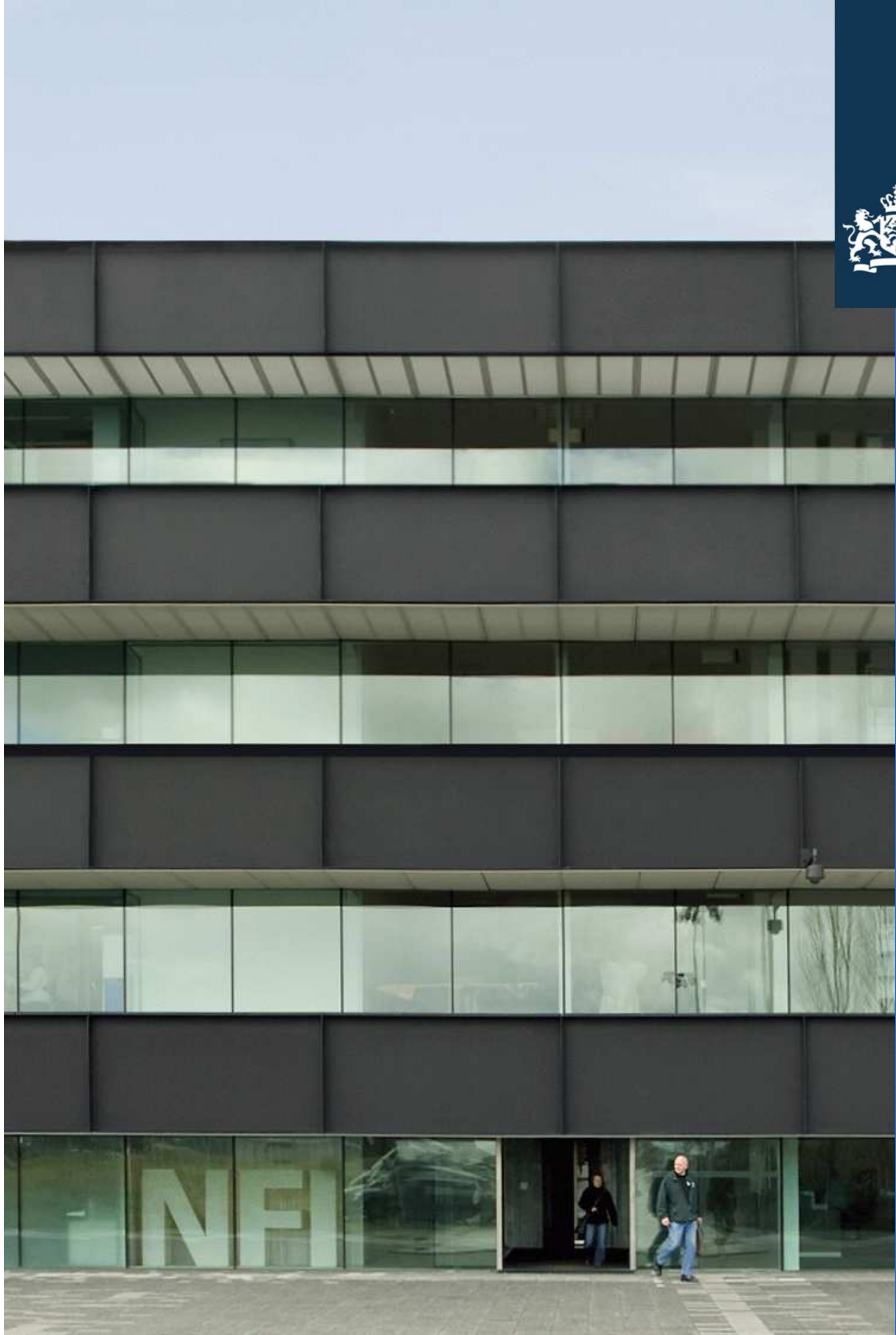

Netherlands Forensic Institute
Ministry of Security and Justice

Interlaboratory comparison for 3D analysis of bullet land engraved areas (LEA)

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John Jay College of Criminal Justice, US:
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Cadre Forensics, US:
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Alabama Department of Forensic Sciences, US:
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Disclaimer:

a) *Neither NFI nor NIST intend to promote any particular acquisition method and/or vendor.*

b) *All measurements presented were taken between 2016 and 2020 and reflect the performance of the acquisition devices back then.*

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Oblique light enables to represent a surface as light shadow pattern

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Why 3D topography?

- *Oblique light illumination is dependent on the light angle and information is lost in shadow areas*

➢ *2D imaging does not yield true depth information*

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High magnification means a short depth of field

Why 3D topography?

- *Oblique light illumination is dependent on the light angle and information is lost in shadow areas*
  - ➢ *2D imaging does not yield true depth information*
- *High magnification means short depth of field and limited field size*
  - ➢ *2D does not provide high resolution images with all areas in focus*

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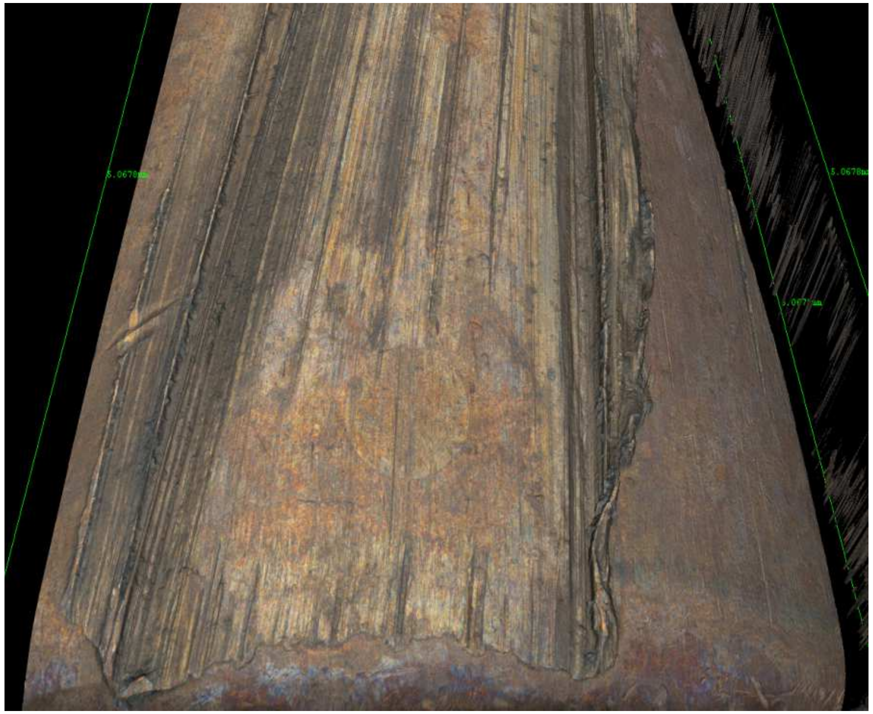
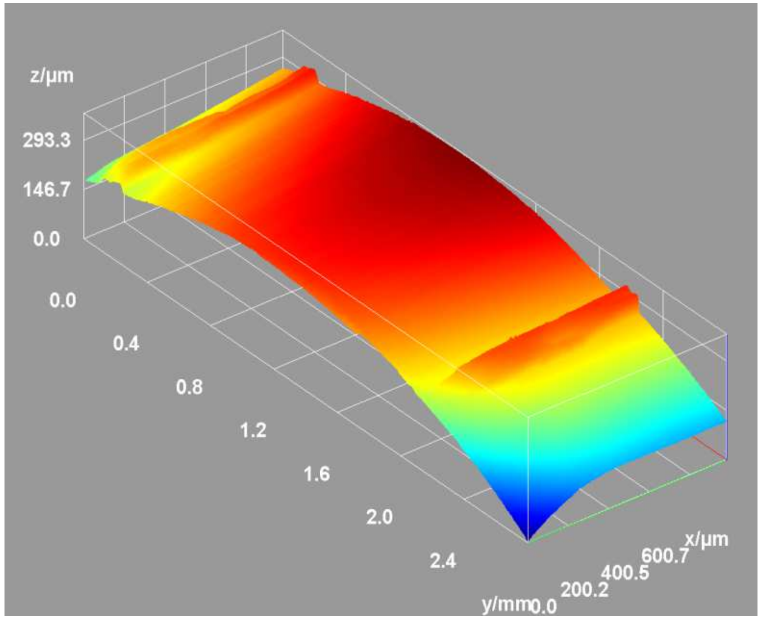
Surface topography yields true depth information and is more objective





[Zheng et al. 2014]

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Topographic microscopy

- *True depth information and no information loss*
- *More objective data and less variability*

Problem

- *How reproducible are the 3D surface measurements in practice?*
- *To date, limited statistical data available*

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Topographic microscopy

- *True depth information and no information loss*
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Problem

- *How reproducible are the 3D surface measurements in practice?*
- *To date, limited statistical data available*

Goal

- *Study the reproducibility of results with data from different labs*

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Research questions

What are the *qualitative* and *quantitative* differences between bullet LEA data as well as known match and known non-match similarity scores if surface data of the *same* set of bullets is:

1.) Acquired at *different* labs, using different technologies, and compared with the *same* (NFI) algorithm?

