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Proposed Congruent Matching Profile Segments (CMPS) Method for Bullet Signature Correlations

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Outline:

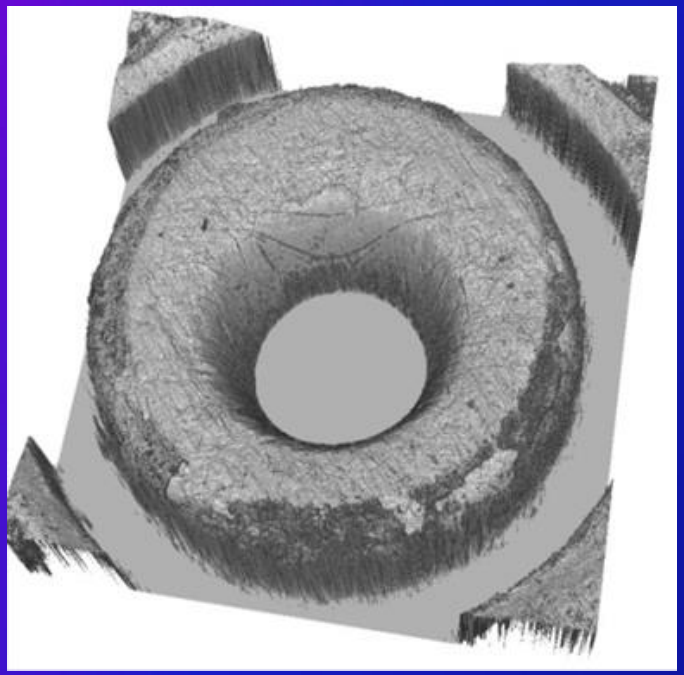
1. Congruent Matching Cells (CMC)-- Theory and Application
2. What is New in Congruent Matching?
3. Congruent Matching Profile Segments (CMPS) for Bullet Signature Correlations
4. Initial Test and Result
5. Summary and Future Work

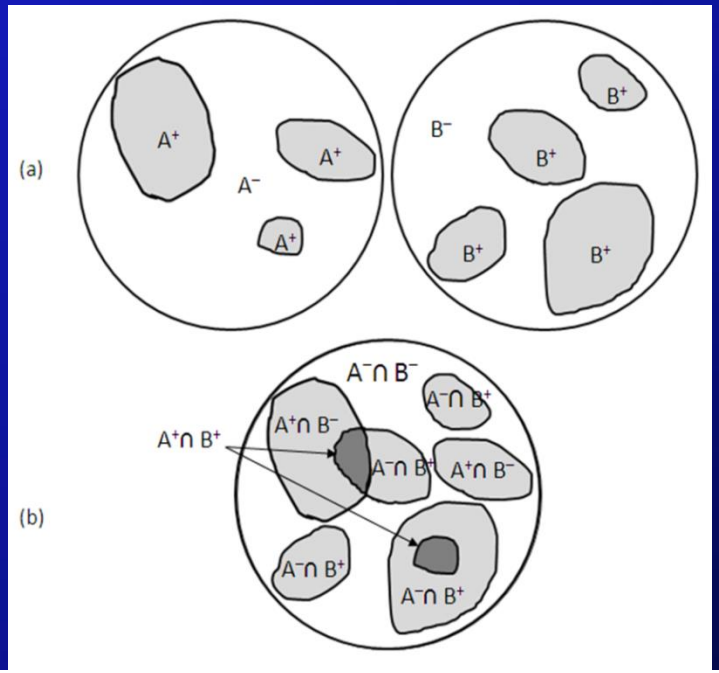
What is Congruent Matching--Theory

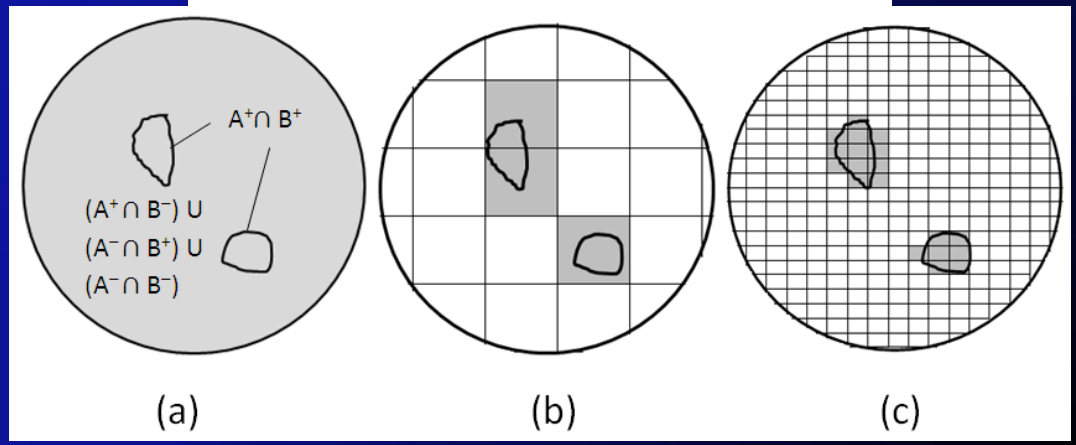
Congruent matching is based on the principle of discretization:

- Divide the entire image into small regions, and use region correlations instead of the whole image.
- Derive multiple identification parameters to quantify:
  1) Topography similarity of correlated regions,
  2) Pattern congruency of the distribution of regions between the reference and the evidence image.
- Congruent matching includes ballistics identification methods using cells (CMC), cross-sections (CMX), topography features (CMF) and profile segments (CMPS).

Congruent matching cells (CMC) method for breech face image correlations



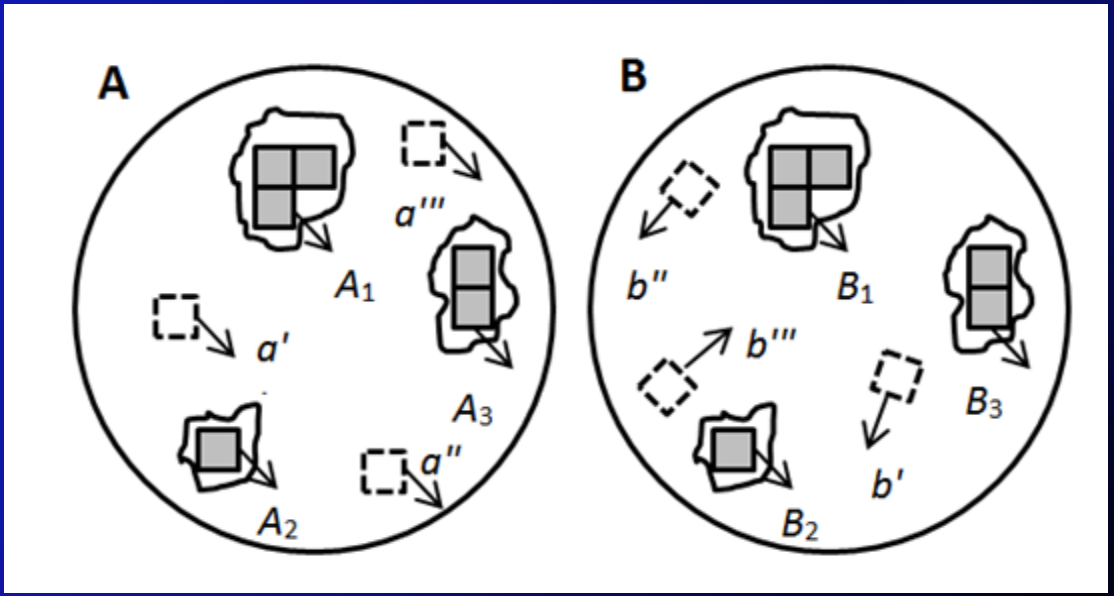




The "Congruent Matching Cells (CMC)" are identified by four parameters:

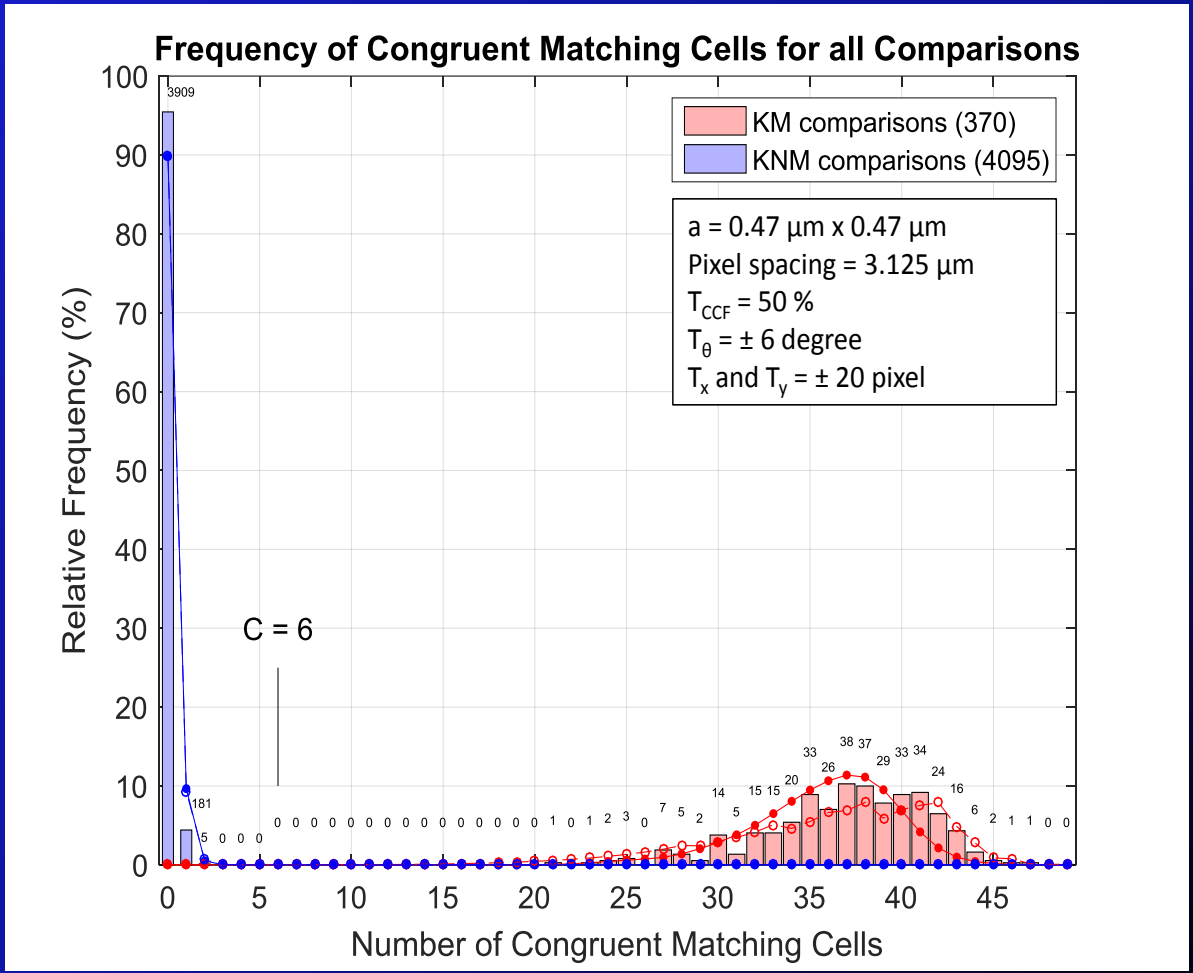
1) Topography similarity of correlated cell pairs is quantified by CCF_{max} with threshold T_{CCF};

2) Pattern congruency of the cell distribution is quantified by registration angle θ and x-y positions with thresholds T_{θ}, T_x and T_y.



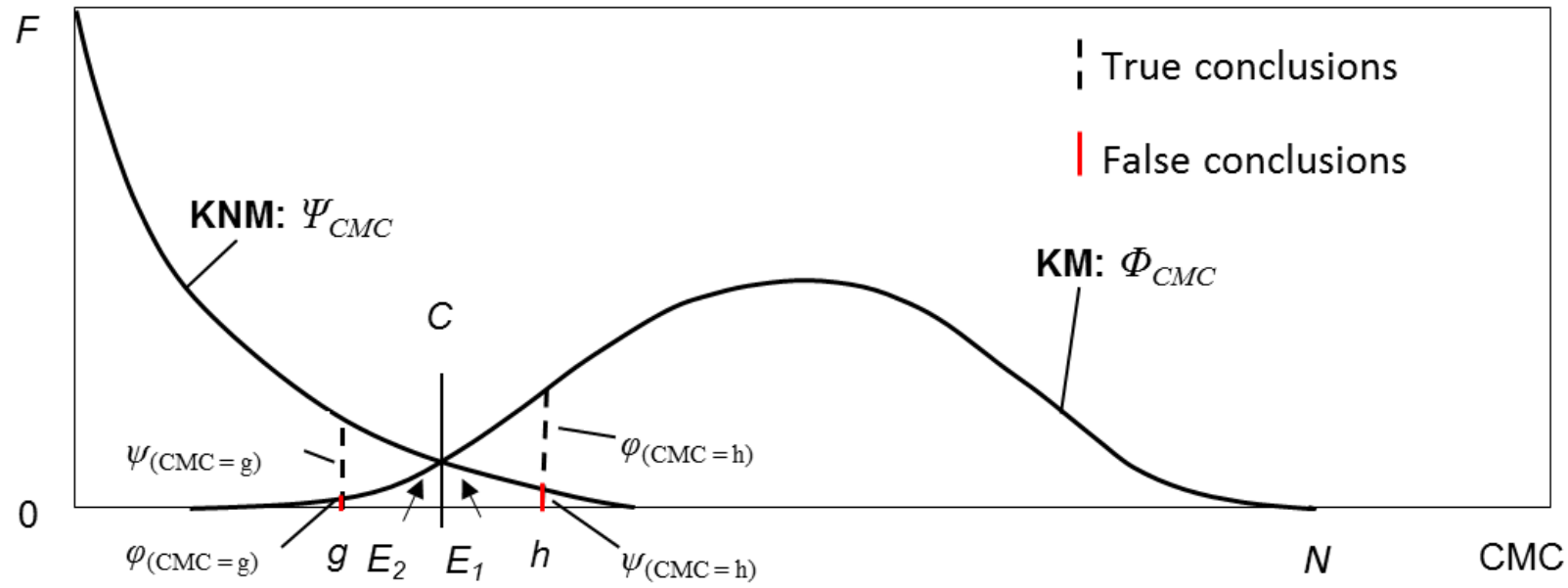
Initial validation tests for breech face images using CMC method showed excellent results

- 95 cartridge cases fired from guns with 10 consecutively manufactured pistol slides.
- A total of 4465 image pairs for 370 KM and 4095 KNM correlations.
- No false positive & false negative errors. *C* = 6 works well.
- Complete initial error rate report.



(By J. A. Soons)

Developed an error rate procedure and completed initial error rate reports



$$E_1 = \sum_{CMC=C}^{CMC=N} e_{1(CMC)} = e_{1(CMC=C)} + e_{1\,(CMC=C+1)} + \cdots + e_{1(CMC=N)}$$

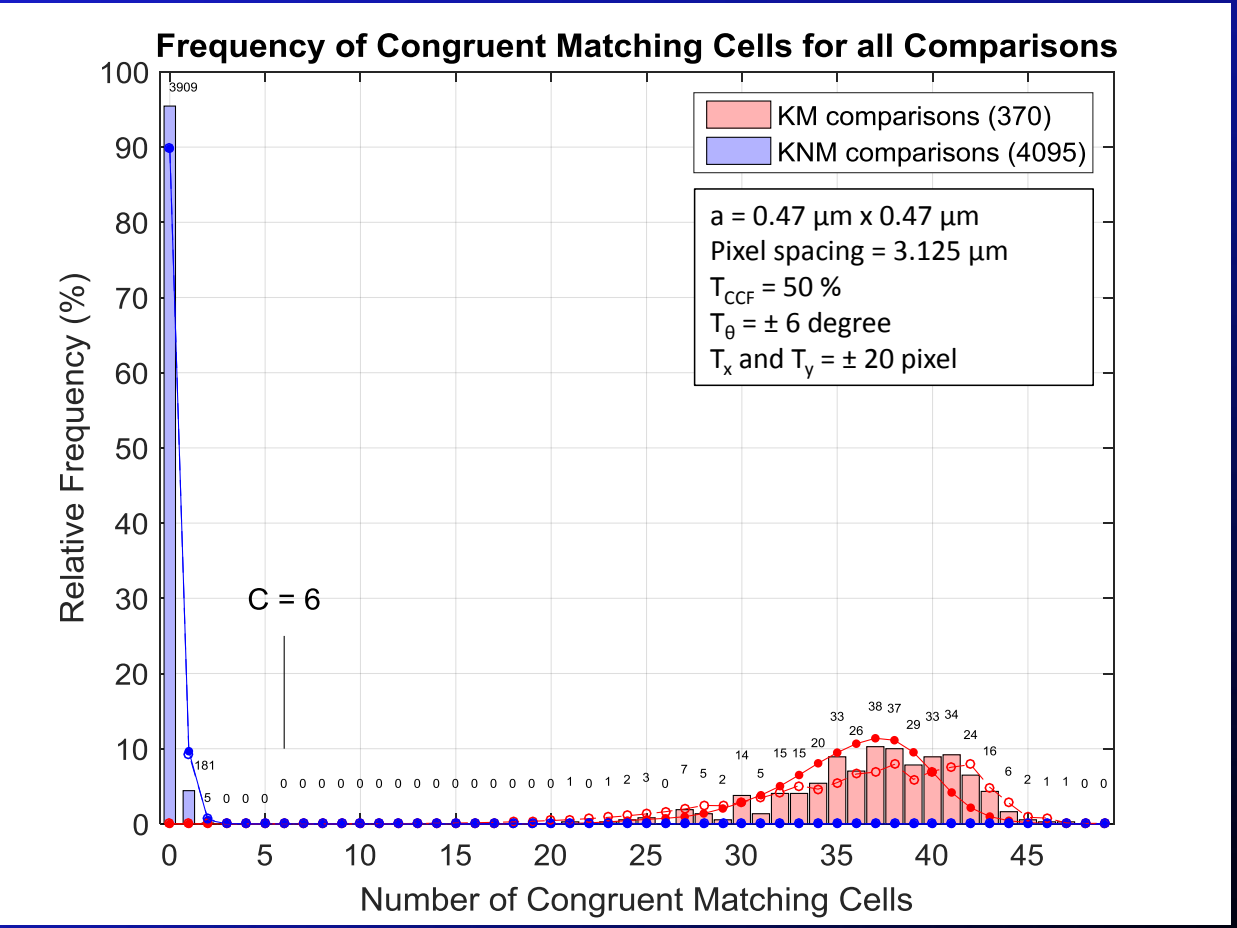
$$= \psi_{(CMC=C)} + \psi_{(CMC=C+1)} + \cdots + \psi_{(CMC=N)}$$

$$= 1 - (\psi_{(CMC=0)} + \psi_{(CMC=1)} + \cdots + \psi_{(CMC=C-1)}). \qquad (1)$$

$$\psi_{(CMC=h)} = C_N^h \cdot (P_1)^h \cdot (1-P_1)^{N-h} \qquad (2)$$

Estimation of false positive and false negative error rate E_1 and E_2

- For 4095 KNM image pairs, CMC = 0 to 2, $E_1 = 3.7 \times 10^{-8}$
- For 370 KM image pairs, CMC = 21 to 47, $E_2 = 1.8 \times 10^{-5}$.



