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Congruent Matching Profile Segments (CMPS) Method for Objective Comparison of Deformed Bullets

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Outline:

1. Motivation
2. Overview -- samples, measurements and filter process
3. Challenges to correlations of deformed bullets
4. Profile/image re-construction process
5. CMPS method
6. Correlation results for deformed reference bullets
7. Correlation results for pristine reference bullets
8. Correlation results for different bullet jackets
9. Discussion and future work

Motivation

- For research of bullet identifications, the bullet samples used in validation tests are often pristine.
- However, the bullets found at a crime scene are often deformed or fragmented.
- Firearm examiners face additional challenges when comparing these samples.
- This study addresses the comparison of deformed bullets.

By Courtesy of Ultra Electronics Forensic Technology, Inc.

Overview of the samples

- 57 bullets of 7 ammo brands (in 7 bags) were received.
- All bullets were fired from the same 9 mm Luger pistol.

With different types of ammo brands, this test considers:

1. bullet design.
2. bullet jacket material, even with the same kind of metal (like copper), the hardness or other characteristics of the jacket between different ammo brands can be different.
3. firing performance, mainly affected by the types and quantities of gunpowder.

Overview of the samples

Bag 1: 6 Remington UMC (copper)

Bag 2: 8 PMC Starfire (copper)

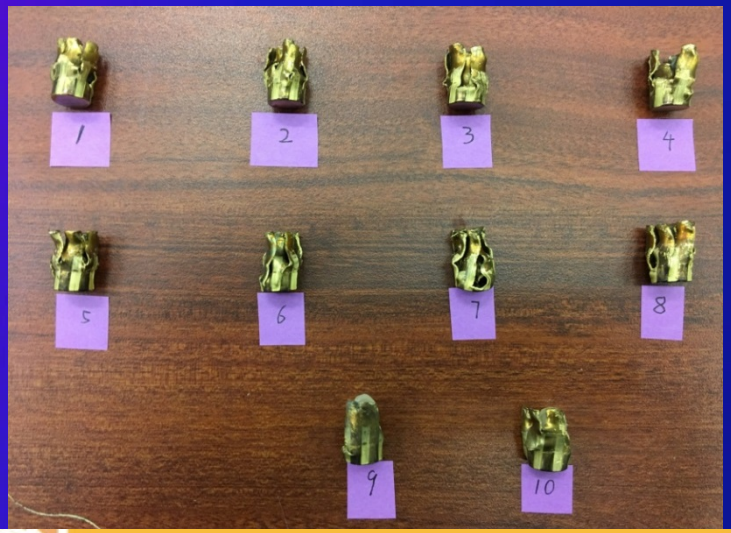
Bag 3: 7 Speer Gold Dot (copper)

Bag 4: 8 Hornady (copper)

(continued)

Bag 5: 9 Federal Premium (copper)

Bag 6: 9 Federal Classic (copper)



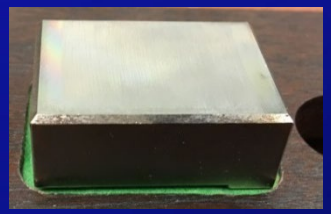
Bag 7: 10 Remington Golden Saber (brass)

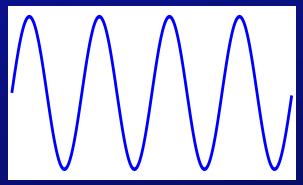
Brass is an alloy of copper and zinc, which is harder than pure copper. The color is also different with copper.

Overview of measurements

The bullets were measured using a confocal microscope. For each measurement day, the measurement procedures were:

1. Mirror calibration to create a reference for the microscope.
2. Check SRM 2073, sinusoid, λc = 0.8 mm, Ra = 3.054 ± 0.038 µm.





3. Check SRM 2460 standard bullet land engraved area (LEA) #1.

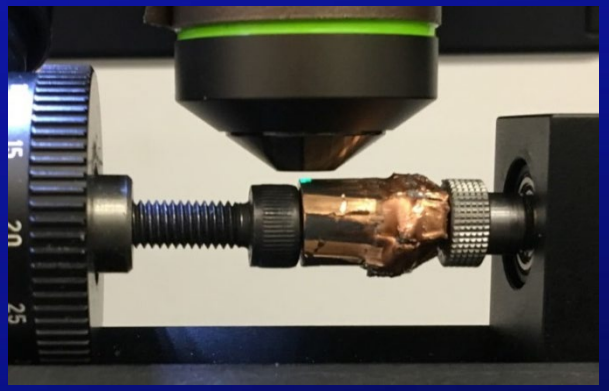
3. Measure bullet samples.
4. Re-check using the two specimens in step 2 and 3.

Overview of measurements

Measurement of relatively intact samples

Metal jacket adheres to the lead core. Nose area expanded due to impact.

Use pliers to bend the nose. Be careful to avoid contact with the base, keep the LEAs on the base untouched.

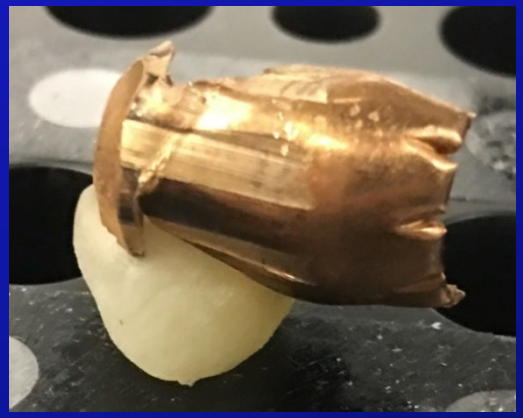


Put the sample on the holder. Sometimes wax is needed on the nose area for fixture.

(continued)

Measurement of deformed and fragmented samples

Metal jacket is detached from the lead core. Pliers were used to bend the jacket to make it measurable.



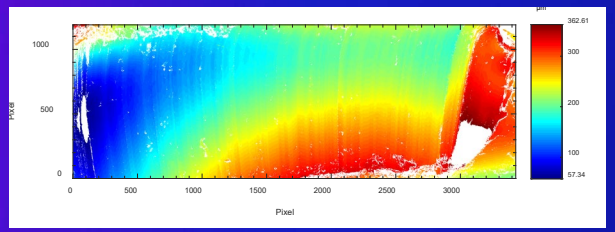
Hold the sample by wax, then wait until the wax fully solidifies. It took about 4~5 minutes for the solidification process.

We used a 20X objective (NA 0.6). The pixel separation distance was 0.68 µm

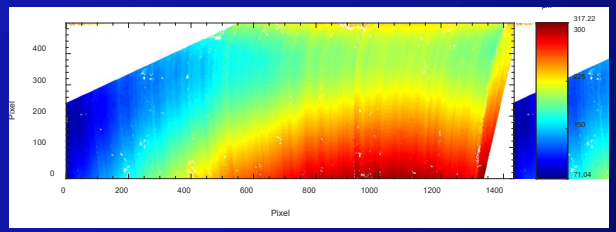
Image pre-processing

- Some outliers, dropouts, and all shoulders of the topography images were removed manually. The pixel spacing was then decreased to 1.35 µm.
- A 2nd-order Gaussian regression high pass filter was applied with a cut-off length λc = 250 µm.

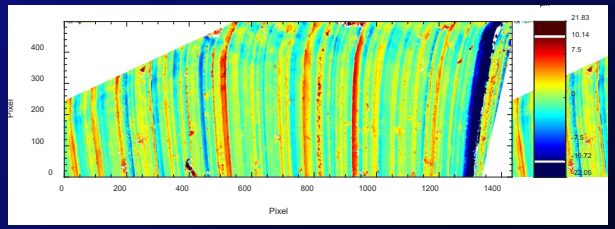
Original topography



Remove shoulders and decrease pixel spacing



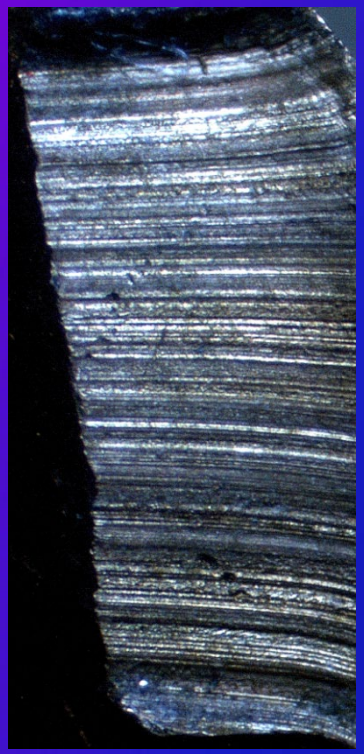
Filtered topography



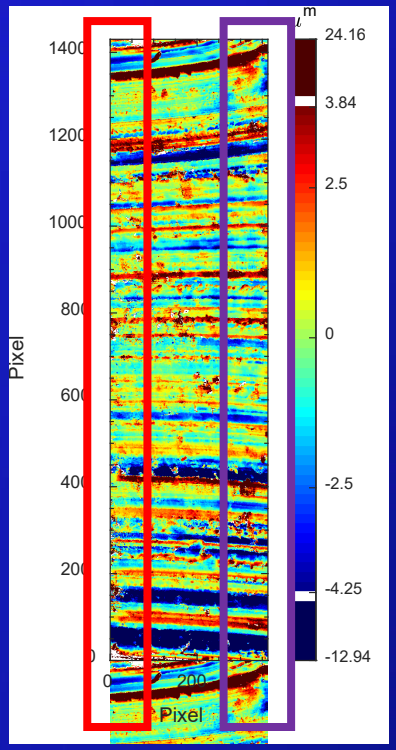
Challenge to correlation of deformed bullets

When fired bullets hit a solid surface like a wall or decelerate in a body or water tank, the nose of the bullet may expand.

Optical image



Filtered topography



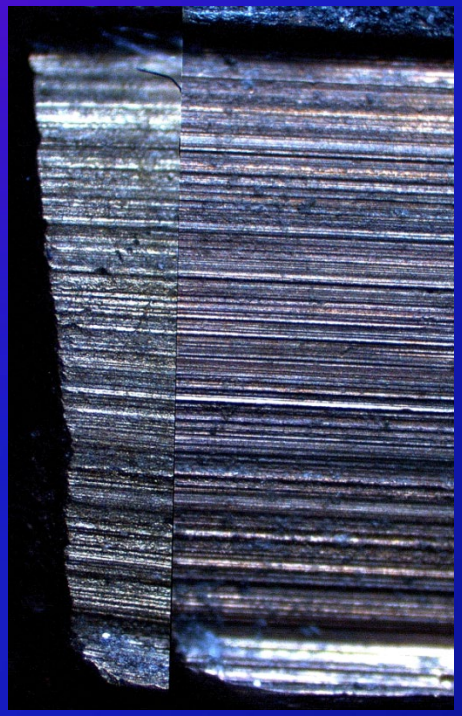
Base area of the bullet land engraved area (LEA) is without or with minor deformation, which can be used as a reference for the image re-construction.

Towards the nose area of the bullet, the LEA is expanded.

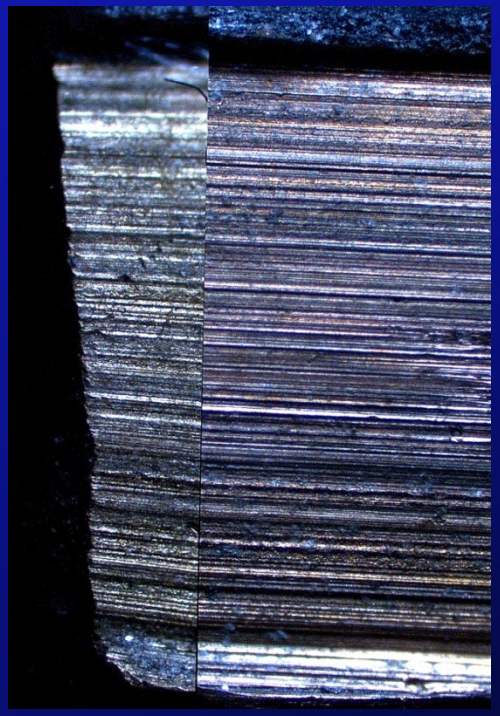
The LEA expansion is higher near the shoulders, and smaller at the central part.

Deformed bullet comparison using a comparison microscope

Upper part matched



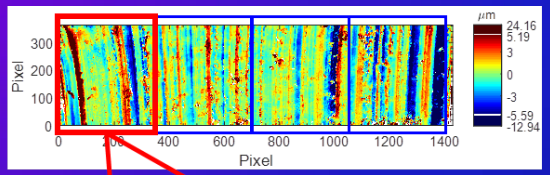
Lower part matched



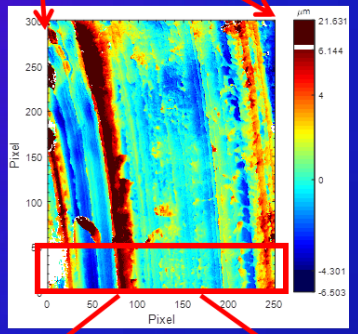
The left bullet is expanded, which makes it difficult to match the whole land engraved area (LEA) with the right reference bullet.

