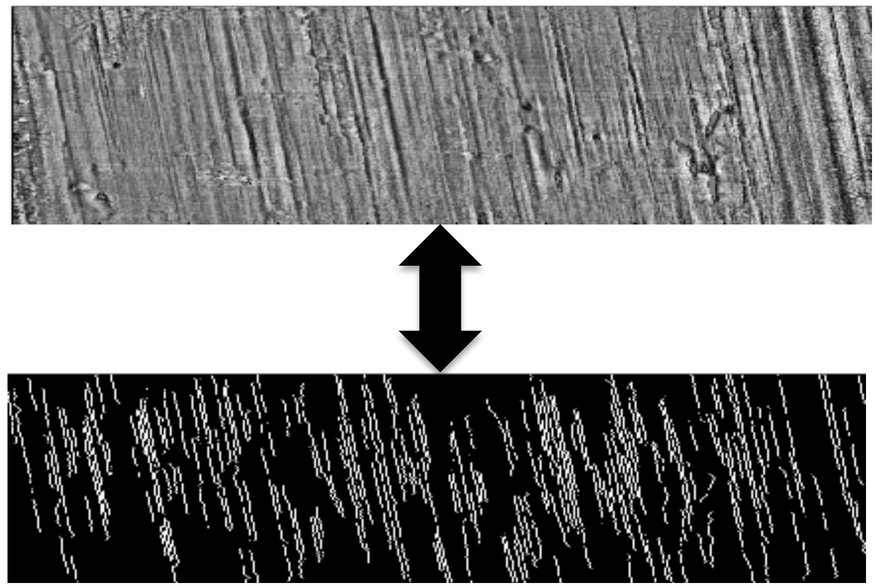
Bullet Signature Identification Using Topography Measurements and Correlations; the Unification of Topographic and Mathematical Comparisons

Presented by Robert M. Thompson
Co-authors: W.Chu, J.Song, T.Vorburger, A.Zheng, T.Renegar, and J.Yen



NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

Contents

Scope of Research

- Use the measurement method that is employed to qualify NIST Standard Reference Material (SRM) Bullets and modify it to compare fired bullets from consecutively rifled barrels.
- Model the surface topography of the bullets to mimic Consecutive Matching Striae (CMS), and compare the bullets using this model and a numerical criteria.
- Review the accuracy of both approaches.

NIST 3D Measurement System

Nanofocus Nipkow disk confocal microscope

Specifications:

- Measurement field: 800/320 µm
- for 20x and 50x lens.
- X/Y-Resolution: 1.5/0.6 µm.
- Z-Resolution: 20/10 nm.

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Example of High Reproducibility of Topography Measurements

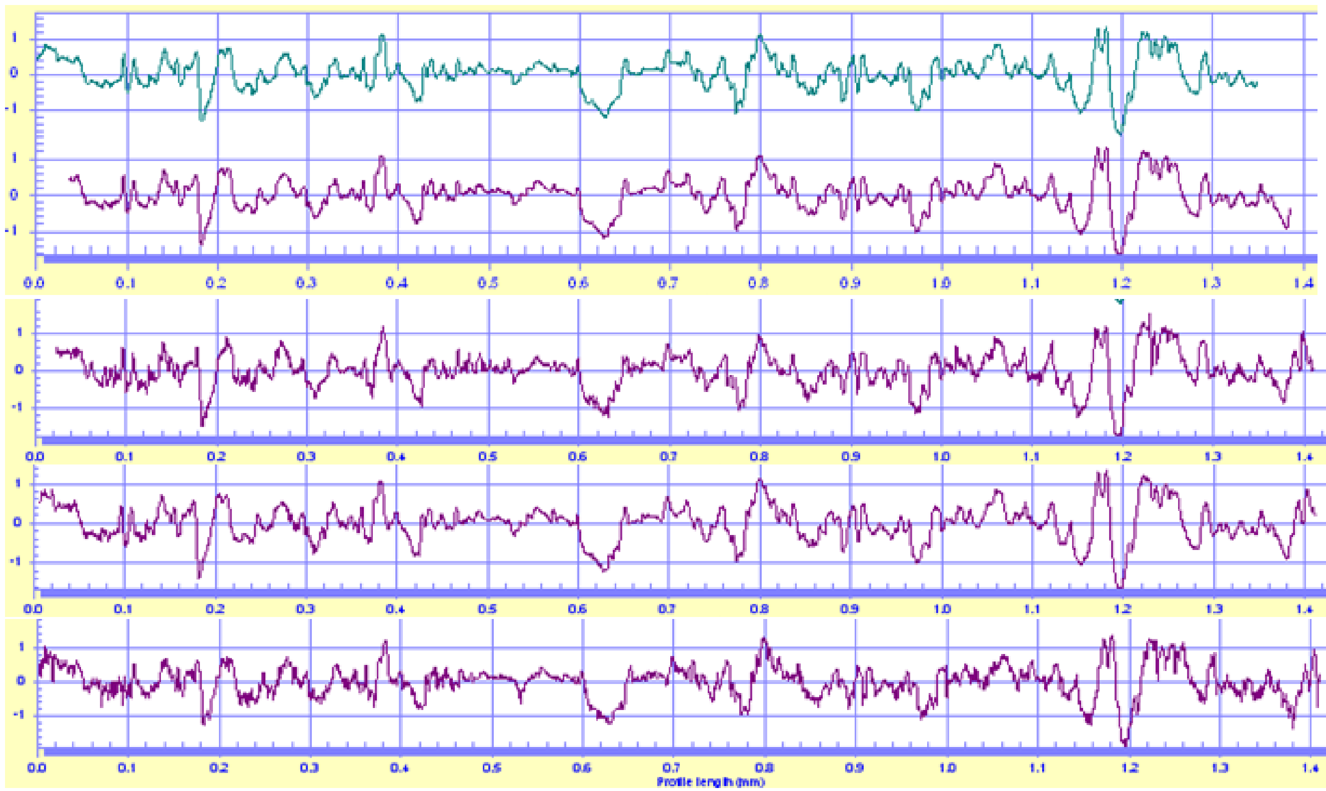
(1)