Why Congruent Matching--Application

- Provide an objective, robust, accurate and conclusive method for image-related forensic evidence identification.
- Provide an error rate and likelihood ratio (LR) procedure to support ballistics identifications in forensic science.
- Support US manufacturer to develop the next generation ballistics identification systems with conclusive id/ex. results and error rate report.
- Support OSAC, NIBIN, ATF and FBI in ballistics and toolmark identifications.

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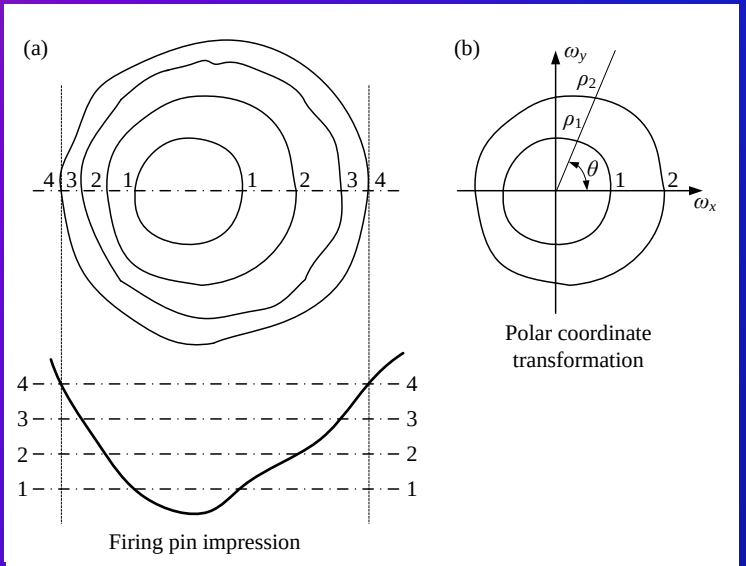
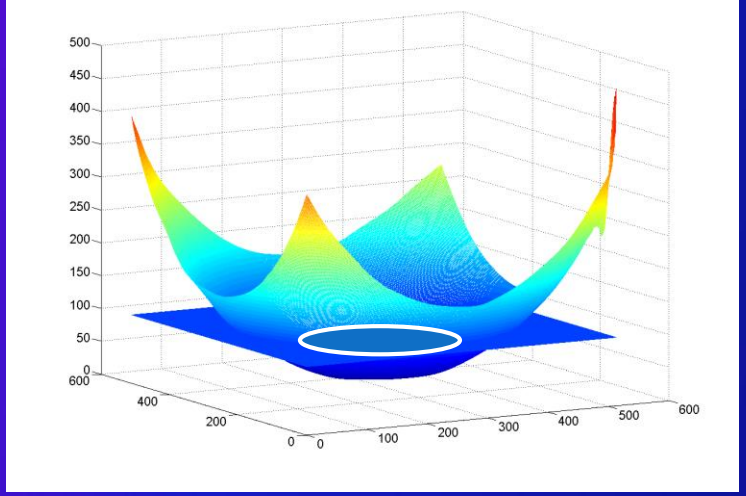
Congruent matching at NIST-- What is new?

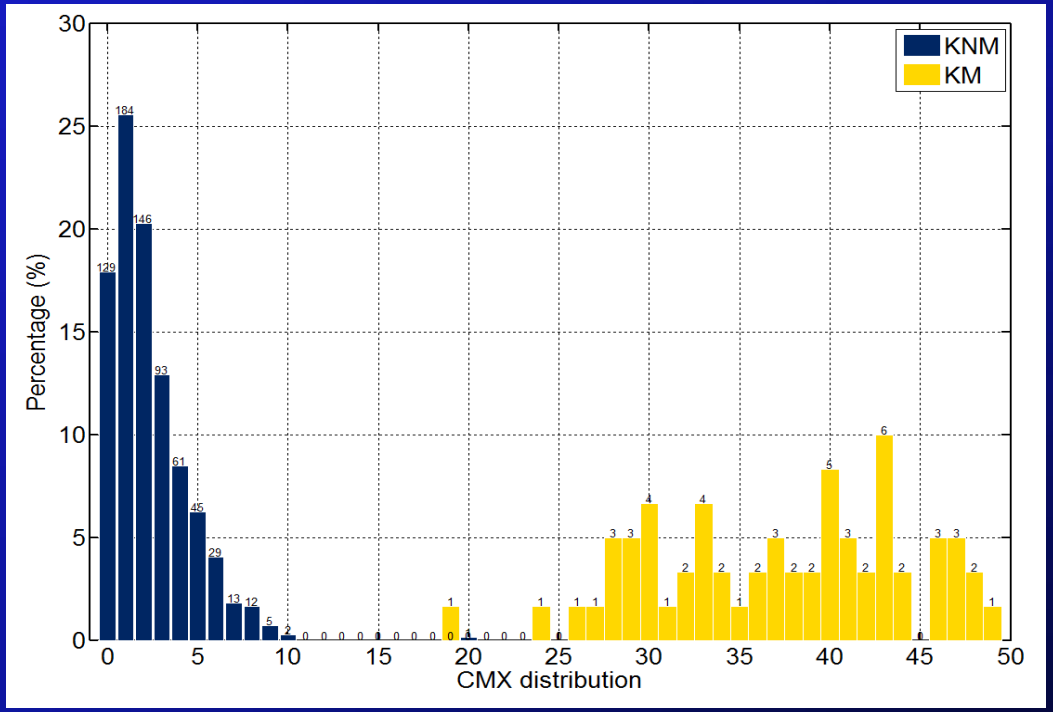
Besides the Congruent Matching Cells (CMC) method, three new methods have been recently developed at NIST for ballistics identifications:

- Congruent matching cross-sections (CMX) method for firing pin image correlations;
- Congruent matching features (CMF) method for complex topography image correlations;
- Congruent matching profile segments (CMPS) for bullet signature correlations.