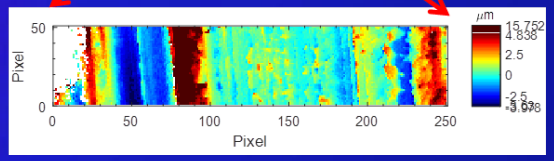
Profile/image re-construction

a.

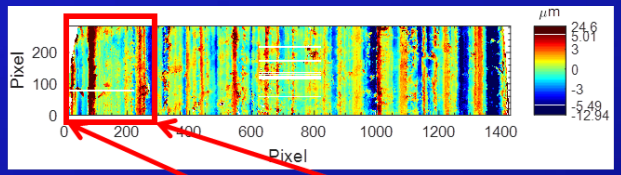


b.

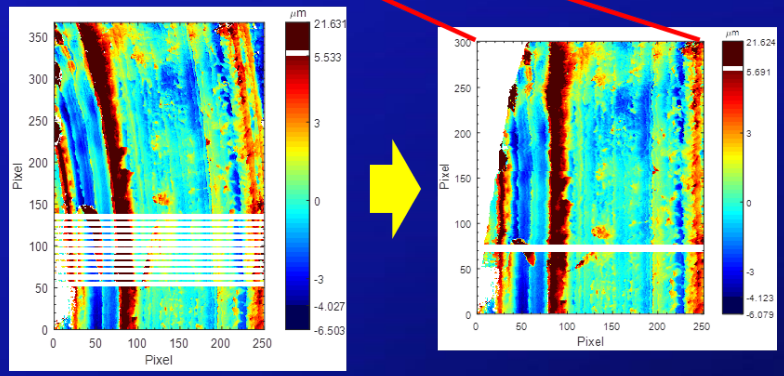




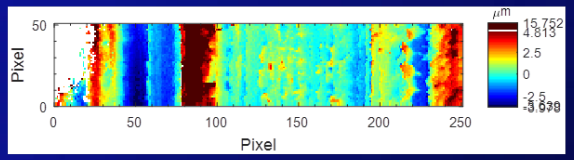
e.



d.



c.



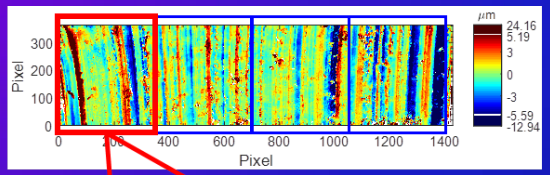
a. Divide the LEA image horizontally into segments.

b. For each segment, find the base part with least deformation.

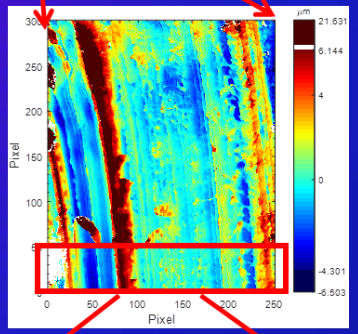
c. Align the profiles of the base part to create a reference for the segment.

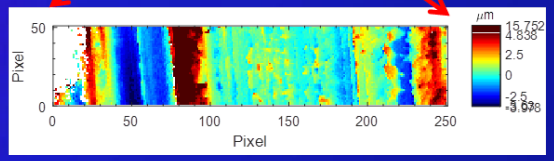
(continued)

a.

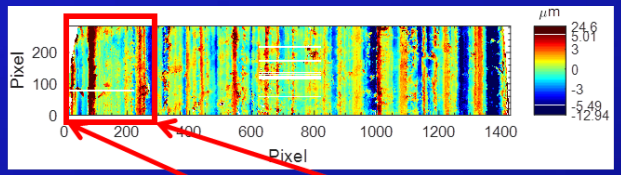


b.

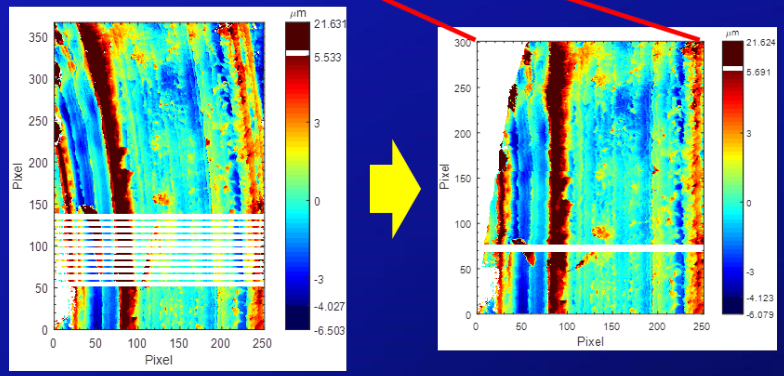




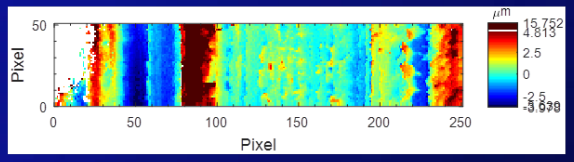
e.



d.



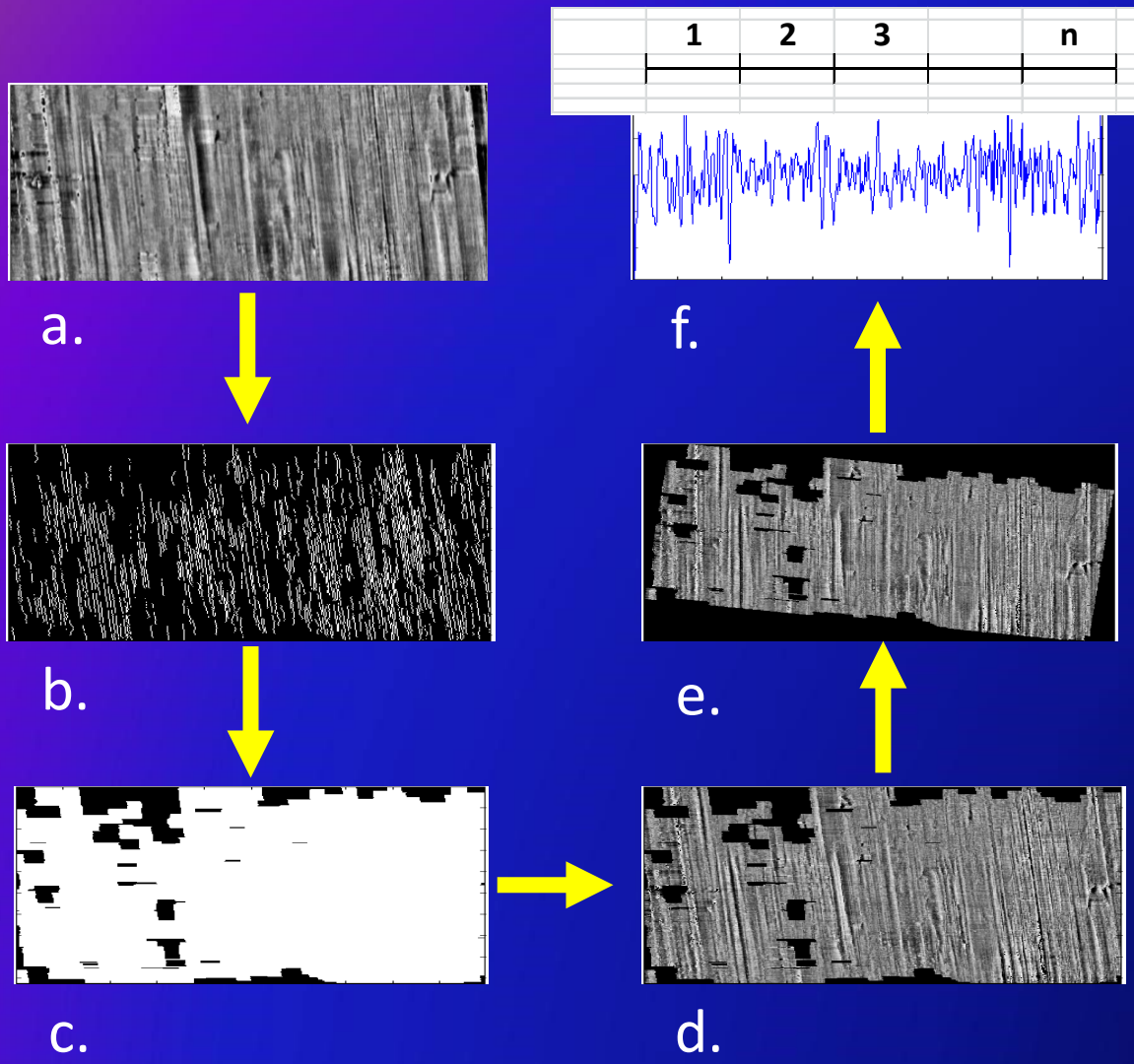
c.



e. Re-construct the segment image by moving and scaling each of the remaining profile sections to match the base reference.

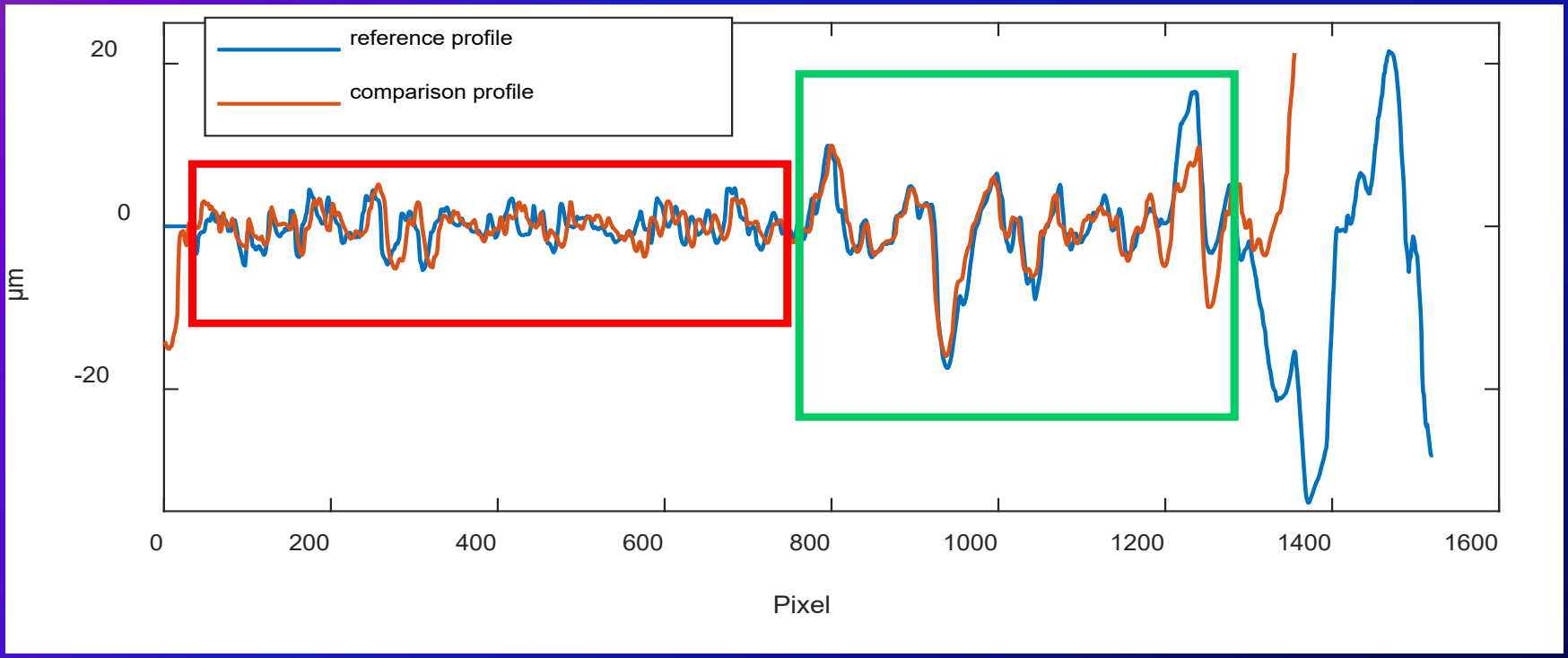
f. Stitch the re-constructed segment images together.

