Automatic identification of bullet signatures based on consecutive matching stria (CMS) criteria

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Presented by Robert M. Thompson

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this report in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

Ballistic Identification

Striation marks are produced by topographical features inside the barrel.

Traditional examination method: Comparison microscopy

Some early models for statistically valid and objective criterion for identification of toolmark stria

- Consecutive Matching Stria; Biasotti; 1959
- Surface featured to “Bar Code”; Blackwell & Framan; 1980
- Mathematical Models using rare features; Uchiyama; 1980
- Model for Automated Identification; Uchiyama; 1988

National Research Council, NAS Reports

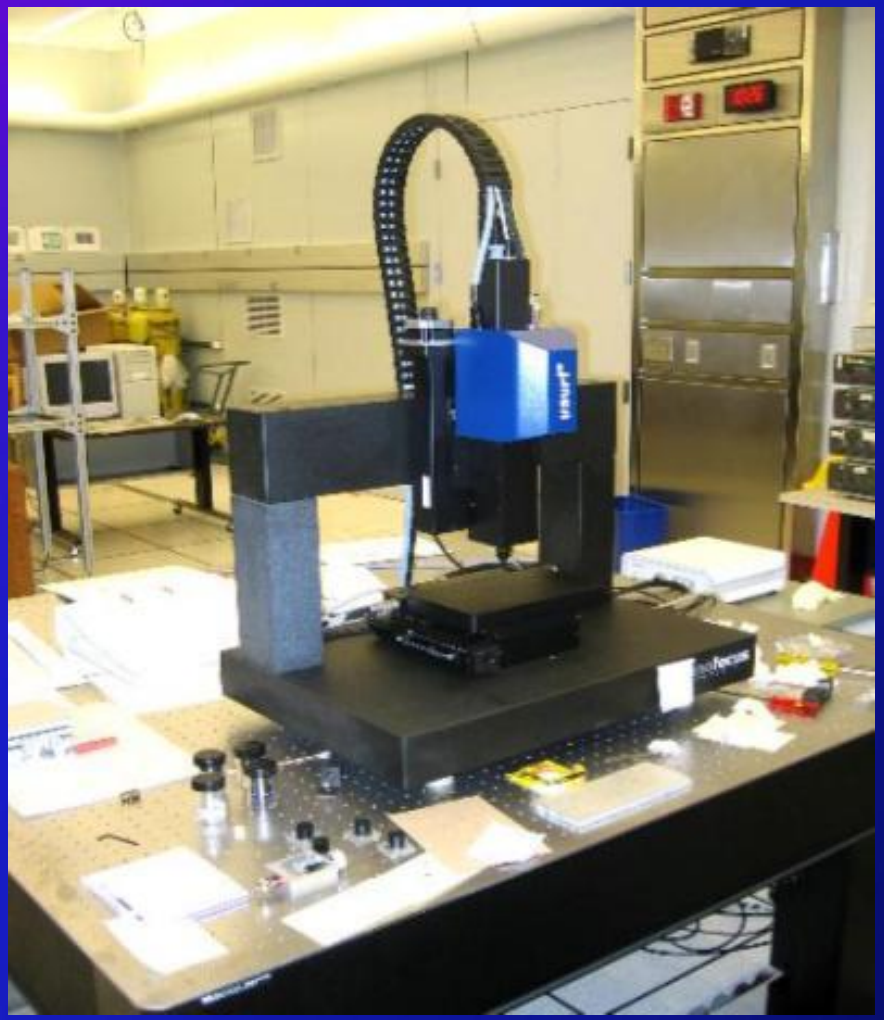
"Ballistic Imaging" 2008

"The validity of the fundamental assumptions of uniqueness and reproducibility of firearms-related tool marks has not yet been fully demonstrated."

"Strengthening Forensic Science in the United States: A Path Forward" 2009

"The fact is that many forensic tests—such as those used to infer the source of tool marks or bite marks—have never been exposed to stringent scientific scrutiny."