(2)

(3)

(4)

(5)



Measurement comparison of four techniques tracing the same SRM bullet:

(1) Virtual standard traced on a ATF master bullet used as a reference;

(2) Stylus instrument traces a SRM bullet: CCF_{max} = 99.6%;

(3) Interferometric microscope: CCF_{max} = 92.1%;

(4) Nipkow disk confocal microscope: CCF_{max} = 99.0%;

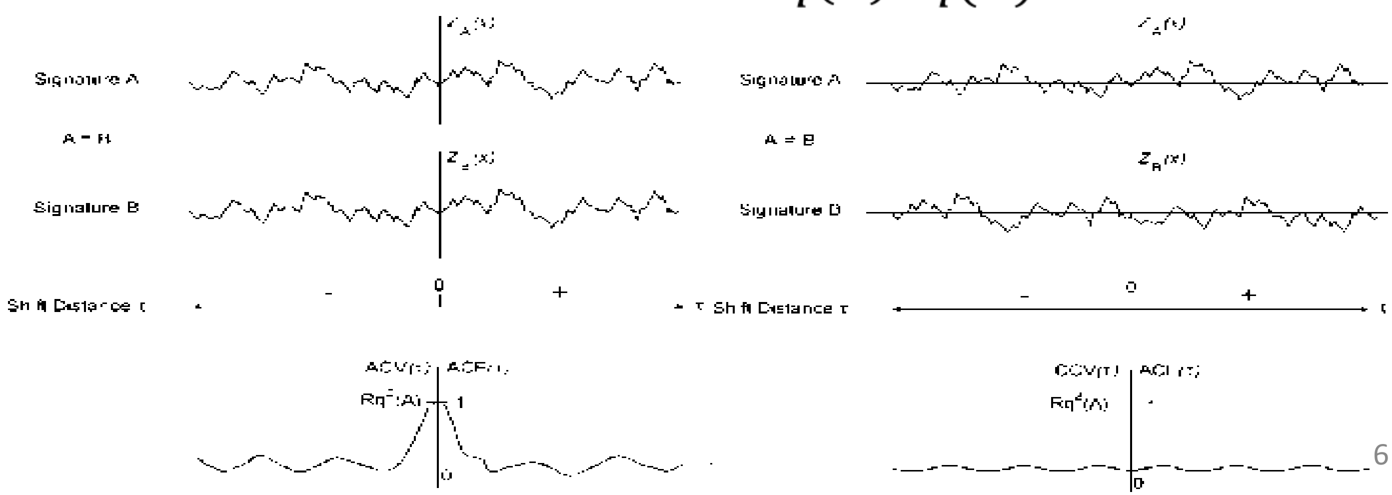
(5) Laser scanning confocal microscope: CCF_{max} = 95.3%.