2.) Acquired at *different* labs, using different technologies, and compared with *lab specific* algorithms (All methods using their own data)?

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Experimental setup to acquire bullet data

- *10 consecutively manufactured barrels of a Beretta 92F/FS*

  (Courtesy of Scott McVeigh of the Prince George's County Police Dept.)
- *3 bullets each with Remington UMC FMJ Copper Jacket, 9 mm*
- *6 LEAs were measured, at the base of the bullet*

➢ *180 surface measurements!*

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Experimental setup to acquire bullet data

- *Eight labs in the US, Netherlands, Czech republic and Spain*
- *Six manufacturers and six acquisition techniques*
- *Operators with varying experience with 3D microscopy (from student interns to experienced operators)*
- *Acquisition parameters: sampling distance (resolution of the data), mark orientation*

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Various techniques were used for surface acquisition


Alicona IFM SL & G5
Focus variation

Nanofocus µsurf
Confocal

Sensofar S Neox & Plu Neox
Confocal or Focus variation


Cadre TopMatch-3D
Photometric stereo

Laboratory Imaging LUCIA BalScan
FV + Photometric stereo

EvoFinder 4X4
FV + Photometric stereo

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Various techniques were used for surface acquisition

Lab	Model	Technology	Lateral sampling	Scanning time (LEA)	Operator
Lab A	Brand 1, Model I	Focus variation	501 nm	≈ 1 min	Experienced operator
Lab B	Brand 2, Model I	Confocal	645 nm	≈ 2 min	Experienced operator
Lab C1	Brand 3, Model I	Confocal	1560 nm	≈ 3.5 min	Experienced operator
Lab C2	Brand 4, Model I	Focus variation + Photometric stereo	3570 nm	≈ 3 s (10 s all lands)(*)	Experienced operator
Lab D	Brand 1, Model II	Focus variation	520 nm	≈ 6 min	Student interns
Lab E1	Brand 2, Model I	Continuous confocal	1300 nm	≈ 1.5 min	Student interns
Lab E2	Brand 2, Model I	Focus variation	1300 nm	≈ 1.5 min	Student interns
Lab F	Brand 2, Model II	Confocal	830 nm	≈ 2.5 min	Experienced operator
Lab G	Brand 5, Model I	Focus variation + Photometric stereo	3070 nm	≈ 18 s (210 s all lands)(*)	Experienced operator
Lab H	Brand 6, Model I	Photometric stereo	1440 nm	≈ 1 min	Student interns

(*) Systems acquire all six lands in one measurement

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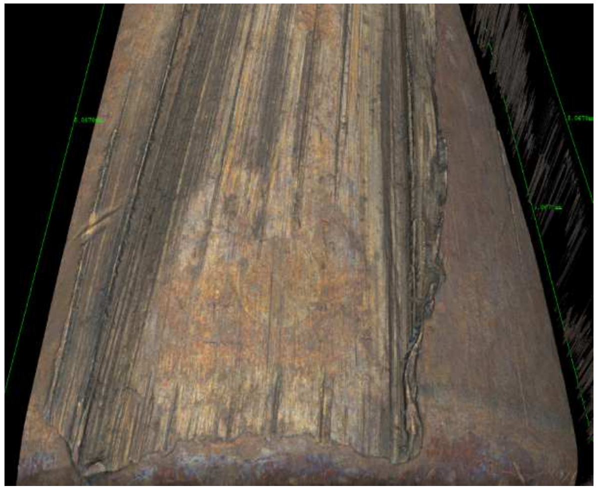
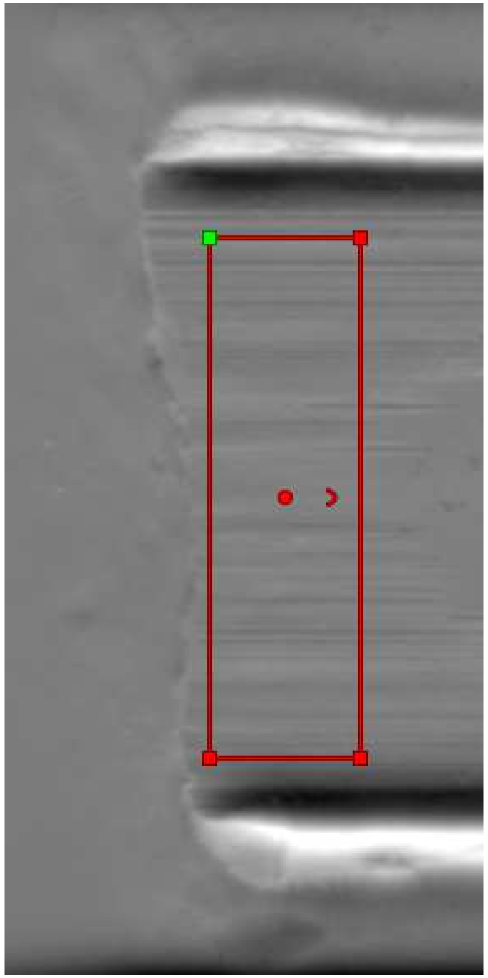
Data post processing and comparison

- *At NFI, using Scratch*
- *Manual cropping of Region of Interest (ROI)*
- *All ROIs had equal size*



LEA surface rendering



LEA height map

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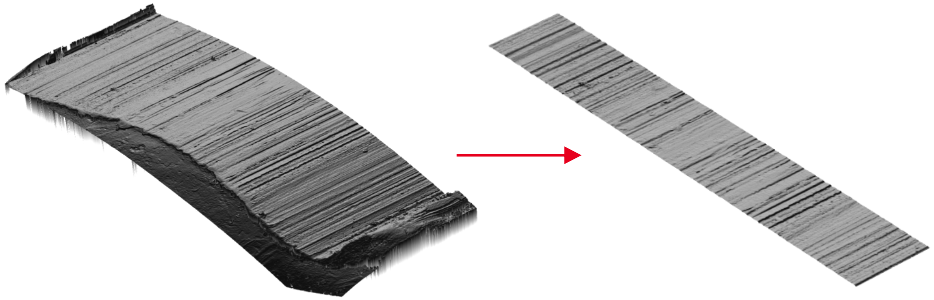
Data post processing and comparison

- *Shape and noise removal using Gaussian filters with cutoffs λ_{ch} = 250 μm, λ_{cl} = 5 μm (Lab C2 and G already flat)*



