47th Annual Training Seminar
May 30th, 2016

New automated composite comparison score for bullet analysis using high-resolution optical 3D surface metrology

Cristina Cadevall
Sensofar Tech & CD6

SENSOFAR

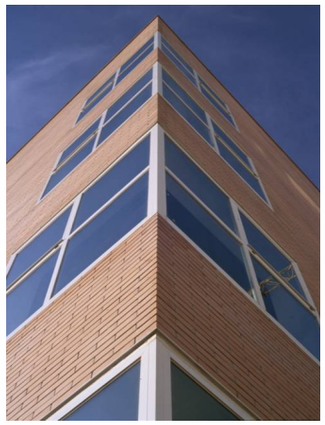
SUMMARY

- Overview
- Methodology
- Results
- Future
- Conclusions

OVERVIEW

Research environment

Surface metrology experts



C. Cadevall and R. Artigas, PhD in Optics

Centre of Sensors, Instruments and Systems Development (CD6 - UPC) (Barcelona, Spain)

+ D. Martinez at al

Sensofar Tech SL (Barcelona, Spain)

+ B. Henderson (+ D. Stella)

Sensofar LLC (US)

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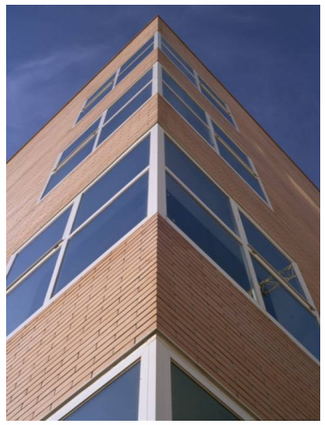

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- Photonics Europe (2016) "Three-dimensional measurements with a novel technique combination of Confocal & Focus Variation with a simultaneous scan"
- AAC (2104) "Using Optical areal measurement methods to assess the surface shape and texture on aluminum anodized surfaces" - **BEST PAPER AWARD**

OVERVIEW
Research environment

Firearms forensics researchers

D. McClarin, E. Smith and J. Stephenson

FBI Labs (Quantico, Virgina)

A. Zheng et al

NIST - Engineering Physics Division

(Gaithersburg, Maryland)

A. Garrido

Guardia Civil

(Barcelona, Spain)

Open Forensics Metrology Consortium

(OpemFMC - International)

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NIST Ballistics Toolmark Database
J. Hamby test

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x3p format

OVERVIEW
Motivation

Handwritten manuscripts

Gutenberg movable type printing 1450

OVERVIEW
Motivation

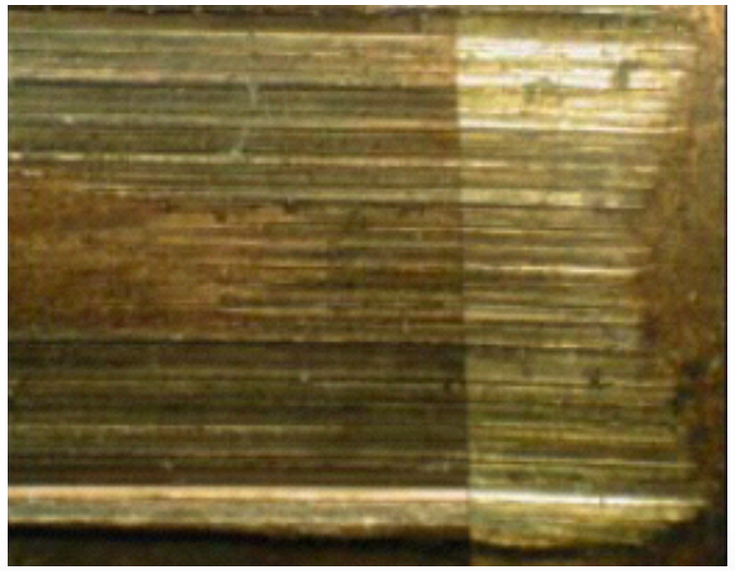
Handwritten manuscripts

Gutenberg movable type printing 1450

speed & consitency

OVERVIEW
High resolution optical 3D surface metrology

- Crime labs
  - Optical (side-by-side) comparison microscopes.
  - Lighting conditions are the same (or nearly so).
- Automated ballistics identification systems
  - Digitized optical microscope images.
  - Lighting conditions are not guaranteed to be equal.
  - Not very successful with lead bullets or bullets with differing compositions

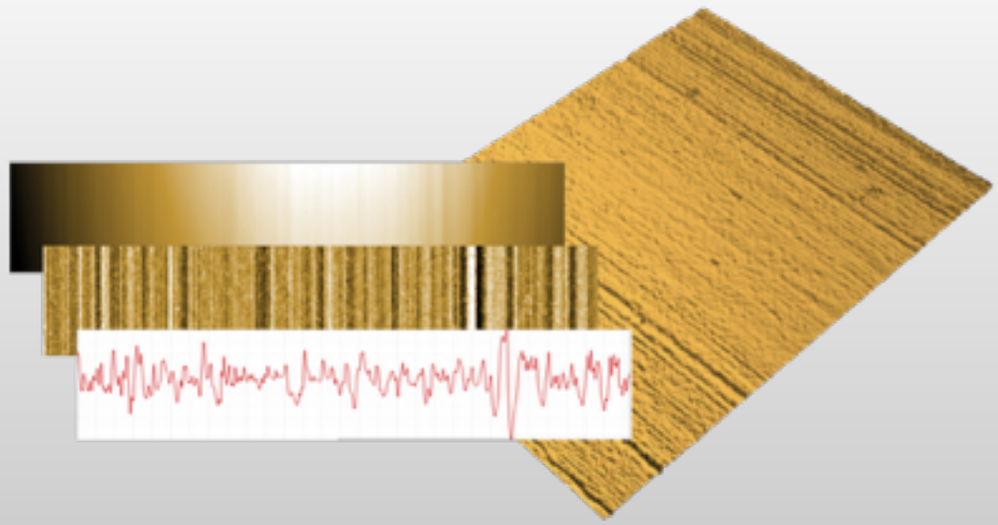


[1] TV Vorburger, J Song, N Petraco. 'Topography measurements and applications in ballistics and tool mark identifications, Surf. Topogr.: Metrol. Prop. 4 (2016) 013002

OVERVIEW

High resolution optical 3D surface metrology

- Bullet signatures are 2D or 3D tool marks (geometrical micro-topographies by nature)
- Direct measurement and correlation of 2D surface profiles and 3D surface topographies have been proposed for ballistic identification
- Automation using 3D measurements is more successful in the analysis of a wider range of bullet types



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OVERVIEW

Qualitative 3D analysis

OVERVIEW

Qualitative 3D analysis

OVERVIEW

Quantitative 3D analysis

- Measure degree of similarity - public domain parameters - 2D & 3D
  - Cross-correlation function (CCF) [2]
  - Signature difference (D_s) [2]
- Full surface or individual characteristics?
  - Congruent Matching Cells (CMC): CCF_{max}, “theta”, x, y for every cell + number of matching cells (CMC number) [3]
  - Principal component analysis (PCA) [4]

[2] J Song, TV Vorburger. ‘Proposed bullet signature comparisons using autocorrelation functions, Proc 2000 NCSL (Toronto)

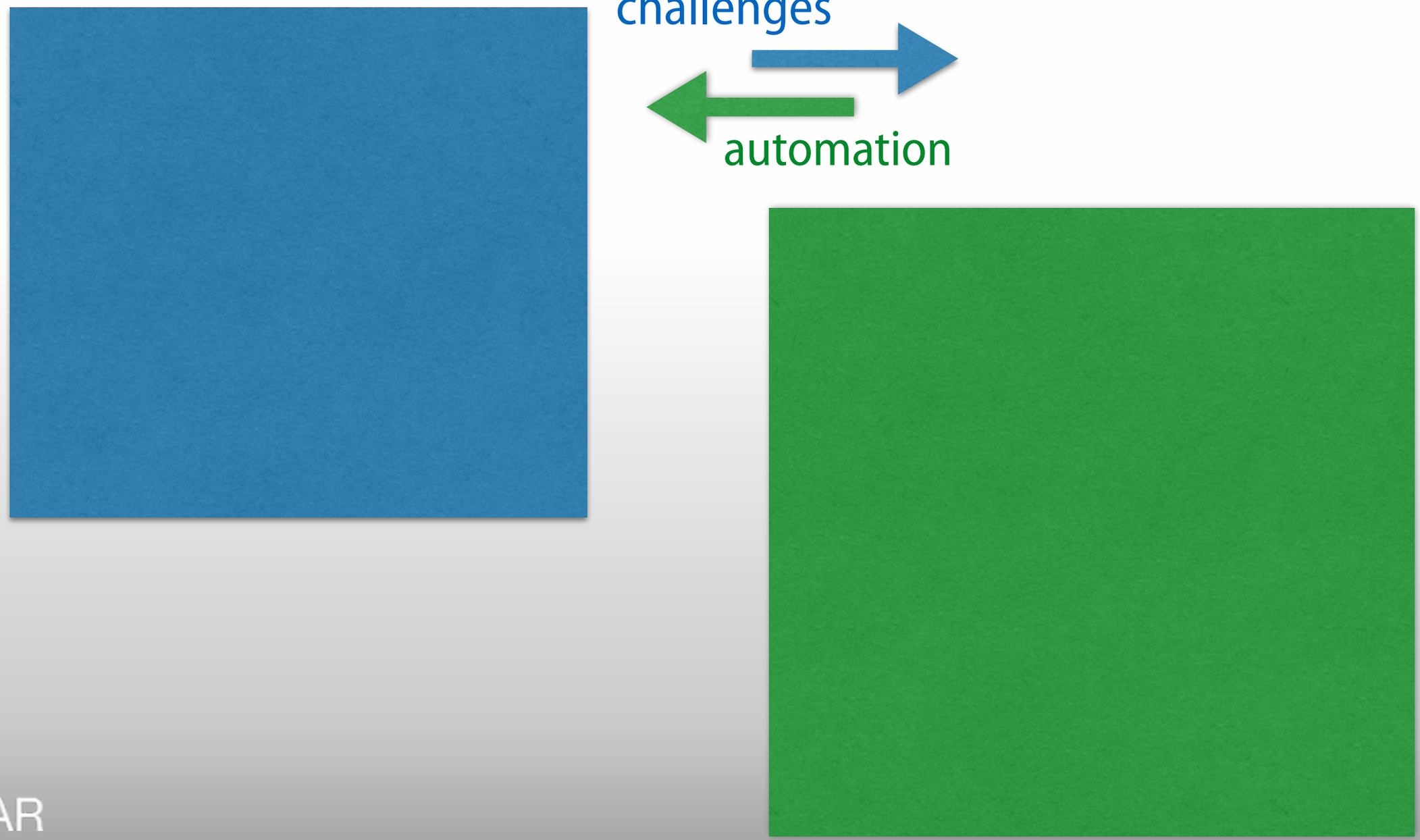
[3] J Song 2013 Proposed NIST ballistics identification system (NBIS) using 3D topography measurements on correlation cells AFTE J. 45 184-94

[4] Petraco N D K et al 2013 Estimates of striation pattern identification error rates by algorithmic methods AFTE J. 45 235-44

OVERVIEW
Challenges

Firearms and tool marks experts & scientists

Surface metrology experts



OVERVIEW
Challenges

Firearms and tool marks experts & scientists

Surface metrology experts

Thousands of comparisons of 3D measurements of land surfaces

challenges

automation

OVERVIEW
Challenges

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Reliability

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Challenges

Firearms and tool marks experts & scientists

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Thousands of comparisons of 3D measurements of land surfaces

Reliability

Traceability

OVERVIEW
Challenges

Firearms and tool marks experts & scientists

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OVERVIEW
Challenges

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Reliability

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Non-proprietary parameters & algorithms

OVERVIEW
Challenges

Firearms and tool marks experts & scientists

Surface metrology experts

challenges

automation

Thousands of comparisons of 3D measurements of land surfaces

Reliability

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Batch comparisons

Non-proprietary parameters & algorithms

Reports with author, date & bullets identification

OVERVIEW
Challenges

Firearms and tool marks experts & scientists

Surface metrology experts

challenges

automation

Thousands of comparisons of 3D measurements of land surfaces

Reliability

Traceability

Batch comparisons

Non-proprietary parameters & algorithms

Reports with author, date & bullets identification

high speed

SUMMARY

- Overview
- Methodology
- Results
- Future
- Conclusions

METHODOLOGY

[5] D.S McClarin. Adding an Objective Component to Routine Casework: Use of Confocal Microscopy for the Analysis of 9 mm Caliber Bullets. AFTE Journal - Volume 47 Number 3 - Summer 2015

METHODOLOGY

1. Land surface measurements

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METHODOLOGY

1. Land surface measurements

2. Land comparisons (CCF_{max})

SENSOFAR

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METHODOLOGY

1. Land surface measurements
2. Land comparisons (CCF_{max})
3. Bullet comparisons: CFF_{max} matrix

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METHODOLOGY

1. Land surface measurements
2. Land comparisons (CCF_{max})
3. Bullet comparisons: CFF_{max} matrix
4. Top N list analysis

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METHODOLOGY

Hamby test **15 v. 20** bullets takes **10 days**

1. Land surface measurements
2. Land comparisons (CCF_{max})
3. Bullet comparisons: CFF_{max} matrix
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SENSOFAR

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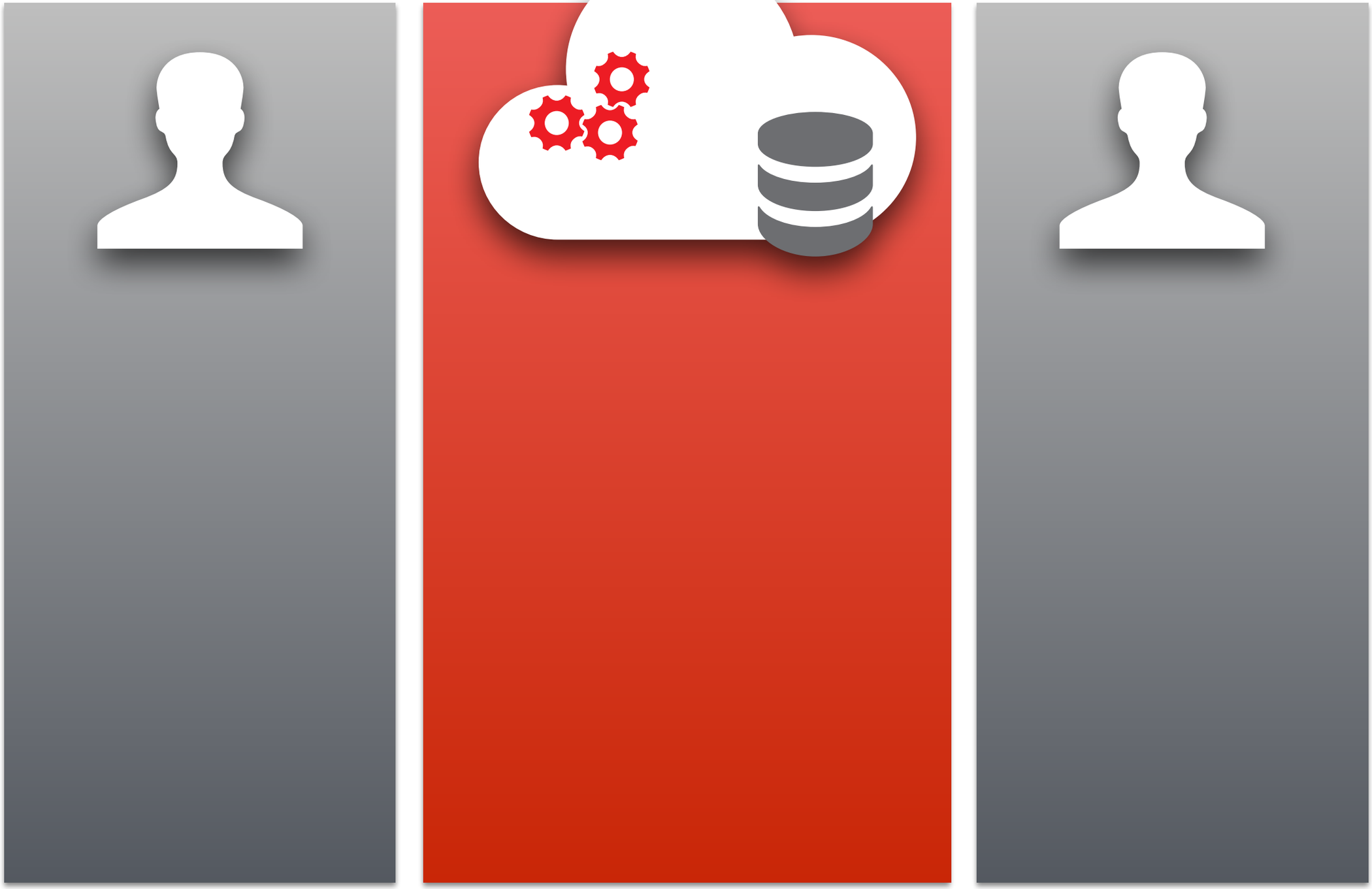
METHODOLOGY