NIST 3D measurement system

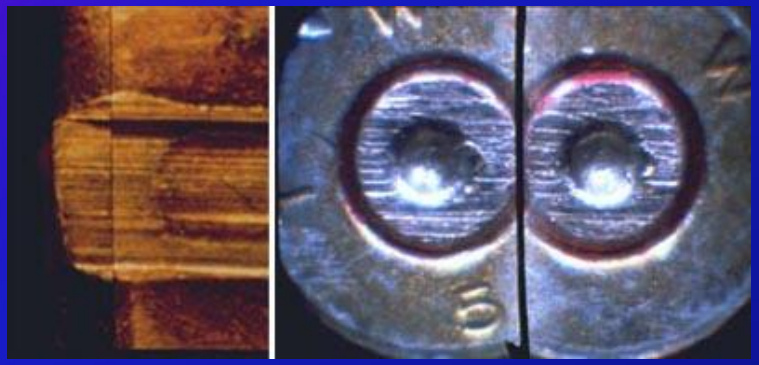


Nanofocus Nipkow disk confocal microscope

Specifications for 20x and 50x lens:

- Measurement field: 800/320 µm
- X/Y-Resolution: 1.5/0.6 µm.
- Z-Resolution: 20/10 nm.

Evaluation of the similarity

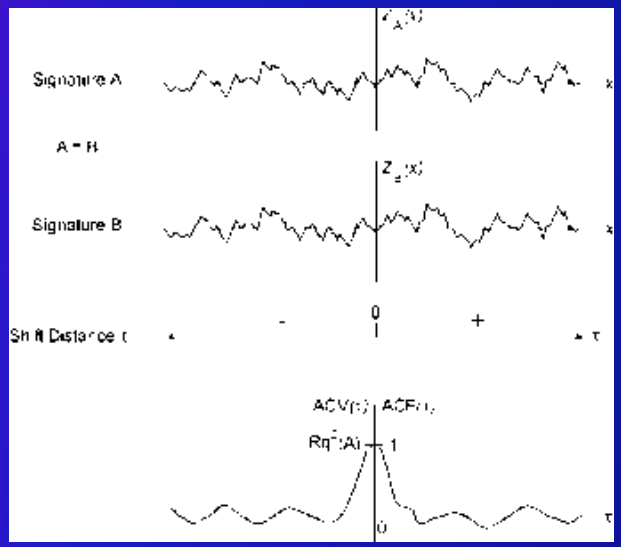


(Wisconsin Department of Justice, http://www.doj.state.wi.us/dles/crimelabs/Firearms.asp)

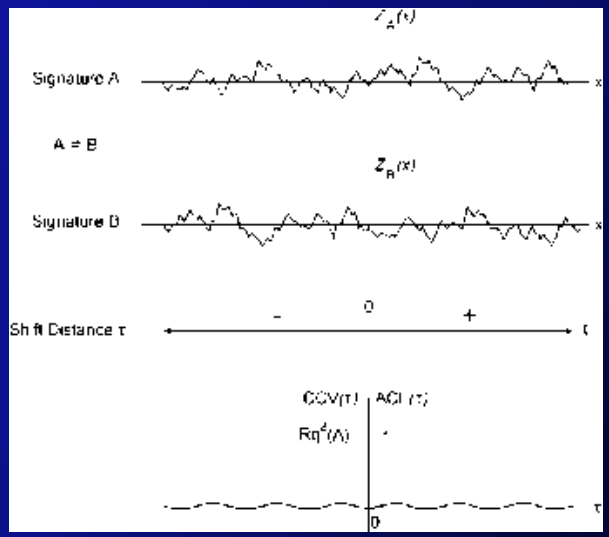
Metric:

Cross-correlation function (CCF)

$$\mathrm{CCF}(r, l_i, \tau) = \frac{\sum_k ((r(k) - \bar{r}) * (l_i(k+\tau) - \bar{l_i}))}{\sqrt{\sum_k (r(k) - \bar{r})^2} \sqrt{\sum_k (l_i(k+\tau) - \bar{l_i})^2}}$$



A=B



A≠B

Application of CCF in NIST standard bullet comparison; mathematical comparison of replicas