Image processing (obtain LEA profile)



a. Filtered 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

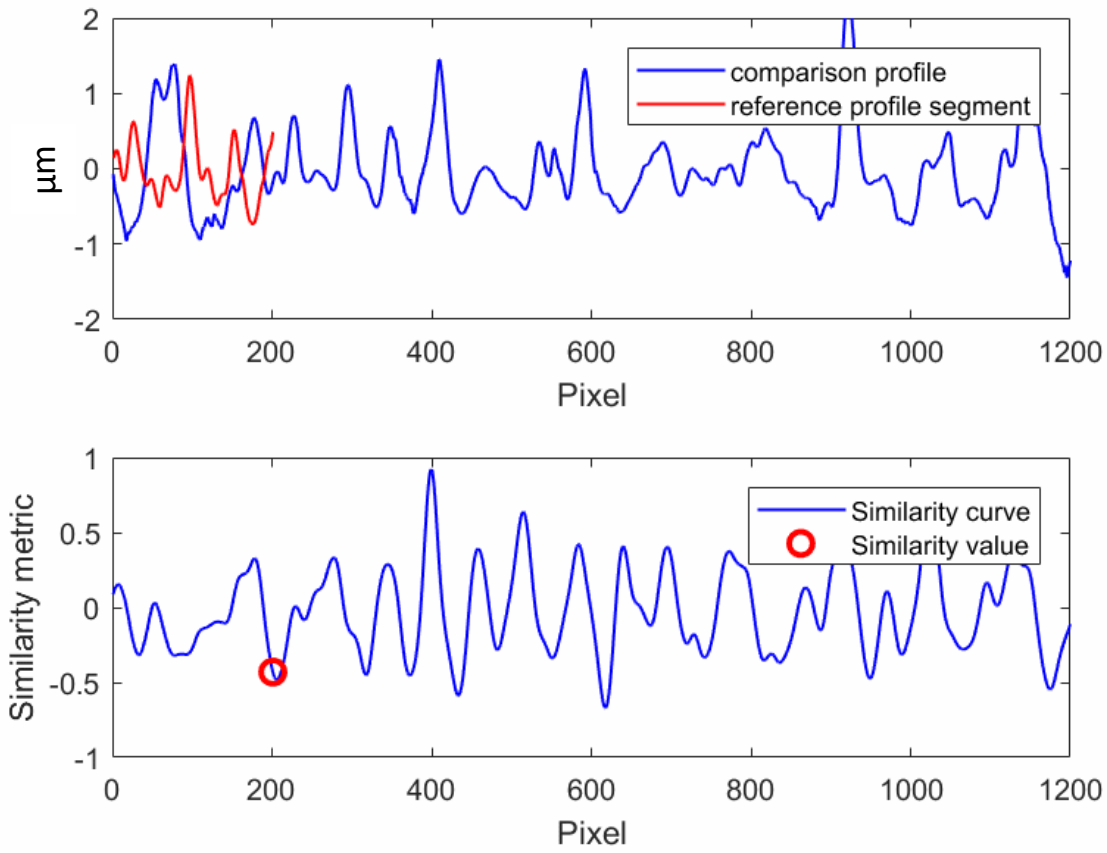
Complete profile correlation



The maximum overall similarity value (using normalized CCF) between the reference and comparison profiles is only 0.43.

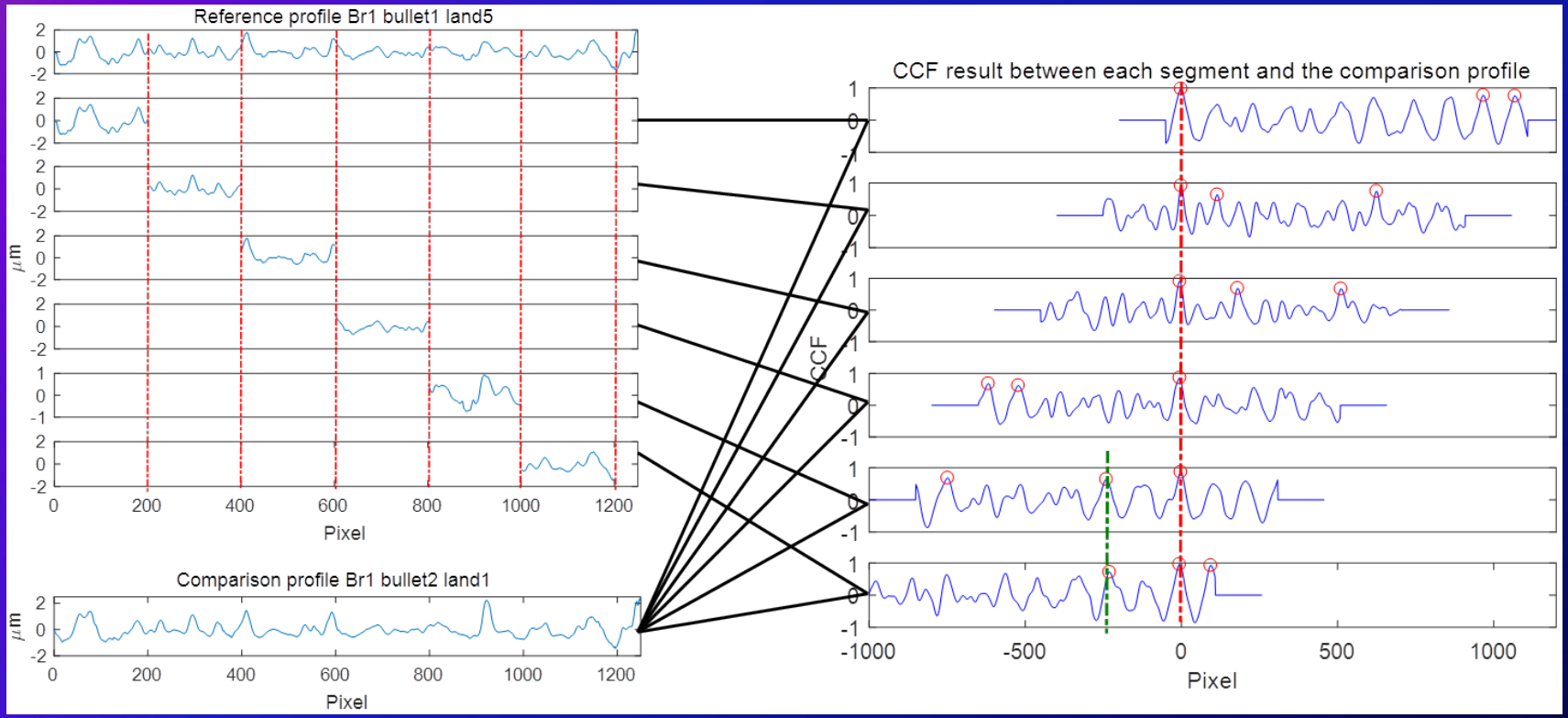
- shows the matching parts between the profiles
- shows profile misalignment due to lateral deformation

Congruent Matching Profile Segments (CMPS)



- Divide the reference profile into segments.
- For each segment, obtain a similarity curve by moving the segment along the comparison profile.
- The similarity curve describes the profile similarity (CCF) as a function of the registration position.

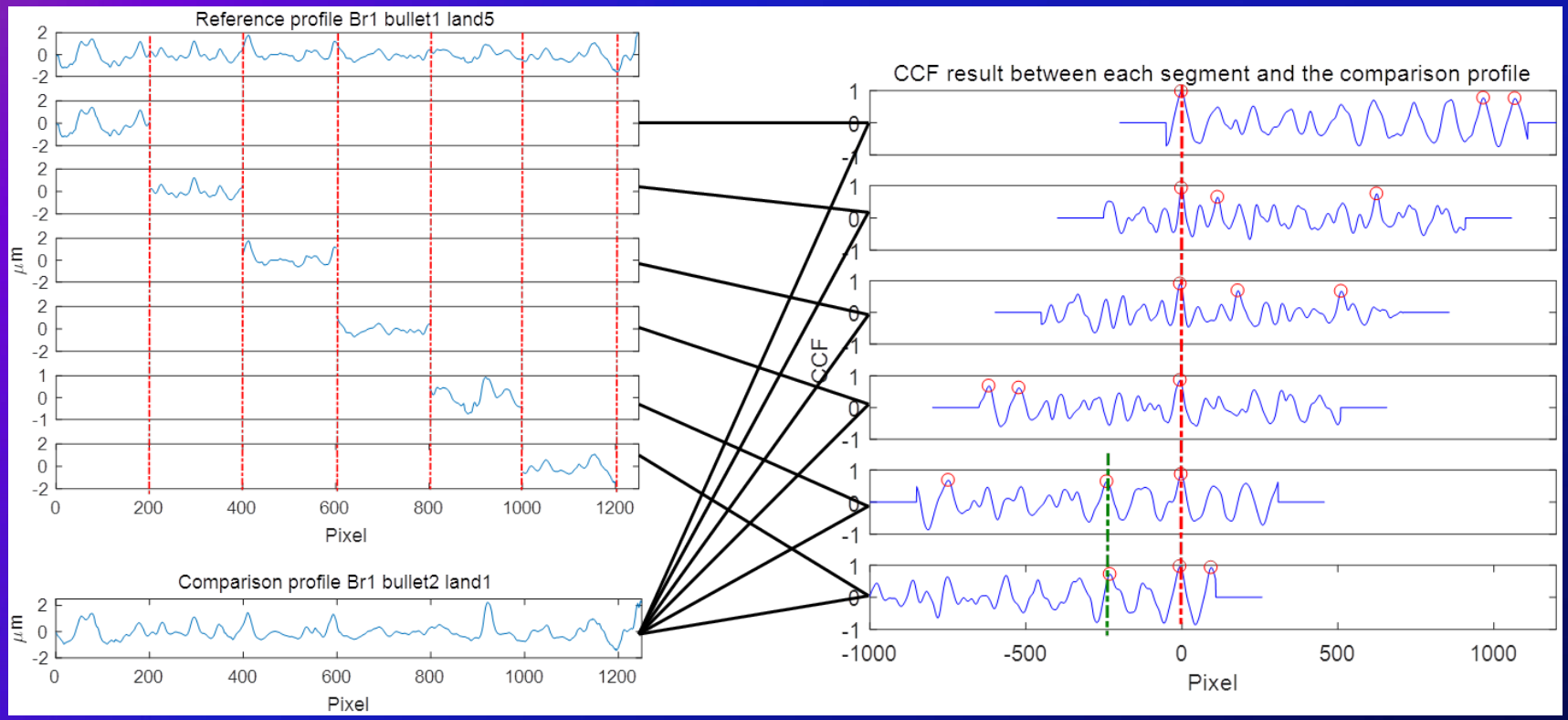
CMPS method (multi-segments correlation)



Similarity: The similarity curve of each segment is summarized by the sample positions of three highest similarity peaks.

Congruency: At the true matching position, most segments should have a similarity peak at approximately the same sample position.

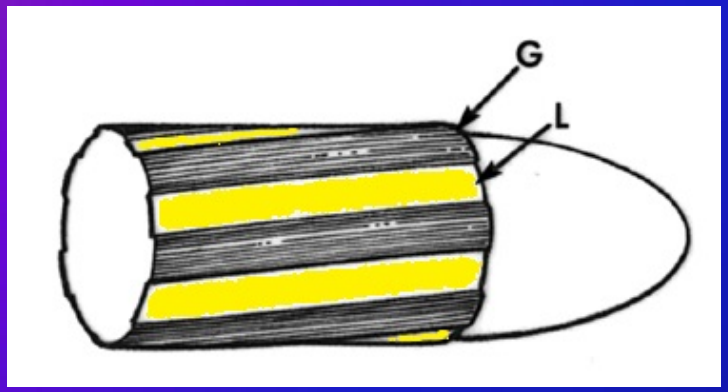
(continued)



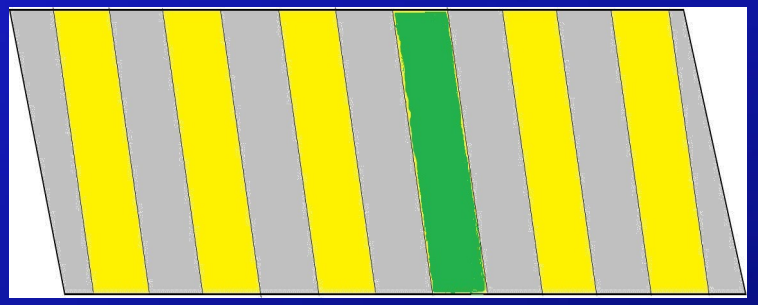
The CMPS number is the maximum number of profile segments that have a similarity peak at the "same" position.