Evaluation of the Similarity

$$Rq = \left[\frac{1}{L}\int_0^L Z^2(x)dx\right]^{\frac{1}{2}} \approx \left[\frac{1}{N}\sum_{i=1}^{N} Z_i{}^2\right]^{\frac{1}{2}}$$

$$CCV(A,B,\tau) = \lim_{L\to\infty}\left(\frac{1}{L}\int_{-L/2}^{L/2} Z_A(x)Z_B(x+\tau)dx\right)$$

$$CCF(A,B,\tau) = \frac{CCV(A,B,\tau)}{Rq(A)Rq(B)}$$



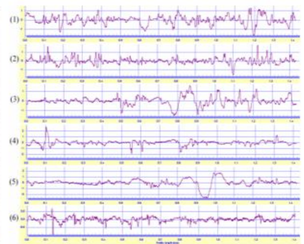
Evaluation of the Similarity

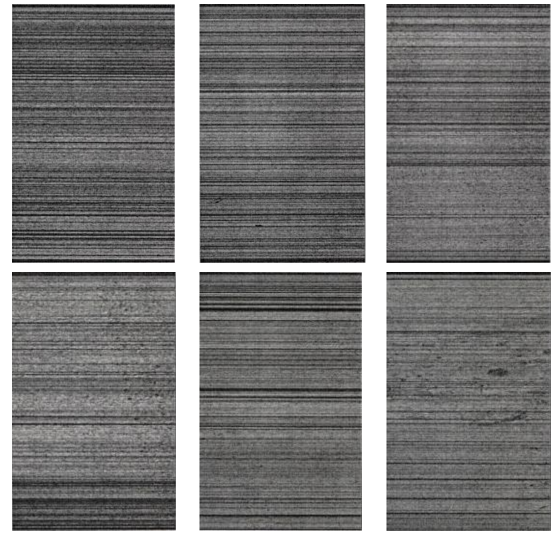
The Cross Correlation Function isn’t sensitive to scale differences between two profiles. A new parameter is needed to meet this need.

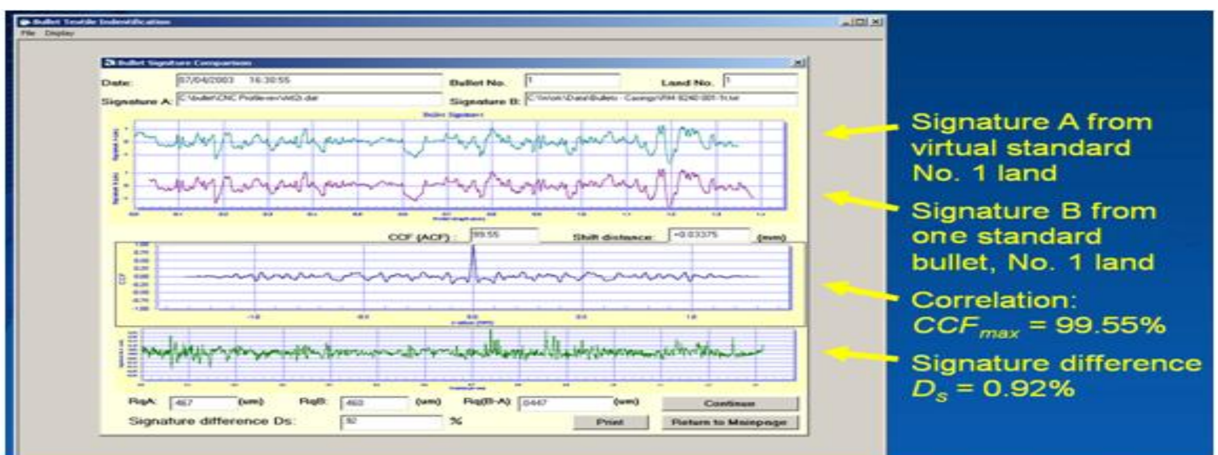
$$Rq = \left[\frac{1}{L}\int_0^L Z^2(x)dx\right]^{\frac{1}{2}} \approx \left[\frac{1}{N}\sum_{i=1}^{N} {Z_i}^2\right]^{\frac{1}{2}}$$