NIST SRM 2460 Standard Bullets

Land 1-3

Land 4-6

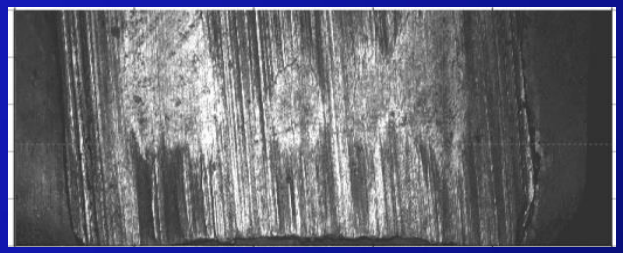
Golden Images for SRM Bullets

An example of CCF calculation result

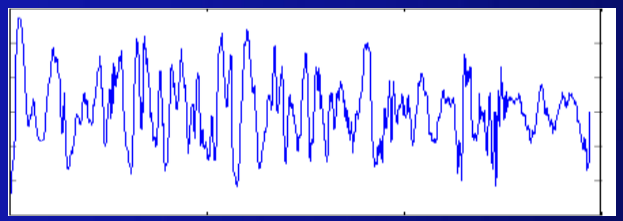
Application example for a fired bullet

Bullet signature

Data acquisition

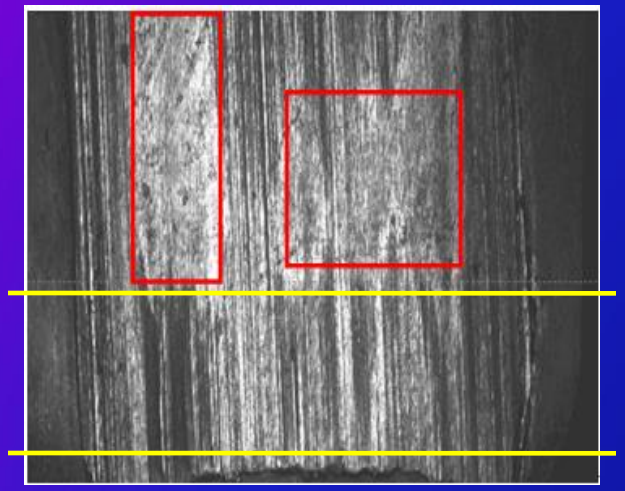


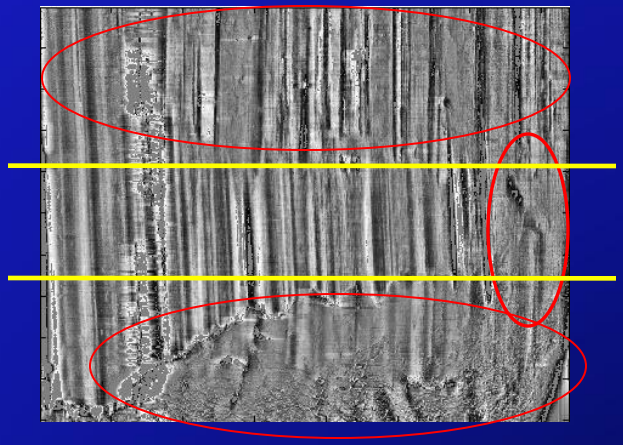
Processing



correlation

Selection of valid correlation areas





Bullets land impression images may include areas contain useless or wrong striation information

- Question: Can valid striated areas be intelligently distinguished from other invalid areas?

How do we improve on selection?

– Application of 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…

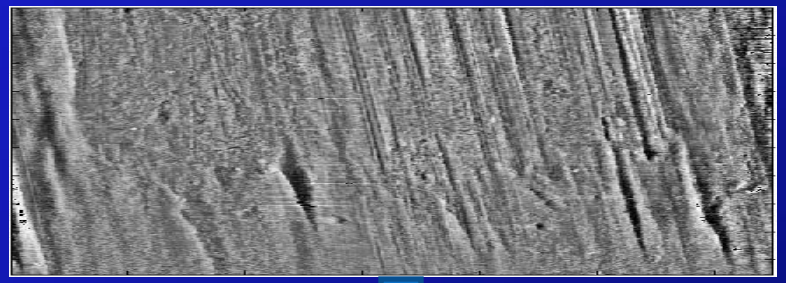
Example of applying Canny edge detector

- Canny detector - An optimal edge detection algorithm
  Properties: good detection, good location, minimum response

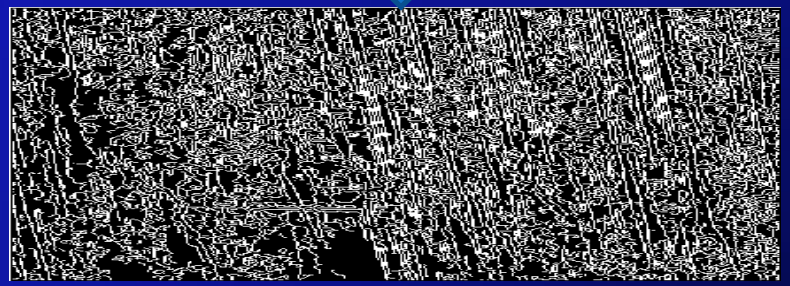
Ref:
J Canny. A Computational Approach To Edge Detection, IEEE Trans. Pattern Analysis and Machine Intelligence, 8: 679-714, 1986.