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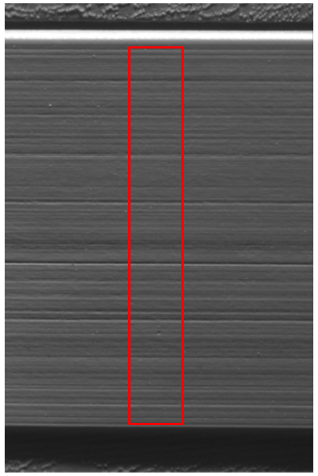
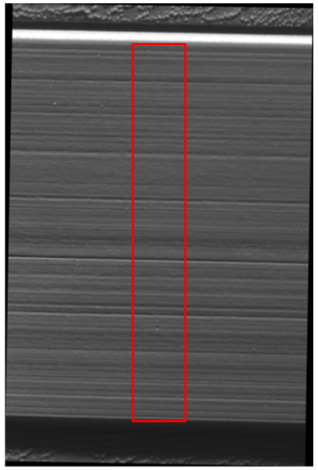
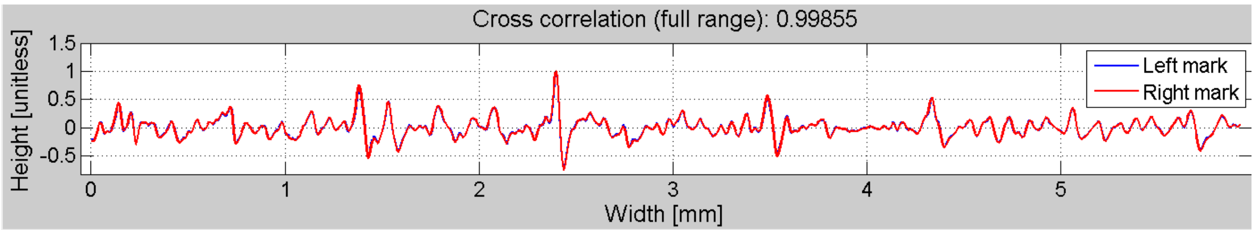
Mark rotation leads to less accurate profiles

0°

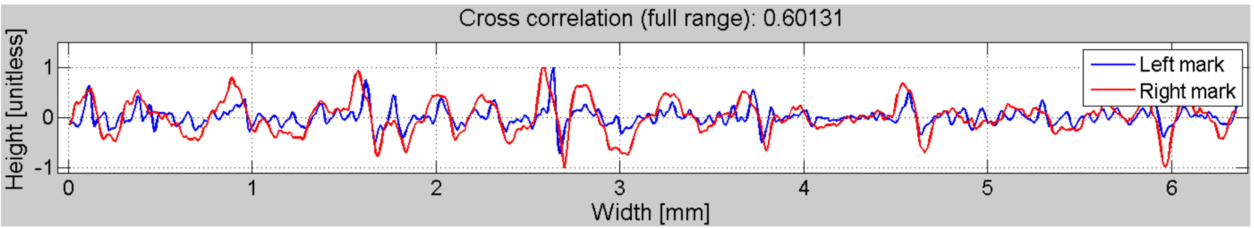




1°



With rotation correction



Without rotation correction

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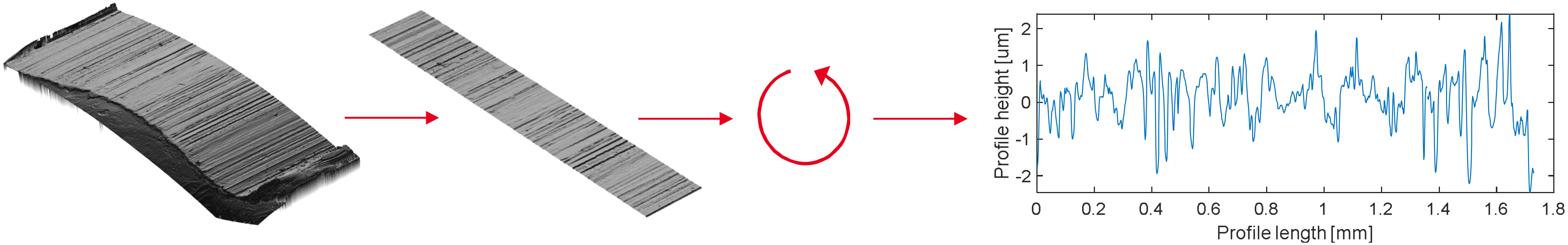
Data post processing and comparison

- *Shape and noise removal using Gaussian filters with cutoffs*

  λ_{ch} *= 250* μ*m,* λ_{cl} *= 5* μ*m*

- *Automated rotation correction*

- *Extracting profile by averaging*



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Data post processing and comparison

- *Shape and noise removal using Gaussian filters with cutoffs*
  λ_{ch} = 250 μm, λ_{cl} = 5 μm
- *Automated rotation correction*
- *Extracting profile by averaging*
- *Automated alignment using multi-scale registration with two degrees of freedom: translation and scaling (set to 1, for now…)*
- *Similarity metric: Cross-correlation*

Details: [Baiker et al. 2014, Quantitative comparison of striated toolmarks]

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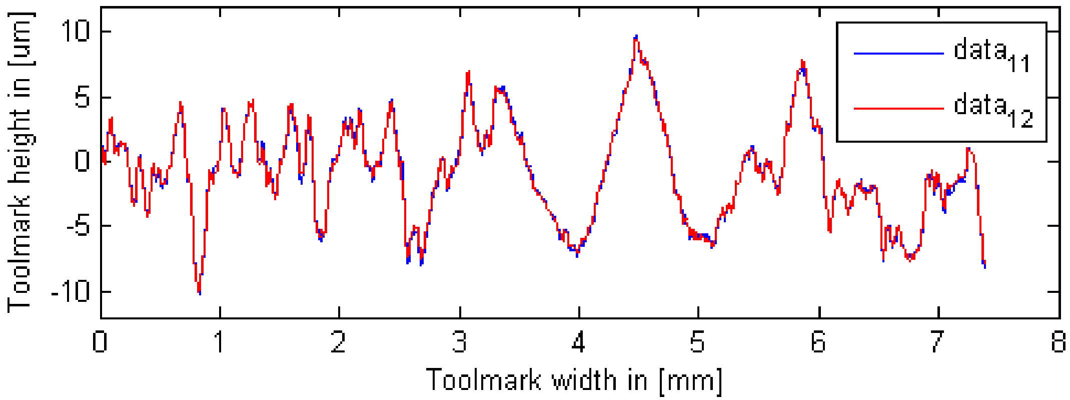
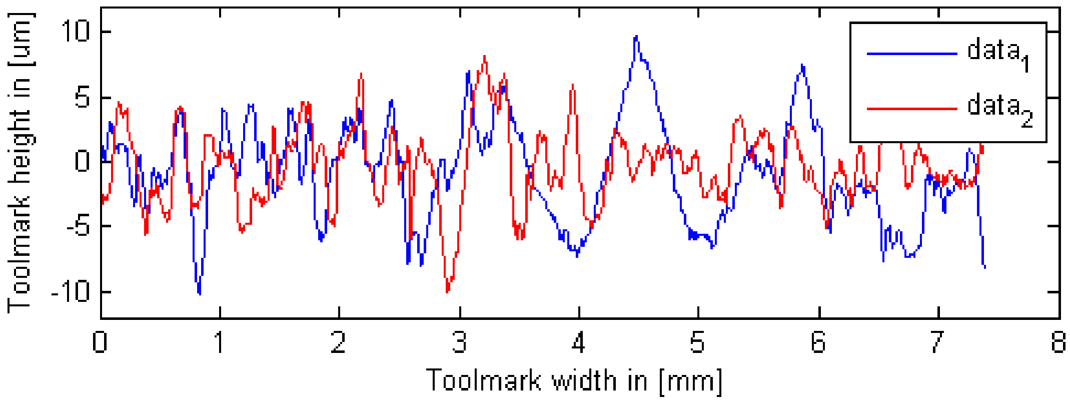
Similarity metric: Cross correlation



Known matches
(xcorr = 0.998)



Known non-matches
(xcorr = 0.2)

[Baiker et al., Quantitative comparison of striated marks, FSI, 2014]
[Baiker et al., Toolmark variability and quality…, FSI, 2015]