New



METHODOLOGY

New

1. Land surface measurements

METHODOLOGY

New

1. Land surface measurements
2. IC extraction

METHODOLOGY

New

1. Land surface measurements

2. IC extraction

3. IC comparison (CCF_{max})

METHODOLOGY

New

1. Land surface measurements

2. IC extraction

3. IC comparison (CCF_{max})

4. Bullet comparisons: new automated comparison score: **Sequence Average Maximum (SAM)**

METHODOLOGY

New

1. Land surface measurements

2. IC extraction

3. IC comparison (CCF_{max})

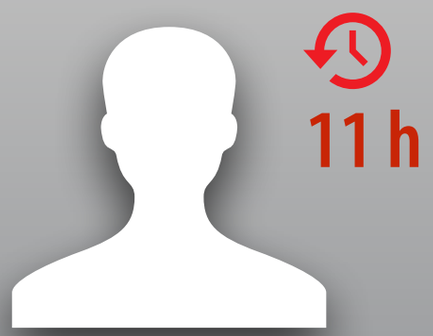
4. Bullet comparisons: new automated comparison score: **Sequence Average Maximum (SAM)**

5. Top N list analysis

METHODOLOGY

New

Hamby test **15 v. 20** bullets takes **< 2 days**



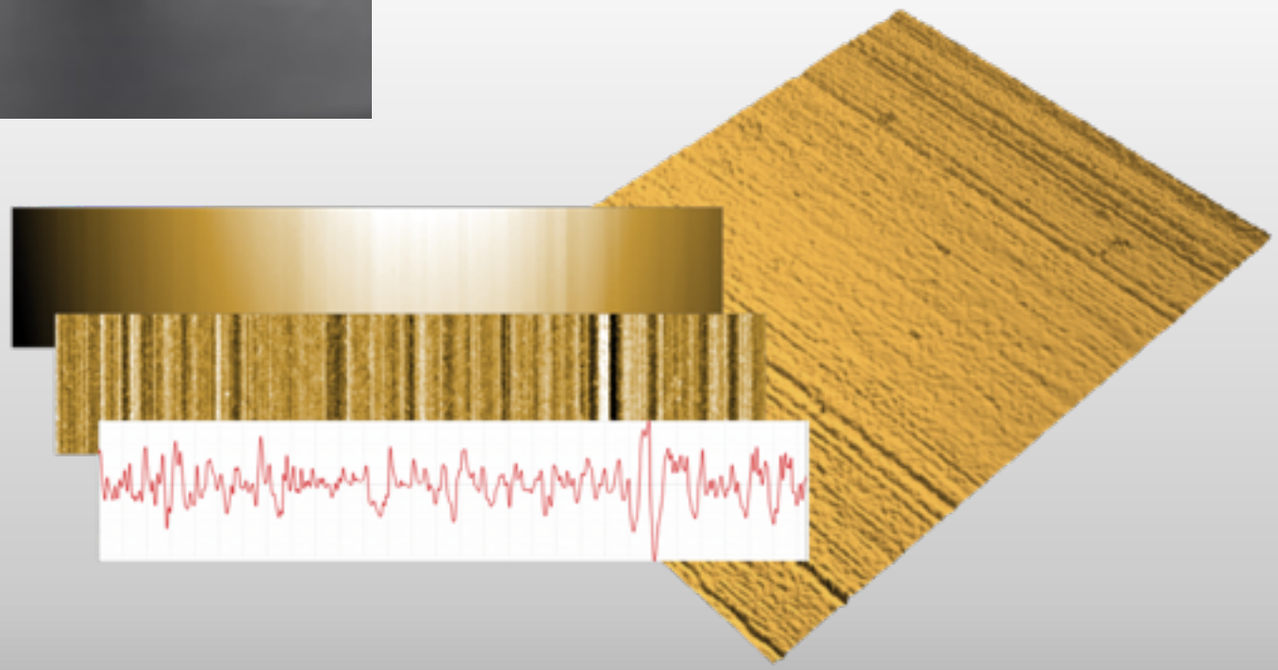
1. Land surface measurements
2. IC extraction

3. IC comparison (CCF_{max})
4. Bullet comparisons: new automated comparison score: **Sequence Average Maximum (SAM)**

5. Top N list analysis

METHODOLOGY

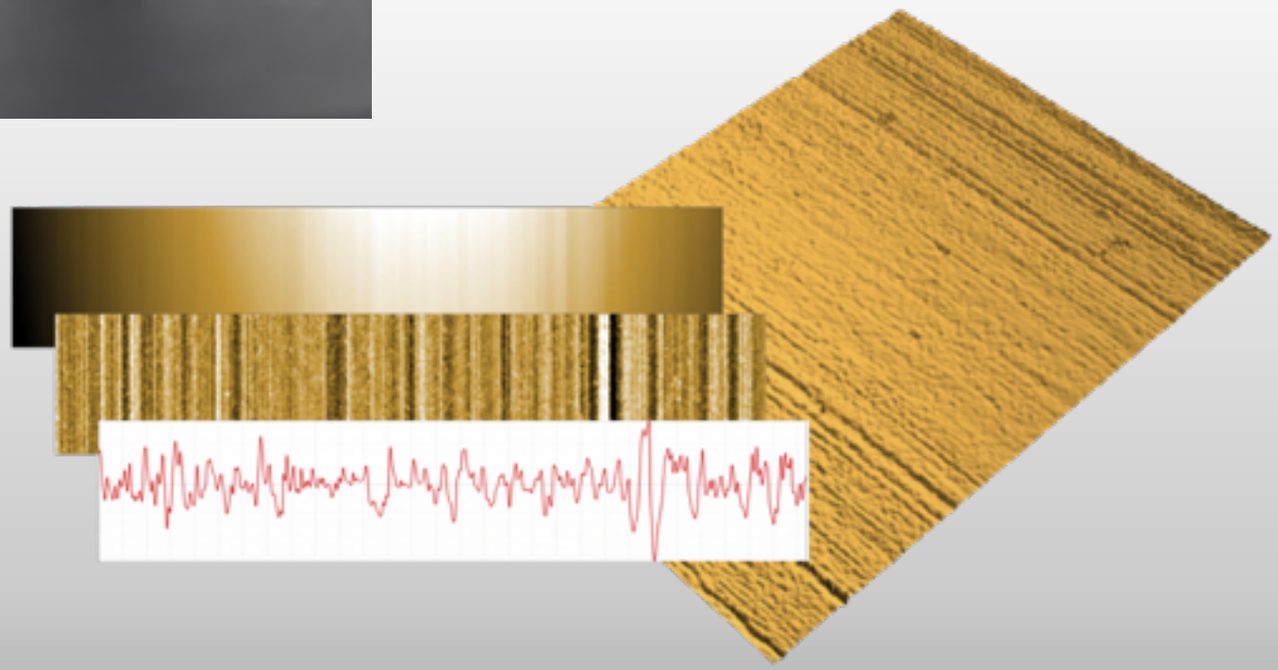
1. Land surface measurements



METHODOLOGY

1. Land surface measurements

1 bullet takes 15 min
(6 lands)



METHODOLOGY

2. IC Extraction

SENSOFAR

Example: Beretta bullet ADFS - Confocal measurement using S neox

METHODOLOGY
2. IC Extraction

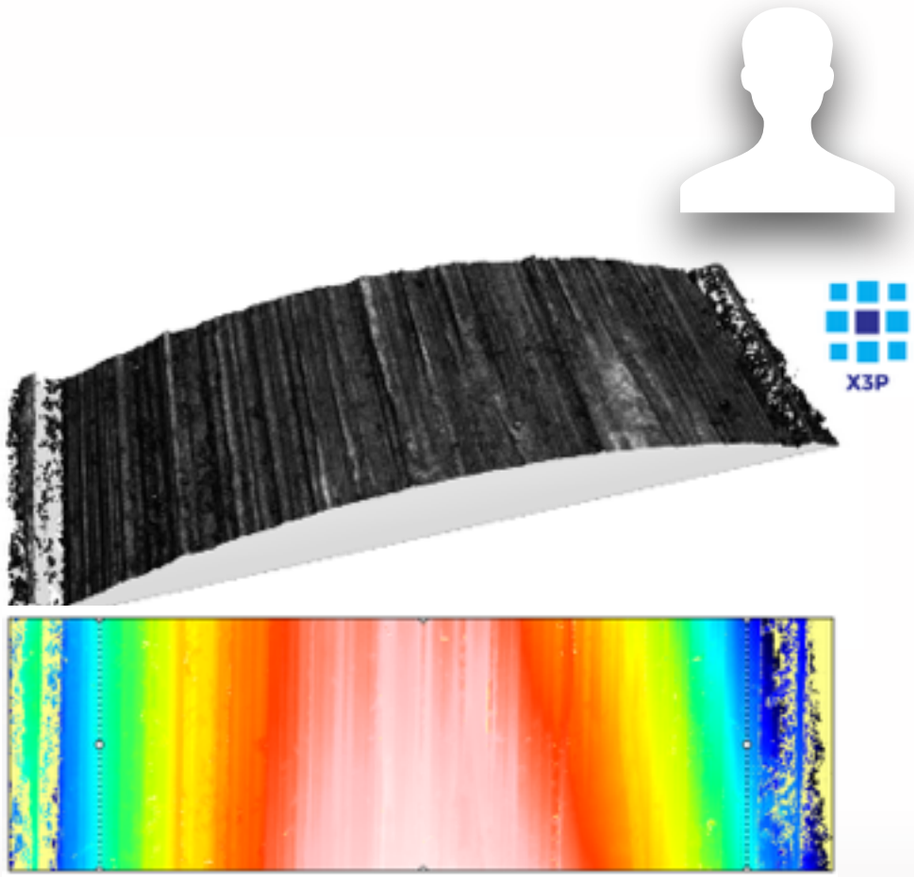
1. Full surface (2.3 mm x 0.66 mm)

Example: Beretta bullet ADFS - Confocal measurement using S neox

METHODOLOGY
2. IC Extraction

1. Full surface (2.3 mm x 0.66 mm)

2. Crop1 - eliminate land shoulders (1.7 mm x 0.66 mm)



Example: Beretta bullet ADFS - Confocal measurement using S neox

METHODOLOGY
2. IC Extraction

1. Full surface (2.3 mm x 0.66 mm)
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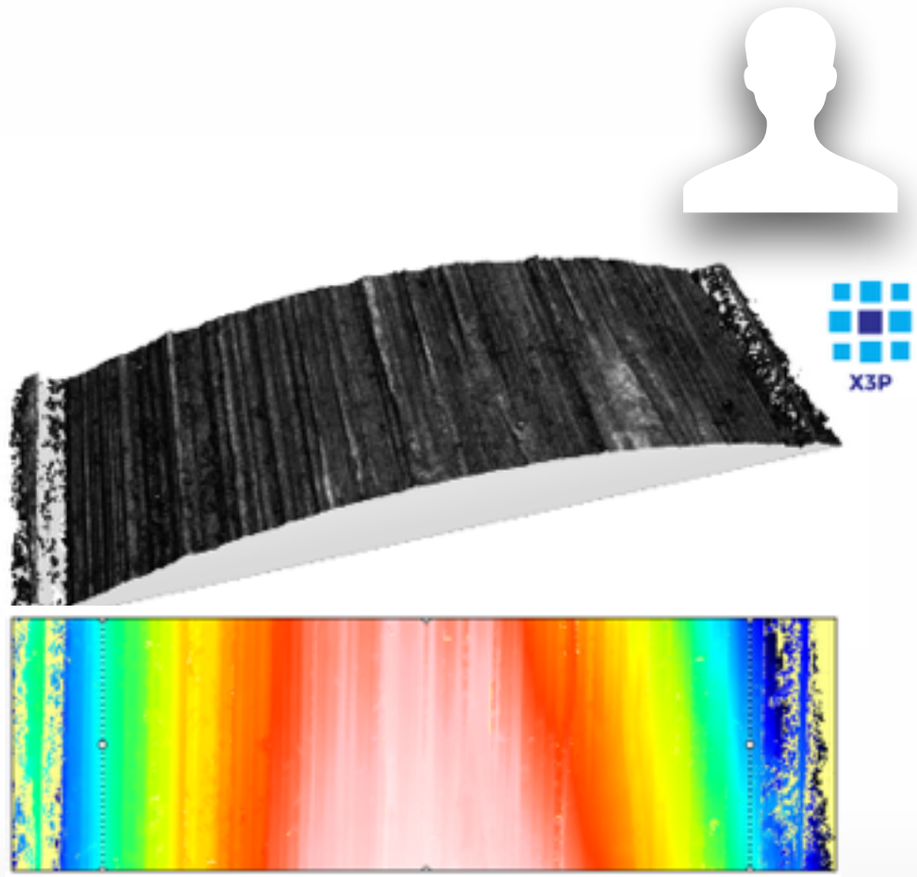
3. Waviness (filter Gaussian, 0.025 mm) - remove surface roughness



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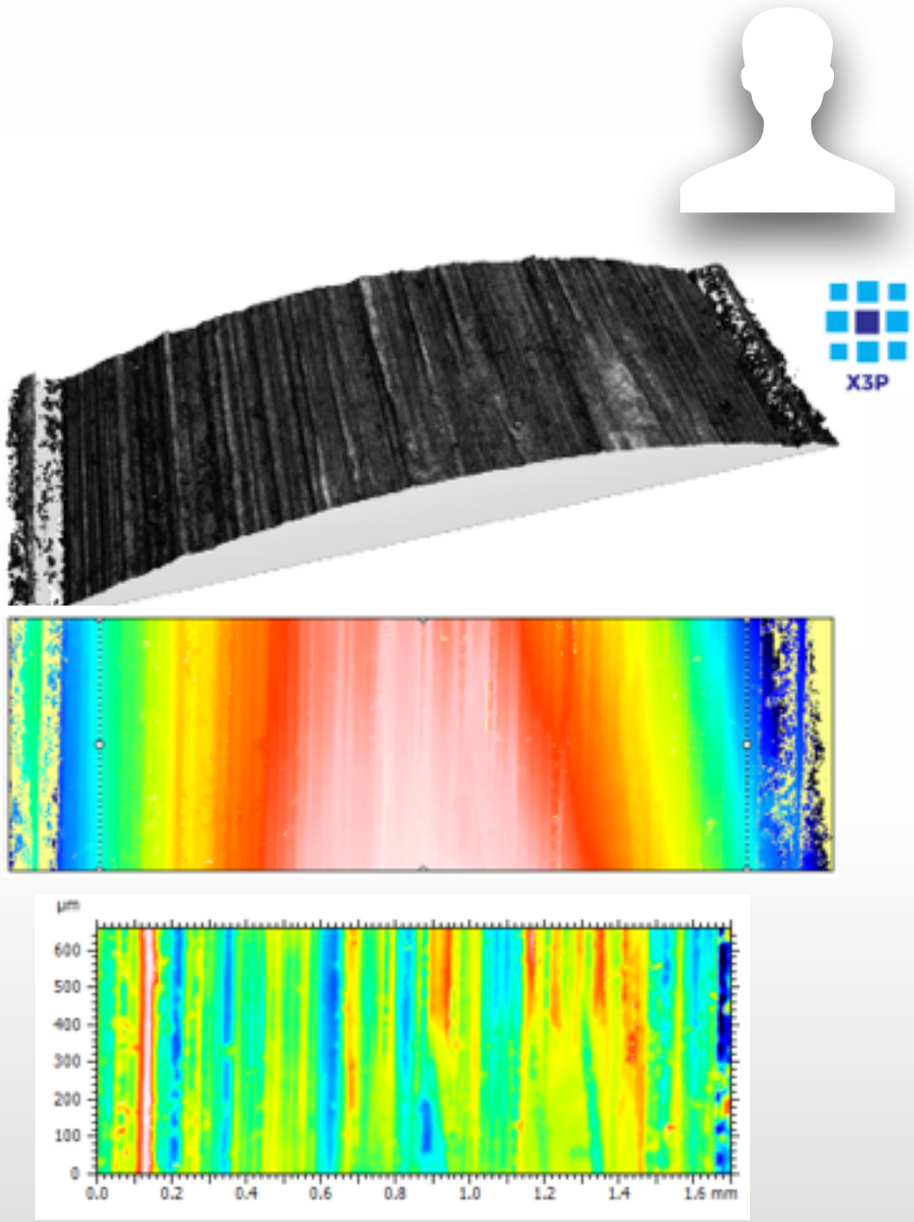