Apply Canny edge detector on bullet land impression image

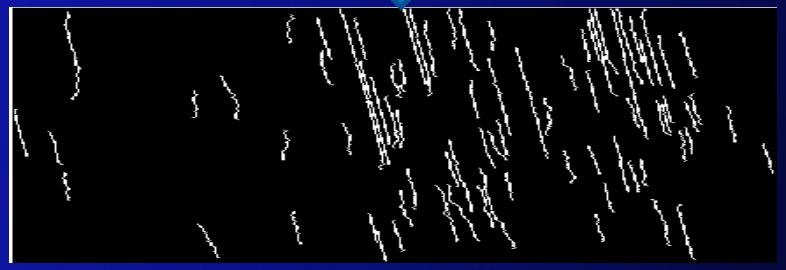
Topography Image after preprocessing



Canny edge detection result

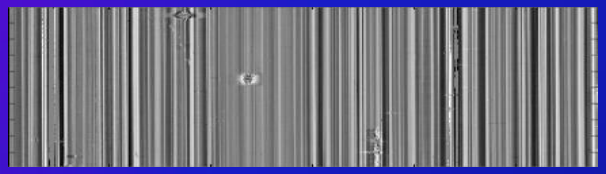
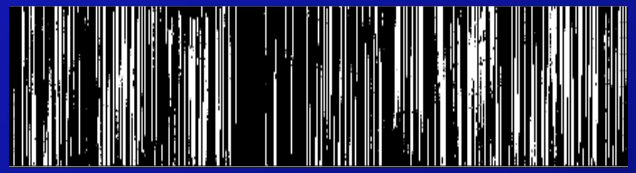


Striation edge image

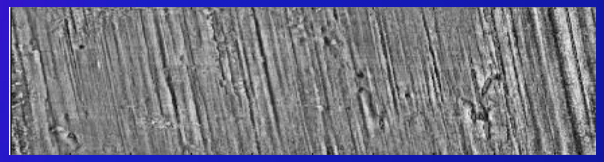
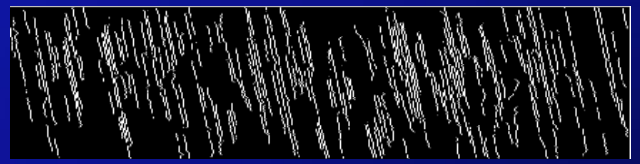


Applications of edge detection results (1)

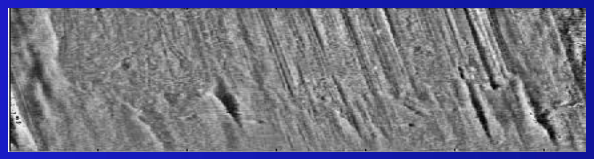
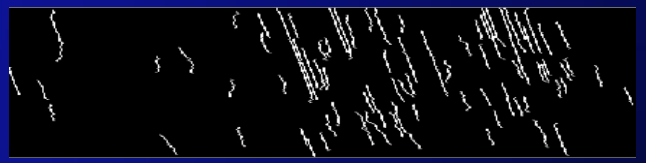
– to predict the identifiability of fired bullets