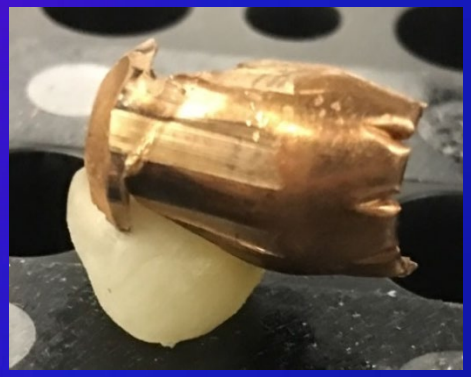
In our test, the segment length is 50 pixels (67.7 μm) and the tolerance zone for a congruent position is 12 pixels (16.25 μm).

Consequences of incomplete samples

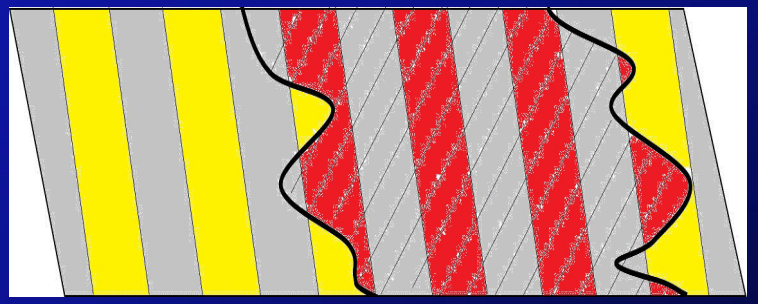


Land engraved areas in Reference bullet





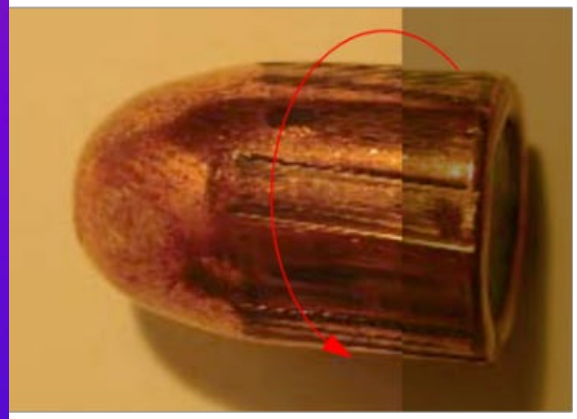
Land engraved areas in Comparison bullet

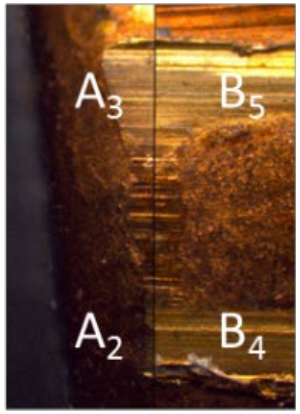


Some LEAs in a bullet are not available for measurement.
This can cause a false negative result.

LEA GEA Missing LEA Possible reference LEA

Consequences of incomplete samples





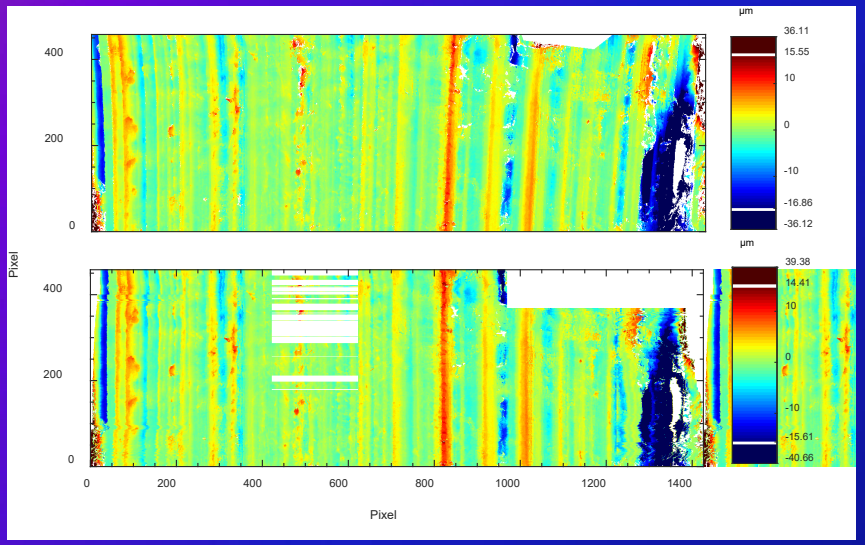
	B1	B2	B3	B4	B5	B6
A1	0	0	2	0	1	0
A2	3	0	0	11	0	1
A3	0	0	3	0	8	0
A4	0	1	1	0	0	18
A5	0	0	0	1	0	2
A6	1	9	0	0	3	0

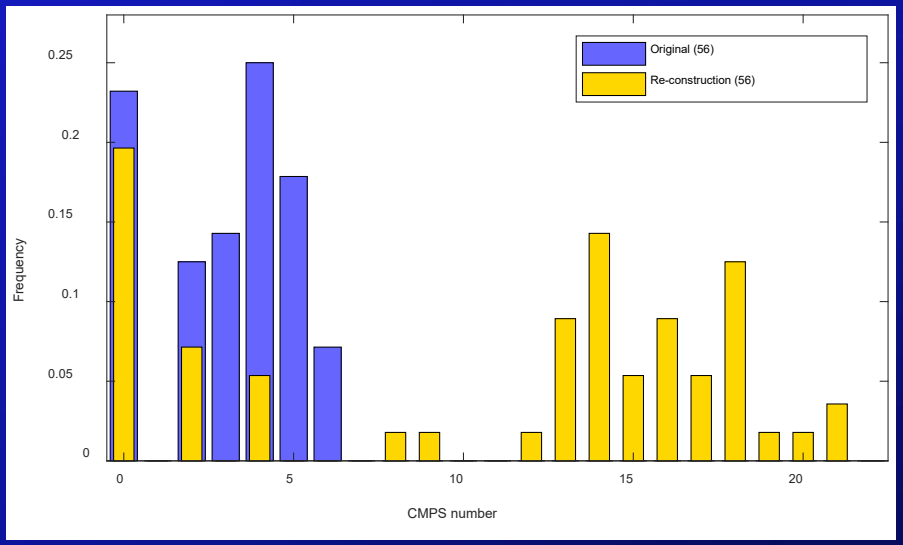
A3 is the reference LEA. Suppose LEA B5 is missing. The maximum correlation score between LEA A3 and bullet B is now 3, instead of 8.

In this study, the maximum CMPS score of all LEA to LEA comparisons is reported for each bullet comparison.

Correlation results of deformed bullets

The re-construction of bag 2 (PMC Starfire) bullet 5 LEA 6

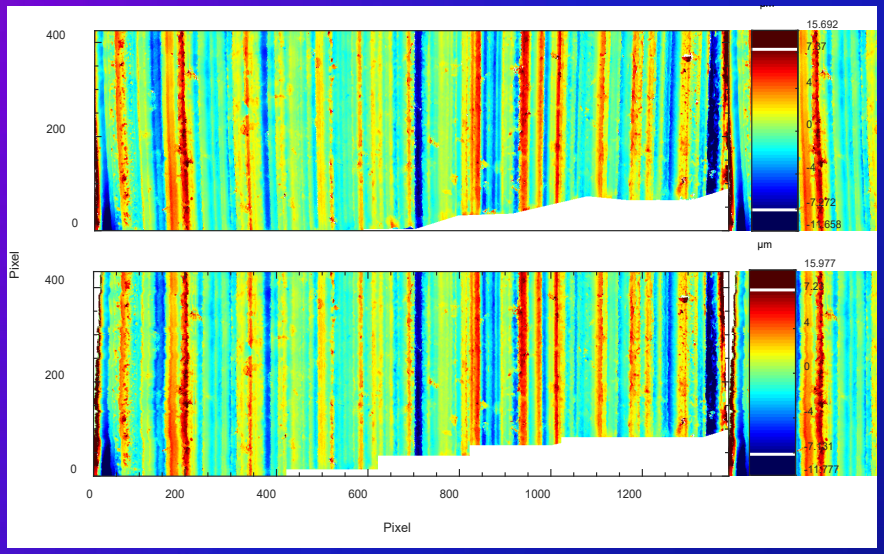


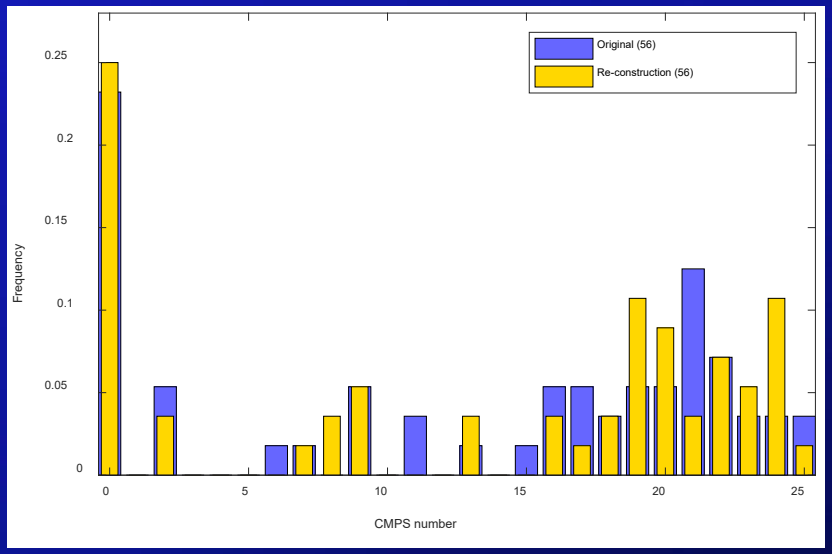


- 15 LEAs (out of 250 in total) showed major deformation.
- 10 of the 15 deformed LEAs show improved CMPS results after the profile re-construction process. Subjectively, samples with relatively large deformations and good image quality tend to have better improved CMPS results after profile re-construction.

Correlation results of deformed bullets

The re-construction of bag 7(Remington Golden Saber) bullet 7 LEA 6



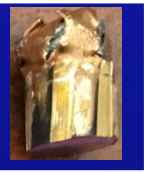


- 5 of the 15 deformed bullet LEAs showed little change in CMPS distributions after the profile re-construction process.
- For samples with approximately parallel striae, the CMPS method can, by itself, correct local scale differences.

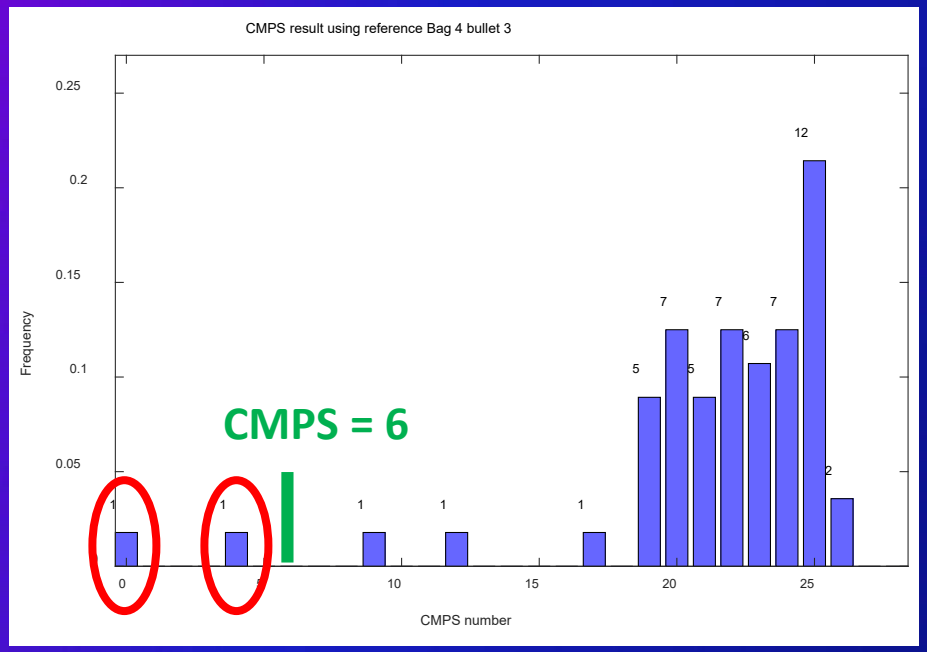
Correlation results using reference bullets