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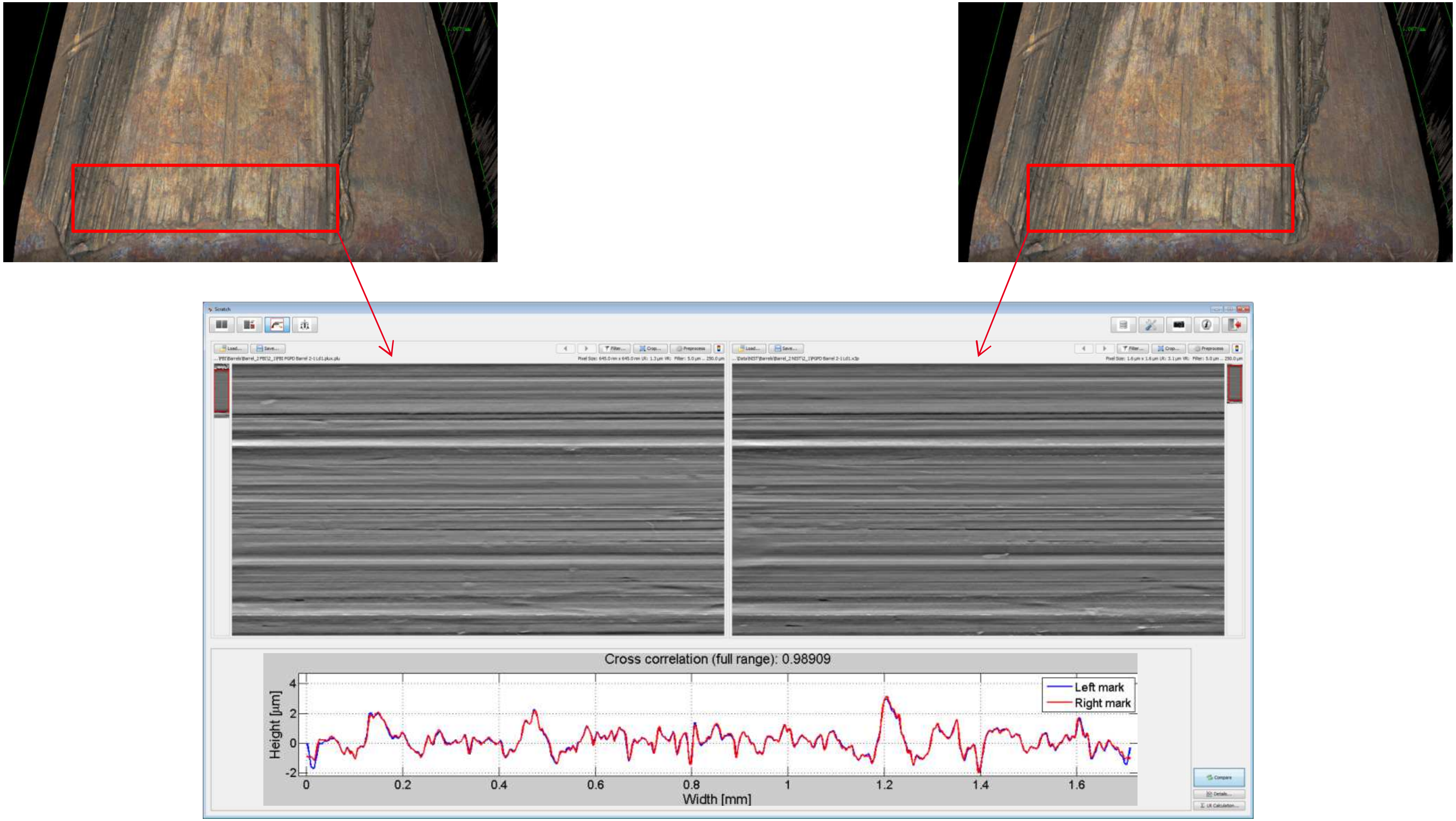

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Qualitative and quantitative assessment of the data

- *All three repetitions were compared to each other, yielding 3 similarity scores for each barrel and each LEA*

-> KM score distributions with 180 known matching scores

- *Each repetition of each LEA was compared to all other LEAs of the same barrel and one repetition of all LEAs of the other barrels*

-> KNM score distributions with 10620 known non-matching scores

- *Some LEAs were discarded (incomplete, damaged, data missing)*
- *Testing for statistical significant differences using Kruskal-Wallis test, combined with Tukey-Kramer honest significant differences criterion*

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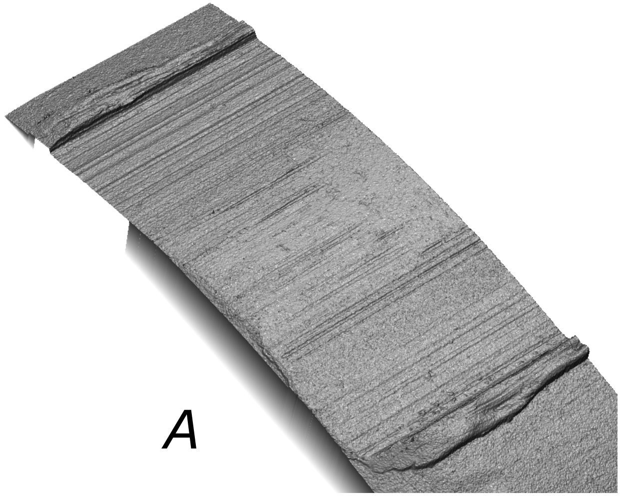