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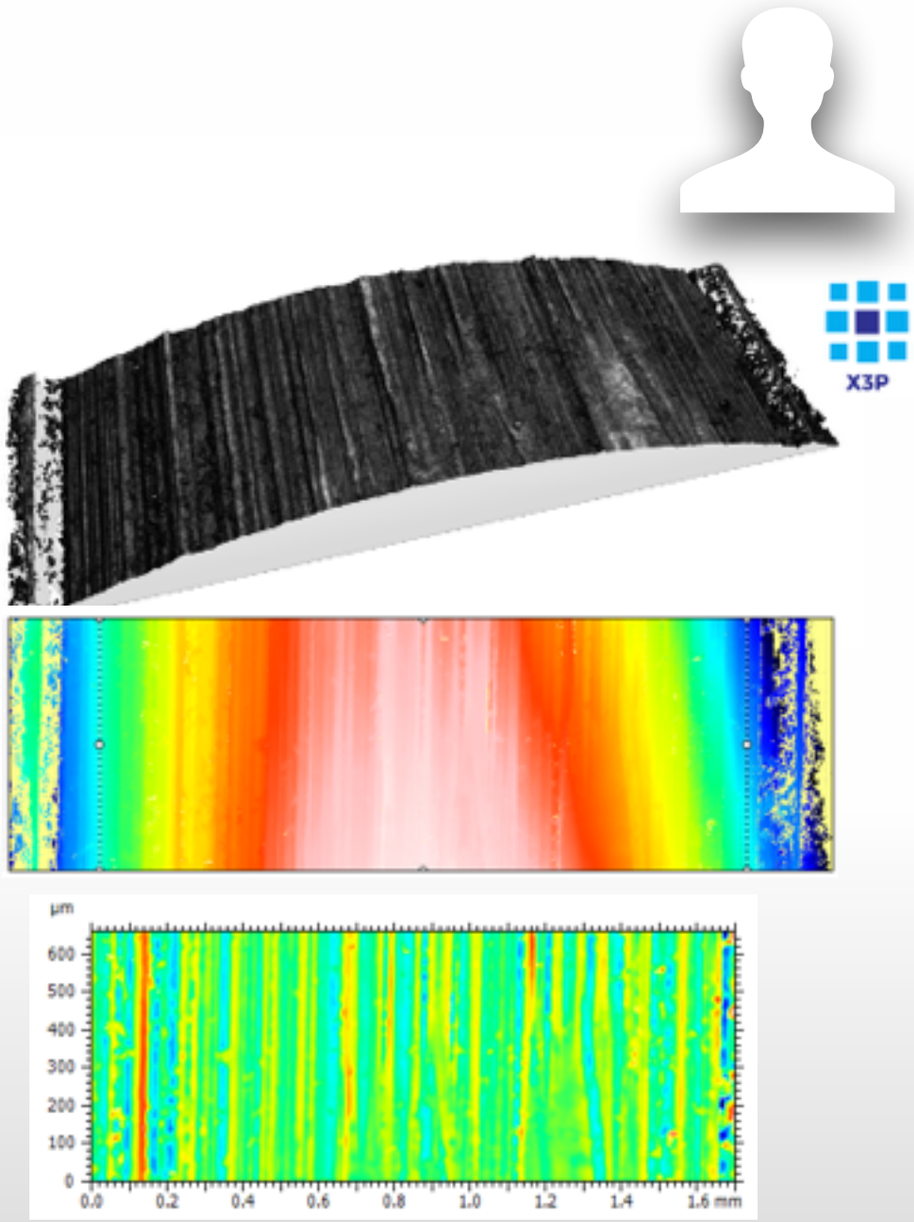

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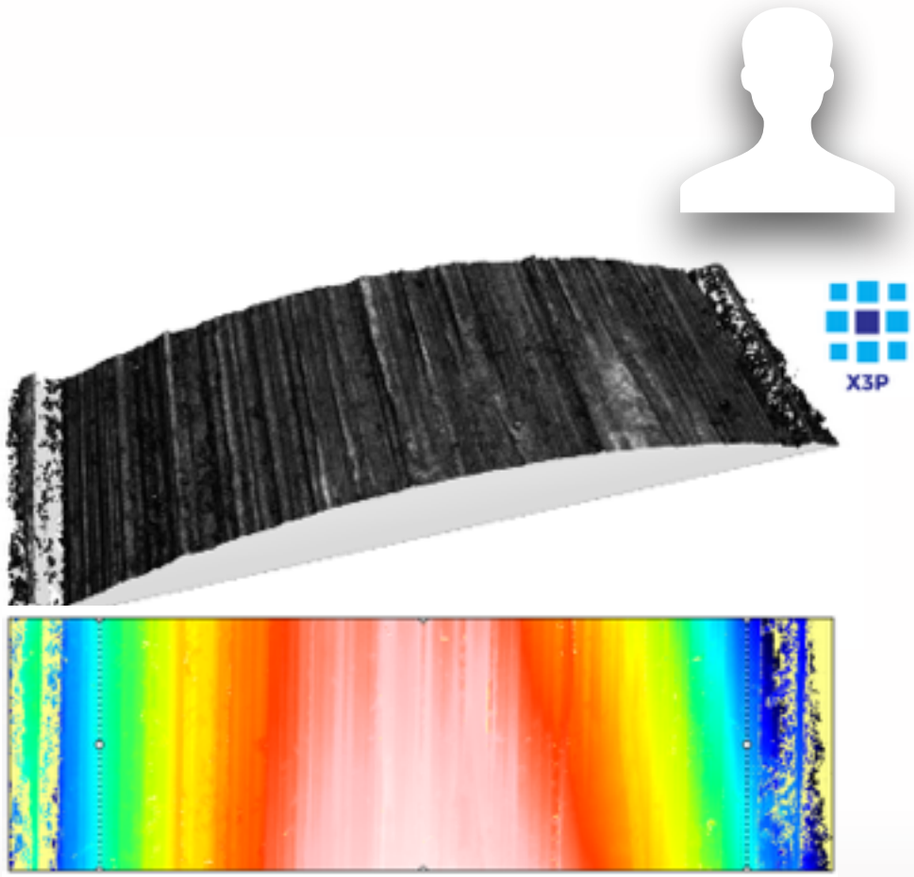

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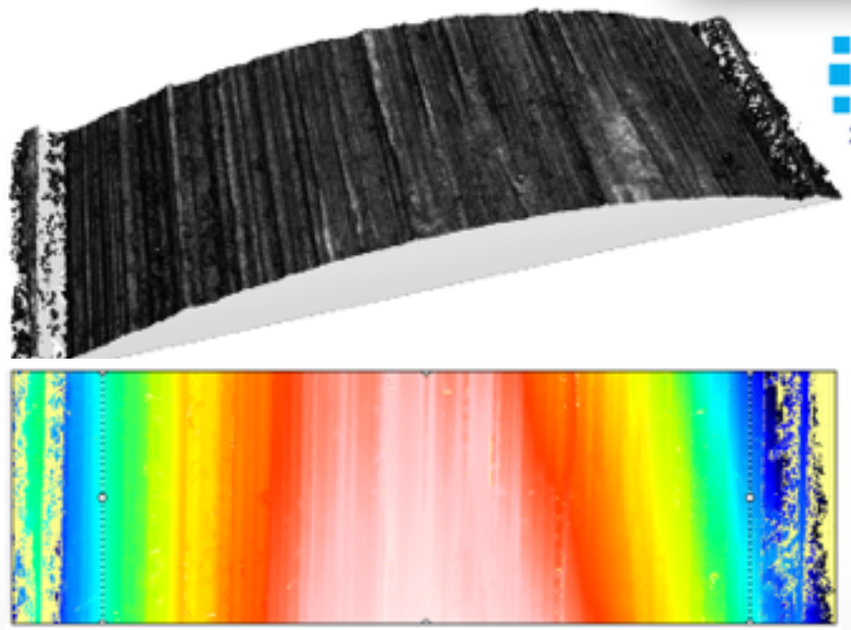
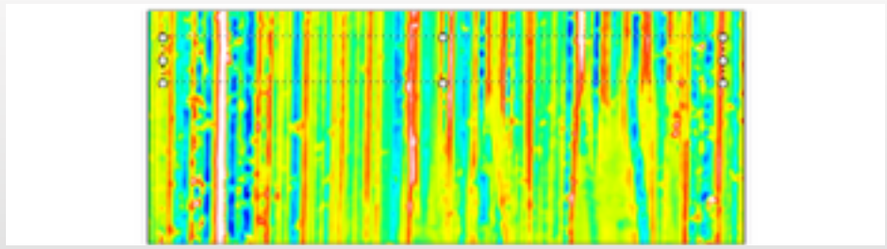
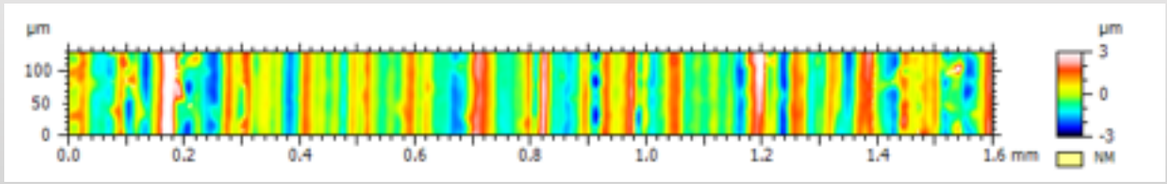
7. Save IC surface (3D) - 1.7 mm x 0.13 mm







Example: Beretta bullet ADFS - Confocal measurement using S neox

METHODOLOGY
2. IC Extraction

1 bullet takes 3 min
(6 lands)

1. Full surface (2.3 mm x 0.66 mm)
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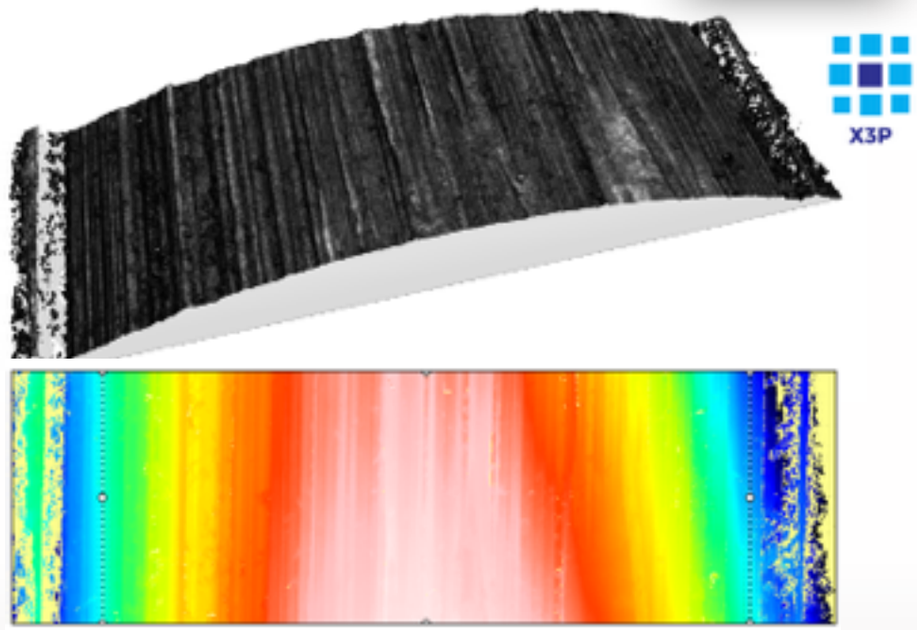
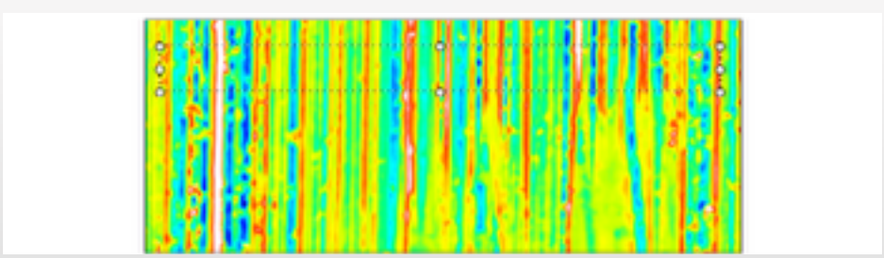
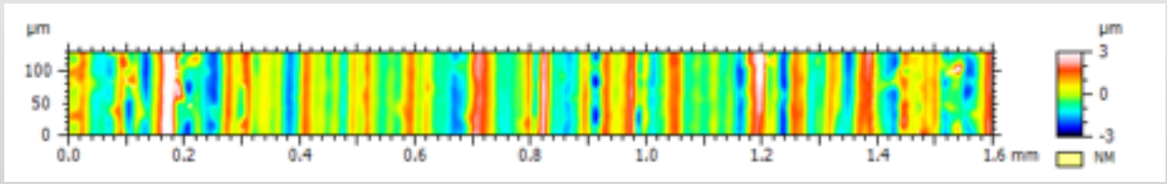






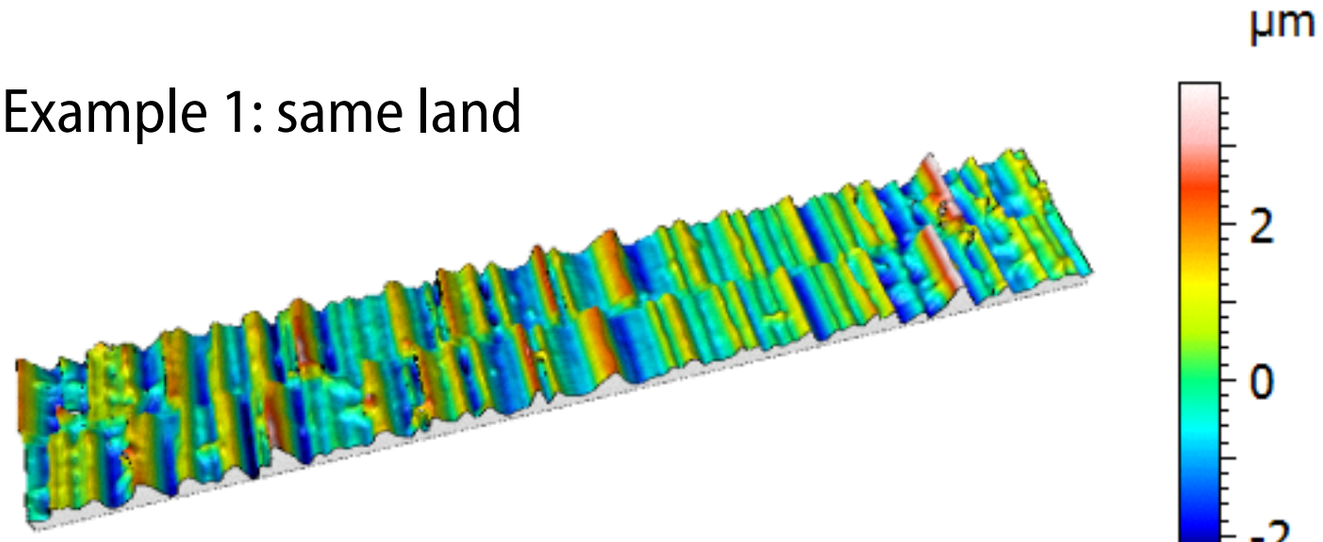
SENSOFAR

Example: Beretta bullet ADFS - Confocal measurement using S neox

METHODOLOGY

3. IC Comparison

Example 1: same land



METHODOLOGY
3. IC Comparison

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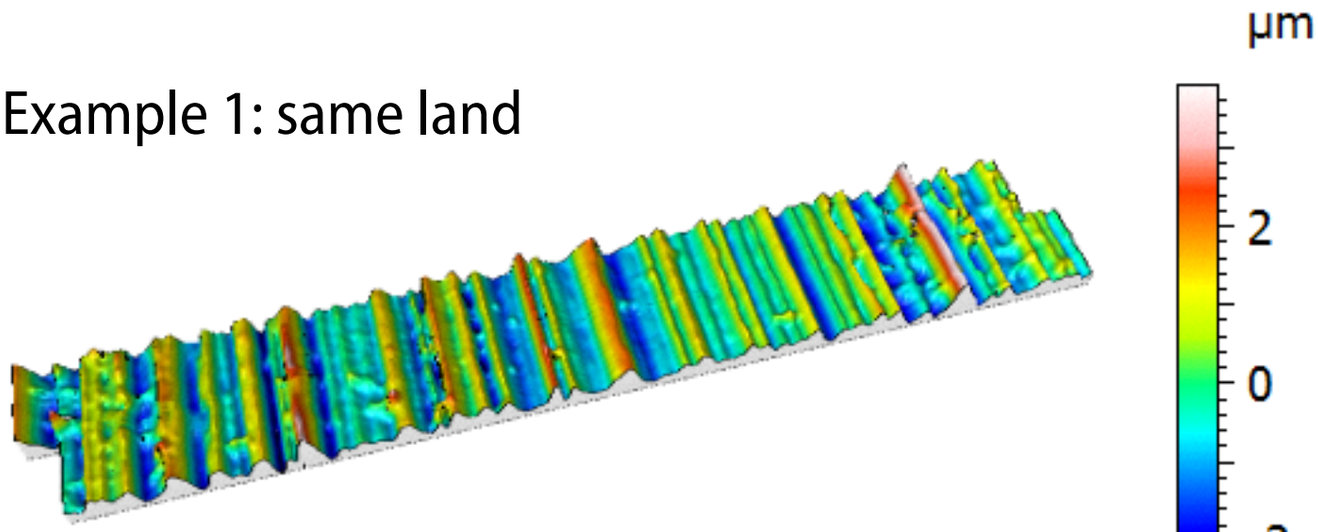

METHODOLOGY
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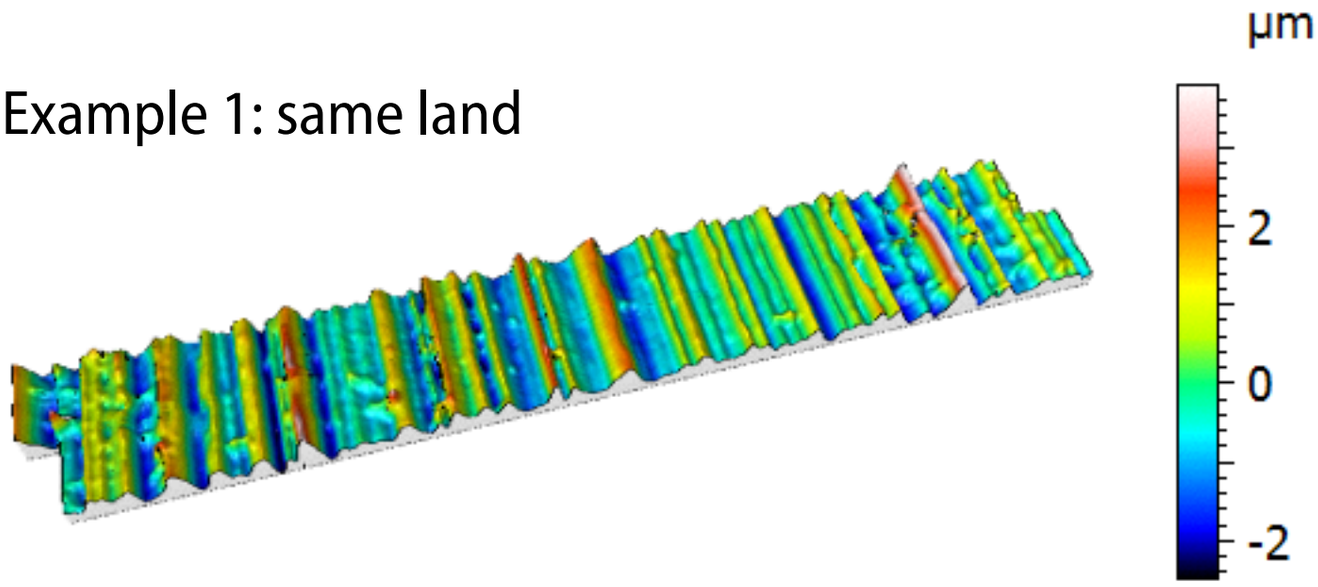

- Cross-correlation of mean profiles

For discrete profiles the normalized cross-correlation for profiles ***f*** and ***g*** of ***N*** points can be defined as:

$$(f * g)[i] \equiv \frac{1}{N-1} \sum_{l=0}^{N-1} \frac{(f[l] - \bar{f}) \cdot (g[l+i] - \bar{g})}{\sigma_f \cdot \sigma_g}$$

Where i is the lag, $\bar{f}$ is the average of profile f, and σ_f is the standard deviation of profile f.