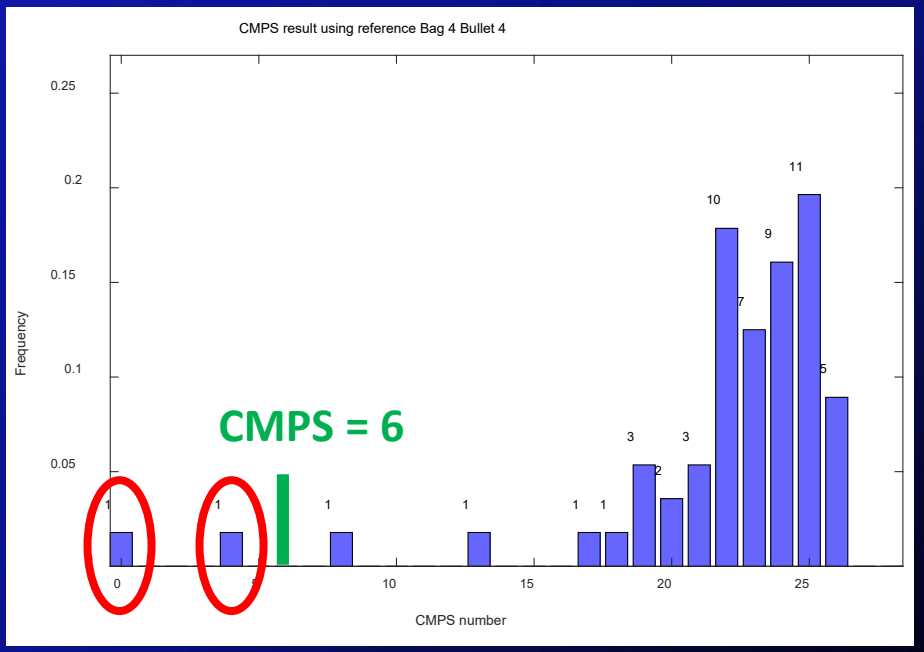
2 bullets with 6 intact lands were selected as references:

Bag 4 (Hornady) Bul. 3	

Bag 4 (Hornady) Bul. 4	

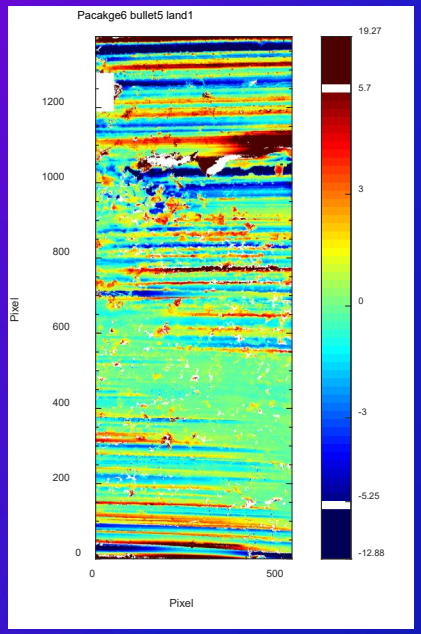
Each bullet is correlated with the other 56 bullets.

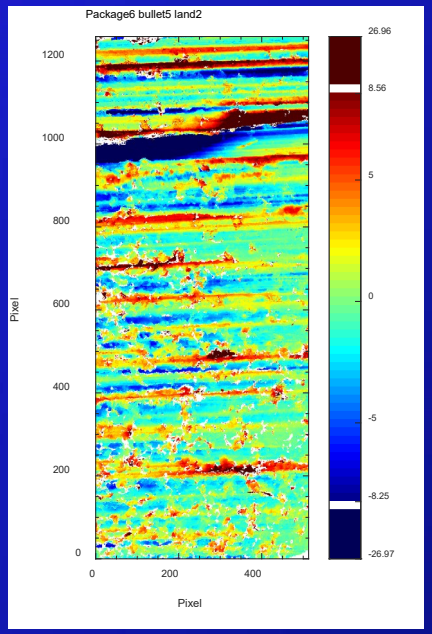


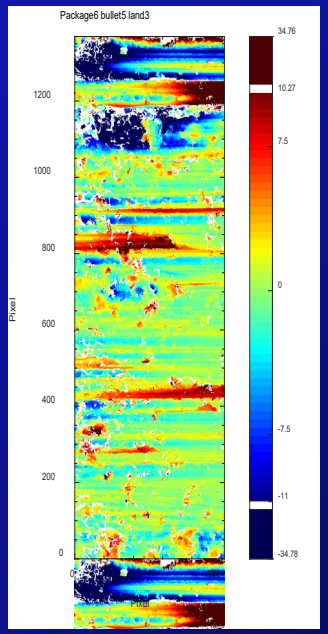


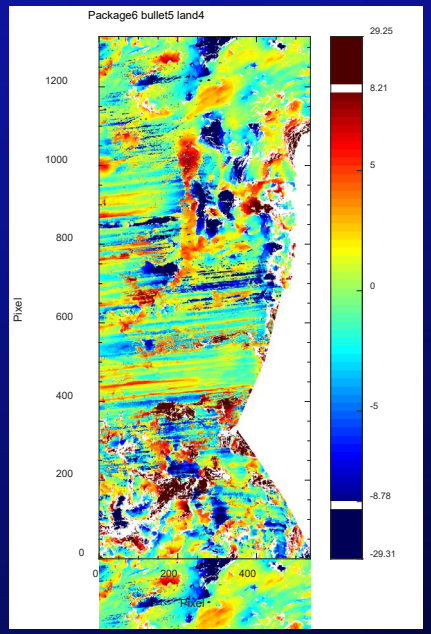
The two false negative CMPS results

1) Bag 6 (Federal Classic) bullet 5





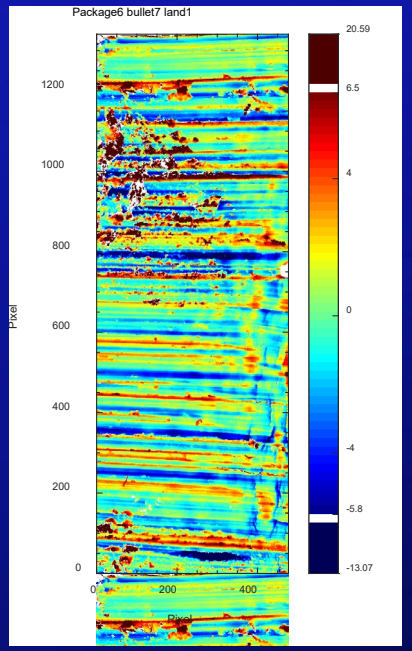




There are 4 LEAs available for measurement in bullet 5. the CMPS results with the 2 reference bullets are both 4.

The two false negative CMPS results

2) Bag 6 (Federal Classic) bullet 7



There is only 1 LEA available for measurement in bullet 7. the correlation results with the 2 reference bullets are both 0.

Main reason for the false negative results is the bad quality of the bullet 7 sample topography.

Correlation results using different jackets

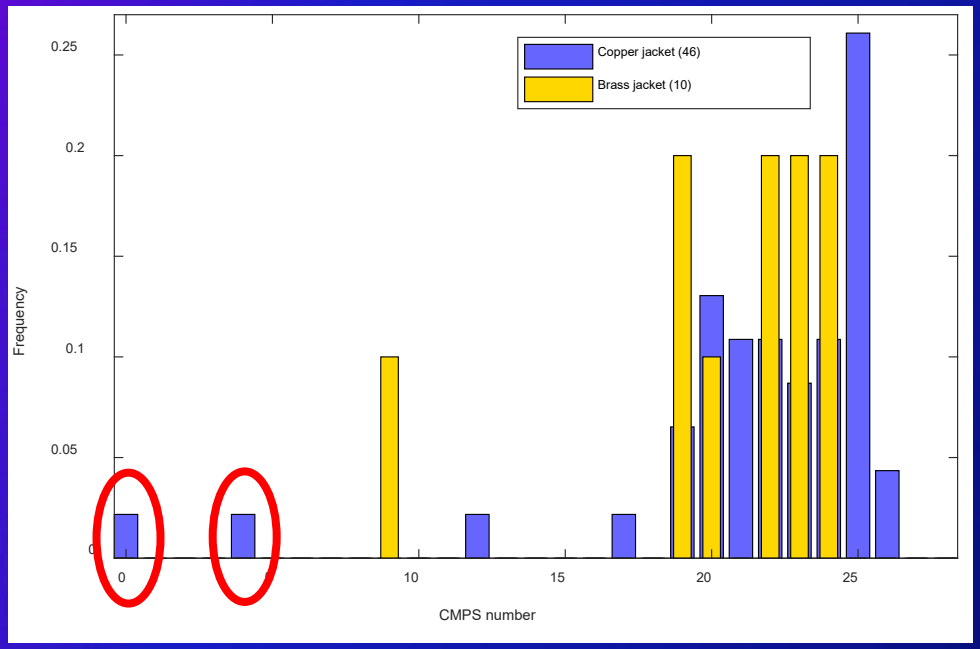
Reference: Bag 4 (Hornady) bullet 3 (copper jacket)

Copper jacket (46 correlations)

Package 6 (Federal Classic) Bullet 1

Brass jacket (10 correlations)

Package 7 (Remington Golden Saber) Bullet 9



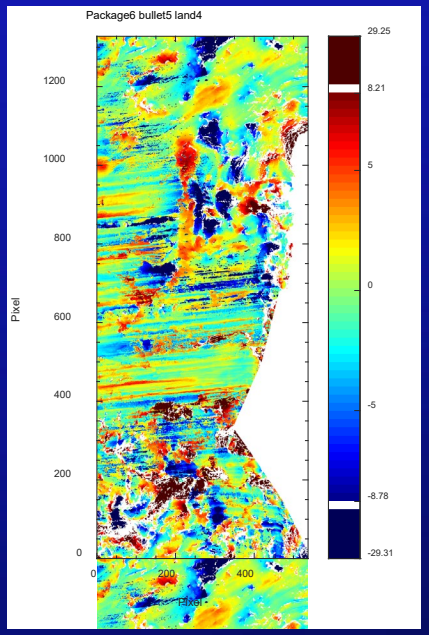
Brass and copper have different hardness and color, but there is no obvious difference between their CMPS scores.

Discussion

- We observed 15 LEAs (out of 250 in 57 bullets) with major deformation.
- 10 out of the 15 deformed bullet LEAs showed improved CMPS results after profile re-construction. Subjectively, profile re-construction seems to work best for samples with relatively large deformations and good image quality.
- 5 out of the 15 deformed bullet LEAs don't have a significant change in CMPS distributions after profile re-construction. For samples with approximately parallel striae, the CMPS method can, by itself, correct local scale differences.

Discussion

- The false negative results mainly occurred for samples with poor quality striation patterns.
- Comparisons involving different jacket materials (copper with copper vs. copper with brass) didn't show an obvious difference in their distributions.



Future work

- Effects of image re-construction on comparison scores of known non-matching (KNM) samples

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

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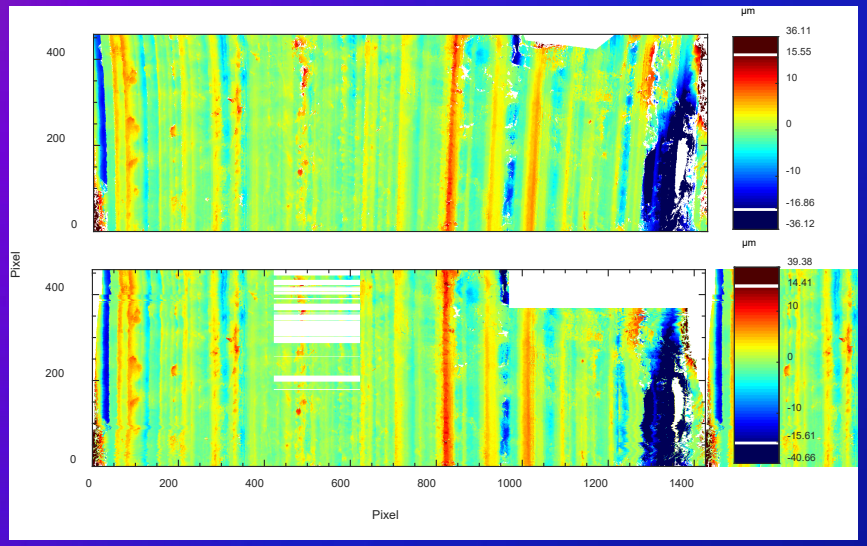
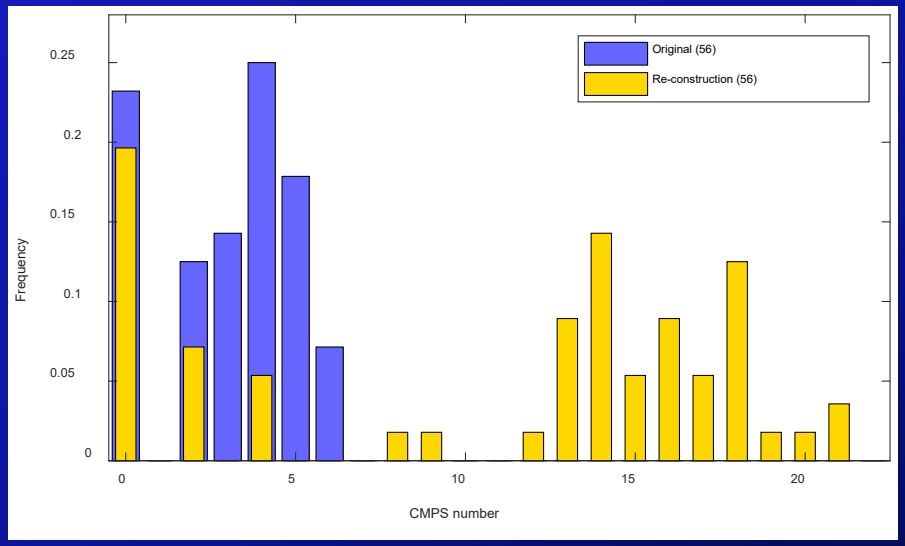
Thank You