Congruent matching cross-sections (CMX) method for firing pin correlations

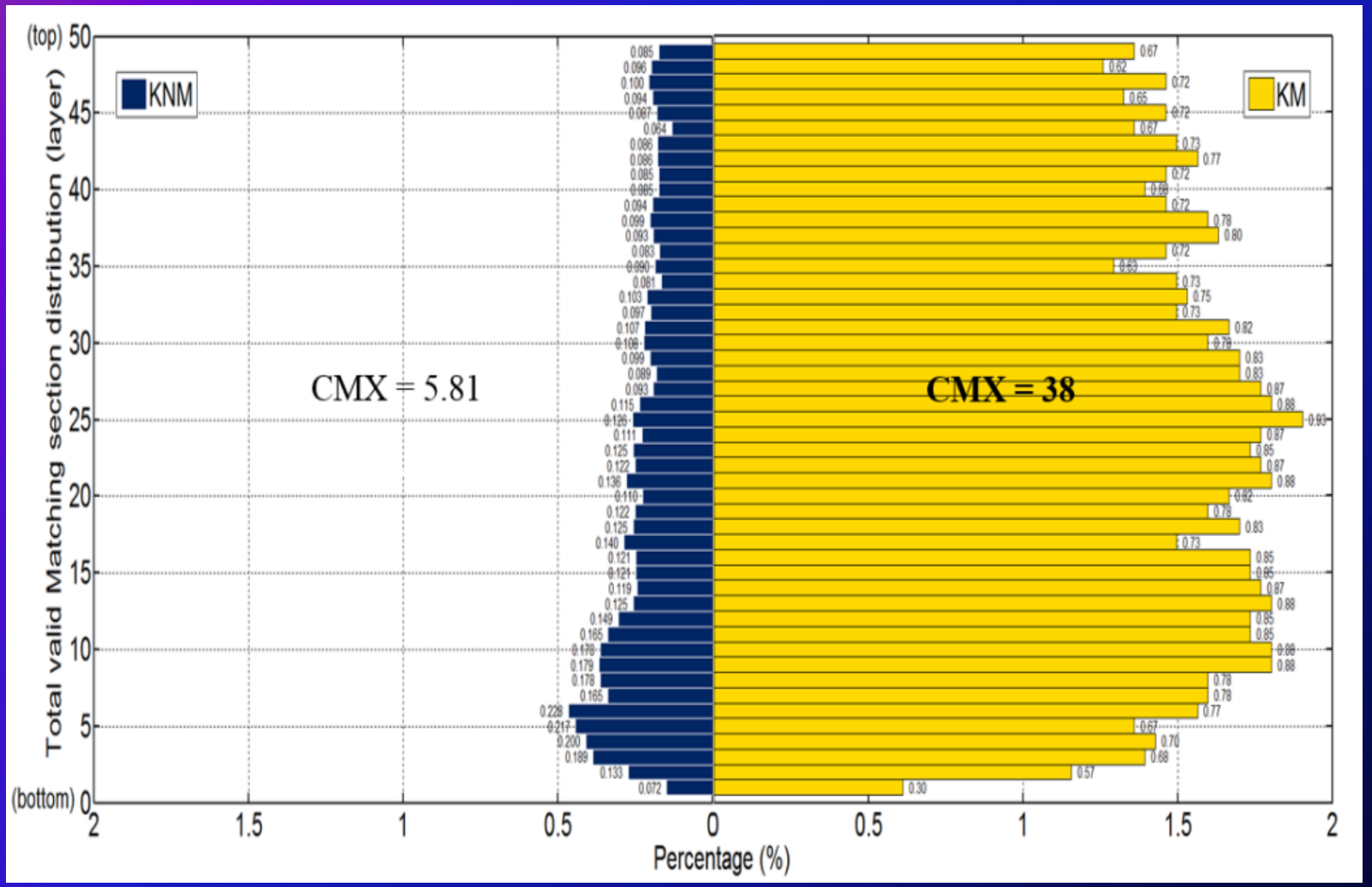






Correlations of 40 firing pin impressions with 720 KNM and 60 KM images pairs show excellent correlation results

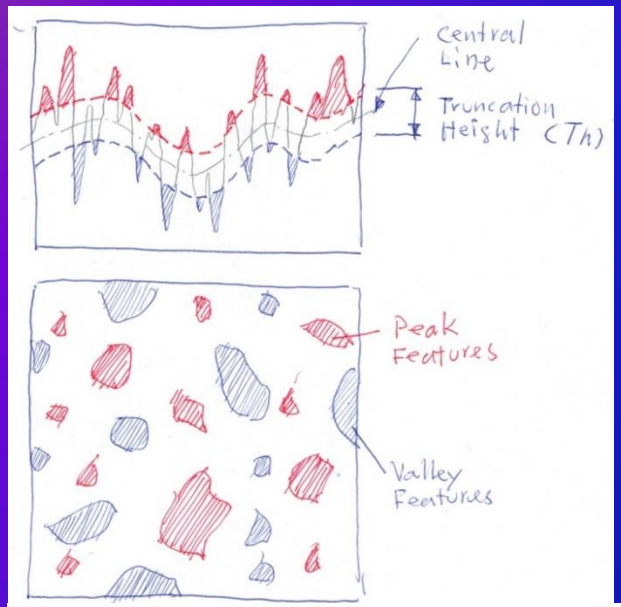
(By H. Zhang)



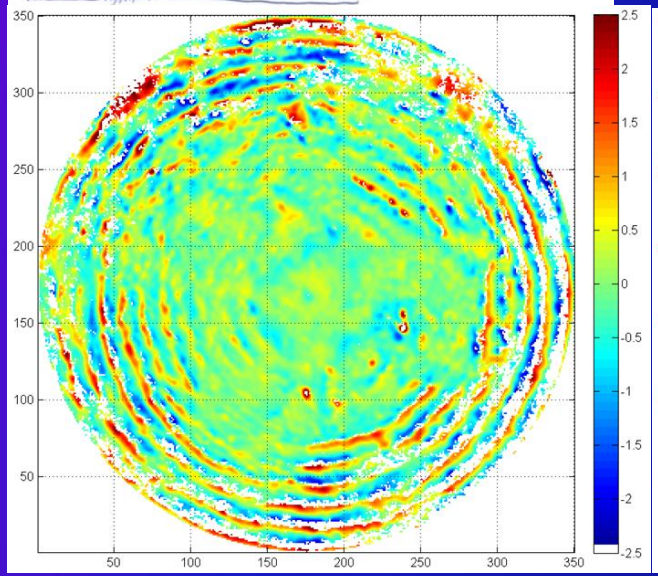
The distribution of CMX scores by horizontal cross-sections. The average CMX score for 60 KM image pairs is 38, and for 720 KNM image pairs CMX = 5.81.

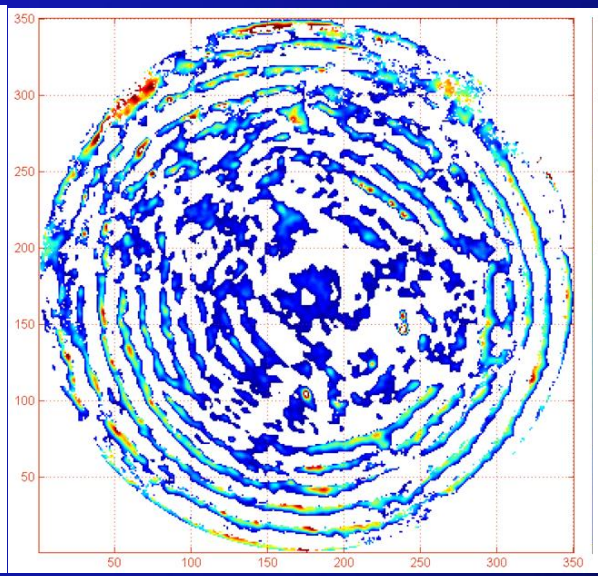
(Presented at 2016 AAFS, to be published in *FSI*)

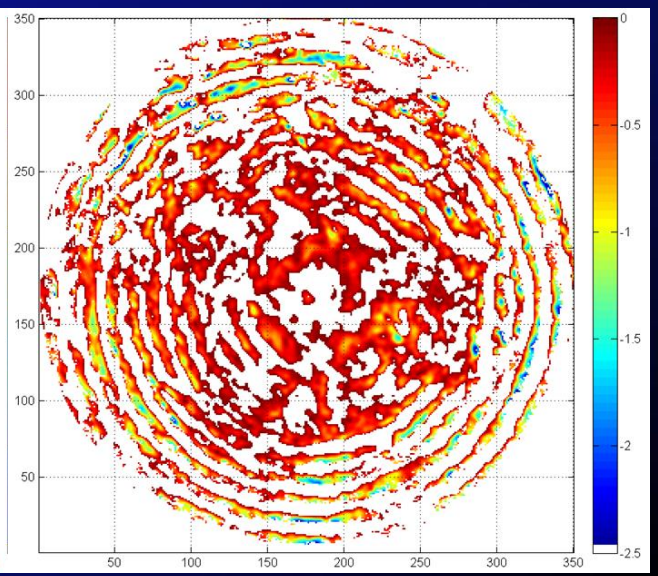
Congruent match features (CMF) method for complex shaped image correlations



CMF method for firing pin correlations of circular-shaped signatures with strong sub-class characteristics. 12 casings fired from 3 guns including 18 KM and 48 KNM image pairs, all are correctly identified by CMC method.







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The proposed CMPS method is based on the principle of discretization:

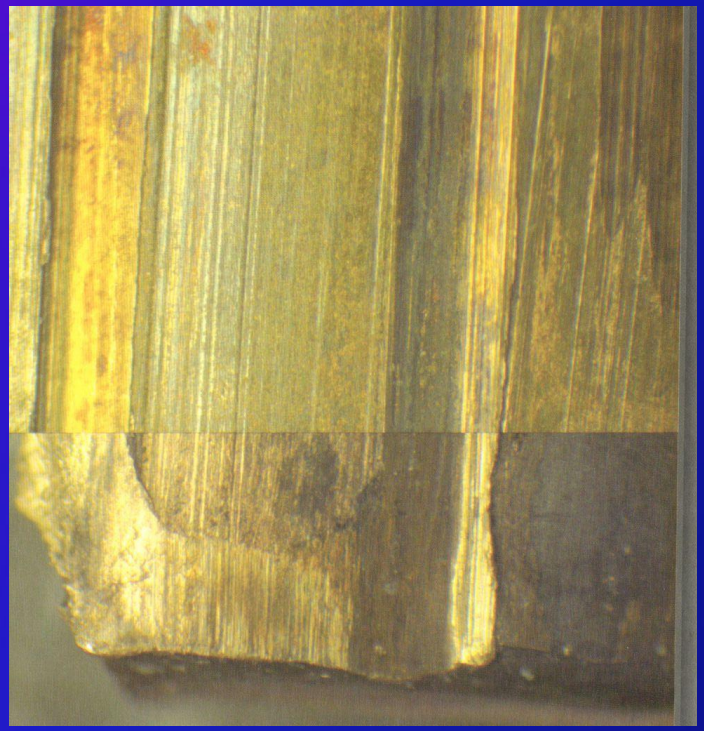
- CMPS divides entire bullet profile image into profile segments, and use segment correlations instead of the whole bullet profile correlation.