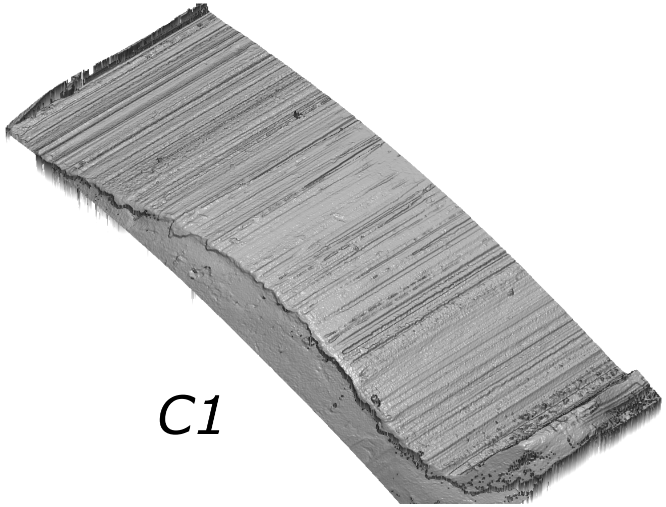

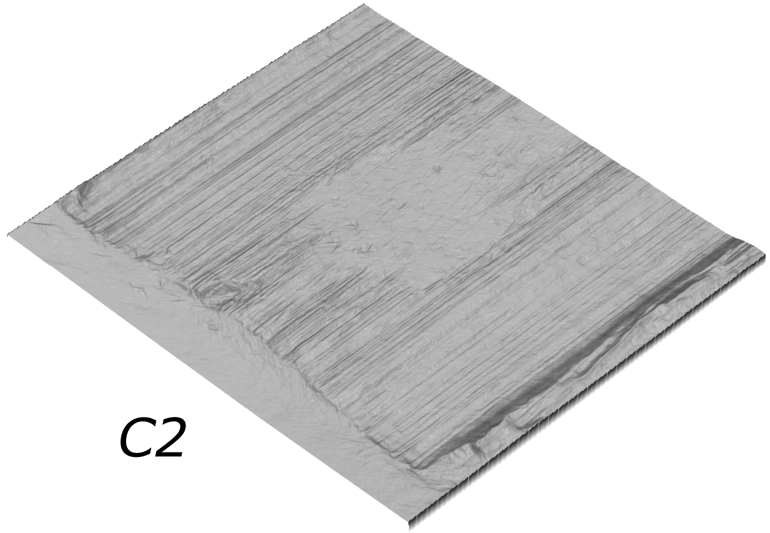

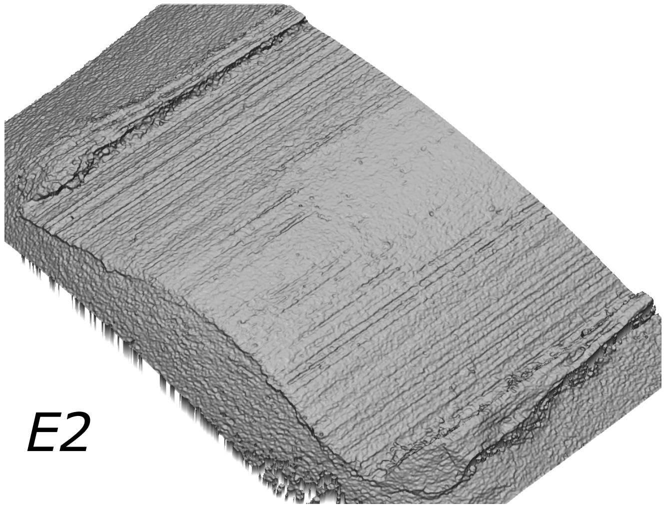

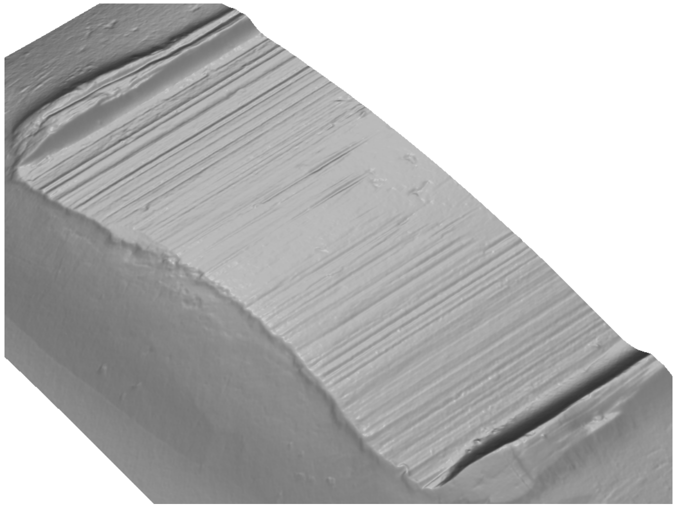

Lab	**Brand/Model** **Technology**
A	Brand 1, Model I *Focus Variation*
C1	Brand 3, Model I *Confocal*
C2	Brand 4, Model I *FV + Photometric Stereo*
E2	Brand 2, Model I *Focus Variation*
H	Brand 6, Model I *Photometric Stereo*

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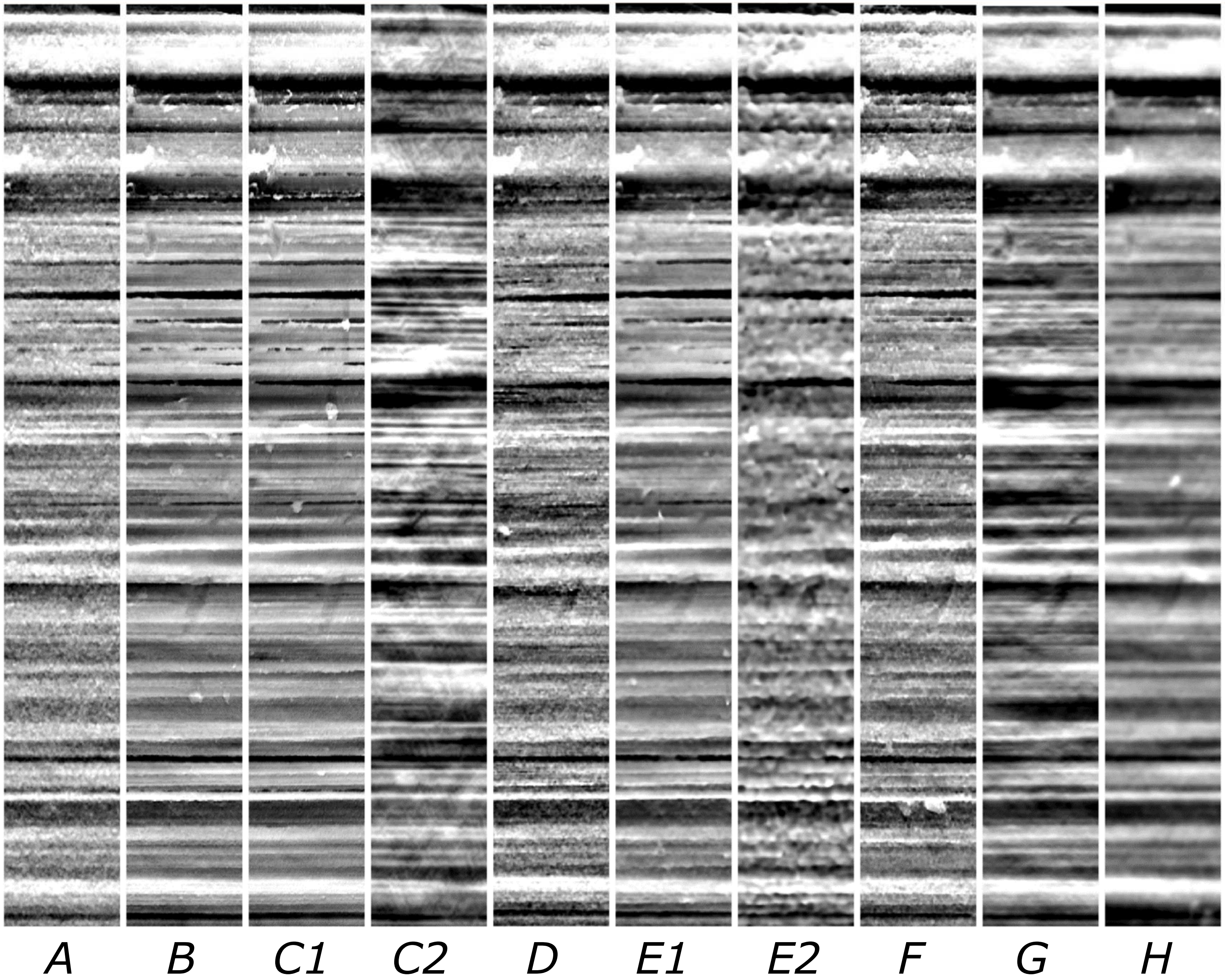

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D	Brand 1, Model II *Focus Variation*
E1	Brand 2, Model I *Continuous Confocal*
E2	Brand 2, Model I *Focus Variation*
F	Brand 2, Model II *Confocal*
G	Brand 5, Model I *FV + Photometric Stereo*
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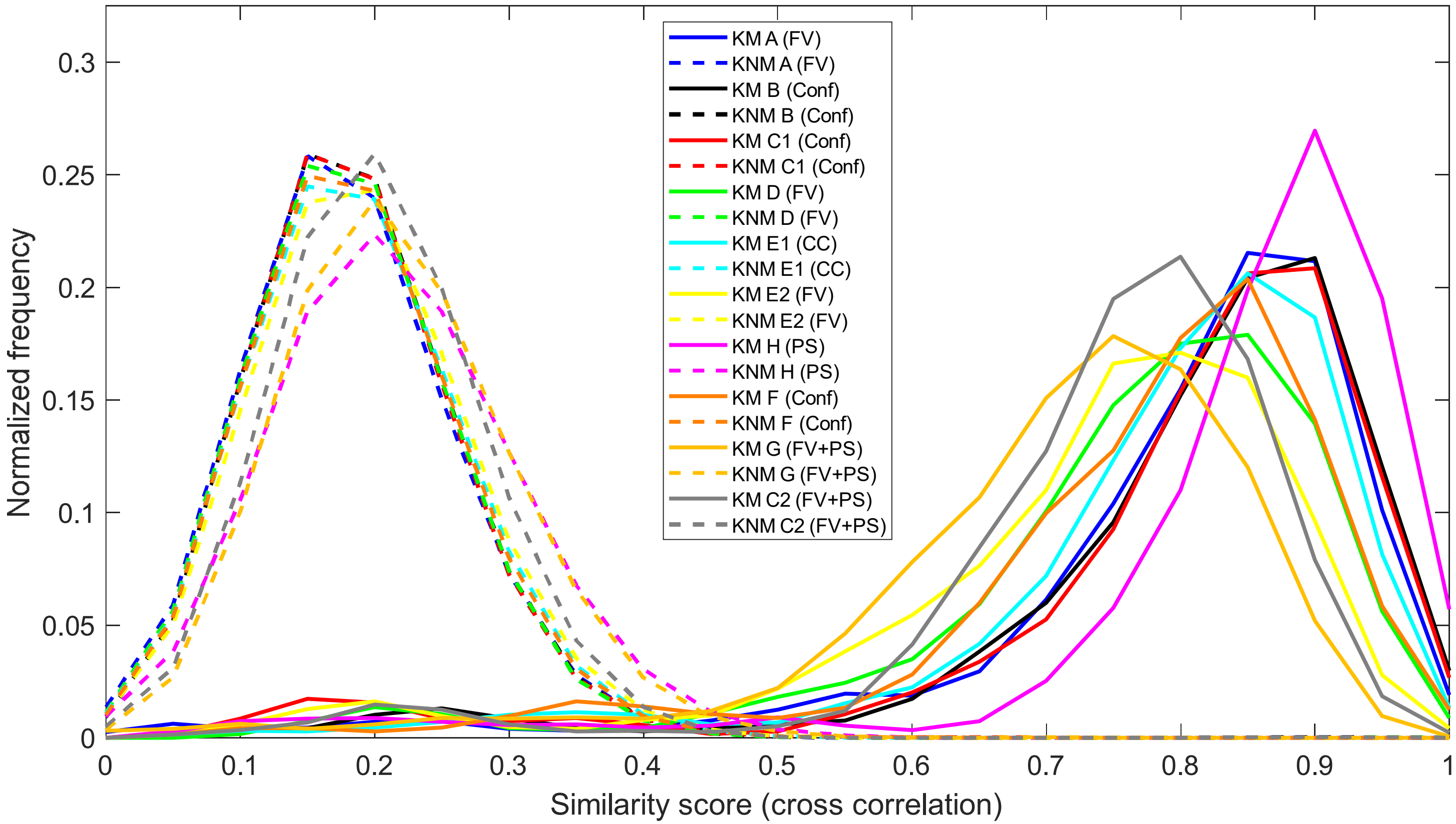
KM and KNM score distributions, all technologies