Contact: zhe.chen@nist.gov

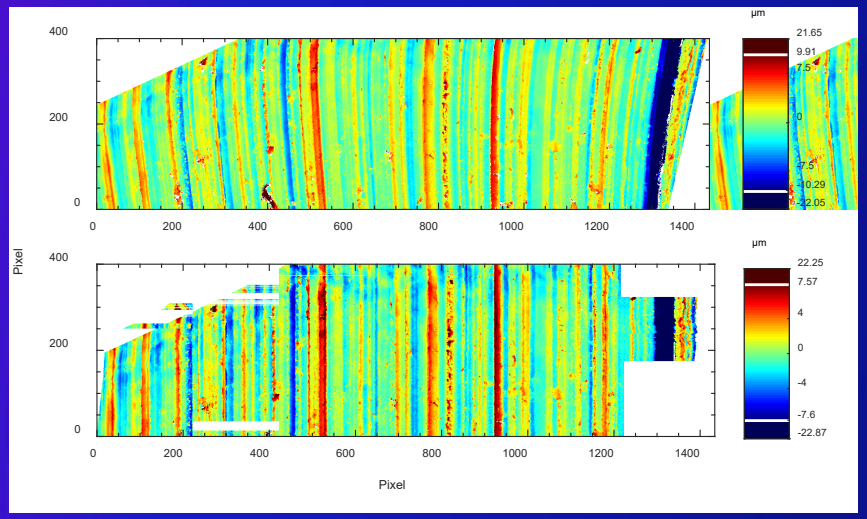
Appendix (10 improved LEA results)

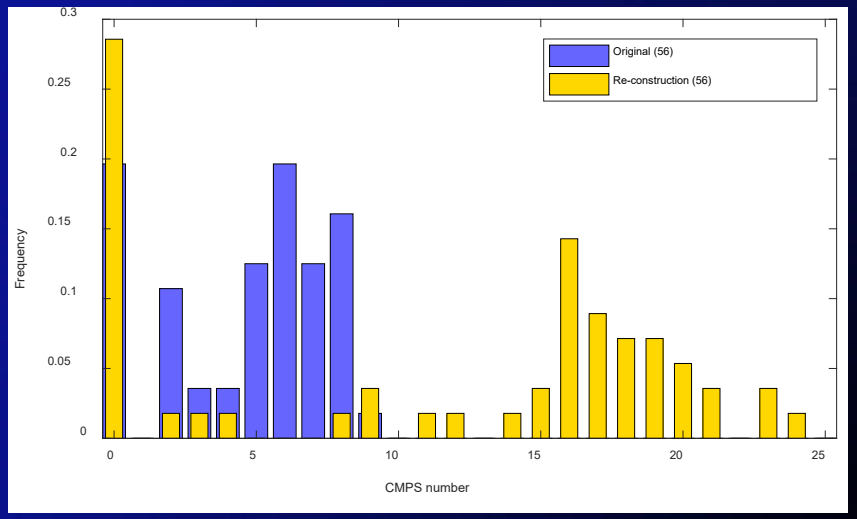
The re-construction of bag 2 bullet 5 land 6





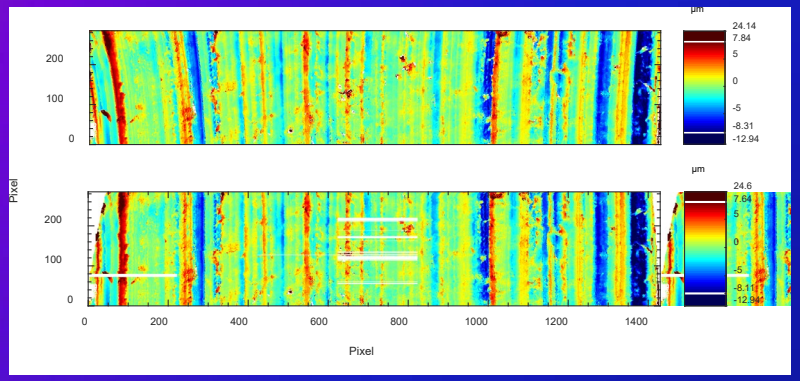
The re-construction of bag 2 bullet 7 land 3

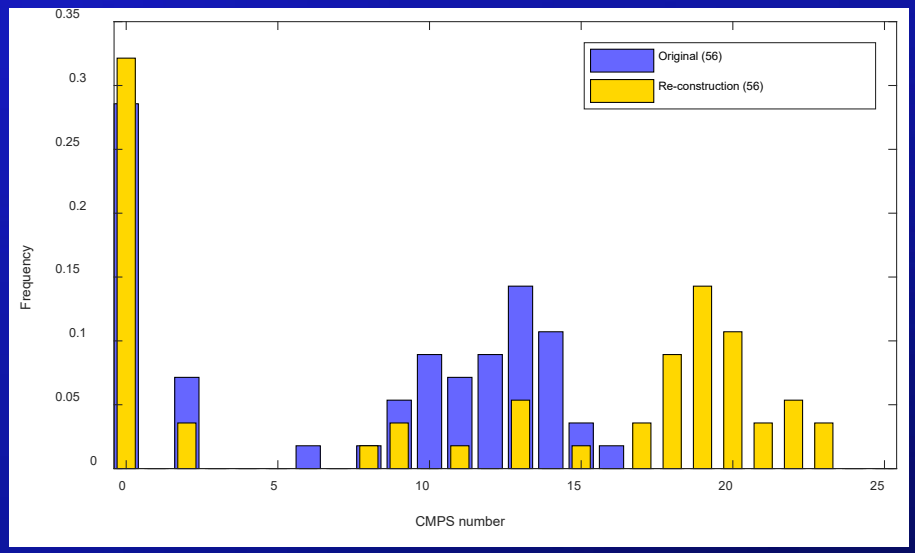




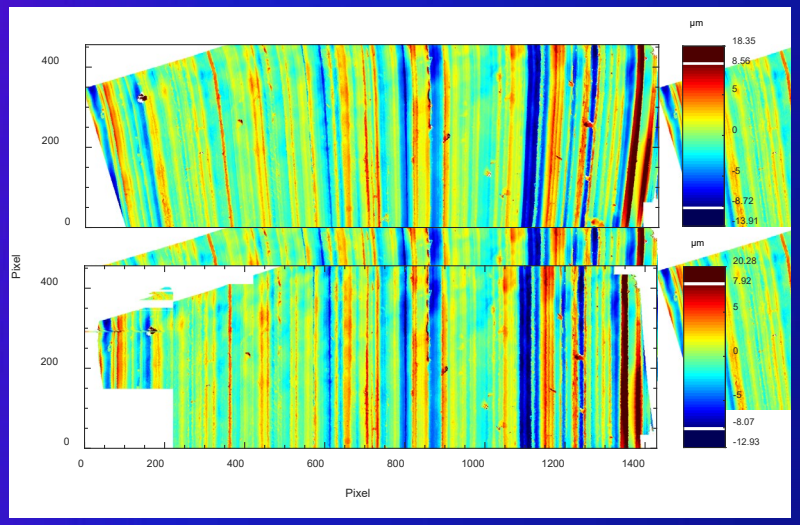
10 improved LEA results

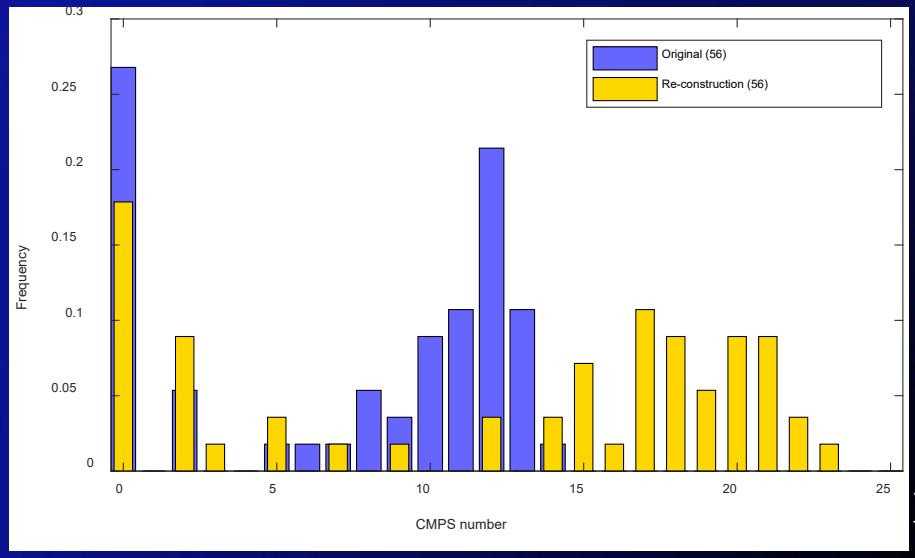
The re-construction of bag 2 bullet 8 land 3





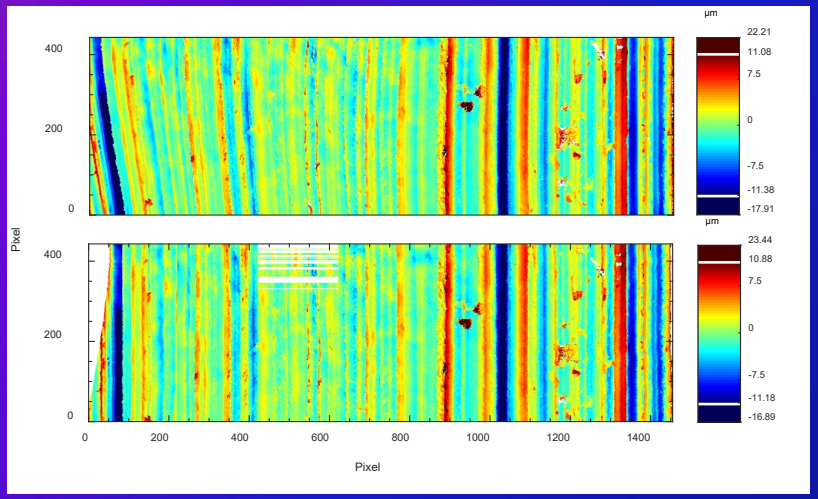
The re-construction of bag 4 bullet 7 land 2