- CMPS uses multiple parameters (with thresholds) for quantify topography similarity and pattern congruency. A CMPS pair is determined by:

  1) High profile similarity—CCF_{max} (T_{CCF});
  2) Same twist angle—θ (T_{θ}).
  3) Congruent pattern—defined by the same profile segment location i.e. the same position in x (T_x) with the same land index #y.

Twist angle θ :

The primary bullet signatures are with the same twist angle of the gun barrel, say 5°. Some 0° and other twist angles may present that may (or may not) be useful for identification.



(By R.M. Thompson)

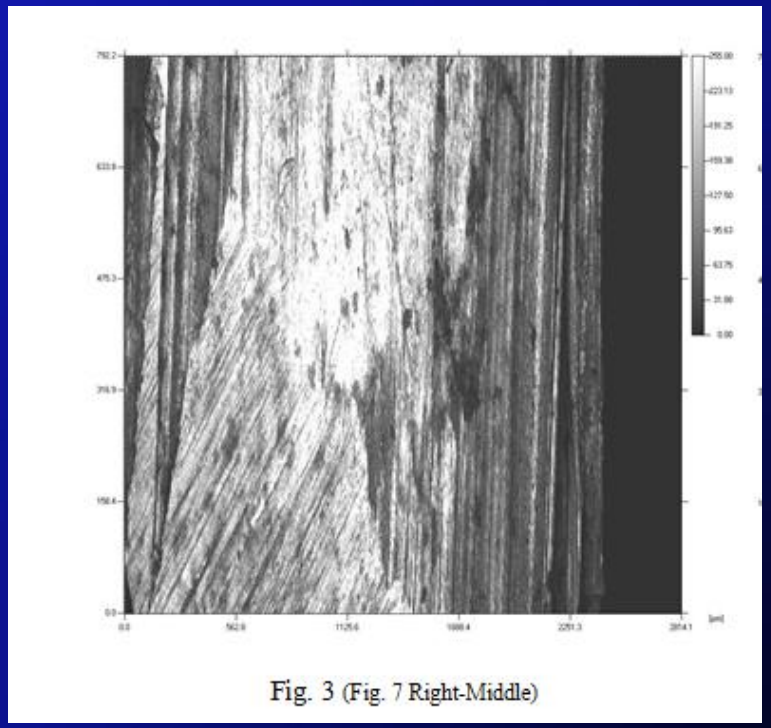
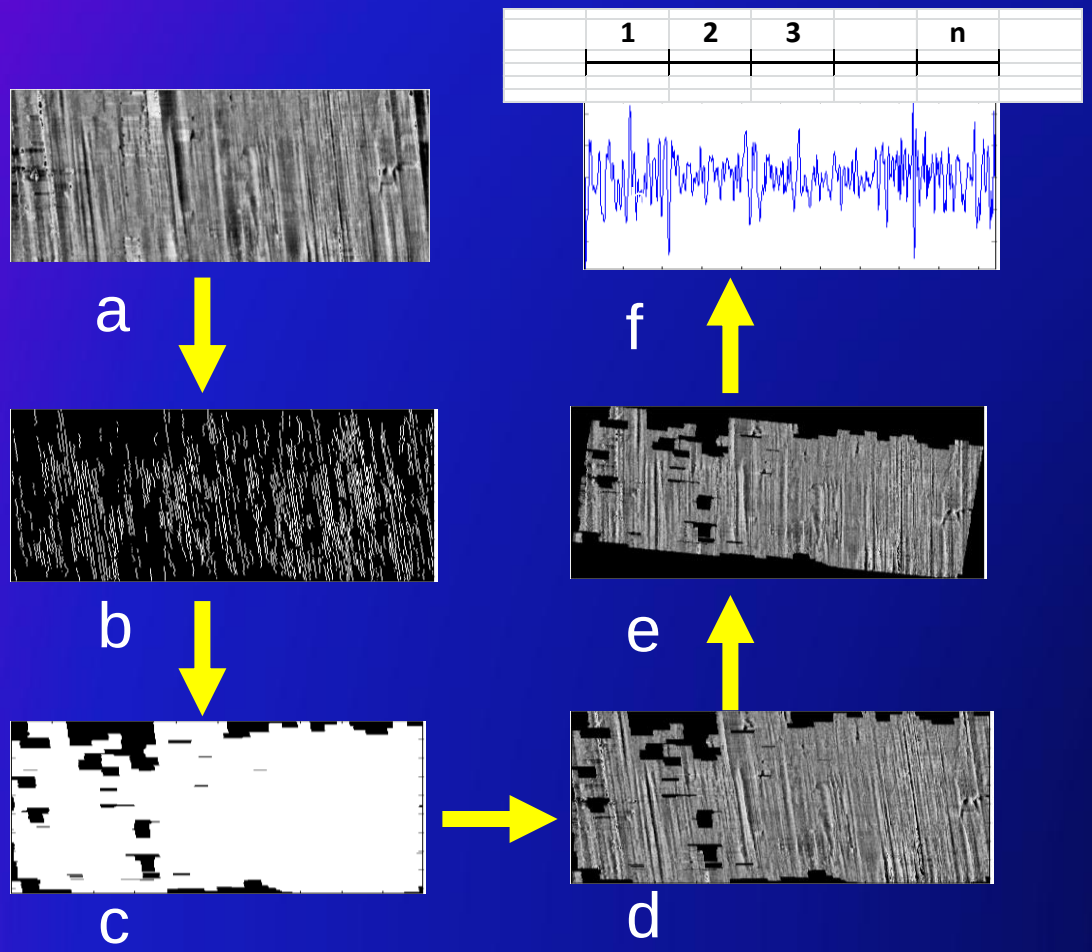


Fig. 3 (Fig. 7 Right-Middle)

(By H. Zhang)

How to determine twist angle θ?

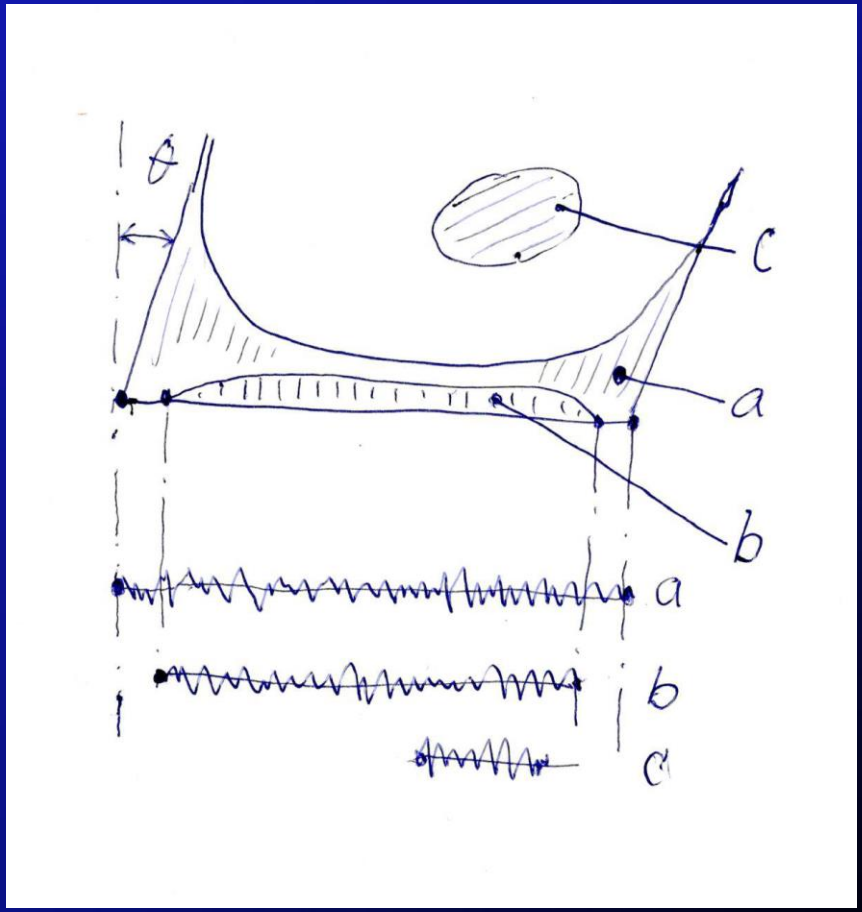
From a 3D confocal image to a set of compressed profile segments with twist angle θ



a. Flattened image after confocal image preprocessing
b. Striation edge detection
c. Mask image
d. Image with invalid area removed
e. Test twist angle θ
f. The compressed signature profiles are divided into profile segments for correlation.

Three groups of twist angles of bullet signatures:

- Group a:
  with the same twist angle of the barrel land,
  say 5° (primary part);
- Group b:
  with 0° twist angle;
- Group c:
  with other twist angles.