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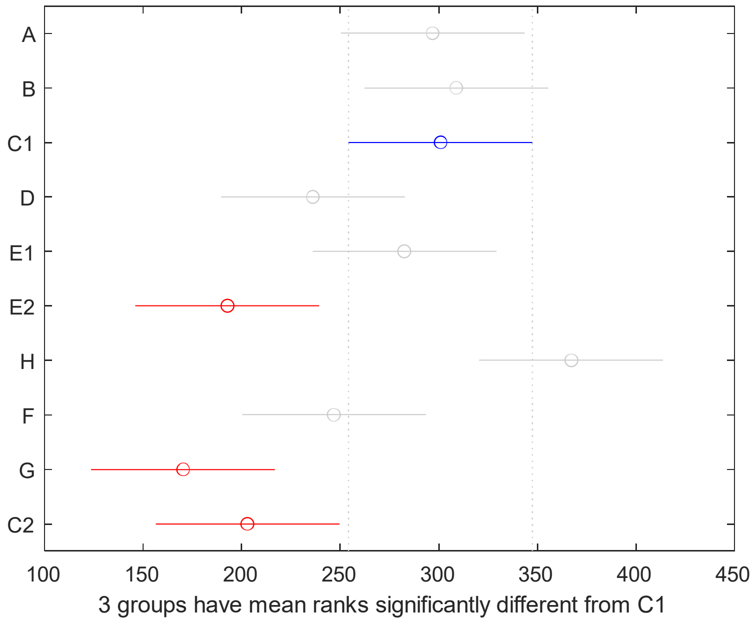
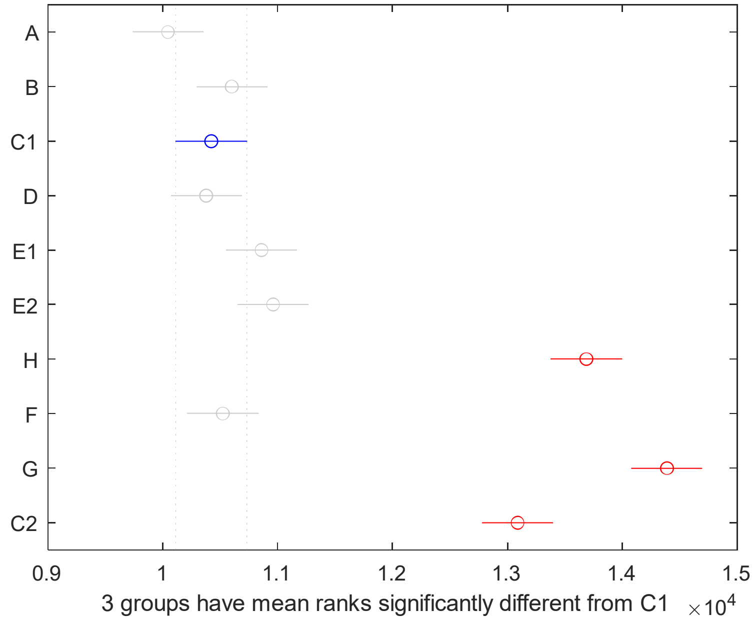
Testing for statistically significant differences



KM



KNM

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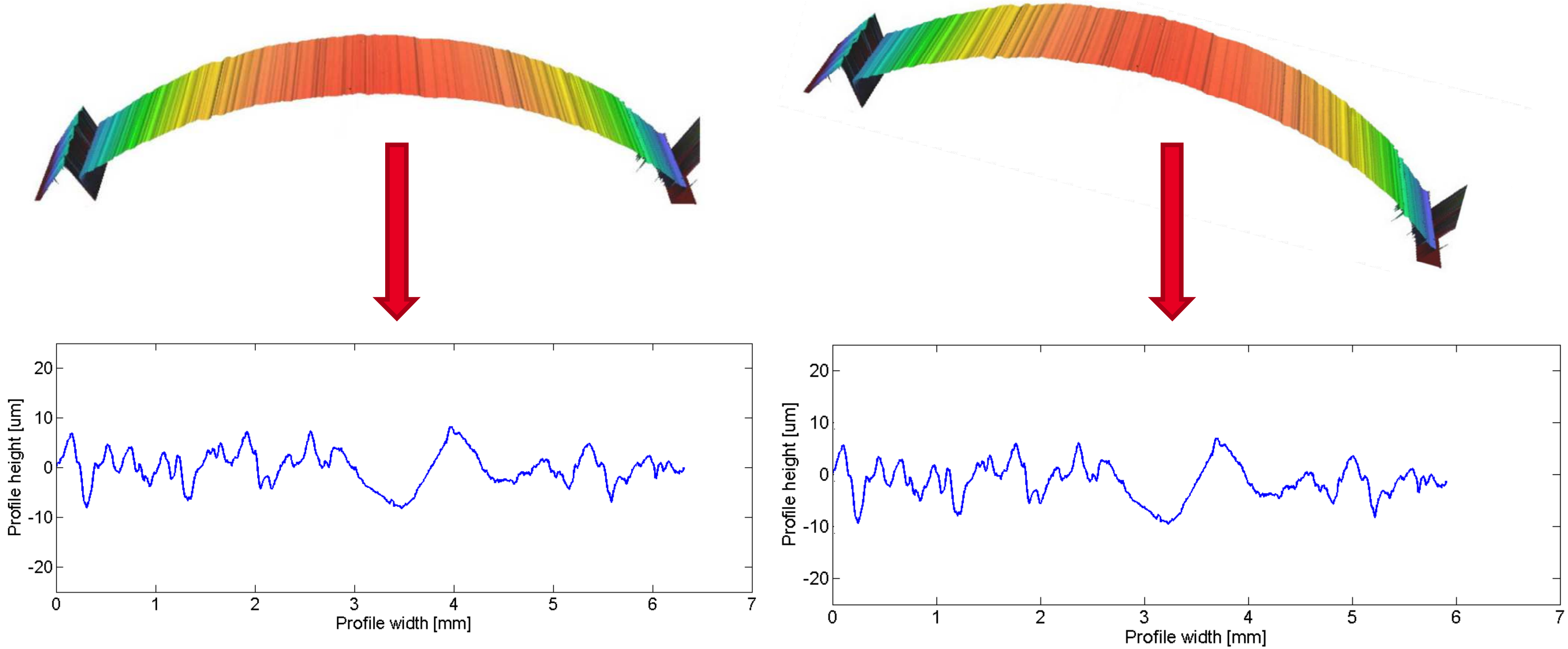
Axial bullet rotation causes (non-linear) compression



