertical range of relative shifts that the profiles undergo to obtain the maximum CCF. These shifts are the phase angle θ which corresponds to a horizontal shift of the 2D profiles and the vertical shift distance of slice section, i.e. where the profiles match in the depth of the impression. These shift parameters are used to determine the congruency of the pairwise profile patterns. When these parameter values and their statistical distributions are collected for analysis, the CMX number is derived as a key parameter for a conclusive identification or exclusion. Validation tests using 40 cartridge cases of three different brands fired from 10 firearms produced by three different manufacturers yielded clear separation between known matching (KM) and known non-matching (KNM) image pairs, which strongly supports the effectiveness and feasibility of the proposed CMX method.

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1. Introduction

Firearm identification by analysis of ballistics evidence under a comparison microscope has a long history in the United States. However, the scientific foundation of firearm and toolmark identification has been challenged by the 2009 National Academies Report [1]. This report made it a national priority in forensic science to establish a scientific foundation and a statistical procedure for quantitative error rate reports to support firearm identifications, in the same way that reporting procedures have been established for forensic identification of DNA evidence [1].

The congruent matching cells (CMC) method was recently invented at the National Institute of Standards and Technology (NIST) for accurate image-related forensic evidence identification and error rate estimation [2,3]. The CMC method is based on the principle of discretization–it divides the entire image into small correlation regions, and uses multiple identification parameters with corresponding thresholds for accurate forensic evidence identification and error rate estimation [3]. The pairwise cell correlations can identify the “valid correlation area” and eliminate

* Corresponding author at: College of Mechanical and Electronic Engineering, Nanjing Forestry University (NJFU), Nanjing 210037, China.
E-mail addresses: zhanghaowo79@sohu.com (H. Zhang), jun-feng.song@nist.gov (J. Song), mingsi.tong@nist.gov (M. Tong), wei.chu@nist.gov (W. Chu).

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the "invalid correlation area" for accurate and robust ballistics identification [2]. The use of multiple identification parameters for the multiple pairwise cell correlations between the evidence and the reference images makes it possible to develop an error rate procedure based on statistical analysis of the total number of correlation cells, the number of the congruent matching cells, and the statistical distributions of the identification parameters [3]. Based on the CMC method, a statistical model was developed at NIST for error rate reporting of ballistics identifications [3]. An initial test report for error rate estimation of breech face correlations using the CMC method has passed NIST review for publication [4].

Initial validation for the CMC method was conducted using 40 cartridge cases ejected from guns with 10 consecutively manufactured pistol slides. These samples generated 780 topography comparisons using the CMC method which did not produce any false identifications or false exclusions [5,6]. However, when the CMC method is used to compare firing pin impressions, challenges arise from the small correlation area and the curvature shape of the firing pin impressions. Unlike the breech face impressions with a flat surface and several mm^2 correlation area, the firing pin impression is a concave shape with a smaller correlation area (1 mm^2 or smaller). As a result, when the firing pin impression is divided into correlation cells, each cell may be too small to contain enough individual characteristics (topography peaks, valleys, ...) for accurate ballistics identification.

Based on the same congruent matching theory, the congruent matching cross-sections (CMX) method is proposed. In the following sections, we introduce the basic concept of the CMX method in Section 2; we discuss the detailed procedure, algorithm in Section 3; and demonstrate experiments and results in Section 4.

2. Congruent matching cross-sections (CMX) method

As mentioned above, due to the small area and concave shape of firing pin impressions, the congruent matching cross-sections (CMX) method was developed. A cross-section refers to a closed curve obtained by slicing the firing pin impression at an arbitrary height. As shown in Fig. 1(a), if slices are obtained at specific intervals in the vertical direction, a set of cross-sections from a firing pin impression can be acquired.

In Fig. 1(b), by means of the polar coordinate transformation [7], these circular sections can be converted to a set of two dimensional linear profiles which represent the original impression uniquely.