METHODOLOGY
3. IC Comparison

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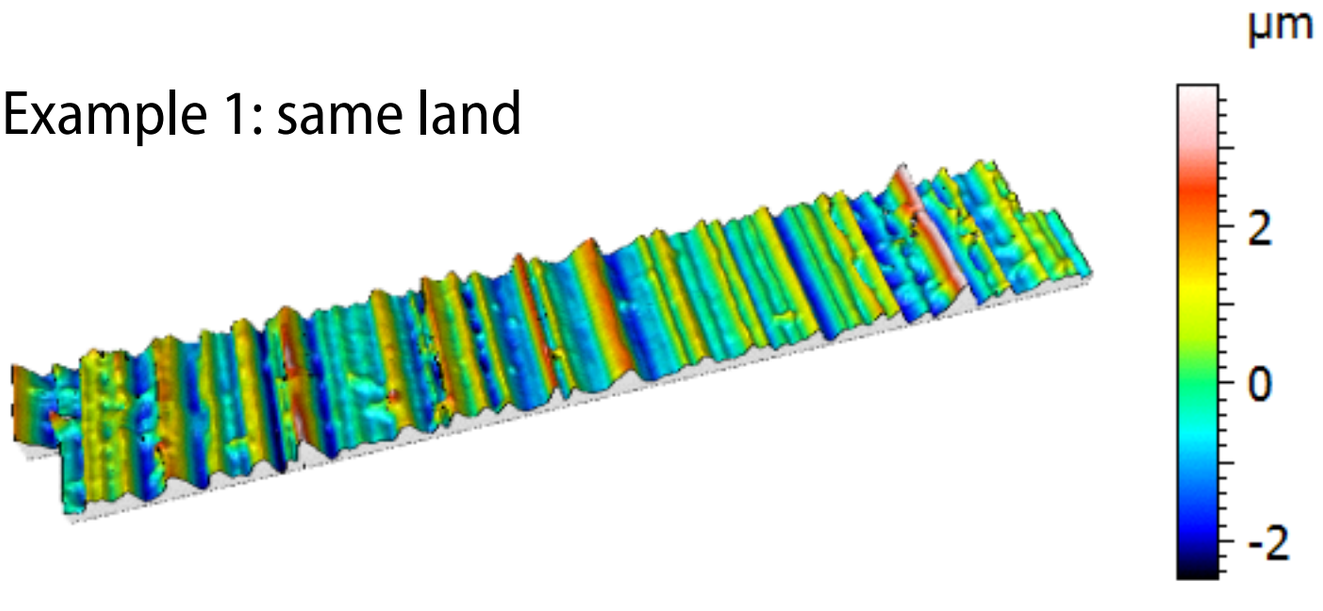

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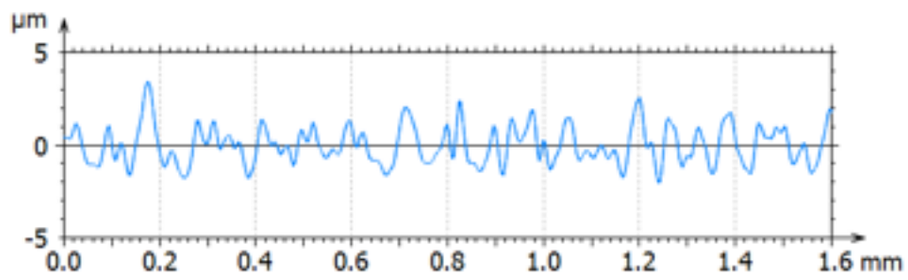
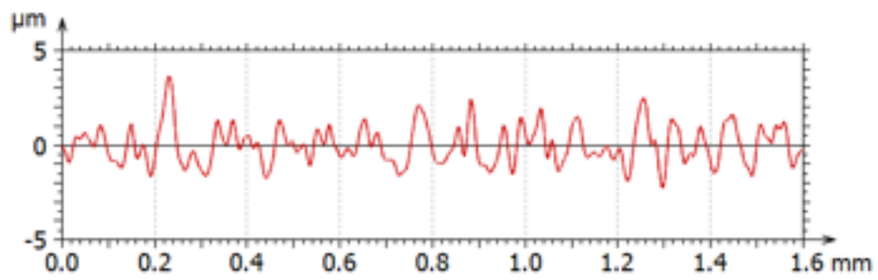
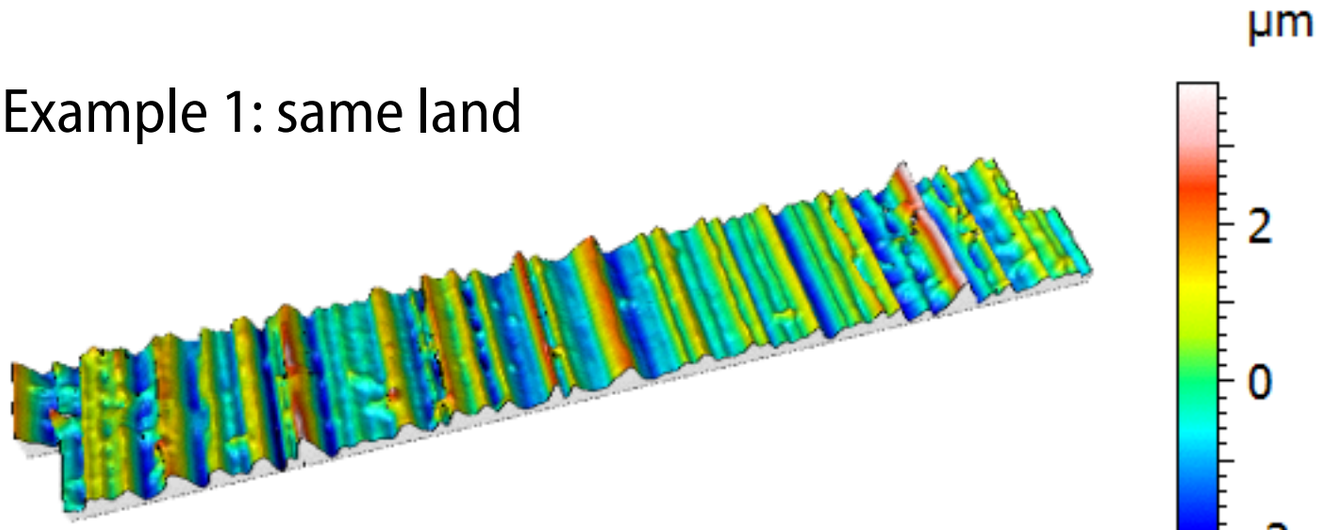


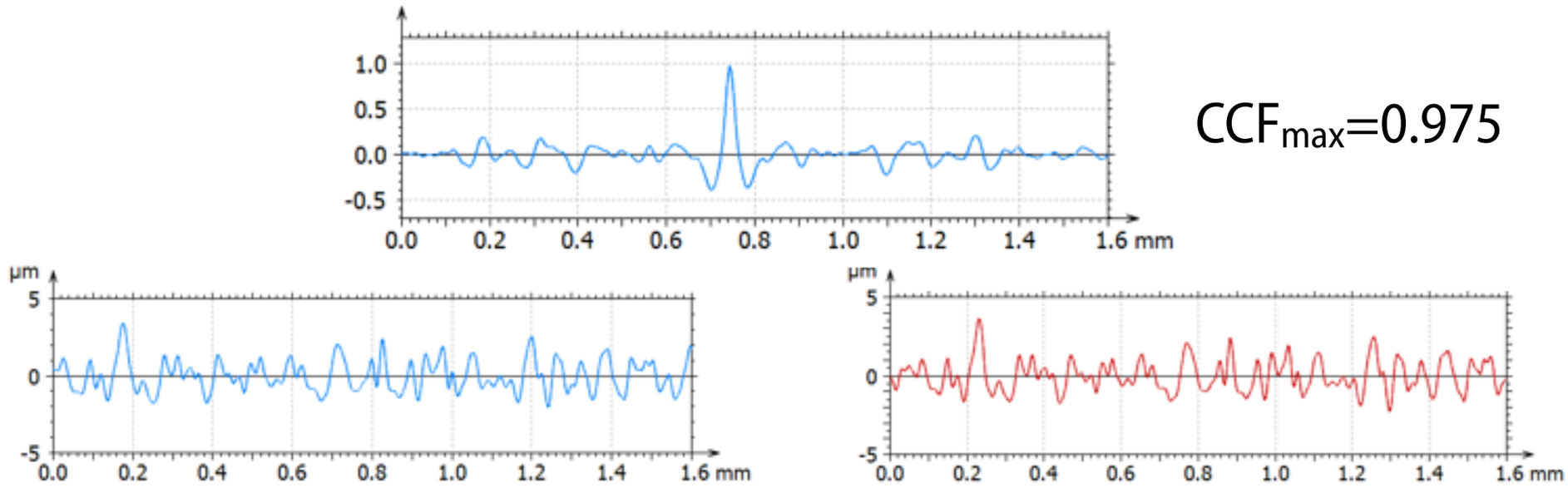


METHODOLOGY
3. IC Comparison

Example 1: same land



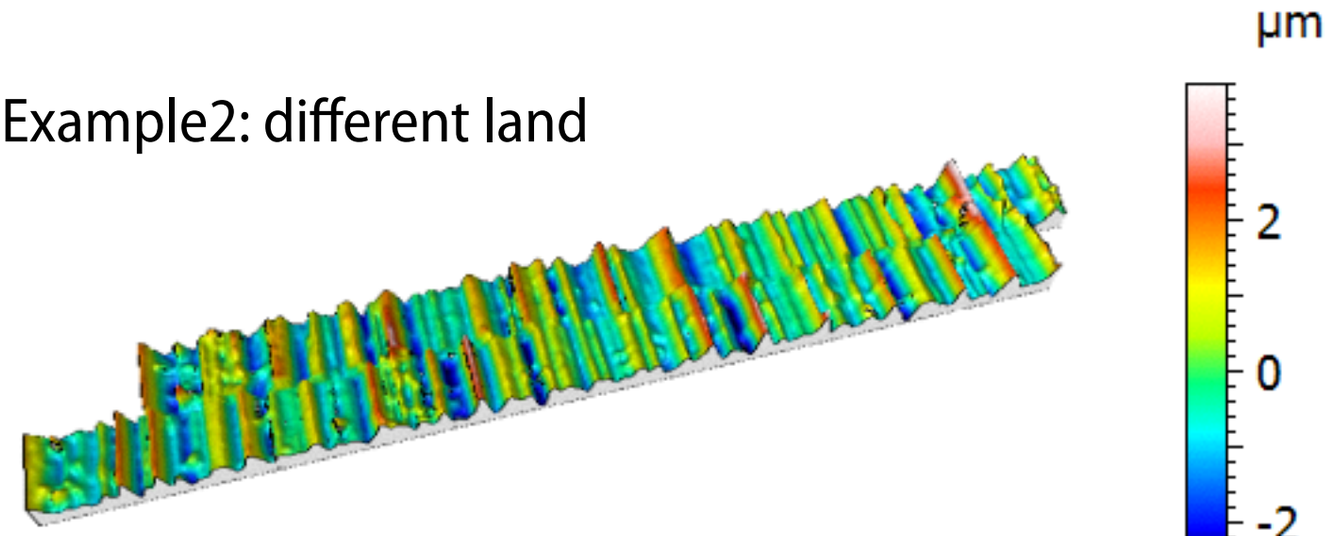
- Cross-correlation of mean profiles



CCF_{max}=0.975

METHODOLOGY
3. IC Comparison

Example2: different land



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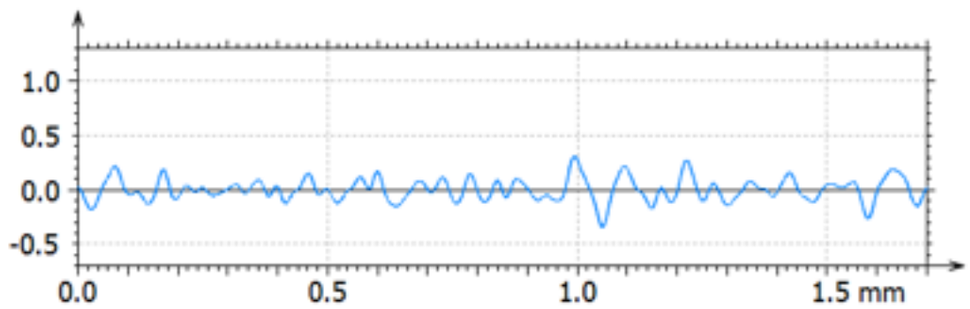
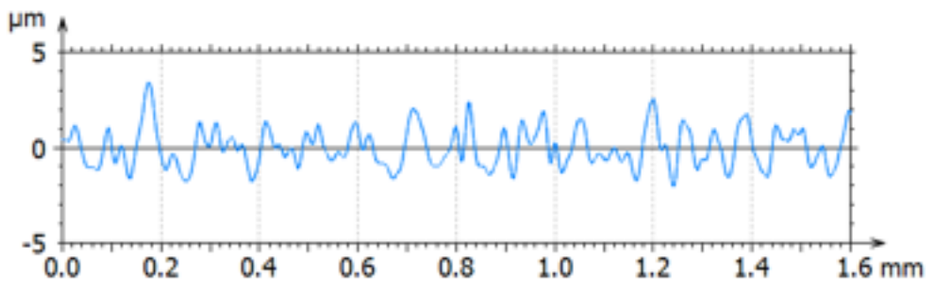
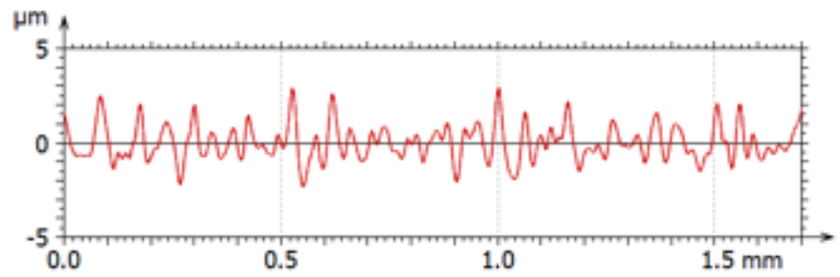