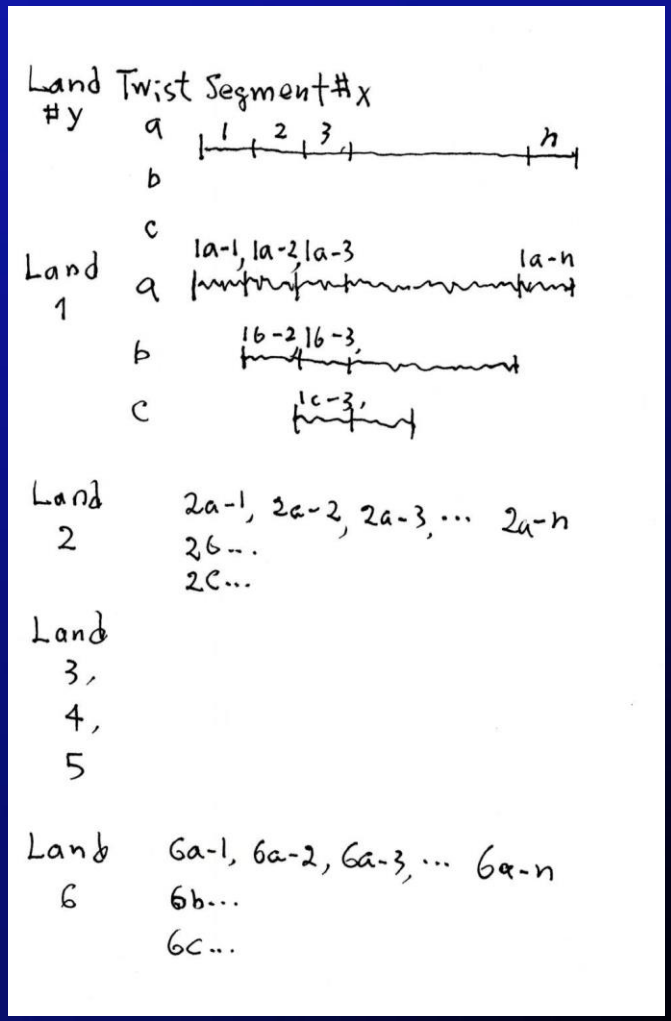


Congruent pattern for bullet signatures

Determined by segment location #x (T_x) and land index #y; and presented by #y + a(or b, c) + #x.

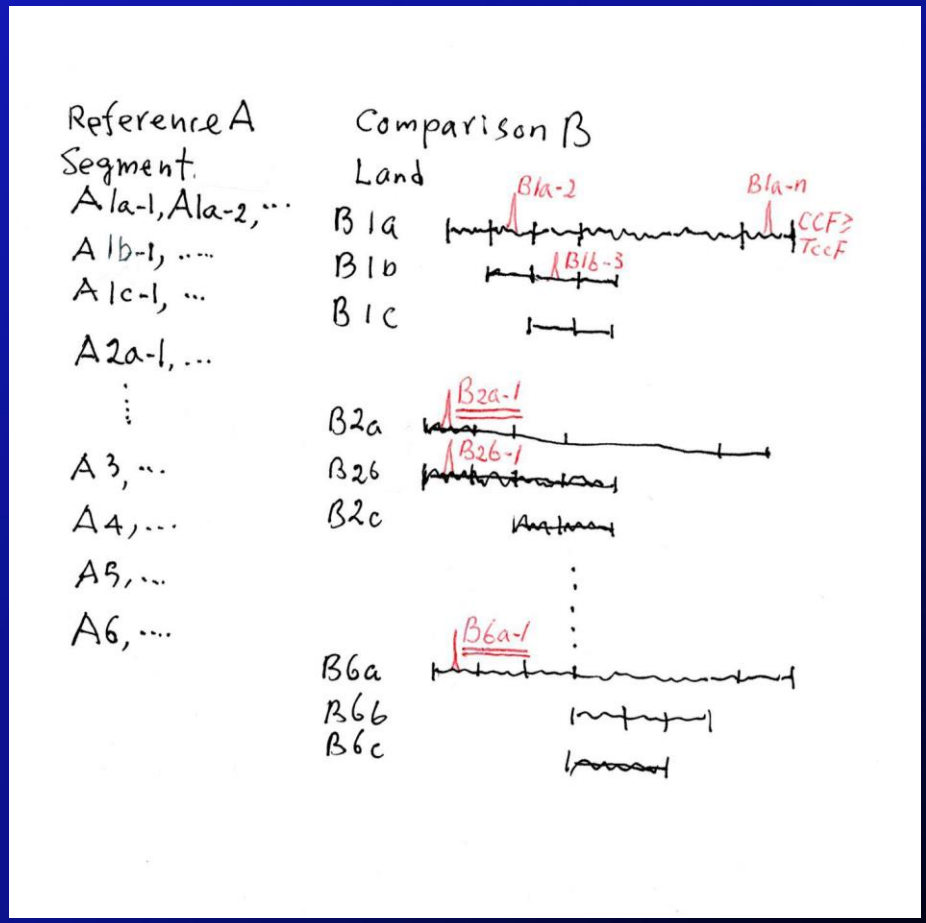
A bullet signature can bee divided Into segments for correlation:

- Land #1:
  Profile 1a-1, 1a-2…
  Profile 1b-1, 1b-2…
  Profile 1c-1, 1c-2…
- Land #2:
  Profile 2a-1, 2a-2…
  Profile 2b-1, 2b-2…
  Profile 2c-1, 2c-2…
- Land #3… to Land 6.

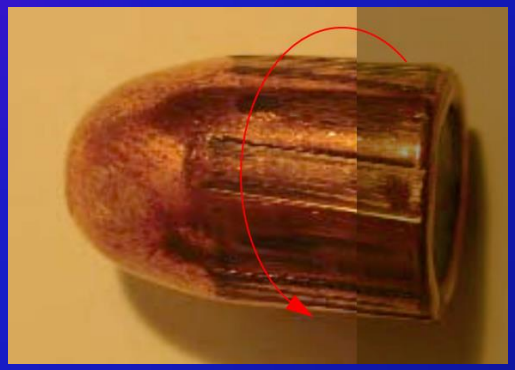


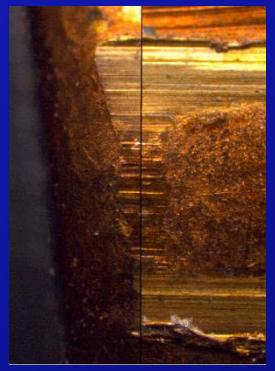
Bullet correlation using CMPS method

- Use reference bullet A's profile A1a-1 scan all profiles of the correlated bullet B;
- Obtain all profile segments on B with $CCF_{max} \geq T_{CCF}$;
- Remove profile segments with different phase angle θ and segment #x;
- The remaining two segments B2a-1 and B6a-1 are possible CMPS, to be used for test of orientation of land index #y.



Cross checking of orientation for the maximum phase position #y





	B_1	B_2	B_3	B_4	B_5	B_6
A_1	0	0	2	0	1	0
A_2	3	0	0	11	0	1
A_3	0	0	3	0	8	0
A_4	0	1	1	0	0	18
A_5	0	0	0	1	0	2
A_6	1	9	0	0	3	0

Method optimization--Developing optimum correlation procedures

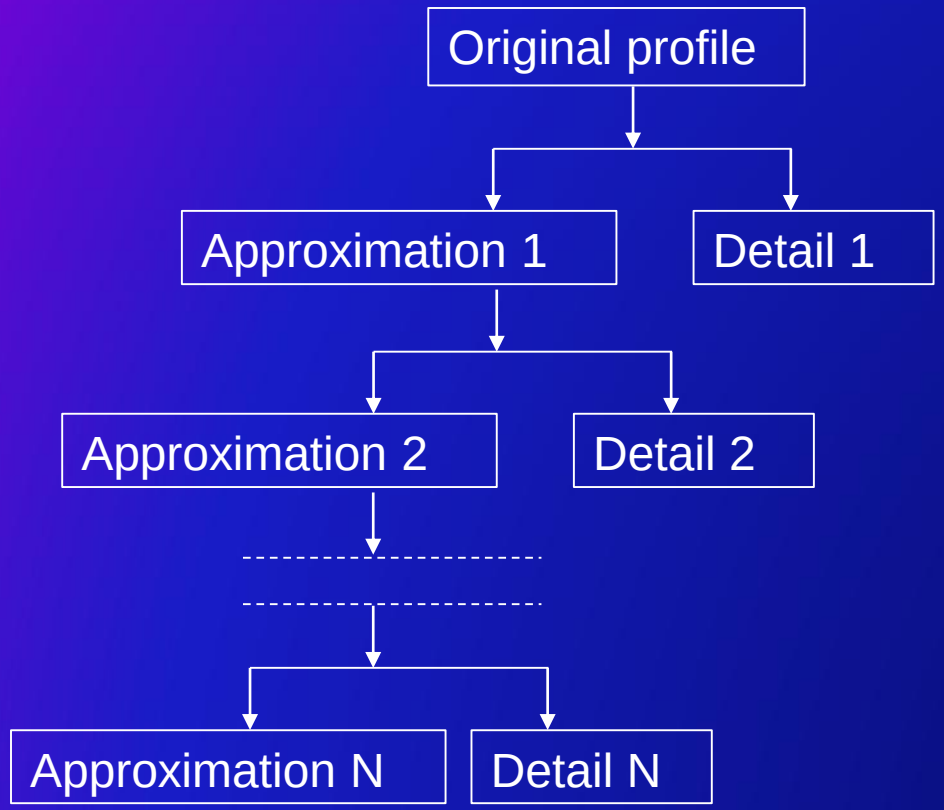
Goal:

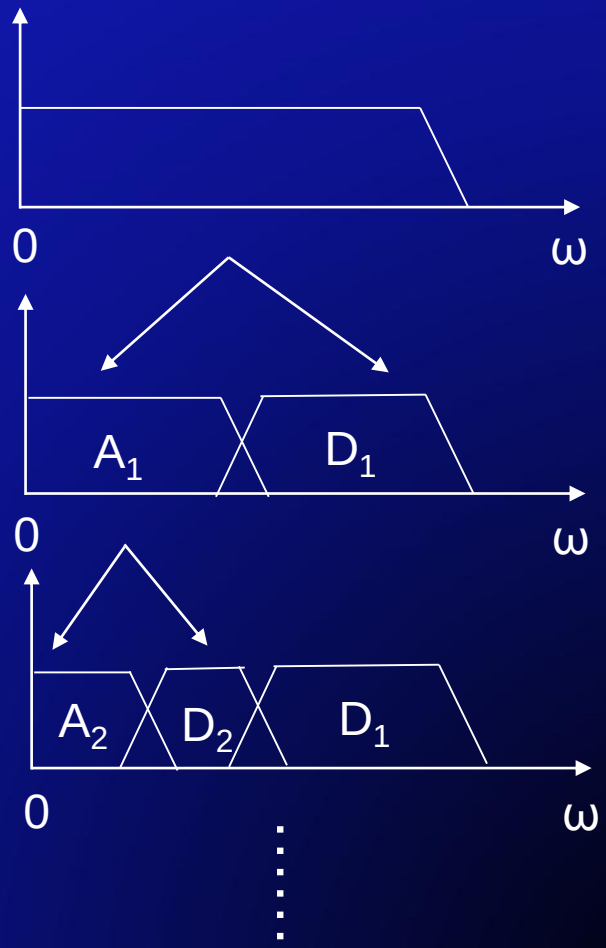
How to increase the CMPS number of KM while prevent that of KNMs from increasing?

Approach:

- Multi-scale decomposition and correlation for original profile,
- Inspecting multi correlation peaks.

Multi-scale decomposition and correlation for original profile



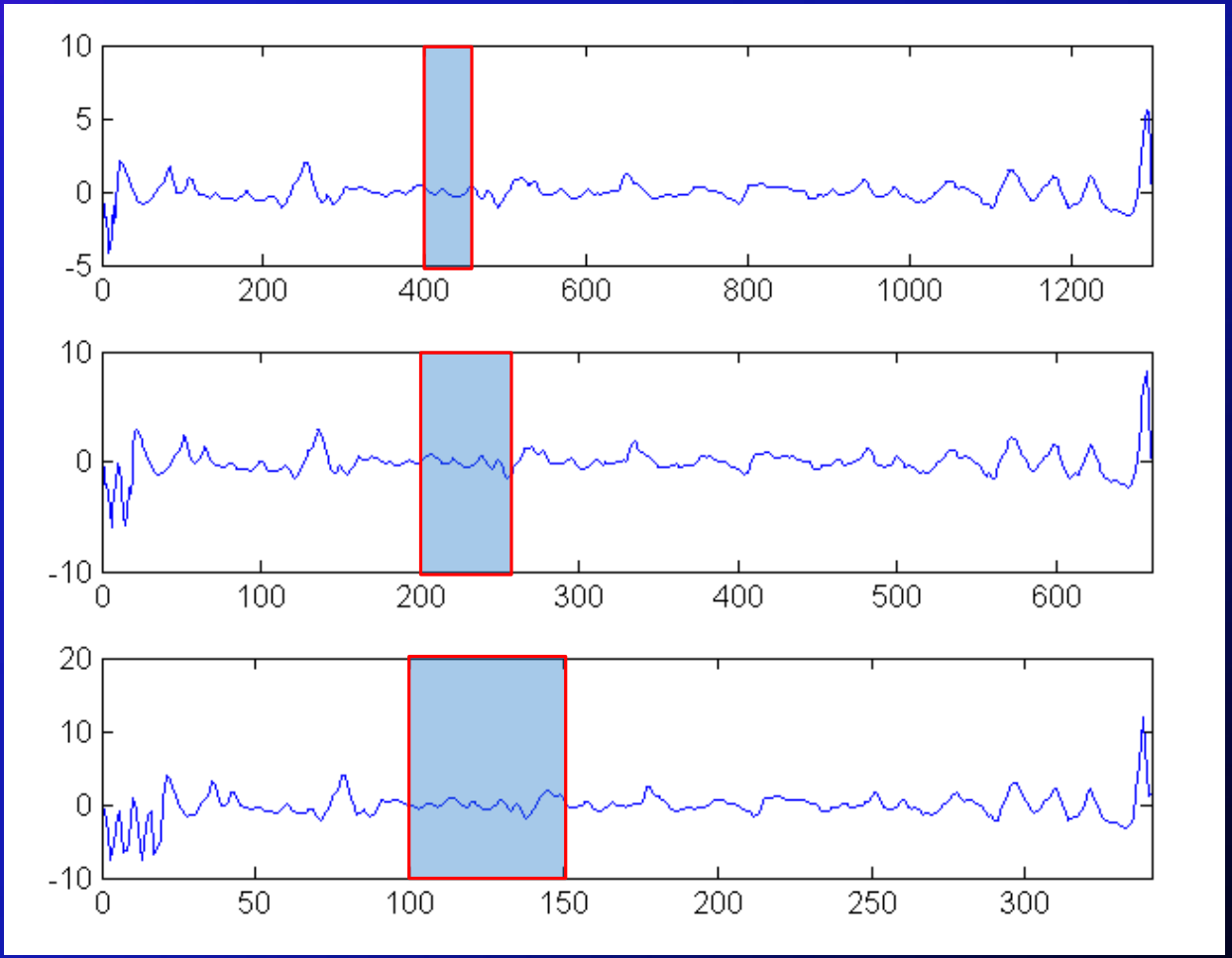


Wavelet decomposition

Original signal.

1st level appr.

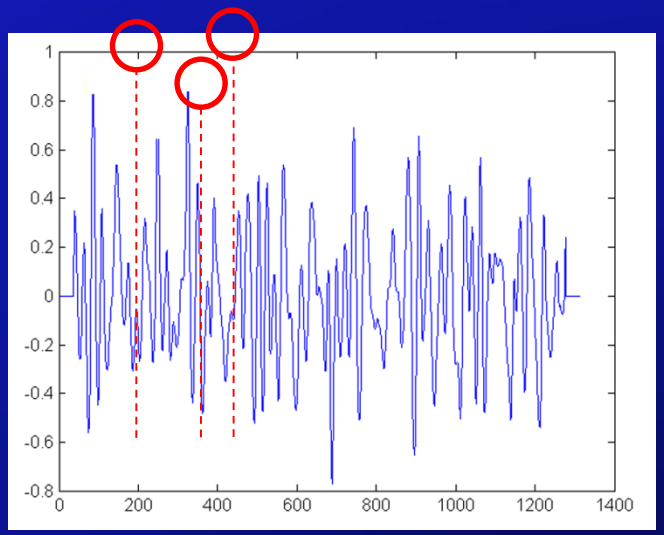
2nd level appr.



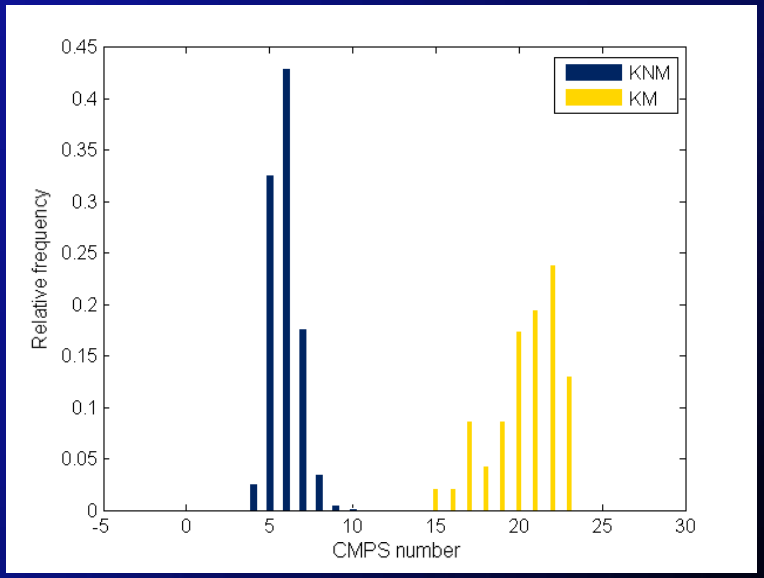
Inspection of multiple CCF peaks

An example (CMPS = 3) (up to 3 peaks inspected)

	50	5	200	120	10	-180	-5	-100	195
50	1								
5		1			1		1		
200			1						1
120				1					
10		1			1				
-180						1			
-5		1					1		
-100								1	
195			1						1



lateral shifts of 3 highest CCF peak value are inspected.