$$Ds = \frac{Rq^2(B - A)}{Rq^2(A)}$$

Application of CCF in NIST Standard Bullet Comparisons





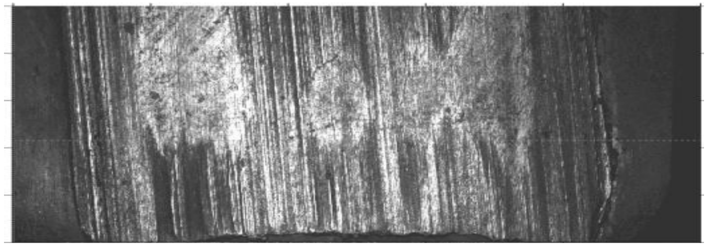


An example of CCF calculation result

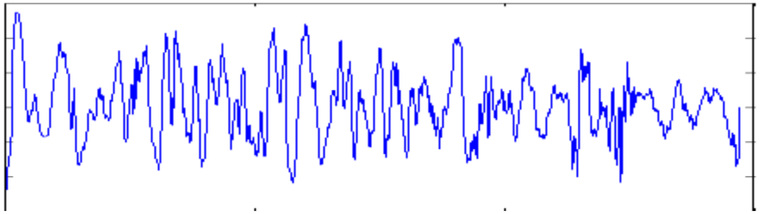
For Actual Bullets

Bullet signature

Data acquisition

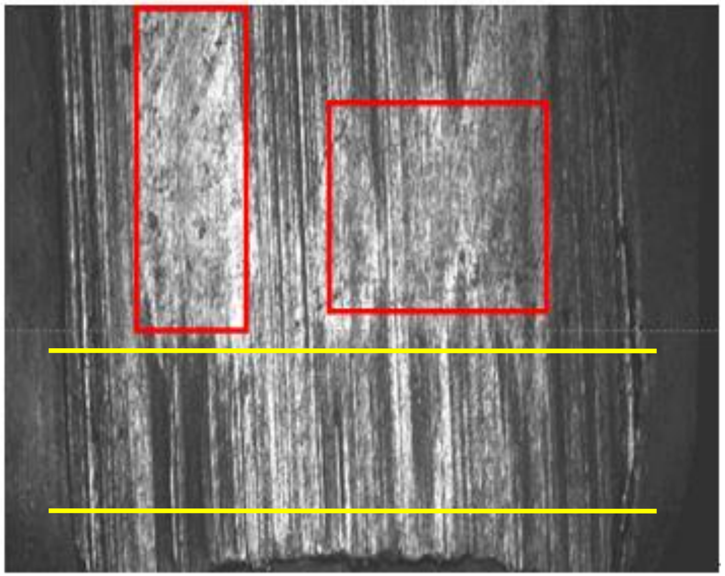


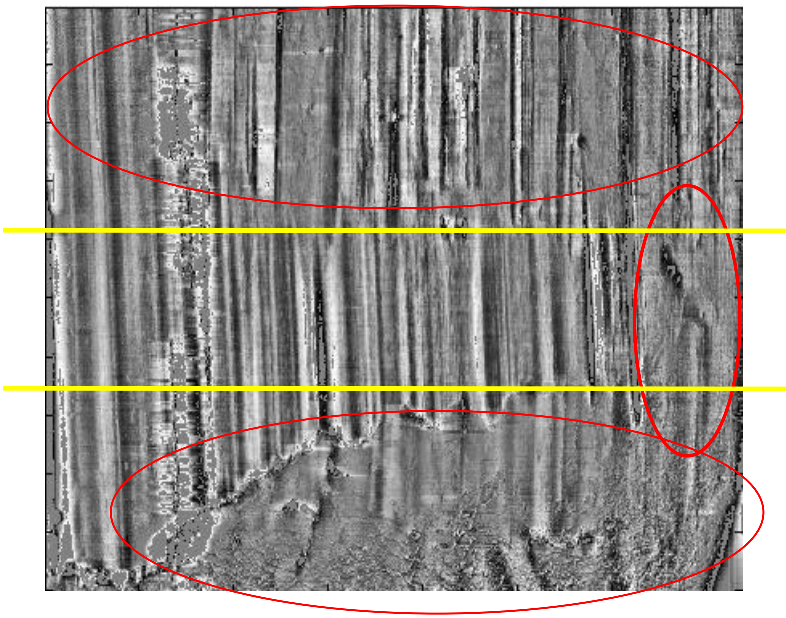
Processing



correlation

Selection of Valid Correlation Areas





Land impression images may include areas that contain useless or wrong striation information (in red).

Question:

Can valid striated areas be intelligently distinguished from other invalid areas?

How to Improve?

- Apply Edge Detection Technology

- Definition:

  Edge detection is a process that mainly measures, detects, and localizes changes of intensity.

- Property:

  An edge as described here does not necessarily correspond to an object boundary, but edges have the desirable property of drastically reducing the amount of information to be processed subsequently while preserving information about the shapes of objects in a scene.