CCF_{max}=0.311

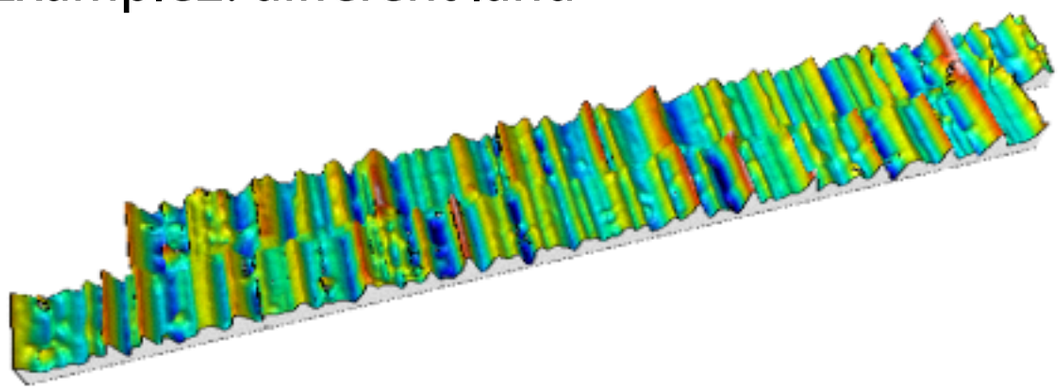


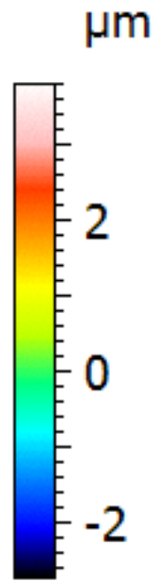


METHODOLOGY
3. IC Comparison

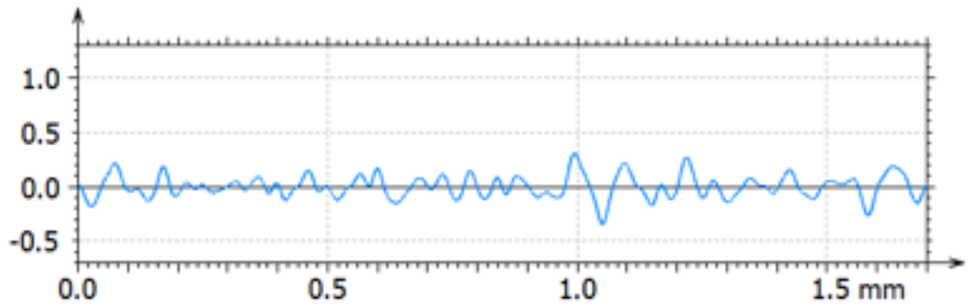
1 IC takes less than1 ms

Example2: different land

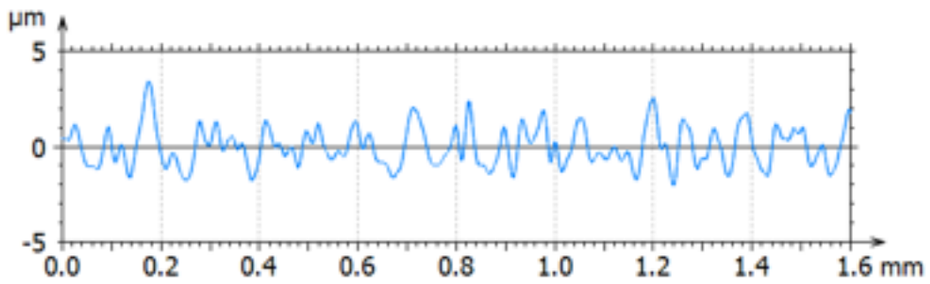


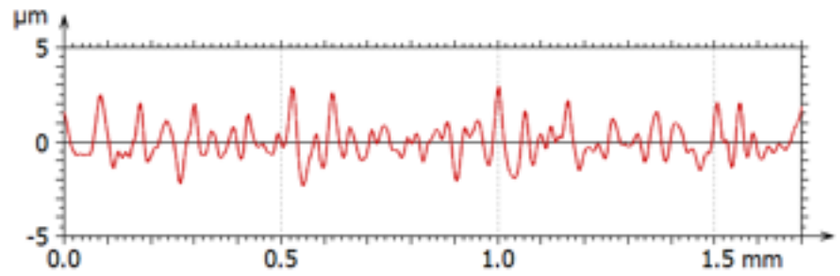


- Cross-correlation of mean profiles



CCF_{max}=0.311

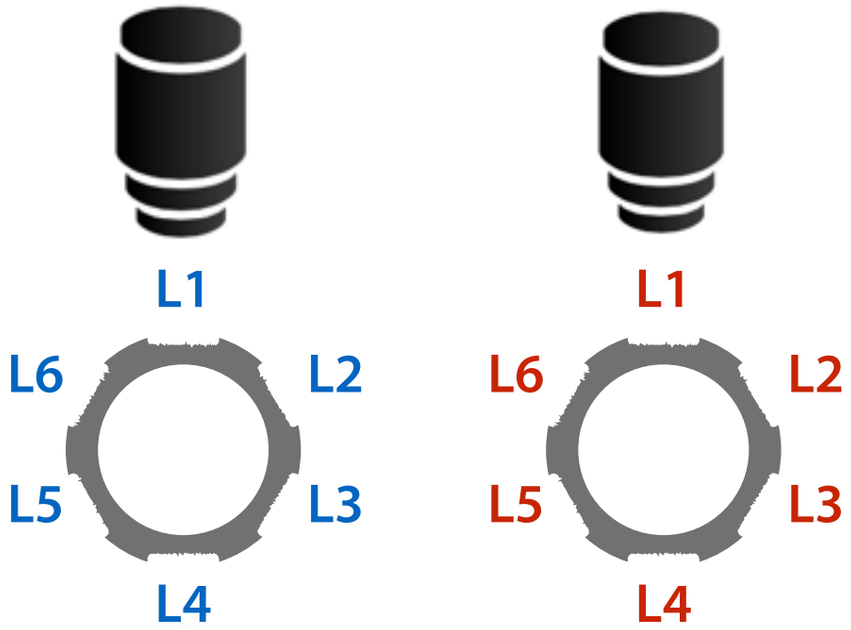




METHODOLOGY

4. Bullets comparison

Example 1: same barrel (Br10)



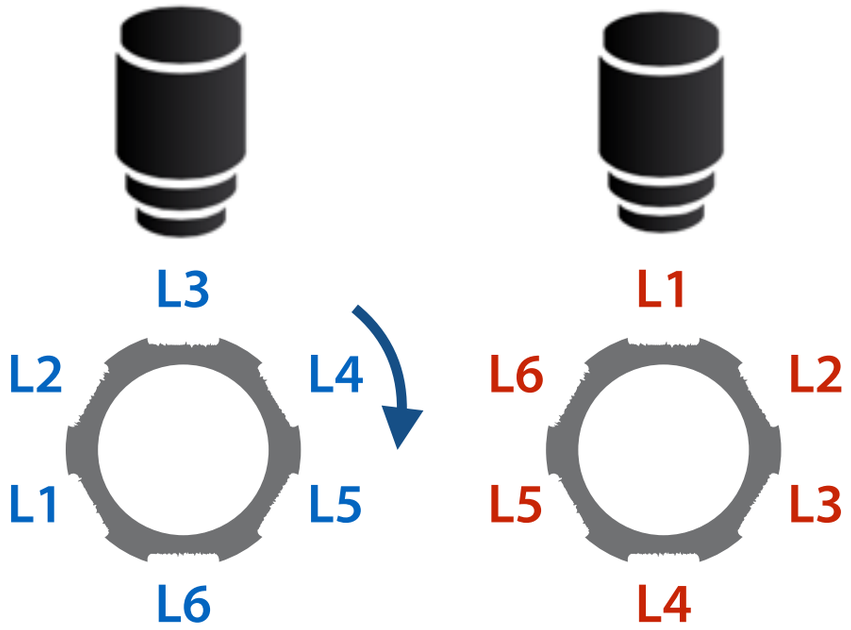
J. Hamby - 10 b1 v. 10 b2

IC	L1	L2	L3	L4	L5	L6
L1	0.22	0.27	0.94	0.26	0.34	0.30
L2	0.33	0.33	0.27	0.84	0.53	0.27
L3	0.21	0.22	0.24	0.27	0.29	0.18
L4	0.21	0.25	0.29	0.36	0.27	0.64
L5	0.79	0.28	0.23	0.34	0.39	0.25
L6	0.27	0.83	0.29	0.34	0.32	0.26

METHODOLOGY

4. Bullets comparison

Example 1: same barrel (J. Hamby Br10)



J. Hamby - 10 b1 v. 10 b2

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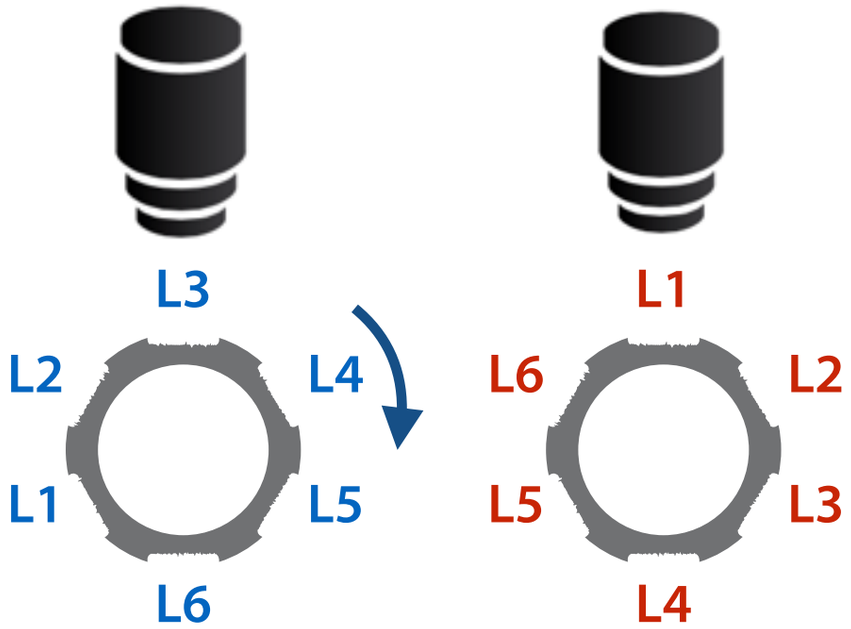
L1	0.22	0.27	0.94	0.26	0.34	0.30
L2	0.33	0.33	0.27	0.84	0.53	0.27
L3	0.21	0.22	0.24	0.27	0.29	0.18
L4	0.21	0.25	0.29	0.36	0.27	0.64
L5	0.79	0.28	0.23	0.34	0.39	0.25
L6	0.27	0.83	0.29	0.34	0.32	0.26

highlighted in green cells where $CCF_{max} > 0.5$: 6 cells

METHODOLOGY

4. Bullets comparison

Example 1: same barrel (J. Hamby Br10)



J. Hamby - 10 b1 v. 10 b2

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L1	0.22	0.27	0.94	0.26	0.34	0.30
L2	0.33	0.33	0.27	0.84	0.53	0.27
L3	0.21	0.22	0.24	0.27	0.29	0.18
L4	0.21	0.25	0.29	0.36	0.27	0.64
L5	0.79	0.28	0.23	0.34	0.39	0.25
L6	0.27	0.83	0.29	0.34	0.32	0.26

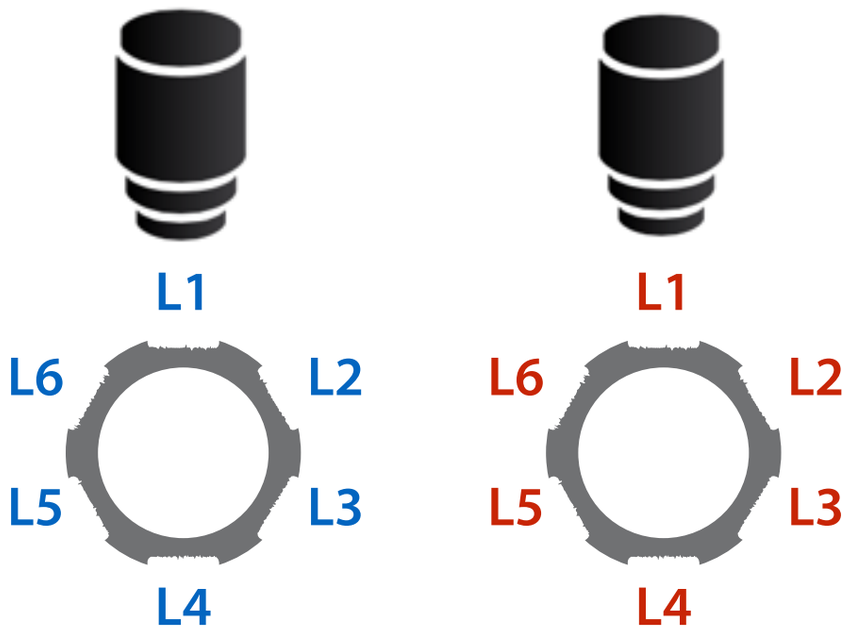
highlighted in green cells where $CCF_{max} > 0.5$: 6 cells

Identification

METHODOLOGY

4. Bullets comparison

Example 2: different barrel (J. Hamby Br7 & Br8)



J. Hamby - 7 b1 v. 8 b1

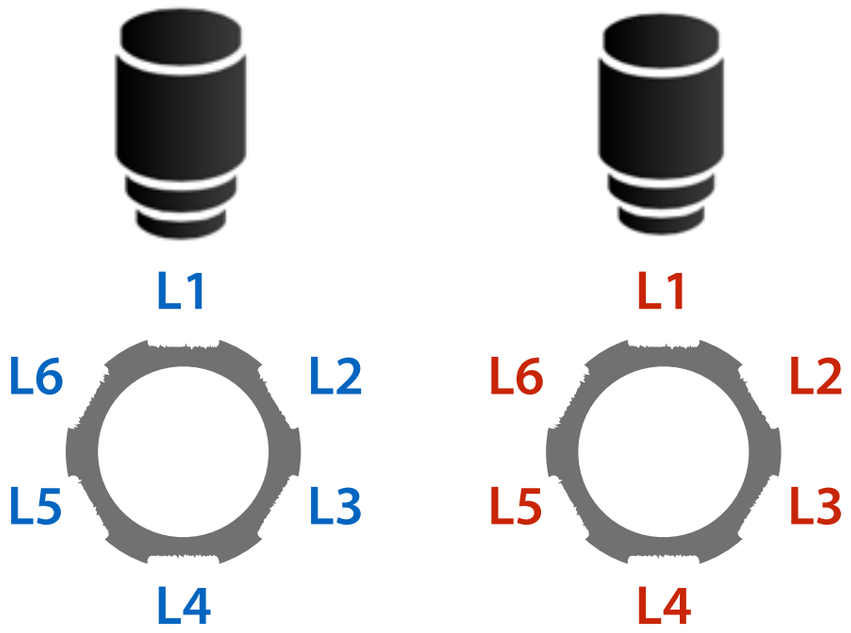
IC	L1	L2	L3	L4	L5	L6
L1	0.26	0.31	0.22	0.30	0.30	0.33
L2	0.19	0.33	0.27	0.27	0.27	0.30
L3	0.23	0.25	0.28	0.19	0.38	0.27
L4	0.30	0.21	0.26	0.23	0.33	0.34
L5	0.26	0.29	0.31	0.27	0.26	0.36
L6	0.34	0.30	0.30	0.22	0.43	0.48

highlighted in green cells where $CCF_{max} > 0.5$: 0 cells

METHODOLOGY

4. Bullets comparison

Example 2: different barrel (J. Hamby Br7 & Br8)



J. Hamby - 7 b1 v. 8 b1

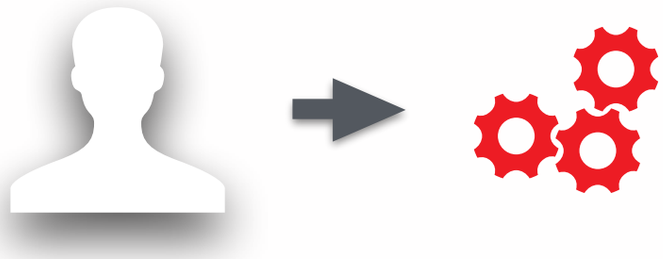
IC	L1	L2	L3	L4	L5	L6
L1	0.26	0.31	0.22	0.30	0.30	0.33
L2	0.19	0.33	0.27	0.27	0.27	0.30
L3	0.23	0.25	0.28	0.19	0.38	0.27
L4	0.30	0.21	0.26	0.23	0.33	0.34
L5	0.26	0.29	0.31	0.27	0.26	0.36
L6	0.34	0.30	0.30	0.22	0.43	0.48

highlighted in green cells where $CCF_{max} > 0.5$: 0 cells

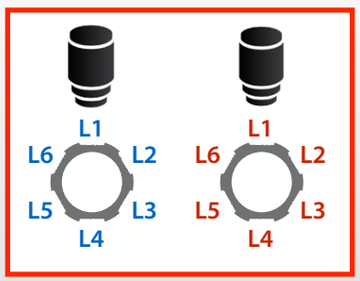
Elimination

METHODOLOGY

4. Bullets comparison



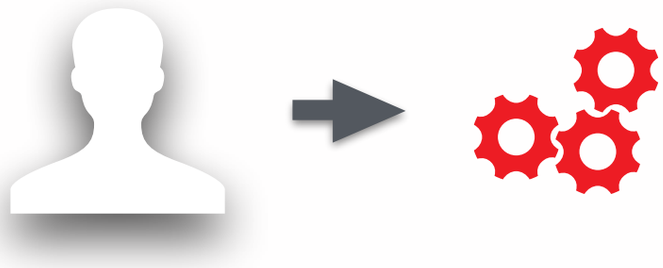
Example 1: same barrel (J. Hamby Br10)