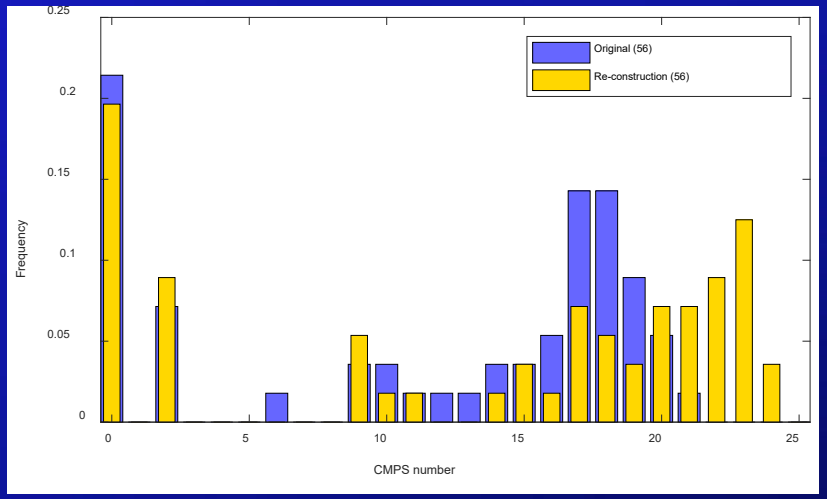




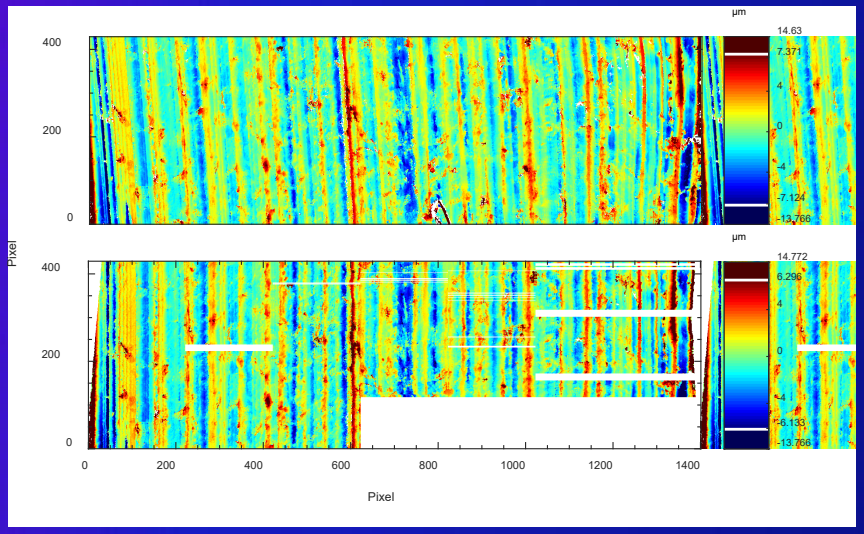
10 improved LEA results

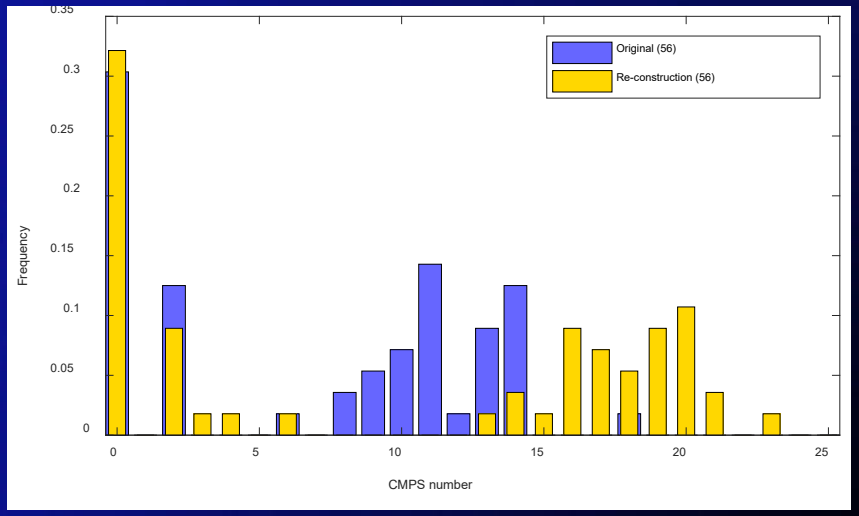
The re-construction of bag 6 bullet 2 land 1





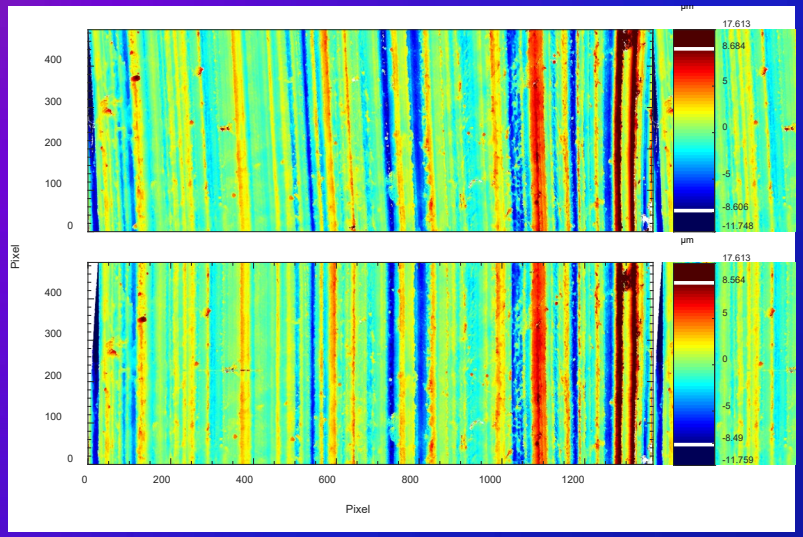
The re-construction of bag 6 bullet 3 land 3

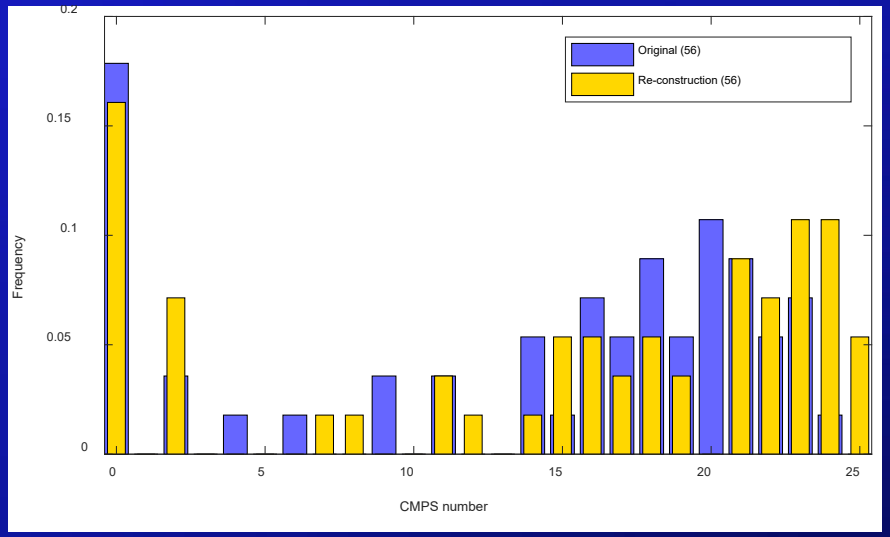




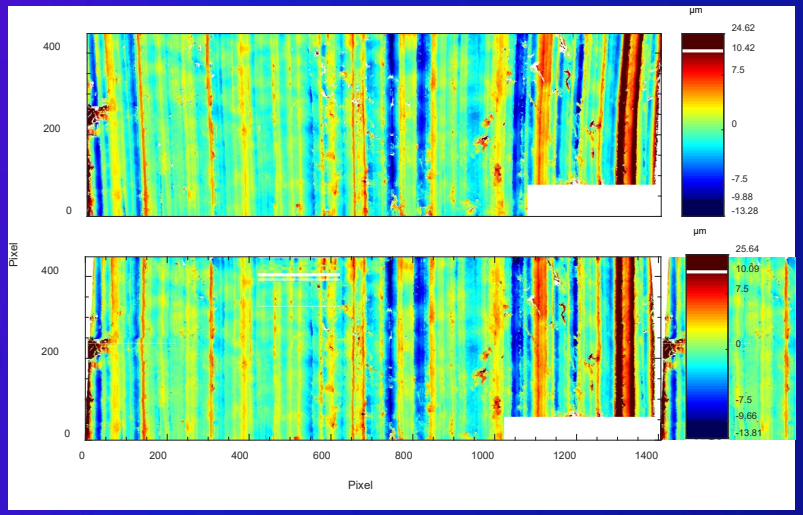
10 improved LEA results

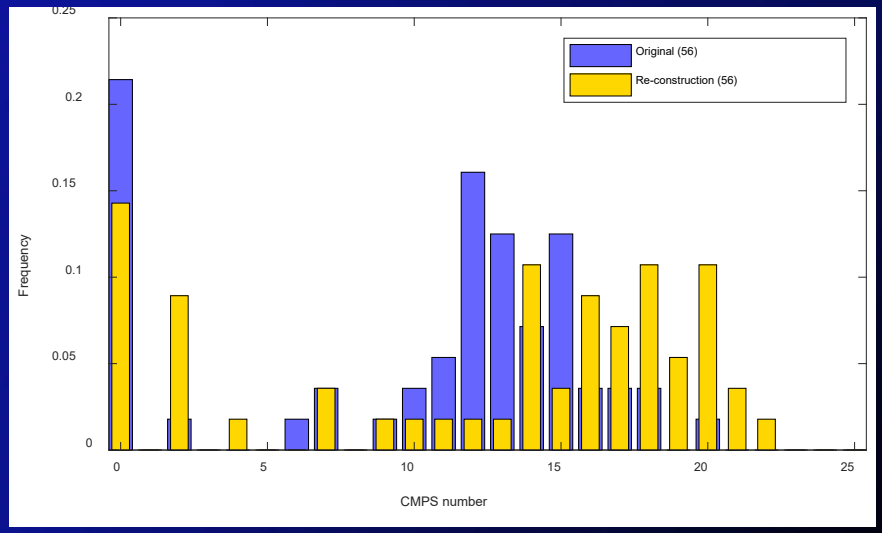
The re-construction of bag 6 bullet 4 land 2





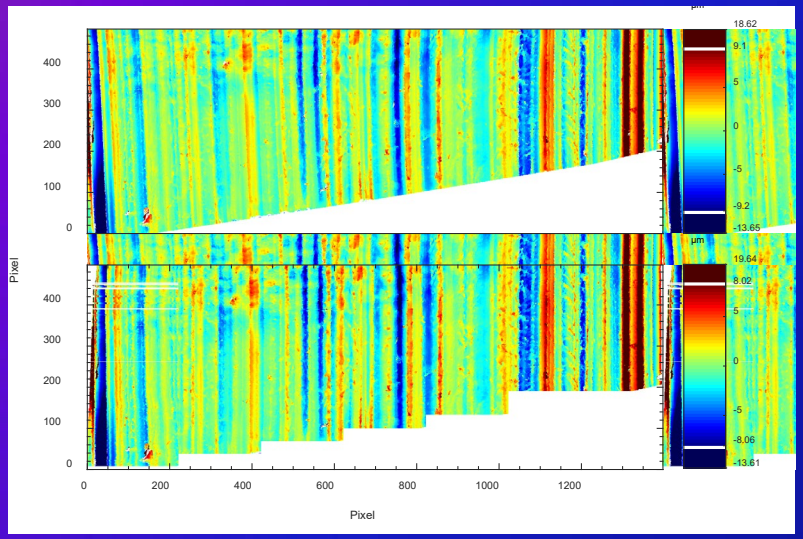
The re-construction of bag 6 bullet 6 land 1

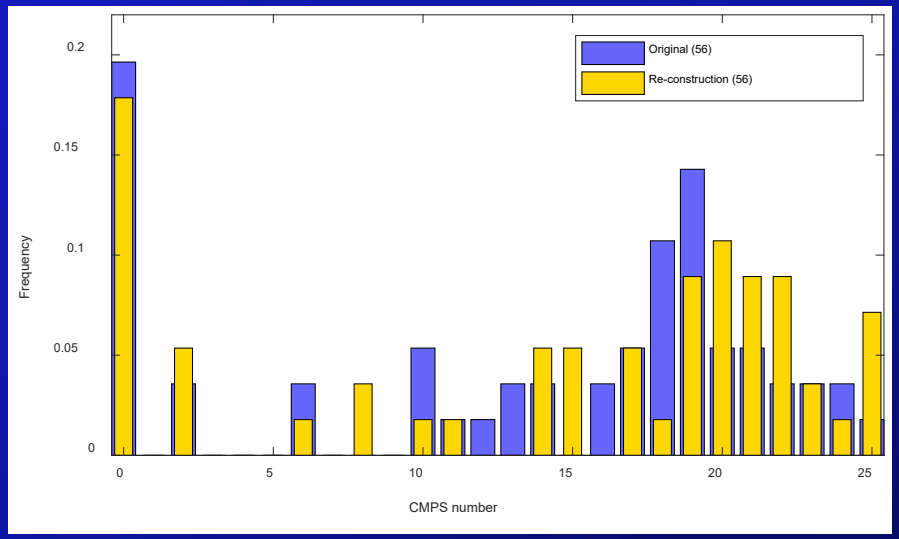




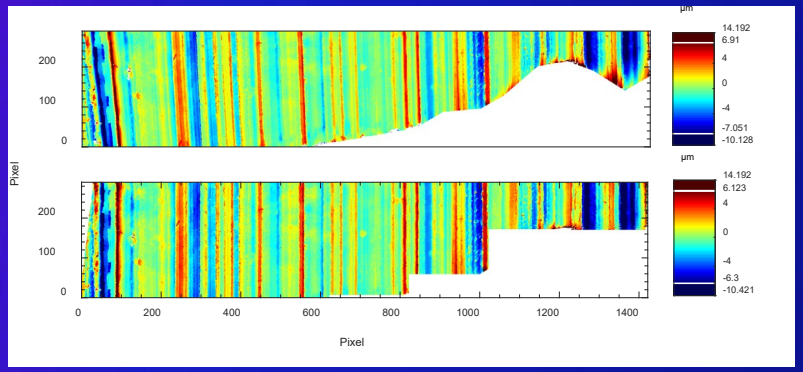
10 improved LEA results

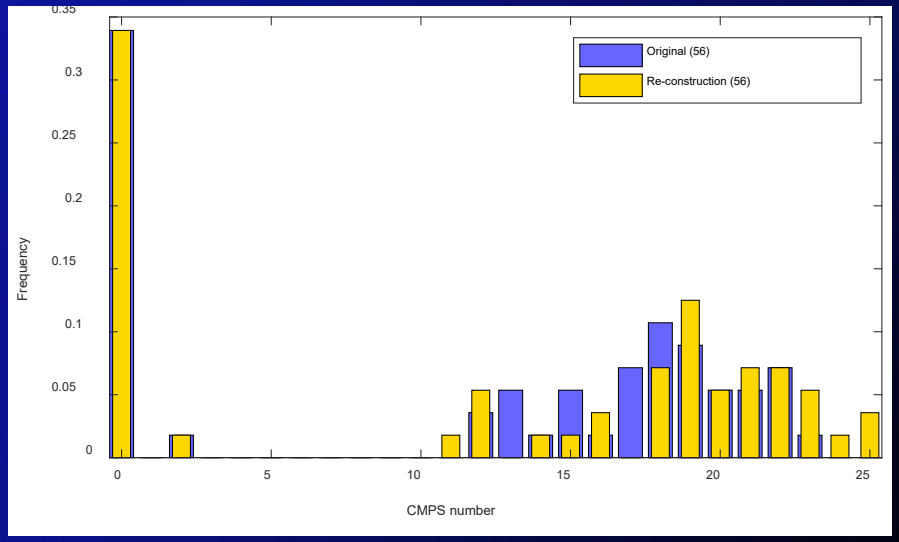
The re-construction of bag 7 bullet 6 land 1