- Edge Detection Methods:

  Roberts, Prewitt, Sobel, Log, Canny, Wavelet, Morphology…

Example of Applying Canny Edge Detector

- Canny detector - An optimal edge detection algorithm

  Properties: good detection

  good location

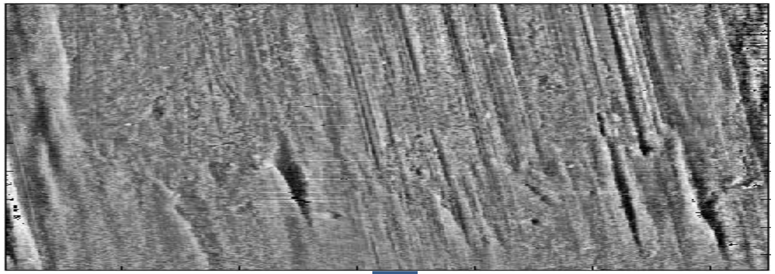
  minimum response

Ref:

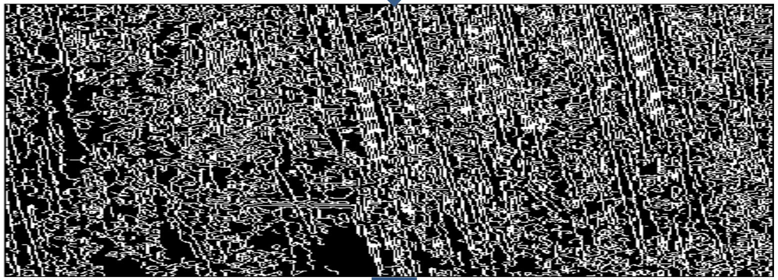
J Canny. A Computational Approach To Edge Detection, IEEE Trans. Pattern Analysis and Machine Intelligence, 8: 679-714, 1986.