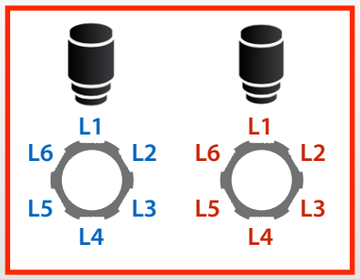
METHODOLOGY

4. Bullets comparison

- Single: Matrix maximum (**Max**)



Example 1: same barrel (J. Hamby Br10)



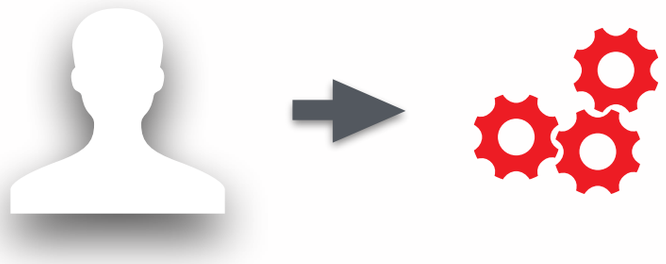
J. Hamby - 10 b1 v. 10 b2

IC	L1	L2	L3	L4	L5	L6
L1	0.22	0.27	**0.94**	0.26	0.34	0.30
L2	0.33	0.33	0.27	0.84	0.53	0.27
L3	0.21	0.22	0.24	0.27	0.29	0.18
L4	0.21	0.25	0.29	0.36	0.27	0.64
L5	0.79	0.28	0.23	0.34	0.39	0.25
L6	0.27	0.83	0.29	0.34	0.32	0.26

Max **0.94**

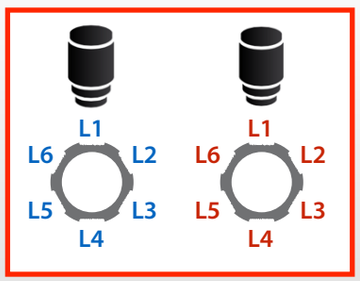
METHODOLOGY

4. Bullets comparison



- Single: Matrix maximum (**Max**)
- Composite
  - Column Maximum Average (**CMA**)

Example 1: same barrel (J. Hamby Br10)

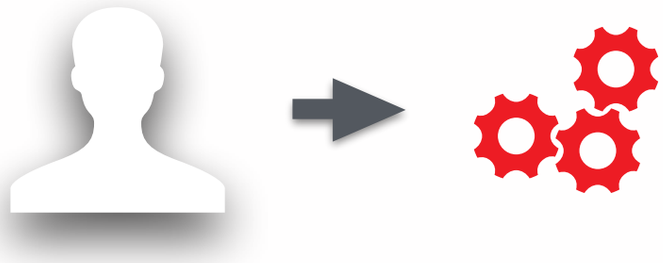


J. Hamby - 10 b1 v. 10 b2

IC	L1	L2	L3	L4	L5	L6	
L1	0.22	0.27	0.94	0.26	0.34	0.30	
L2	0.33	0.33	0.27	0.84	0.53	0.27	
L3	0.21	0.22	0.24	0.27	0.29	0.18	
L4	0.21	0.25	0.29	0.36	0.27	0.64	
L5	0.79	0.28	0.23	0.34	0.39	0.25	
L6	0.27	0.83	0.29	0.34	0.32	0.26	
							CMA
Col. Max.	0.79	0.83	0.94	0.84	0.53	0.64	0.76

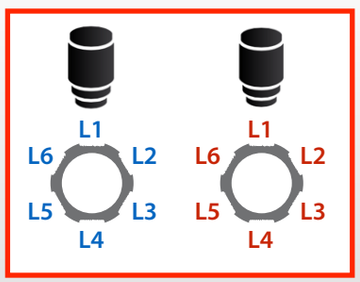
METHODOLOGY

4. Bullets comparison



- Single: Matrix maximum (**Max**)
- Composite
  - Column Maximum Average (**CMA**)
  - Sequence Average Maximum (**SAM**)

Example 1: same barrel (J. Hamby Br10)



J. Hamby - 10 b1 v. 10 b2

IC	L1	L2	L3	L4	L5	L6	Seq. Av	
L1	0.22	0.27	0.94	0.26	0.34	0.30	0.30	
L2	0.33	0.33	0.27	0.84	0.53	0.27	0.27	
L3	0.21	0.22	0.24	0.27	0.29	0.18	0.72	SAM
L4	0.21	0.25	0.29	0.36	0.27	0.64	0.29	
L5	0.79	0.28	0.23	0.34	0.39	0.25	0.27	
L6	0.27	0.83	0.29	0.34	0.32	0.26	0.30	

METHODOLOGY
4. Bullets comparison

- Statistical study of **CCF_{max}**: J. Hamby Known bullets set is compared to itself.; for every matching bullet 6 lands are Known Matches (KM) and 30 are Known Non Matches (30). For the full set we get:
  - Known Matches (180)
  - Known Non Matches (10620)

METHODOLOGY
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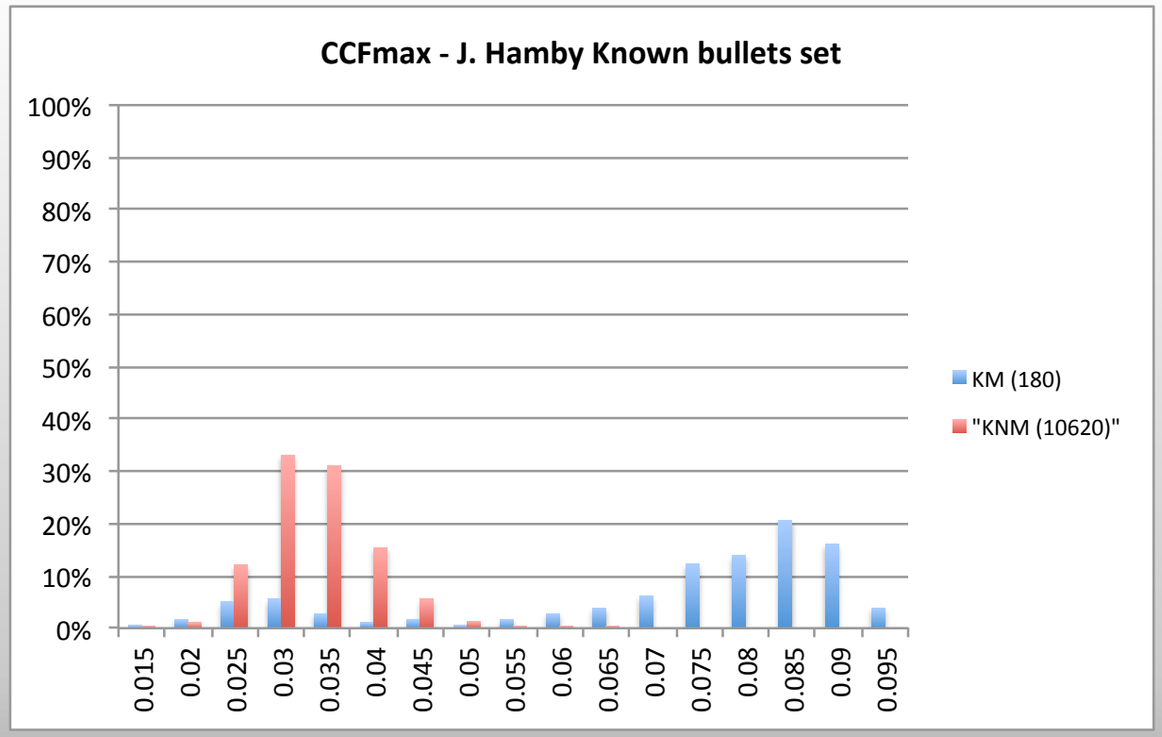

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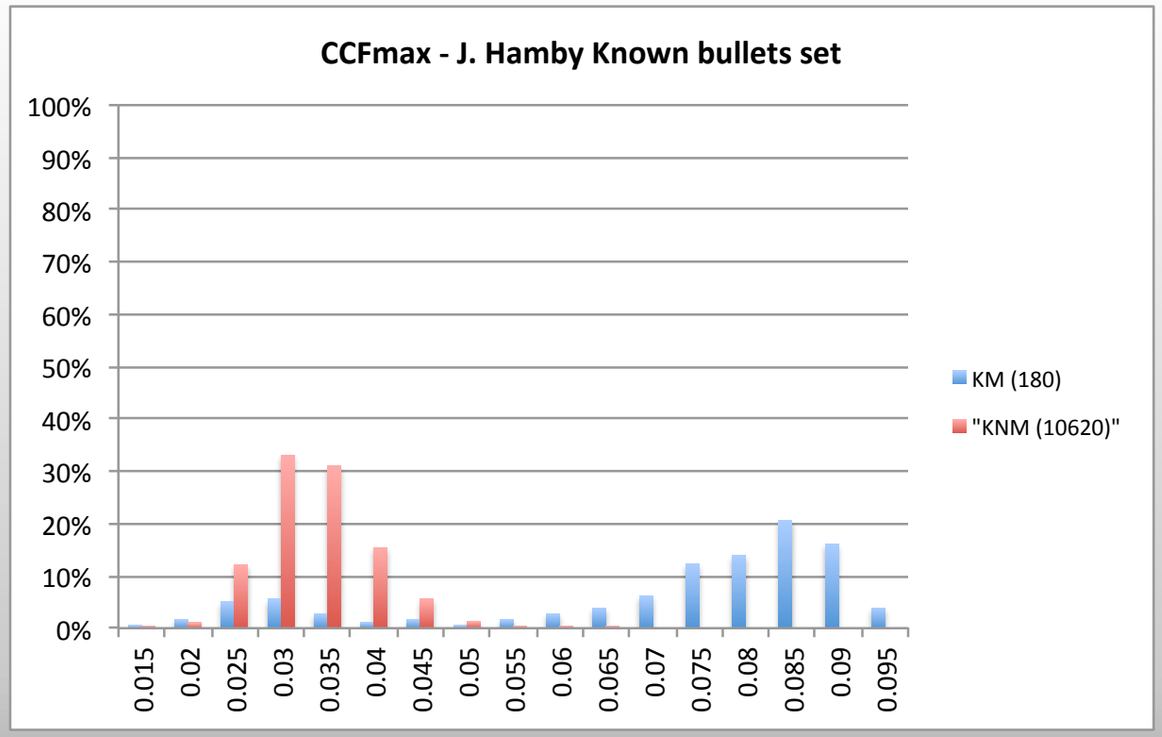
KM is bimodal



METHODOLOGY
4. Bullets comparison

- Statistical study **bullet score**: J. Hamby Known bullets set is compared to itself.; for every bullet we get 1 KM &18 KNM
  - Known Matches (20)
  - Known Non Matches (320)

METHODOLOGY
4. Bullets comparison

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  - best KNM
  - separation KM vs KNM

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  - best KNM
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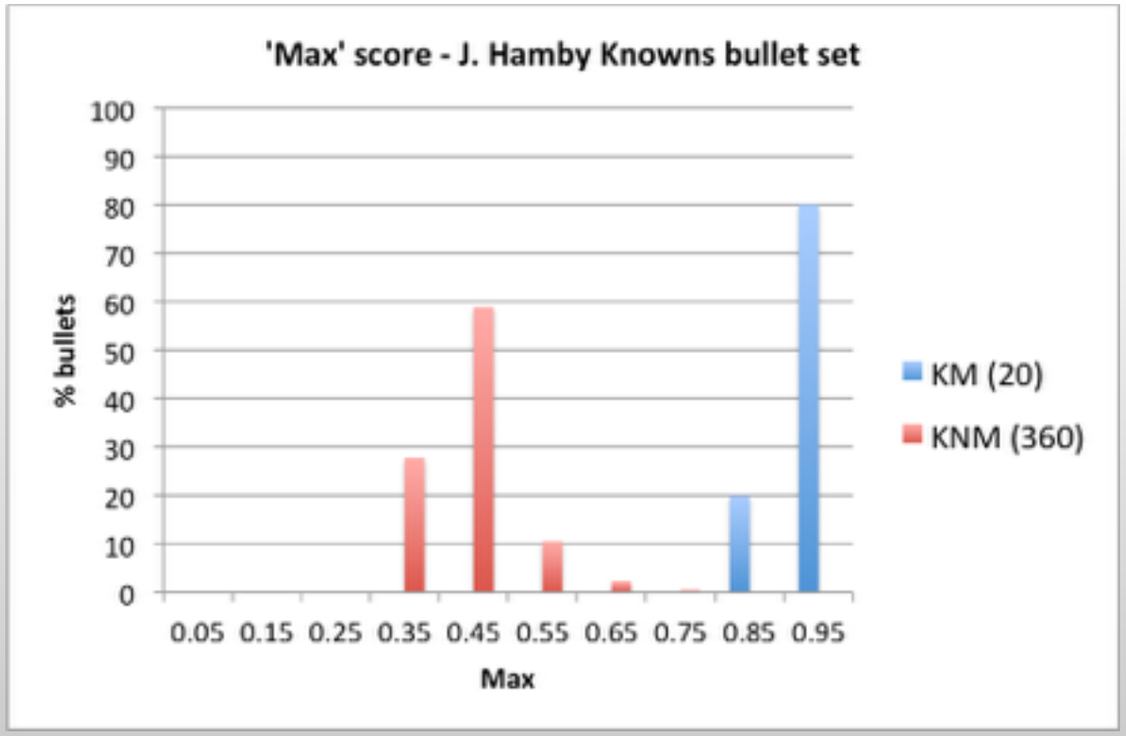

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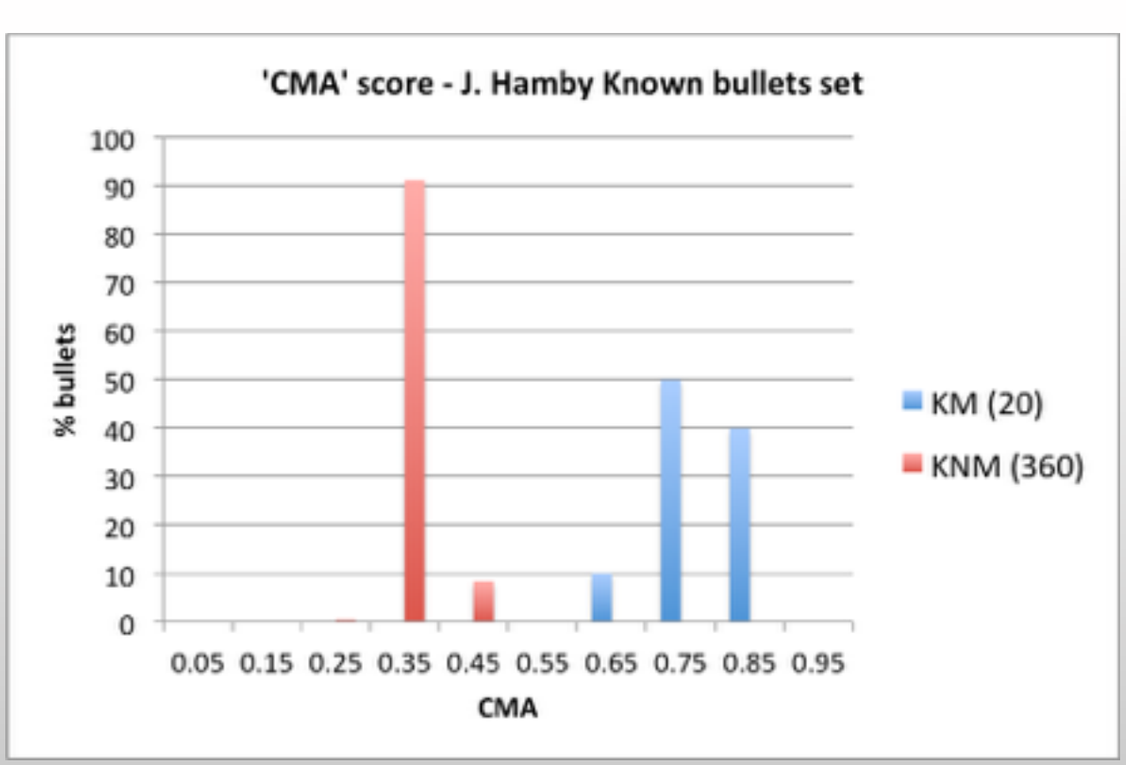