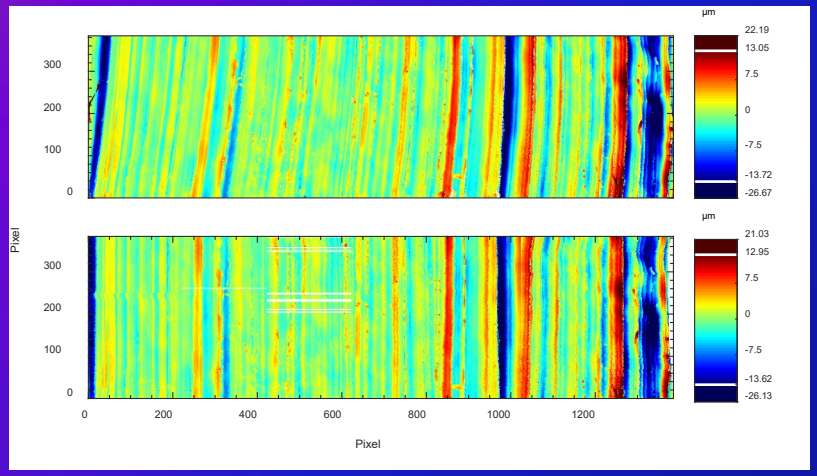
The re-construction of bag 7 bullet 7 land 5

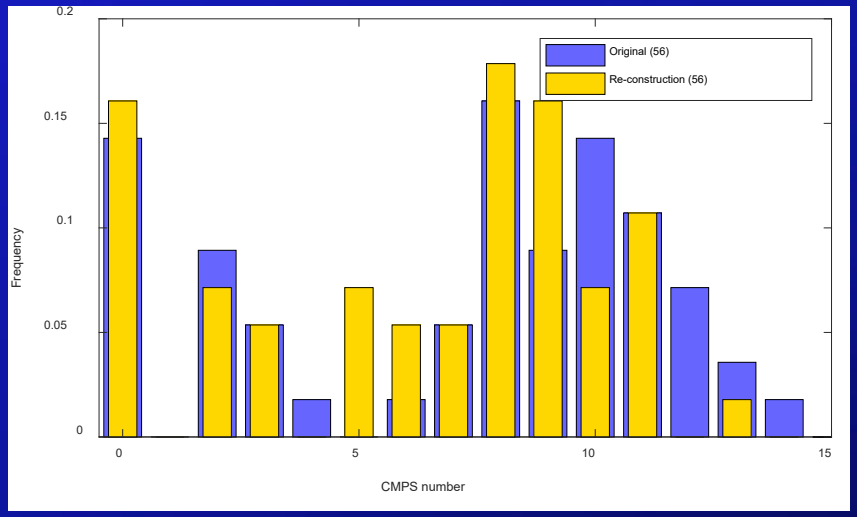




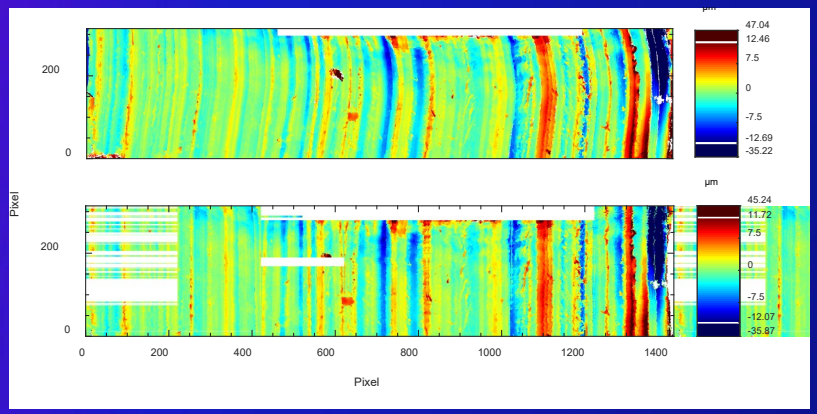
5 little changed LEA results

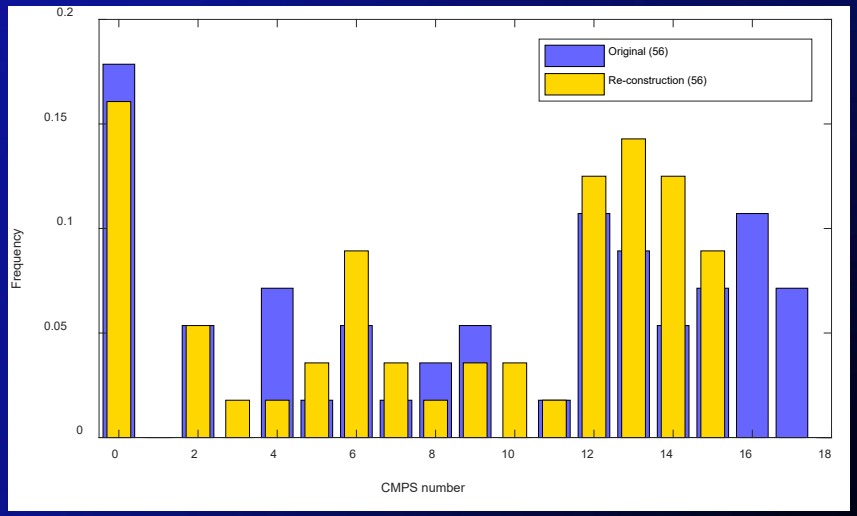
The re-construction of bag 1 bullet 3 land 3





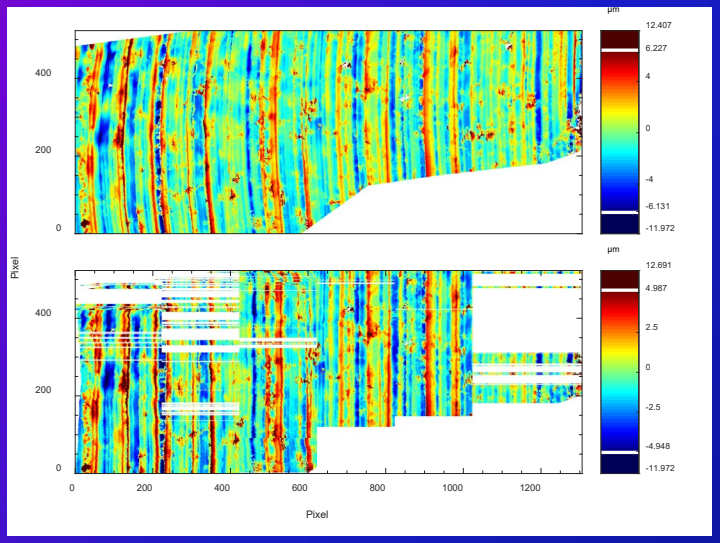
The re-construction of bag 2 bullet 8 land 1

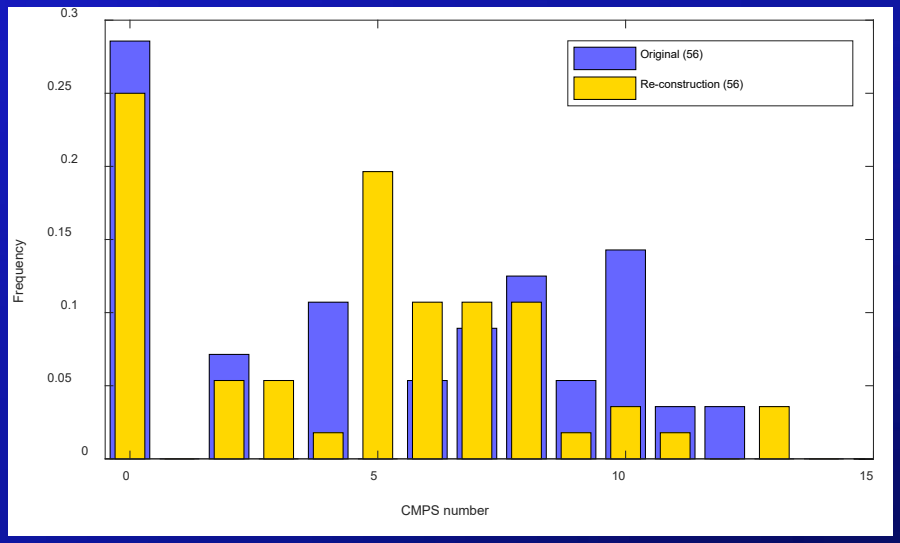




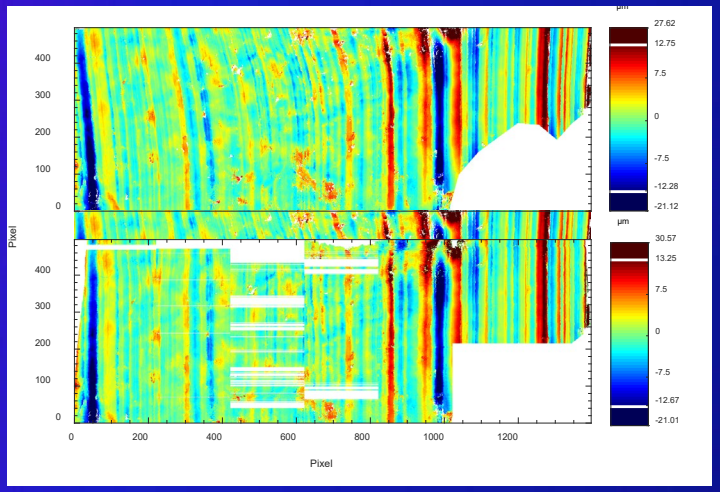
5 little changed LEA results

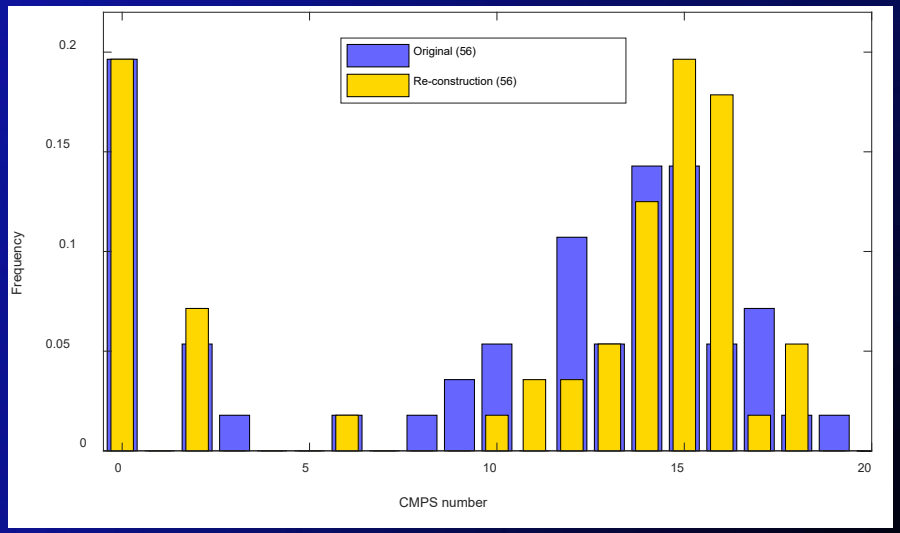
The re-construction of bag 4 bullet 8 land 1





The re-construction of bag 6 bullet 6 land 2





5 little changed LEA results

The re-construction of bag 7 bullet 7 land 6