Apply Canny Edge Detector to Bullet Land

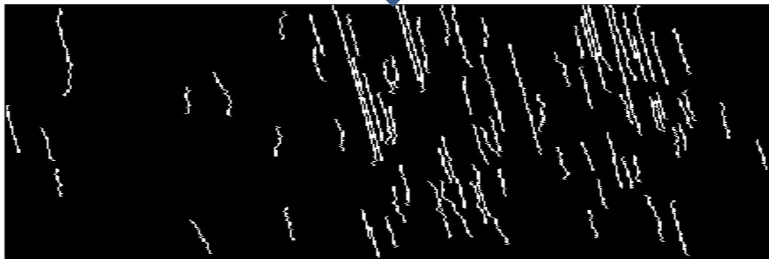
Topography Image
after preprocessing



Canny edge detection result

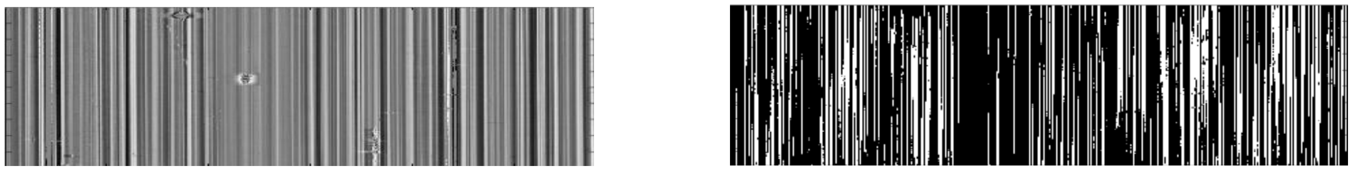


Striation edge image

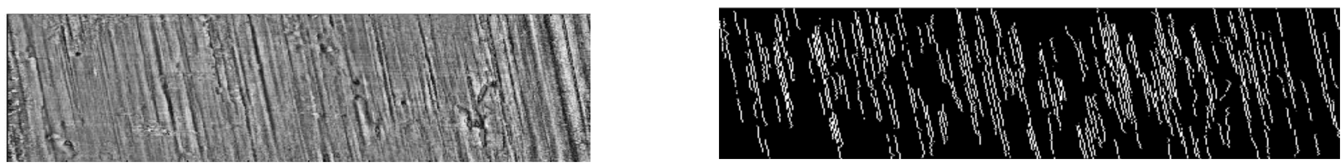


Applications of Edge Detection Results

- To predict the identifiability of fired bullets



NIST standard bullet: 7.49%



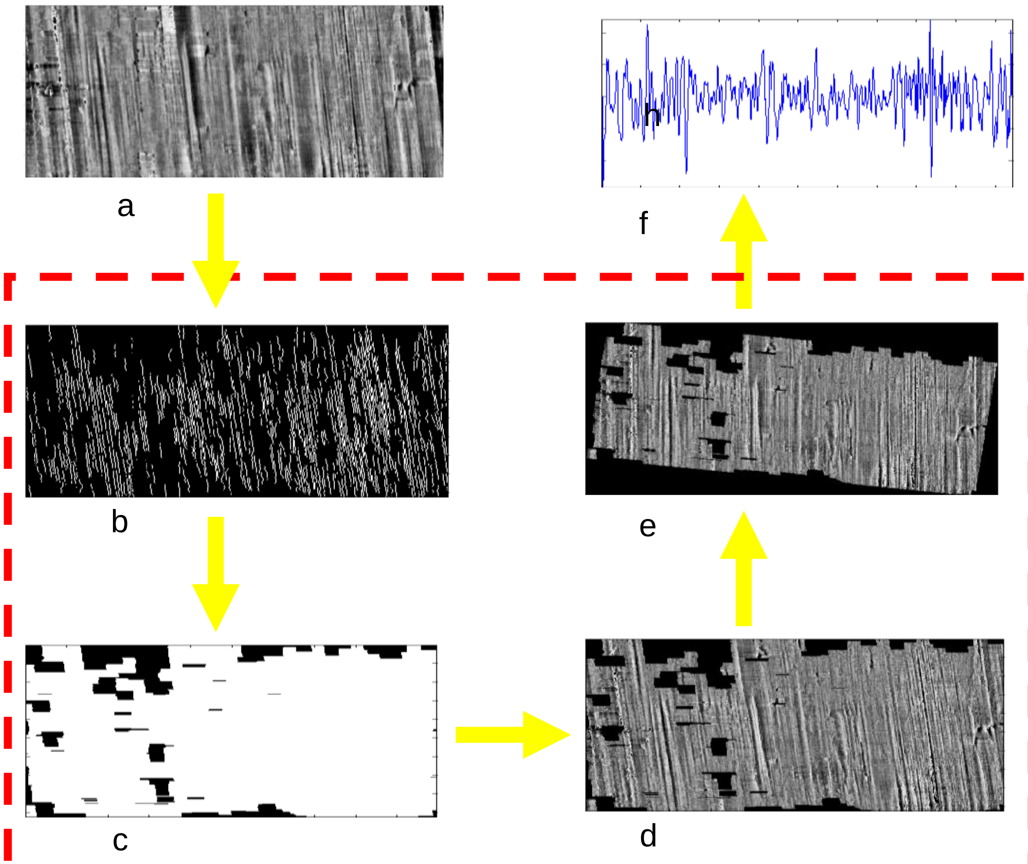
Striation density(Beretta): 5.83%

Striation density(Taurus): 2.27%

Striation density(Bryco): 0.16%

Applications of Edge Detection Results

- Removal of invalid correlation areas



Steps to remove invalid area for correlation

a. Flattened image after confocal image preprocessing

b. Striation edge image

c. Mask image

d. Image with invalid area removed

e. Upright image after rotation

f. Signature profile

Experiment

Sample: 20 known matching + 15 unknown bullets fired from 10 consecutively rifled barrels, each bullet with 6 Land Engraved Areas (LEA's)

Barrel brand: Ruger

Participants:

We are 551st, as of August, 2010

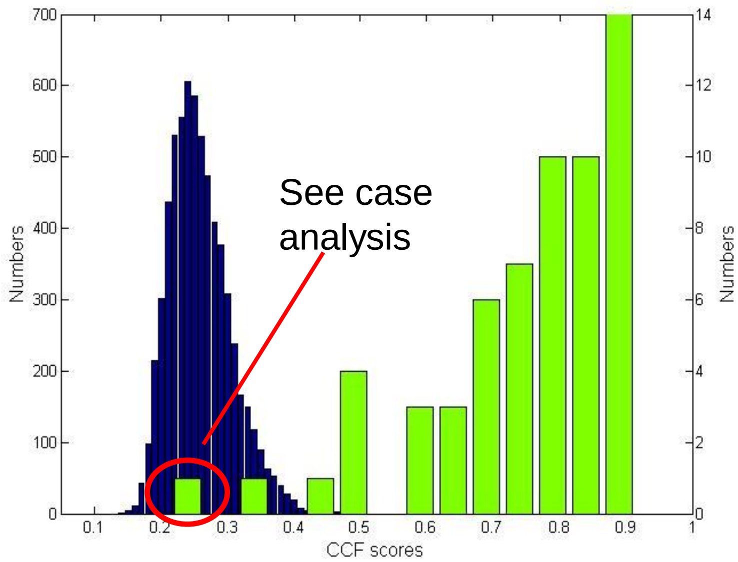
Reference:

J Hamby, D Brundage, *The identification of bullets fired from 10 consecutively rifled 9mm Ruger pistol barrels: a research project involving 507 participants from 20 countries,* AFTE Journal, 41(2):99-110