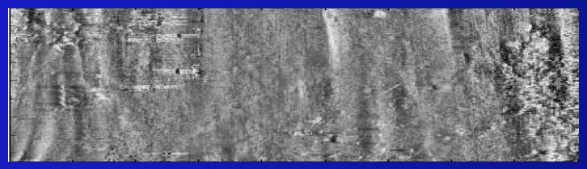
NIST standard bullet: 7.49%

Striation density(Beretta): 5.83%

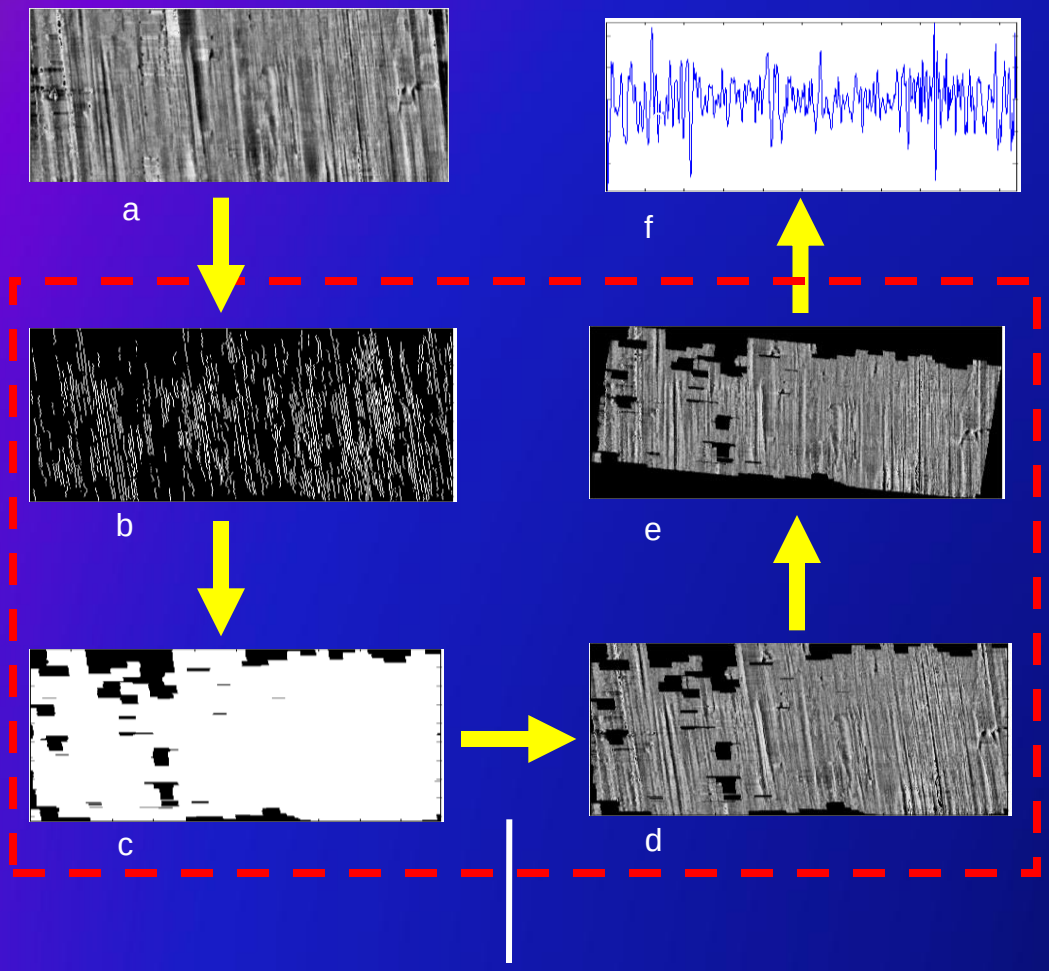
Striation density(Taurus): 2.27%




Striation density(Bryco): 0.16%

Applications of edge detection results (2)

– removal of invalid correlation area



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

Steps to remove invalid area for correlation

Experiment

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

Comparison methods:

1. Cross correlation function (CCF)

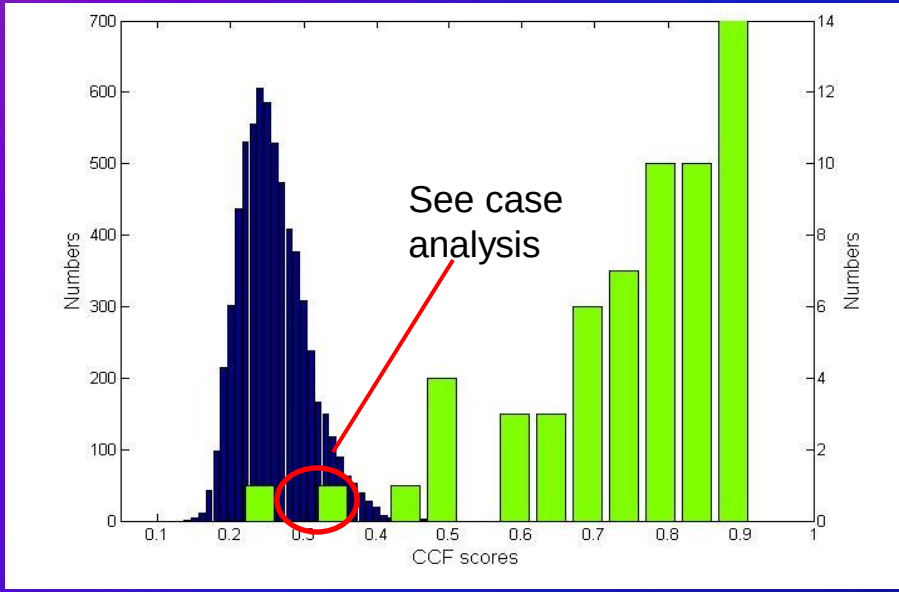
2. Consecutive matching stria (CMS)