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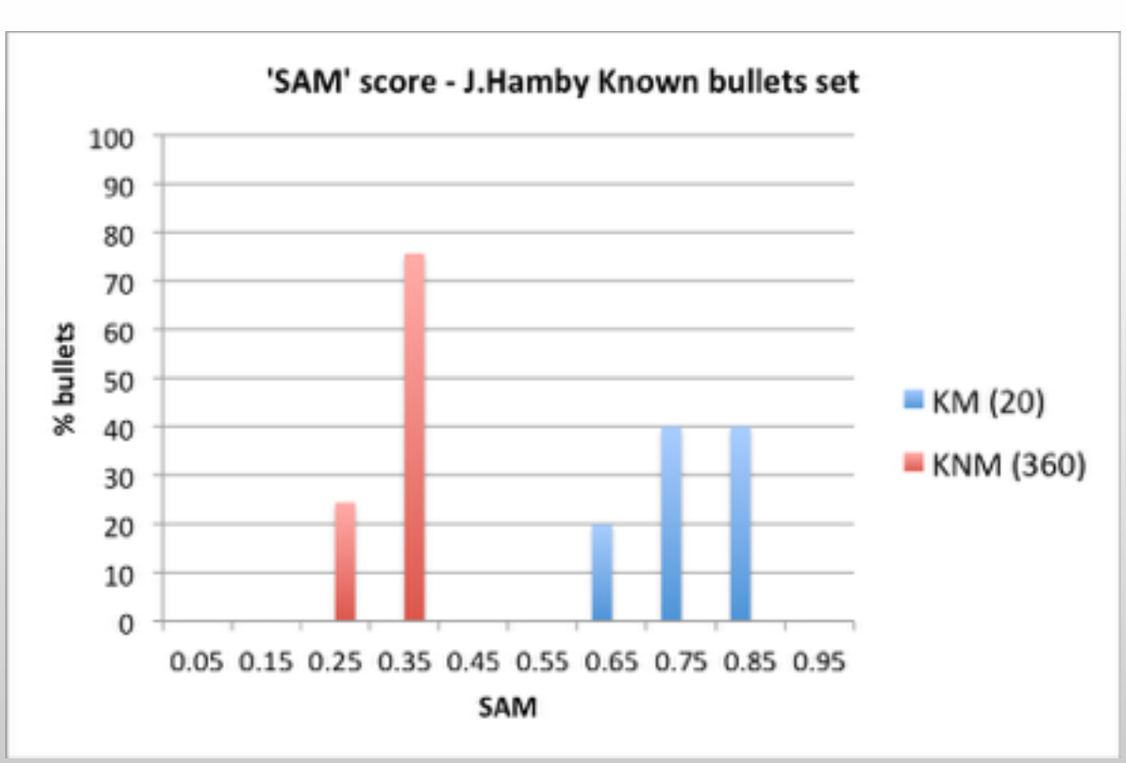

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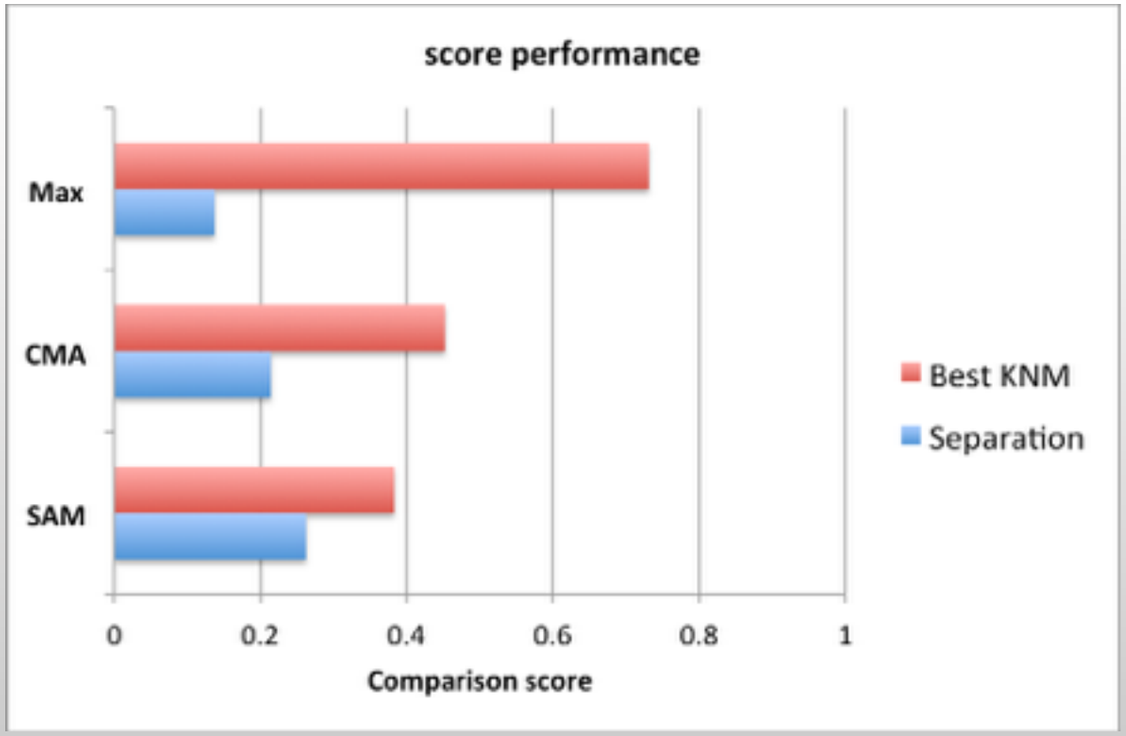

METHODOLOGY
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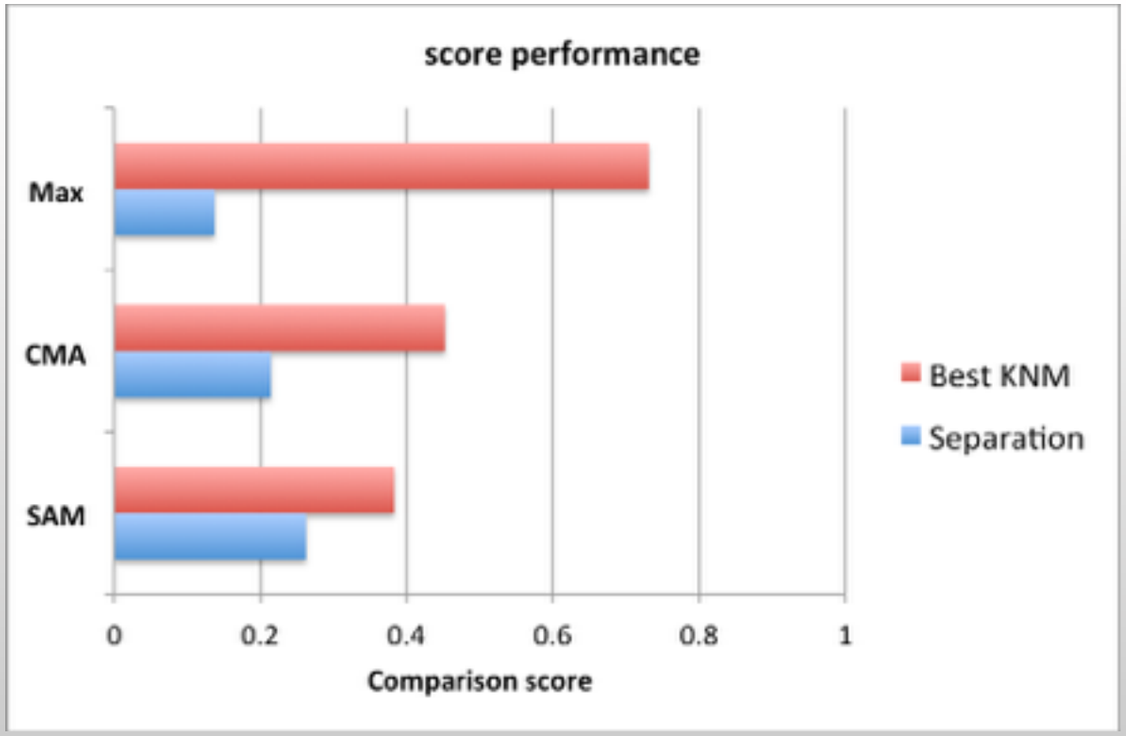
New composite score:
Sequence Average Maximum (SAM)



METHODOLOGY
4. Bullets comparison

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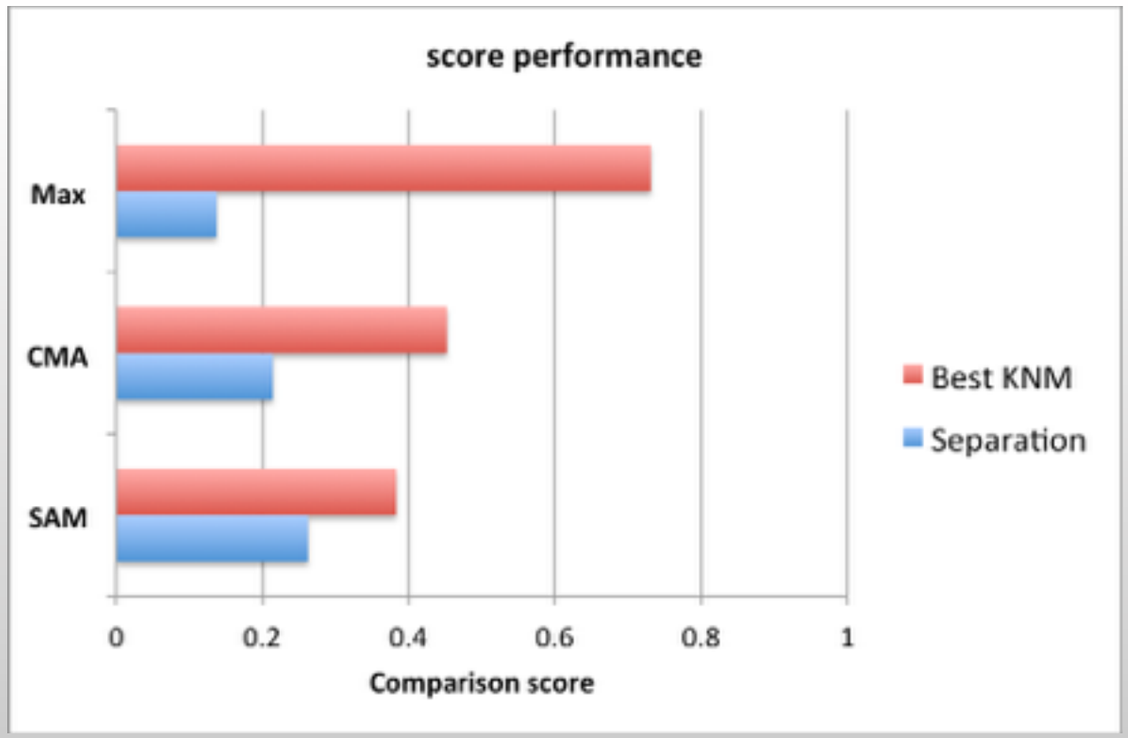

New composite score:
Sequence Average Maximum (SAM)

Identification Threshold
0.5

SENSOFAR

SUMMARY

- Overview
- Methodology
- Results
- Future
- Conclusions

RESULTS

SensoMATCH® bullet comparison engine

- Streamlines bullet comparison tasks
- Published algorithms and subject to open tests
- Result files
  - Top N list
  - SAM & match matrix
  - IC comparison matrix
- Training mode
- Missing lands management
- Customized templates
- Non-proprietary 3D inputs

RESULTS

SensoMATCH® bullet comparison engine

FBI labs

- Streamlines bullet comparison tasks
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RESULTS

SensoMATCH® bullet comparison engine

FBI labs

commercially available

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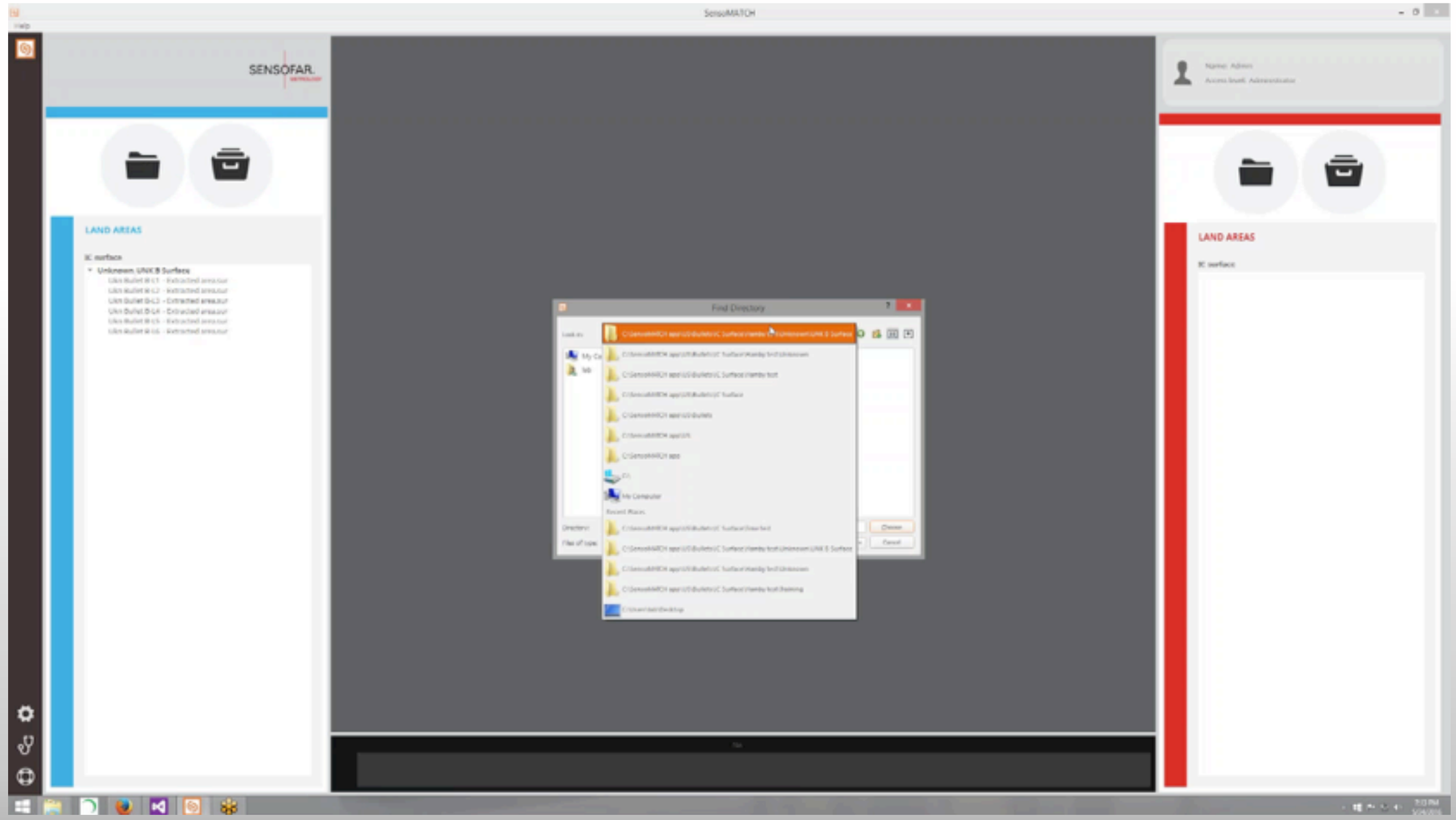
- Published algorithms and subject to open tests
- Result files
  - Top N list
  - SAM & match matrix
  - IC comparison matrix
- Training mode
- Missing lands management
- Customized templates
- Non-proprietary 3D inputs

RESULTS

Pristine bullets J. Hamby test: 15x20x6x6 (10800 IC)

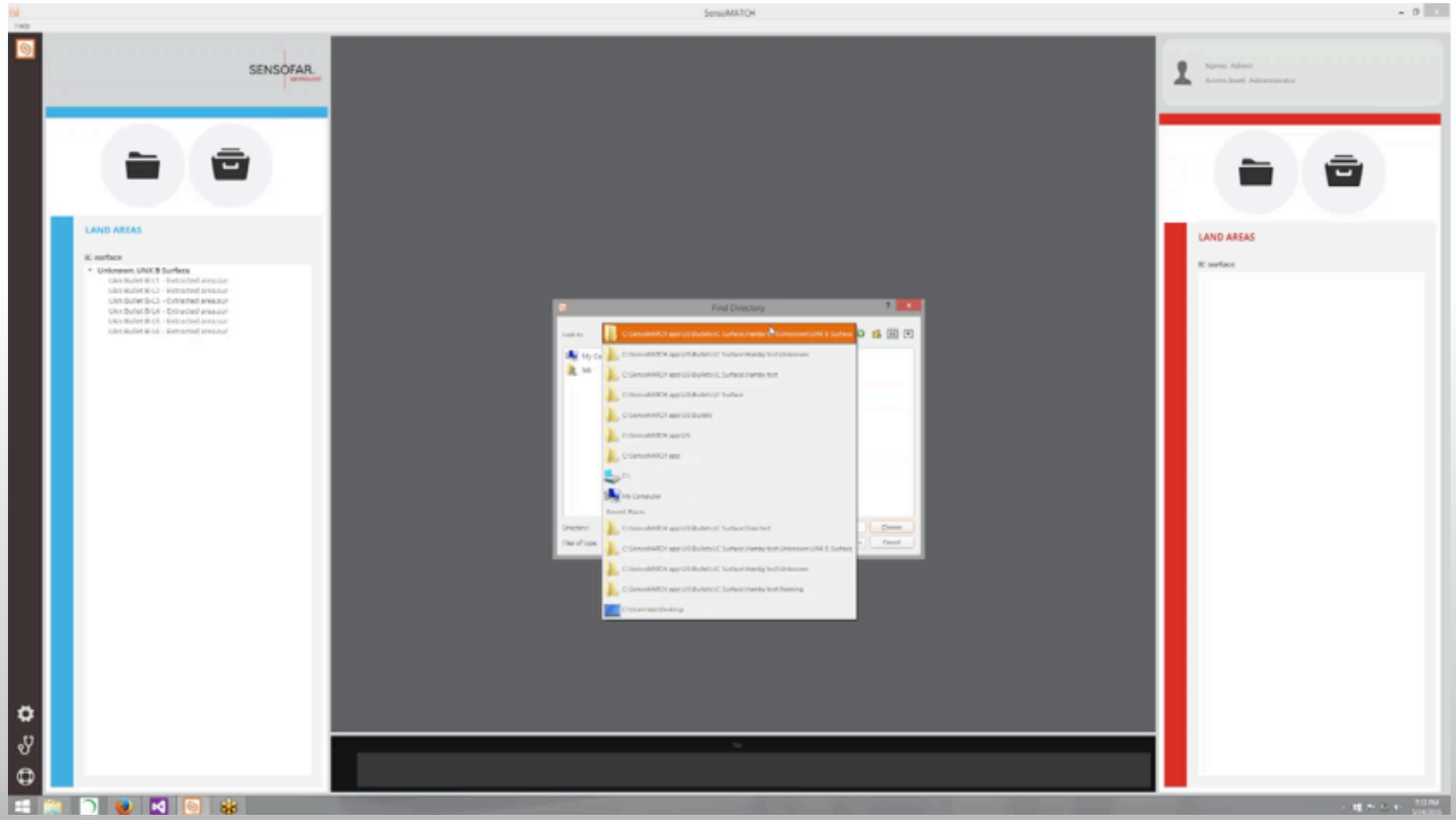
15 v. 20 bullets
takes **4 sec.**



RESULTS

Pristine bullets J. Hamby test: 15x20x6x6 (10800 IC)