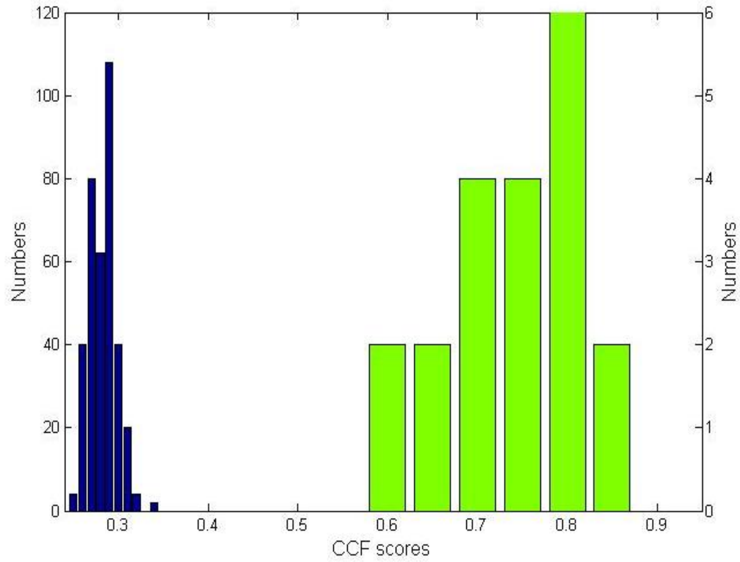
Comparison methods:

1. Cross correlation function (CCF)
2. Consecutive matching striae (CMS)

CCF Results



LEA comparison



Bullet comparison

Correlation values of all ten pairs of known-matching bullets scored highest on their correlation lists, yielding a correct identification rate 100 %.

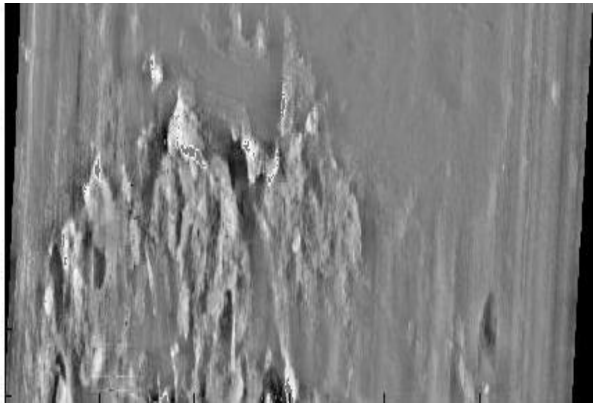
For 15 unknown bullets, all 30 pairs of matching bullets scored at the topmost position on their respective correlation lists. (Blind Test)

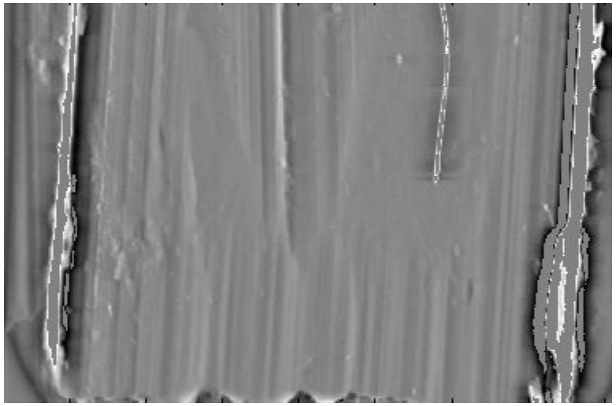
Case Analysis

There is only one comparison of matching LEA that did not have highest correlation score (22.85 %)