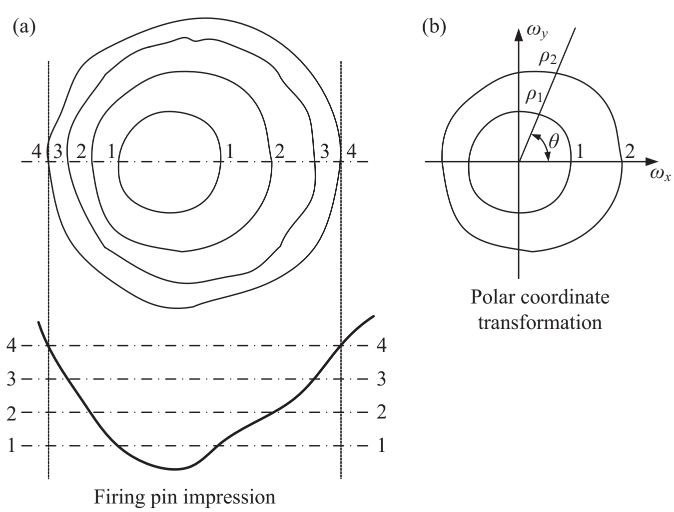

Fig. 1. Sketch of acquisition of cross-sections and profiles: (a) slicing and (b) polar coordinate transformation.

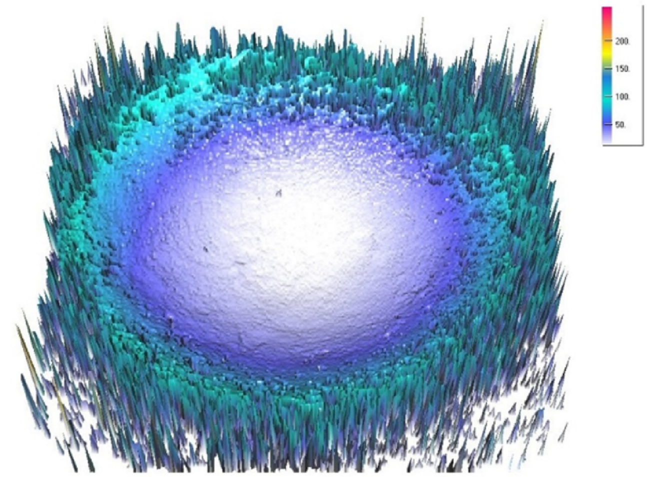

Fig. 2. Typical topography image of a firing pin impression.

The phase of these linear profiles corresponds to an angular position of the circular profiles. Then, the cross-correlation function (CCF) was calculated for pairwise profiles from the same altitude of the two compared impressions. During CCF calculation, the pairwise linear profile should be assumed periodic so that this calculation can be done over all phases. Ideally, the profiles from the same vertical slice of two cartridge cases fired by the same firing pin should have a high correlation score when registered at the same phase angle θ. The horizontal shift distance of the phase angle θ and vertical shift distance of the slice location are used to determine the congruency of the pairwise correlated profile patterns. We define the CMX number as the number of potentially congruent profile pairs. If this CMX number is equal to or more than a designed identification criterion, these casings are identified as a 'matching pair'.

3. Methods

3.1. Topography measurement and data processing

Topography measurements were performed with a Nanofocus μSurf[1] disk-scanning confocal microscope to produce topography images of the impressions. White light from a xenon bulb source enters through the objective of the microscope and illuminates the surface. The light reflects back into the objective and is directed onto a pinhole. Only the light reflected back from the current focal plane can focus through the pinhole and onto the detector. The microscope scans through a range of z-slices or focal heights during the acquisition. At the end, all the slices are compiled into a three-dimensional topography map [8]. Fig. 2 shows a typical topography image of the firing pin impression. A single field of view of 20× objective is square with approximate dimensions 0.8 mm × 0.8 mm. The raw topography images have 1.56 μm X/Y resolution and consist of 512 × 512 pixels. The z-slice interval is 0.2–0.3 μm and about 400 image slices are measured for a total vertical range of 120 μm.

The raw data acquired by the confocal microscope is bound to contain unreliable components including noise, dropouts and outliers. After acquisition, a data processing procedure was performed consisting of four steps:

[1] Certain commercial equipment, instruments, or materials are identified in this paper to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.