Participants: We are 551st, as of August, 2010

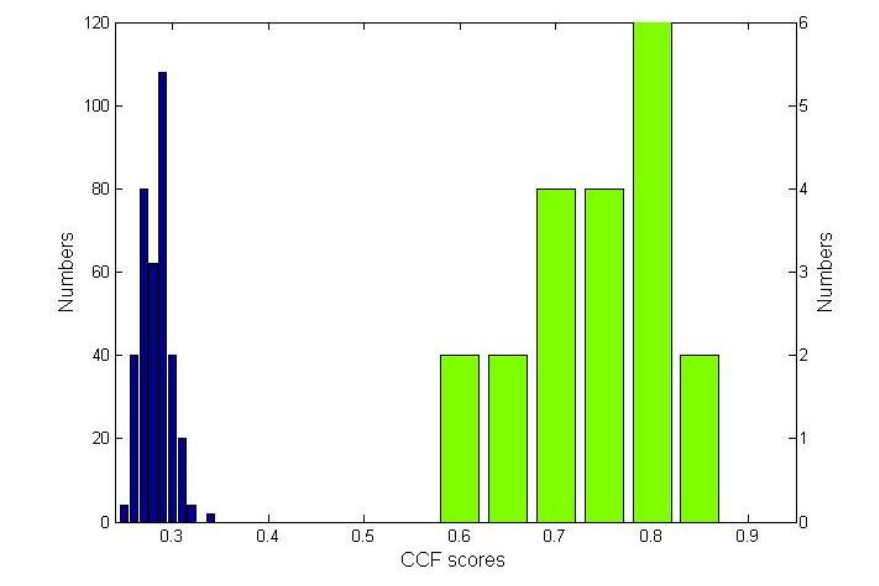
Reference:

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

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 %.

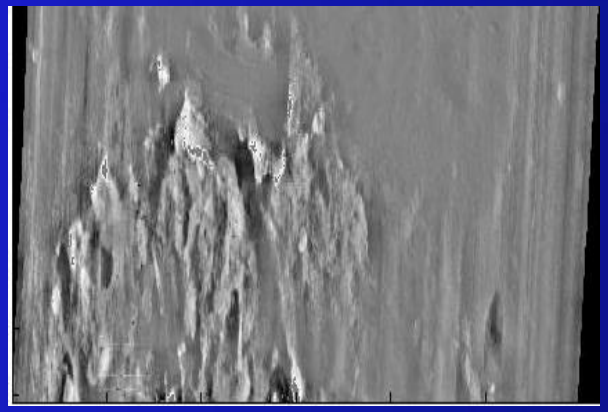
For 15 unknown bullets, all 30 pairs of matching bullets scored at the topmost position on their respective correlation lists. (Blind Test)

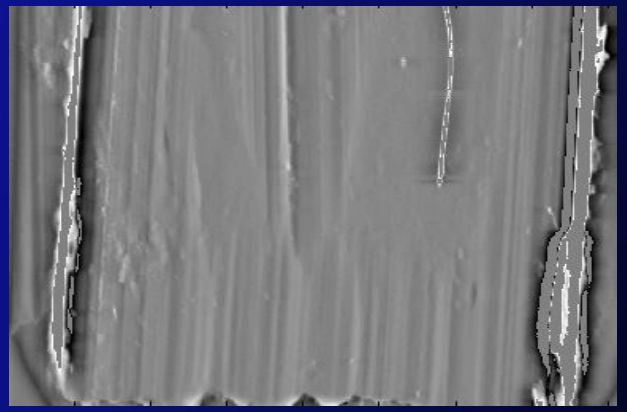
Case analysis

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

Confocal raw images; LEA to LEA comparison

Processing





CMS conservative numerical criteria:

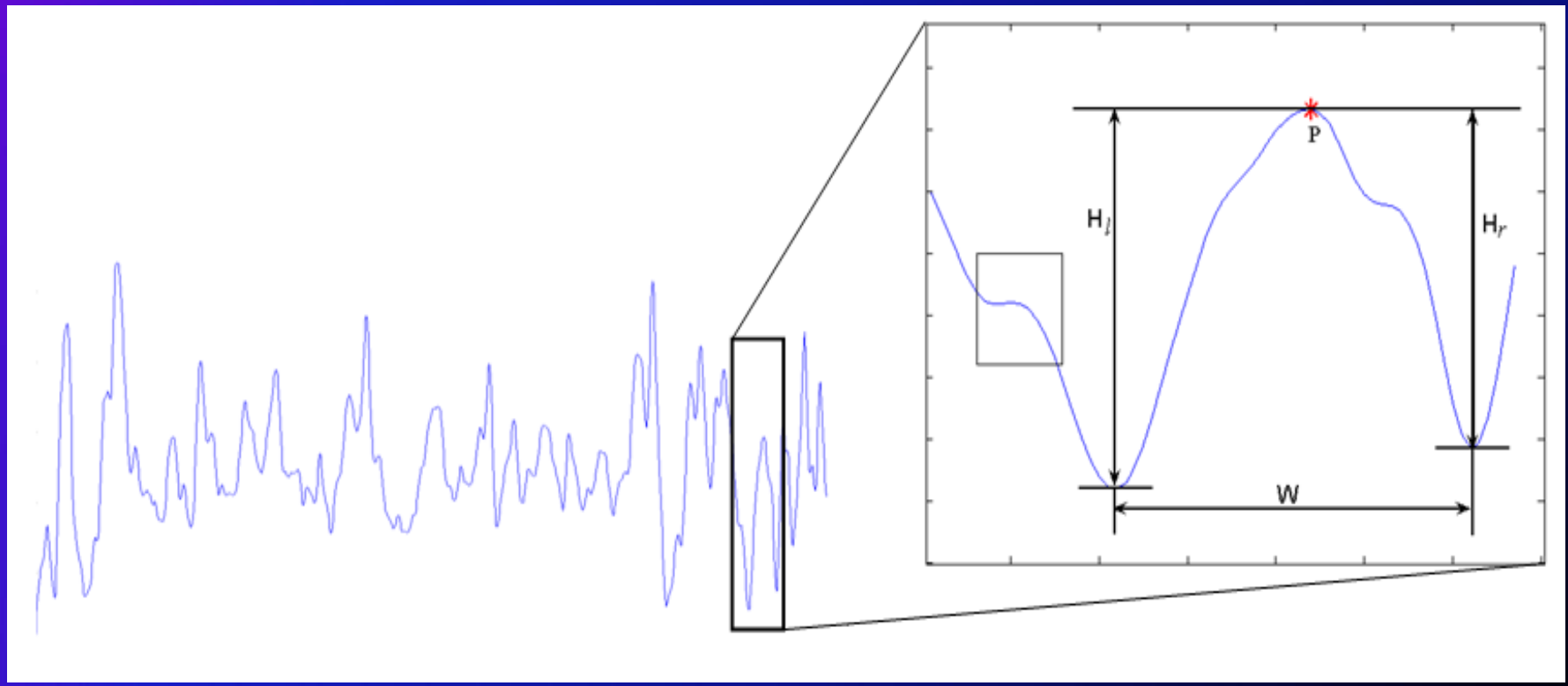
Definition

In three-dimensional tool marks when at least two different groups of at least three consecutive matching stria appear in the same relative position, or one group of six consecutive matching stria are in agreement in an evidence tool mark compared to a test tool mark

Originally, the CMS criteria is employed in comparisons of optical images using comparison microscopy. 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 stria marks are identified and removed for subsequent processing, the generated feature profiles will be highly consistent with stria marks.



CMS comparison results of known matching bullets

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

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 matching LEA comparisons (of tally 60)

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

Results

10 pairs of known-matching bullets – all correctly identified

15 unknown bullets – each has 2 counterparts in known-matching group bullets.

29 of 30 bullet comparisons are correctly identified.

Significance Outcomes

- Filled the gap between manual operation and automated systems.

- Increased the objectivity of firearm identification processing.

- Has produced solid groundwork for future statistical analysis.

Questions?