- ➢ *Correct for shape by applying 'unfolding'*

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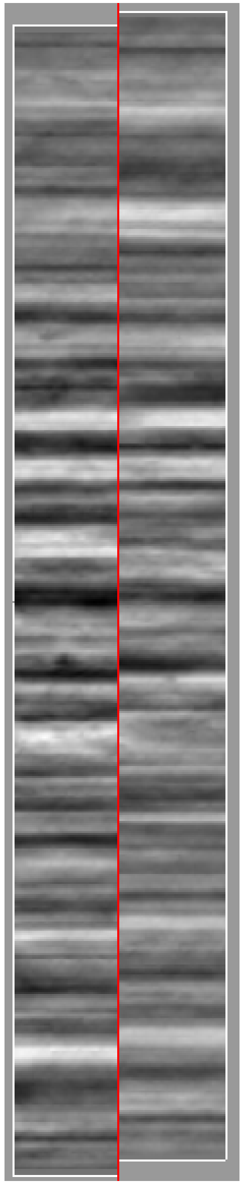
Linear compression sometimes remains

- *Still occurs sometimes, even after automated rotation*
- *Inherent to the measurement data*

➢ *Correct for scaling as well*



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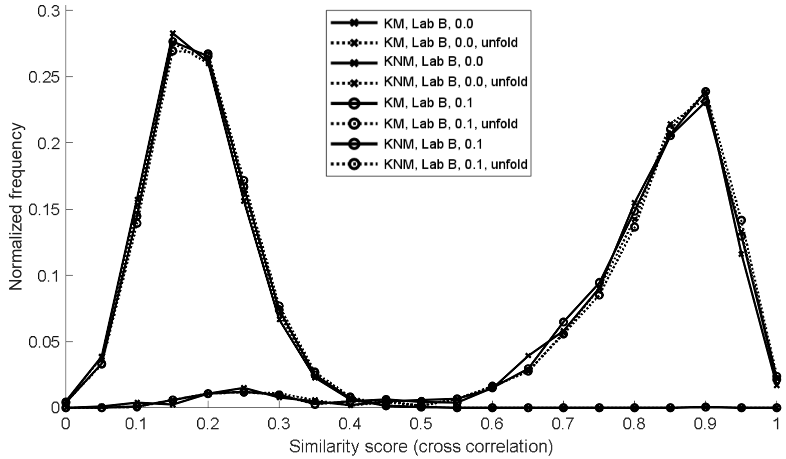
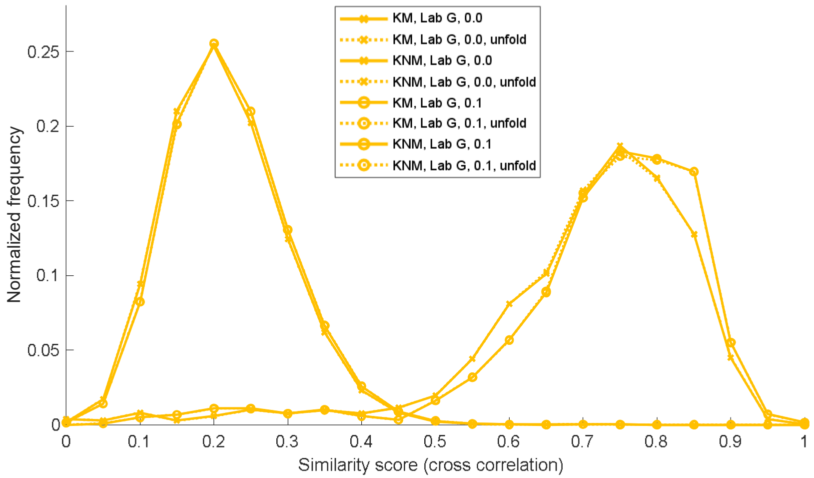
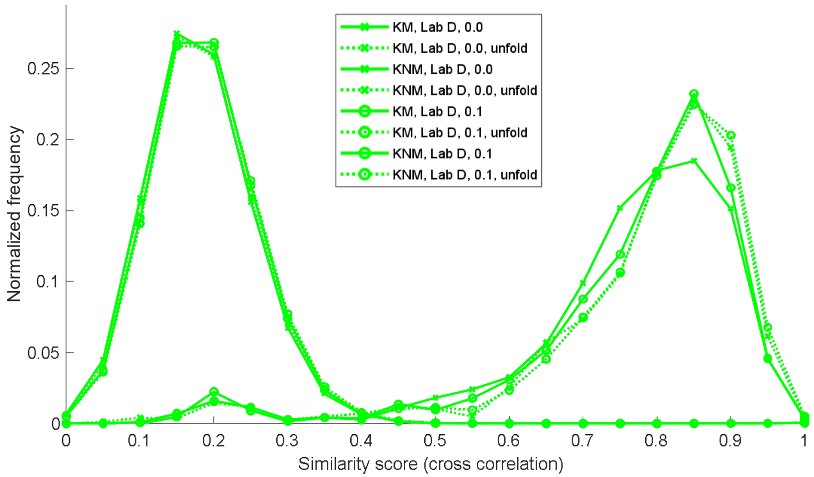
Effect of automated scaling and 'shape unfolding'(*)







(*) Not applied on already flattened data

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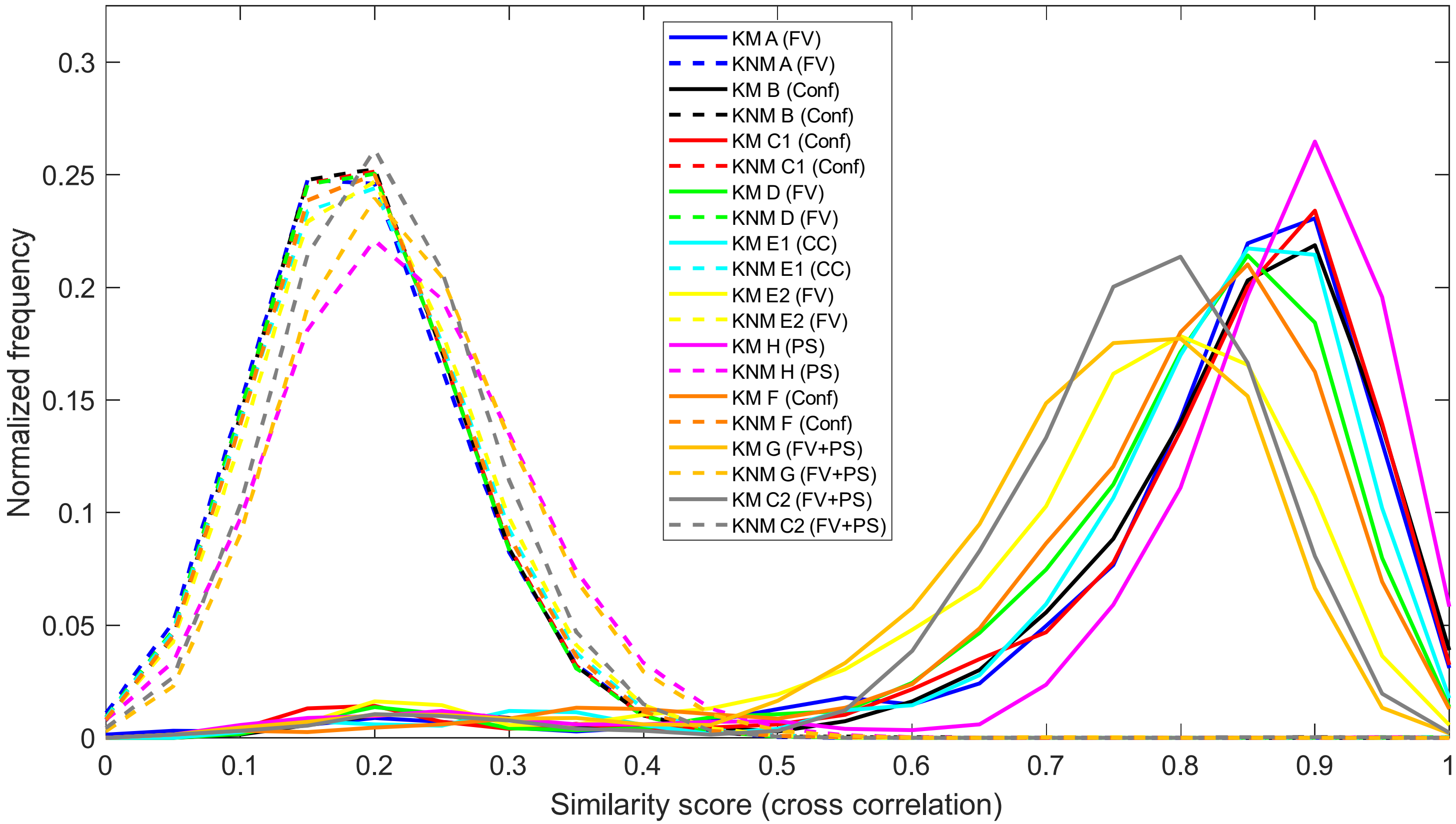
KM and KNM score distributions, with corrections