15 v. 20 bullets
takes **4 sec.**



RESULTS

Pristine bullets

J. Hamby test: 15x20x6x6 (10800 IC)

15 v. 20 bullets
takes **4 sec.**

SensoMATCH (SAM>0.5)

SAM	B	C	D	E	F	H	J	L	M	Q	S	U	X	Y	Z
# Lands	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
1 b1	0.33	**0.77**	0.32	0.32	**0.77**	0.32	0.31	0.28	0.30	0.30	0.31	0.31	0.30	0.32	0.34
1 b2	0.28	**0.73**	0.31	0.31	**0.70**	0.32	0.31	0.29	0.32	0.33	0.31	0.31	0.32	0.32	0.32
2 b1	0.29	0.33	0.30	0.31	0.31	**0.81**	0.29	0.30	0.30	0.31	0.29	0.32	0.28	0.32	0.29
2 b2	0.29	0.33	0.31	0.31	0.31	**0.81**	0.30	0.29	0.29	0.32	0.30	0.31	0.31	0.31	0.30
3 b1	0.28	0.30	0.32	0.30	0.32	0.28	0.33	0.28	0.29	0.30	**0.61**	0.29	**0.64**	0.30	0.31
3 b2	0.29	0.29	0.31	0.31	0.30	0.29	0.31	0.30	0.29	0.29	**0.61**	0.30	**0.78**	0.32	0.30
4 b1	**0.67**	0.31	0.33	0.33	0.31	0.31	0.32	0.29	0.30	0.32	0.32	0.33	0.30	0.35	0.33
4 b2	**0.61**	0.32	0.33	0.35	0.31	0.29	0.31	0.32	0.32	0.32	0.32	0.35	0.31	0.34	0.34
5 b1	0.30	0.34	**0.88**	0.37	0.34	0.29	0.33	0.30	0.35	0.33	0.32	0.31	0.29	0.34	**0.85**
5 b2	0.30	0.36	**0.88**	0.39	0.35	0.31	0.33	0.32	0.36	0.35	0.34	0.32	0.32	0.35	**0.84**
6 b1	0.27	0.31	0.32	**0.78**	0.32	0.30	0.27	0.28	**0.62**	0.28	0.28	0.28	0.28	**0.74**	0.32
6 b2	0.29	0.31	0.34	**0.74**	0.32	0.28	0.30	0.28	**0.72**	0.32	0.31	0.29	0.31	**0.68**	0.31
7 b1	0.33	0.32	0.33	0.32	0.30	0.32	**0.85**	0.30	0.29	0.31	0.36	0.30	0.31	0.32	0.33
7 b2	0.32	0.33	0.31	0.33	0.31	0.29	**0.82**	0.29	0.29	0.30	0.34	0.30	0.30	0.33	0.33
8 b1	0.31	0.32	0.31	0.31	0.29	0.33	0.29	**0.78**	0.30	0.29	0.32	0.32	0.30	0.32	0.28
8 b2	0.31	0.29	0.33	0.32	0.28	0.31	0.28	**0.79**	0.31	0.30	0.32	0.32	0.28	0.31	0.28
9 b1	0.30	0.33	0.32	0.31	0.35	0.33	0.30	0.36	0.31	0.30	0.33	**0.69**	0.32	0.32	0.33
9 b2	0.29	0.32	0.32	0.31	0.31	0.31	0.32	0.33	0.32	0.29	0.32	**0.71**	0.32	0.32	0.31
10 b1	0.30	0.28	0.32	0.34	0.28	0.30	0.28	0.26	0.31	**0.55**	0.32	0.31	0.29	0.34	0.34
10 b2	0.31	0.32	0.34	0.36	0.32	0.31	0.31	0.31	0.30	**0.60**	0.34	0.32	0.32	0.35	0.32

NIST reference

	B	C	D	E	F	H	J	L	M	Q	S	U	X	Y	Z
	4	1	5	6	1	2	7	8	6	10	3	9	3	6	5
Result	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

RESULTS

Pristine bullets

J. Hamby test: 15x20x6x6 (10800 IC)

15 v. 20 bullets
takes **4 sec.**

SensoMATCH (SAM>0.5)

SAM	B	C	D	E	F	H	J	L	M	Q	S	U	X	Y	Z
# Lands	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
1 b1	0.33	**0.77**	0.32	0.32	**0.77**	0.32	0.31	0.28	0.30	0.30	0.31	0.31	0.30	0.32	0.34
1 b2	0.28	**0.73**	0.31	0.31	**0.70**	0.32	0.31	0.29	0.32	0.33	0.31	0.31	0.32	0.32	0.32
2 b1	0.29	0.33	0.30	0.31	0.31	**0.81**	0.29	0.30	0.30	0.31	0.29	0.32	0.28	0.32	0.29
2 b2	0.29	0.33	0.31	0.31	0.31	**0.81**	0.30	0.29	0.29	0.32	0.30	0.31	0.31	0.31	0.30
3 b1	0.28	0.30	0.32	0.30	0.32	0.28	0.33	0.28	0.29	0.30	**0.61**	0.29	**0.64**	0.30	0.31
3 b2	0.29	0.29	0.31	0.31	0.30	0.29	0.31	0.30	0.29	0.29	**0.61**	0.30	**0.78**	0.32	0.30
4 b1	**0.67**	0.31	0.33	0.33	0.31	0.31	0.32	0.29	0.30	0.32	0.32	0.33	0.30	0.35	0.33
4 b2	**0.61**	0.32	0.33	0.35	0.31	0.29	0.31	0.32	0.32	0.32	0.32	0.35	0.31	0.34	0.34
5 b1	0.30	0.34	**0.88**	0.37	0.34	0.29	0.33	0.30	0.35	0.33	0.32	0.31	0.29	0.34	**0.85**
5 b2	0.30	0.36	**0.88**	0.39	0.35	0.31	0.33	0.32	0.36	0.35	0.34	0.32	0.32	0.35	**0.84**
6 b1	0.27	0.31	0.32	**0.78**	0.32	0.30	0.27	0.28	**0.62**	0.28	0.28	0.28	0.28	**0.74**	0.32
6 b2	0.29	0.31	0.34	**0.74**	0.32	0.28	0.30	0.28	**0.72**	0.32	0.31	0.29	0.31	**0.68**	0.31
7 b1	0.33	0.32	0.33	0.32	0.30	0.32	**0.85**	0.30	0.29	0.31	0.36	0.30	0.31	0.32	0.33
7 b2	0.32	0.33	0.31	0.33	0.31	0.29	**0.82**	0.29	0.29	0.30	0.34	0.30	0.30	0.33	0.33
8 b1	0.31	0.32	0.31	0.31	0.29	0.33	0.29	**0.78**	0.30	0.29	0.32	0.32	0.30	0.32	0.28
8 b2	0.31	0.29	0.33	0.32	0.28	0.31	0.28	**0.79**	0.31	0.30	0.32	0.32	0.28	0.31	0.28
9 b1	0.30	0.33	0.32	0.31	0.35	0.33	0.30	0.36	0.31	0.30	0.33	**0.69**	0.32	0.32	0.33
9 b2	0.29	0.32	0.32	0.31	0.31	0.31	0.32	0.33	0.32	0.29	0.32	**0.71**	0.32	0.32	0.31
10 b1	0.30	0.28	0.32	0.34	0.28	0.30	0.28	0.26	0.31	**0.55**	0.32	0.31	0.29	0.34	0.34
10 b2	0.31	0.32	0.34	0.36	0.32	0.31	0.31	0.31	0.30	**0.60**	0.34	0.32	0.32	0.35	0.32

NIST reference

	B	C	D	E	F	H	J	L	M	Q	S	U	X	Y	Z
	4	1	5	6	1	2	7	8	6	10	3	9	3	6	5
Result	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Identification
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RESULTS

Damaged or fragmented bullets

J. Hamby test - random lands elimination: 15x20x6xN (4080 IC)

15 v. 20 bullets
takes 3 **sec.**

SensoMATCH (SAM>0.5)

SAM	B	C	D	E	F	H	J	L	M	Q	S	U	X	Y	Z
# Lands	6	2	3	2	3	2	3	2	2	3	3	2	1	1	1
1 b1	0.37	**0.88**	0.31	0.30	**0.63**	0.36	0.33	0.30	0.33	0.30	0.31	0.36	0.32	0.39	0.30
1 b2	0.29	**0.90**	0.33	0.32	**0.51**	0.34	0.35	0.31	0.32	0.31	0.32	0.38	0.30	0.42	0.30
2 b1	0.29	0.40	0.32	0.34	0.34	**0.80**	0.32	0.28	0.31	0.33	0.30	0.33	0.31	0.34	0.31
2 b2	0.29	0.38	0.30	0.33	0.32	**0.75**	0.35	0.29	0.31	0.34	0.30	0.35	0.31	0.44	0.34
3 b1	0.30	0.34	0.31	0.31	0.30	0.33	0.31	0.31	0.30	0.30	**0.63**	0.32	**0.81**	0.37	0.36
3 b2	0.32	0.35	0.33	0.33	0.33	0.27	0.34	0.32	0.31	0.32	**0.63**	0.33	**0.71**	0.35	0.34
4 b1	**0.59**	0.39	0.34	0.36	0.32	0.38	0.36	0.33	0.32	0.33	0.32	0.37	0.34	0.45	0.39
4 b2	**0.52**	0.42	0.33	0.40	0.31	0.40	0.34	0.39	0.36	0.33	0.35	0.38	0.34	0.42	0.33
5 b1	0.32	0.44	**0.91**	0.36	0.33	0.34	0.38	0.32	0.42	0.34	0.33	0.34	0.33	0.37	**0.88**
5 b2	0.31	0.44	**0.91**	0.38	0.32	0.35	0.40	0.31	0.44	0.35	0.36	0.36	0.32	0.38	**0.91**
6 b1	0.26	0.34	0.32	**0.63**	0.33	0.32	0.30	0.28	**0.63**	0.28	0.28	0.31	0.30	0.36	0.34
6 b2	0.30	0.34	0.34	**0.84**	0.31	0.33	0.34	0.33	**0.90**	0.31	0.33	0.34	0.39	0.47	0.35
7 b1	0.34	0.35	0.39	0.33	0.32	0.31	**0.89**	0.31	0.33	0.33	0.38	0.37	0.38	0.37	0.41
7 b2	0.32	0.34	0.34	0.31	0.32	0.31	**0.82**	0.32	0.31	0.32	0.34	0.33	0.39	0.38	0.33
8 b1	0.31	0.33	0.34	0.34	0.32	0.32	0.29	**0.67**	0.35	0.32	0.29	0.36	0.34	0.43	0.33
8 b2	0.31	0.32	0.37	0.32	0.30	0.33	0.30	**0.66**	0.36	0.31	0.31	0.37	0.32	0.39	0.32
9 b1	0.29	0.38	0.33	0.32	0.37	0.35	0.35	0.39	0.34	0.32	0.33	**0.61**	0.34	0.36	0.34
9 b2	0.30	0.36	0.32	0.33	0.34	0.35	0.36	0.36	0.34	0.33	0.36	**0.66**	0.42	0.36	0.30
10 b1	0.32	0.31	0.31	0.33	0.32	0.30	0.30	0.28	0.30	**0.65**	0.30	0.39	0.32	0.39	0.30
10 b2	0.34	0.36	0.34	0.36	0.30	0.32	0.33	0.38	0.33	**0.70**	0.36	0.43	0.36	0.42	0.32

NIST reference

	B	C	D	E	F	H	J	L	M	Q	S	U	X	Y	Z
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Result	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓

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Damaged or fragmented bullets

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SAM	B	C	D	E	F	H	J	L	M	Q	S	U	X	Y	Z
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1 b1	0.37	**0.88**	0.31	0.30	**0.63**	0.36	0.33	0.30	0.33	0.30	0.31	0.36	0.32	0.39	0.30
1 b2	0.29	**0.90**	0.33	0.32	**0.51**	0.34	0.35	0.31	0.32	0.31	0.32	0.38	0.30	0.42	0.30
2 b1	0.29	0.40	0.32	0.34	0.34	**0.80**	0.32	0.28	0.31	0.33	0.30	0.33	0.31	0.34	0.31
2 b2	0.29	0.38	0.30	0.33	0.32	**0.75**	0.35	0.29	0.31	0.34	0.30	0.35	0.31	0.44	0.34
3 b1	0.30	0.34	0.31	0.31	0.30	0.33	0.31	0.31	0.30	0.30	**0.63**	0.32	**0.81**	0.37	0.36
3 b2	0.32	0.35	0.33	0.33	0.33	0.27	0.34	0.32	0.31	0.32	**0.63**	0.33	**0.71**	0.35	0.34
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5 b1	0.32	0.44	**0.91**	0.36	0.33	0.34	0.38	0.32	0.42	0.34	0.33	0.34	0.33	0.37	**0.88**
5 b2	0.31	0.44	**0.91**	0.38	0.32	0.35	0.40	0.31	0.44	0.35	0.36	0.36	0.32	0.38	**0.91**
6 b1	0.26	0.34	0.32	**0.63**	0.33	0.32	0.30	0.28	**0.63**	0.28	0.28	0.31	0.30	0.36	0.34
6 b2	0.30	0.34	0.34	**0.84**	0.31	0.33	0.34	0.33	**0.90**	0.31	0.33	0.34	0.39	0.47	0.35
7 b1	0.34	0.35	0.39	0.33	0.32	0.31	**0.89**	0.31	0.33	0.33	0.38	0.37	0.38	0.37	0.41
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8 b1	0.31	0.33	0.34	0.34	0.32	0.32	0.29	**0.67**	0.35	0.32	0.29	0.36	0.34	0.43	0.33
8 b2	0.31	0.32	0.37	0.32	0.30	0.33	0.30	**0.66**	0.36	0.31	0.31	0.37	0.32	0.39	0.32
9 b1	0.29	0.38	0.33	0.32	0.37	0.35	0.35	0.39	0.34	0.32	0.33	**0.61**	0.34	0.36	0.34
9 b2	0.30	0.36	0.32	0.33	0.34	0.35	0.36	0.36	0.34	0.33	0.36	**0.66**	0.42	0.36	0.30
10 b1	0.32	0.31	0.31	0.33	0.32	0.30	0.30	0.28	0.30	**0.65**	0.30	0.39	0.32	0.39	0.30
10 b2	0.34	0.36	0.34	0.36	0.30	0.32	0.33	0.38	0.33	**0.70**	0.36	0.43	0.36	0.42	0.32

NIST reference

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Result	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✓

Identification
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SUMMARY

- Overview
- Methodology
- Results
- Future
- Conclusions

FUTURE

Open questions ?

- influence of IC extraction template & it's automation
- influence of IC comparison parameter
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Adapt methodology & SensoMATCH to Cartridge cases

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We're ready to help

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CONCLUSIONS

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1. New methodology for for bullet analysis using high-resolution optical 3D surface metrology: **separating IC extraction from IC comparison streamlines batch comparison tasks & allows lighter databases**

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4. Study of automated bullet comparison scores: Max, CMA and **SAM = new composite score**
5. **SensoMATCH bullet comparison engine** solves J. Hamby test in 4 seconds. **New tool for R&D** (easy, flexible & open)

Than you for your attention!

Cristina Cadevall
cadevall@sensofar.com

come & visit us at Sensofar LLC
www.sensofar-us.com
Exhibition hall
Workshop on Thursday 2nd June at 1pm