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Initial Test of CMPS Method and Result

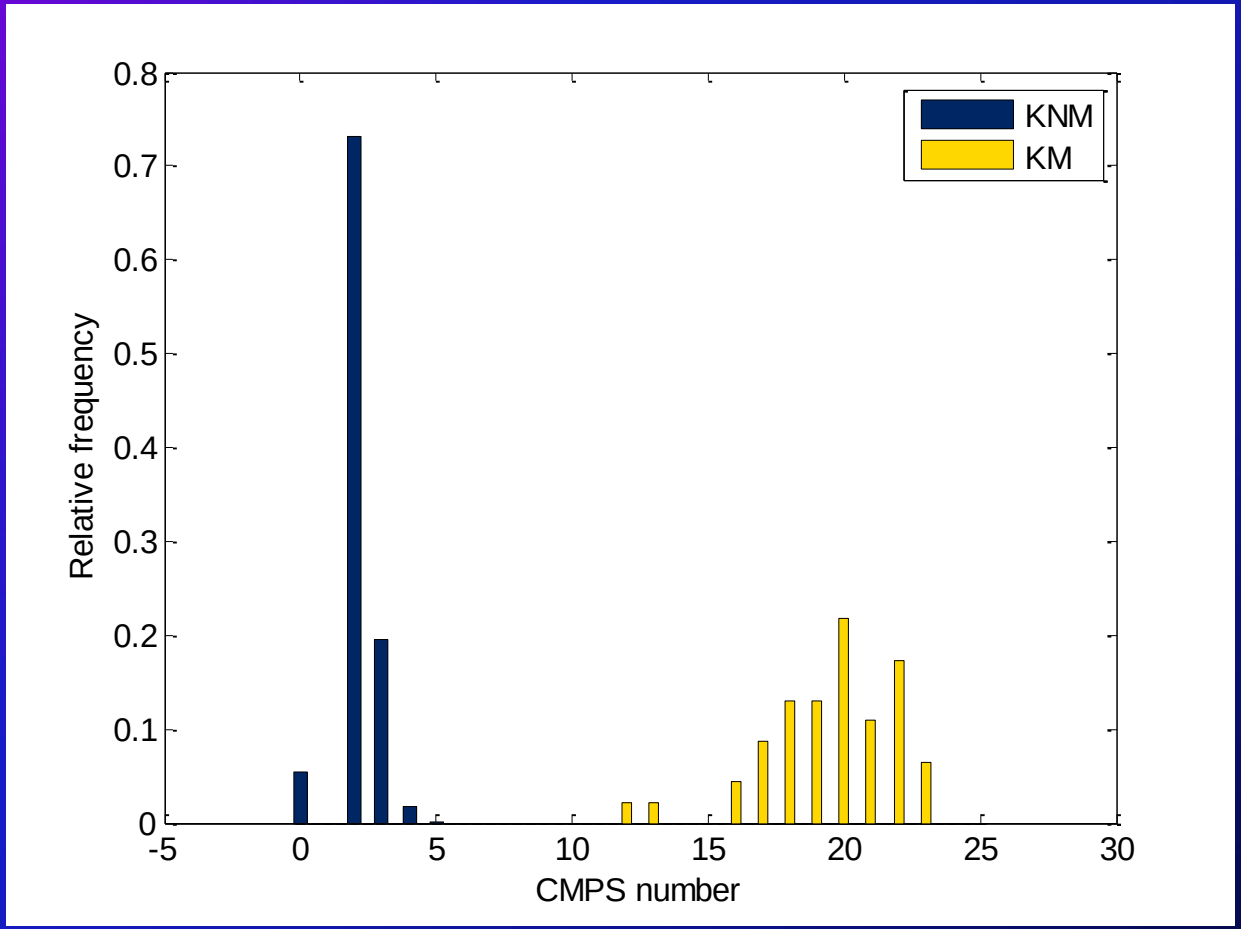
- Test simples
  - A set of Dr. J. Hamby's test bullets fired from 10 consecutively manufactured gun barrels.
  - 35 bullets including 10 pairs of KM bullets for training, 15 unknown bullets for tests.
  - The total correlations include 46 KM and 549 KNM comparisons with a total of 595 image pairs correlated by the CMPS method.
  - Each pairwise bullet image correlation consists of 6 x 6 land comparisons.

Initial Test of CMPS Method and Result

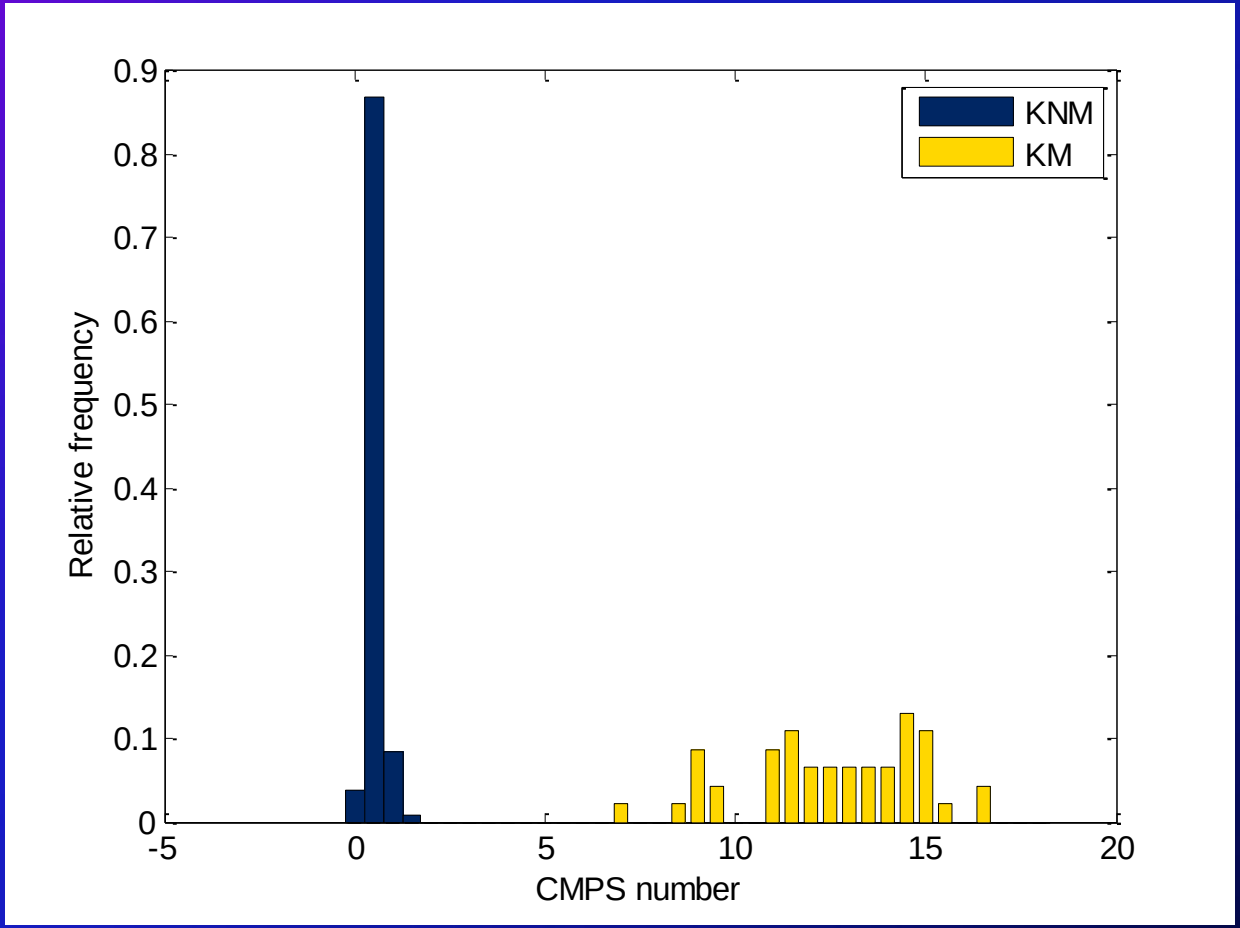
Two methods for calculating the CMPS score:

1) Using the maximum CMPS number of the 6 x 6 land matrix as the correlation result;

2) Using average CMPS numbers of 6 lands at the maximum orientation phase $\overline{\mathrm{CMPS}}_1, \overline{\mathrm{CMPS}}_2, \ldots \overline{\mathrm{CMPS}}_6$ and consider the maximum score $\overline{\mathrm{CMPS}}_{\max}$ as the correlations result.



If we consider the maximum CMPS number of the 6 x 6 land matrix as the correlation result, the KNM CMPS scores range from 0 to 4; the KM CMPS scores range from 12 to 23.



If we consider the maximum average score $\overline{\mathrm{CMPS}}_{\max}$ as the correlations result, the KNM $\overline{\mathrm{CMPS}}_{\max}$ scores range from 0 to 1.5; the KM $\overline{\mathrm{CMPS}}_{\max}$ scores range from 7 to 16.5.

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Summary

- Based on the principle of discretization, the CMPS method is proposed for bullet signature correlation. A CMPS is determined by profile similarity CCF_{max}, twist angle θ, profile segment position #x and land index #y.
- Initial tests showed good results without false identification and false exclusion.
- The CMPS method uses less parameters for identification than the previously developed automatic CMS method, thus makes it more useful.

Future work

- Develop an error rate procedure, report error rate based on the total segment number *N*, the qualified CMPS number, and the statistical distribution of the identification parameters: similarity parameter CCF_{max} (T_{CCF}) and segment registration position x (T_x).
- Develop a Computer Learning Program based on CMC, CMX, CMF and CMPS methods for automatic ballistics identification and error rate report.

Questions?

Contact: song @nist.gov