Confocal raw images; LEA to LEA comparison

Processing





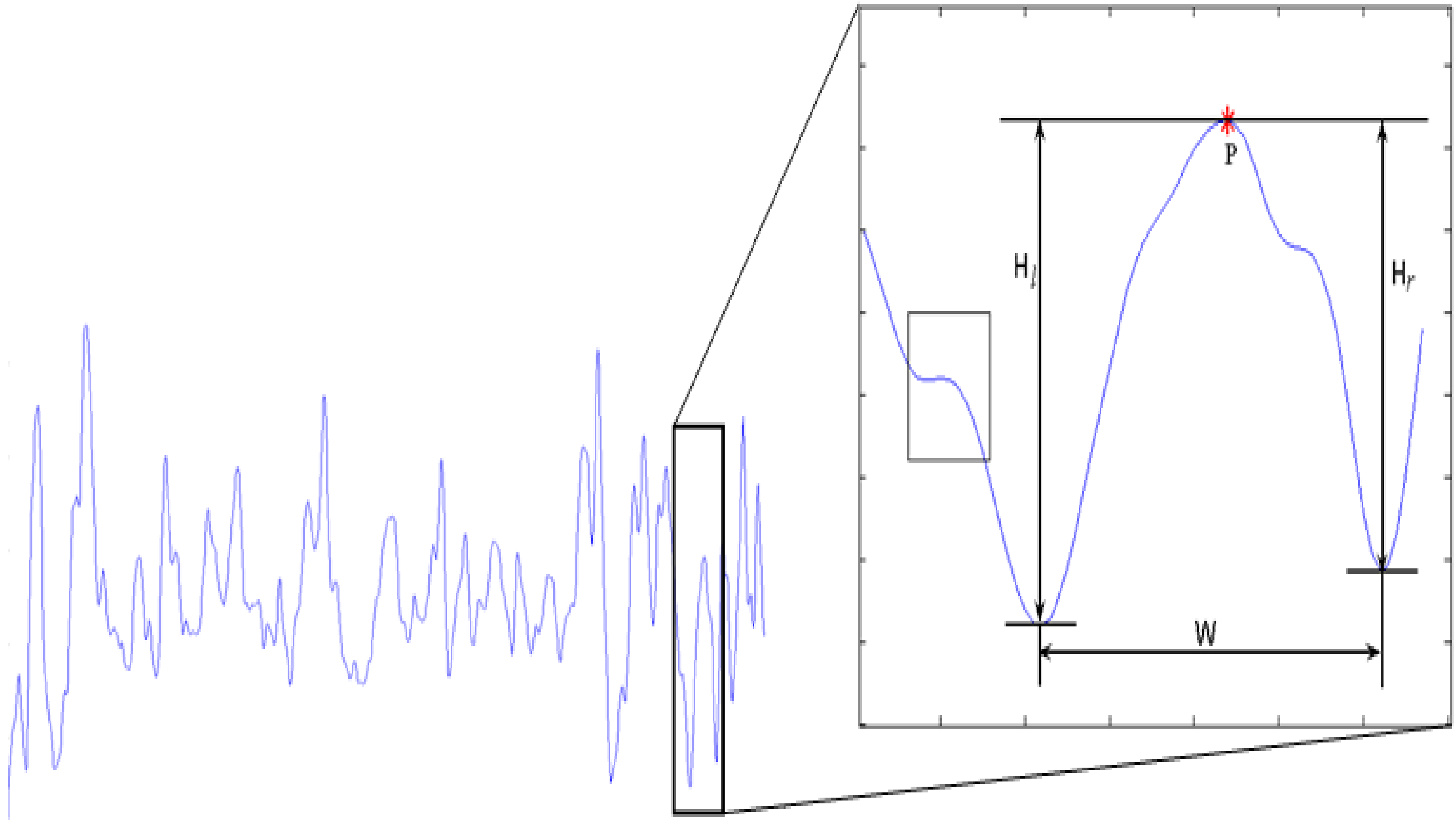
QCMS Conservative Numerical Criteria

Definition

- In three-dimensional toolmarks when at least two different groups of at least three consecutive matching striae appear in the same relative position, or one group of six consecutive matching striae are in agreement in an evidence toolmark compared to a test toolmark
- Originally, it is defined for comparison of optical images, especially under comparison microscope. Can it be extended to 3D topography data? Can we “unify” the two methods?

Model Based CMS Counting

Since the areas that do not contain valid striae marks are identified and removed for subsequent processing, generated feature profiles will be highly consistent with striae marks.



CMS Comparison Results (Known)

CMS	amount	proportion
0	3887	29.99%
1	8219	63.42%
2	782	6.03%
3	70	0.54%
4	2	0.02%
>=5	0	0%

CMS results for known non-matching LEA comparison (total 12960)

CMS	amount	proportion
<=2	16	26.67%
3	5	8.33%
4	6	10%
5	4	6.67%
Meet CMS criterion	29	48.33%

CMS results for known matching LEA comparisons (total 60)

Results of CMS Comparisons

- 10 pairs of known-matching bullets:
  all correctly identified

- 15 unknown bullets:
  29 of 30 bullet comparisons are correctly identified. No erroneous identifications.
  (Blind Test)

Significance

- Filled the gap between manual operation and automated systems.

- Increased the objectivity of firearm identification processing.

- Laid solid groundwork for future statistical analysis.

Other Important Points

1. 3D topographic measurement
2. Removal of invalid correlation area
3. Optimization of model parameters
4. Surface topography related to CMS
5. Unification of decades of empirical CMS testing to a mathematical based striated toolmark comparison

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Thank you for your attention!

Questions?

Robert.M.Thompson@nist.gov