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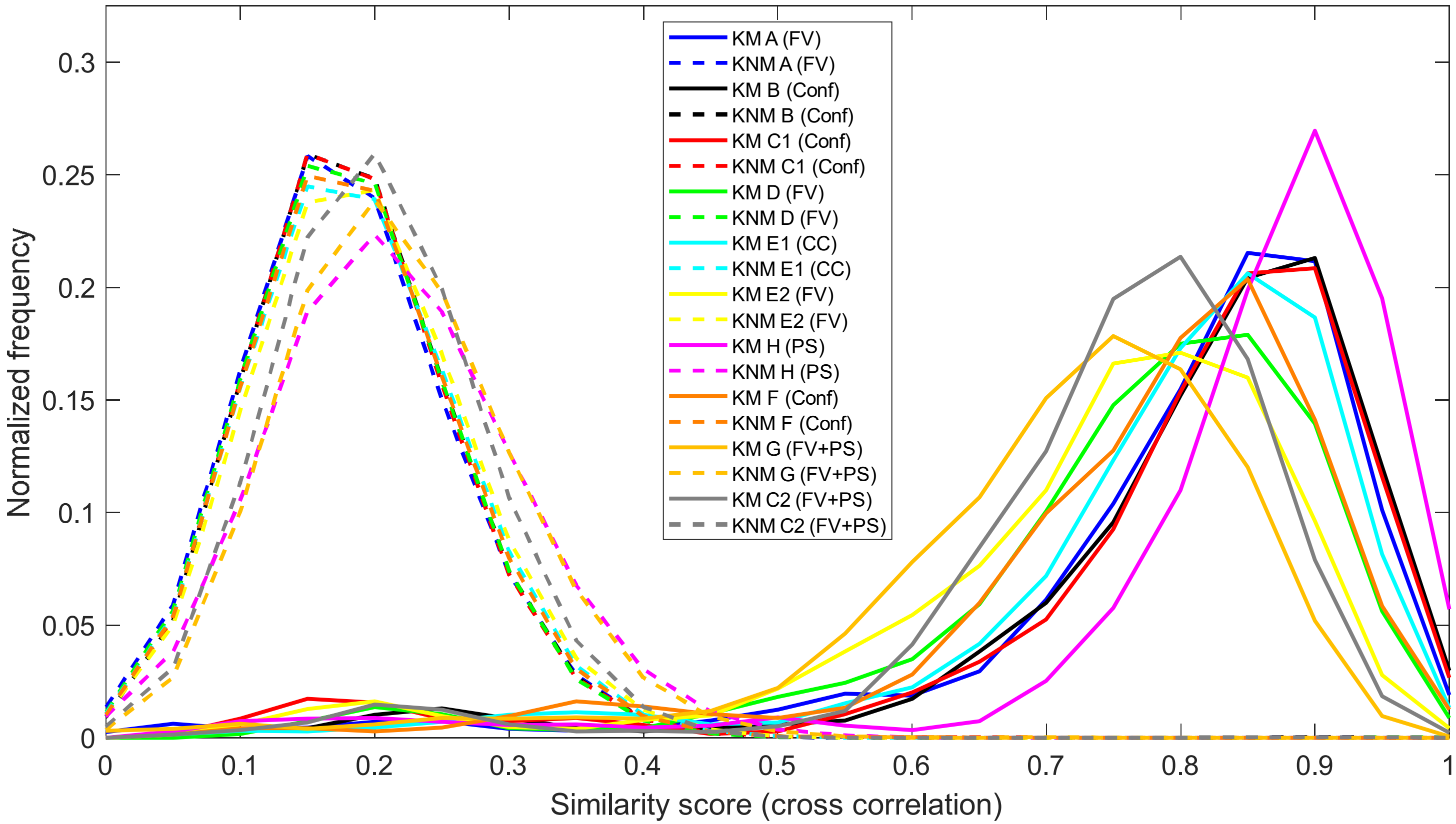
KM and KNM score distributions, no corrections



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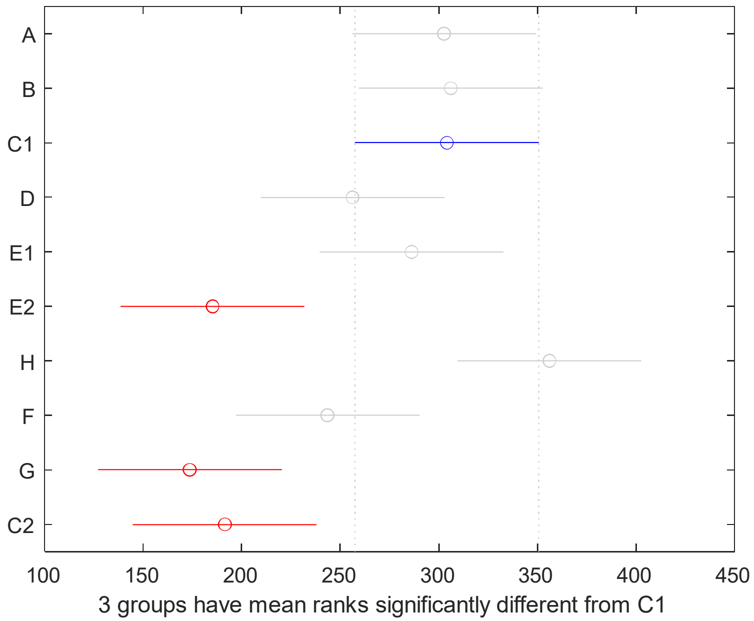
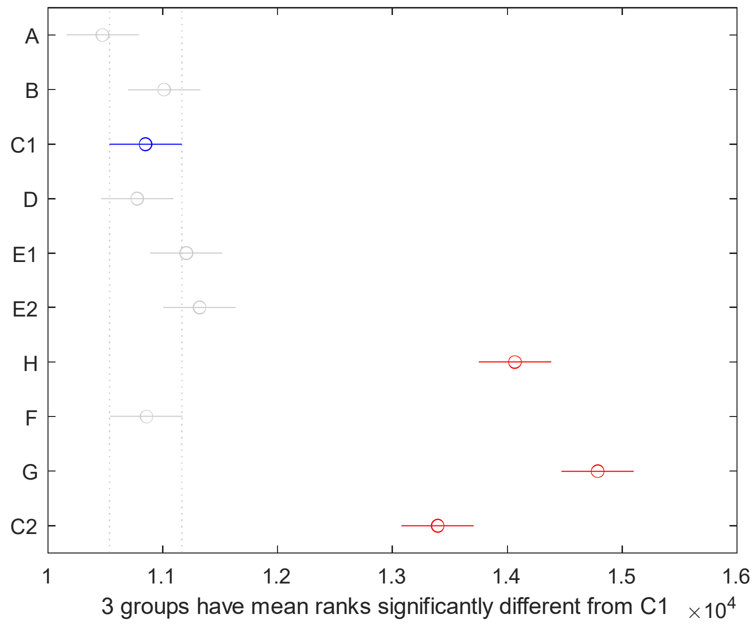
Testing for statistically significant differences



KM



KNM

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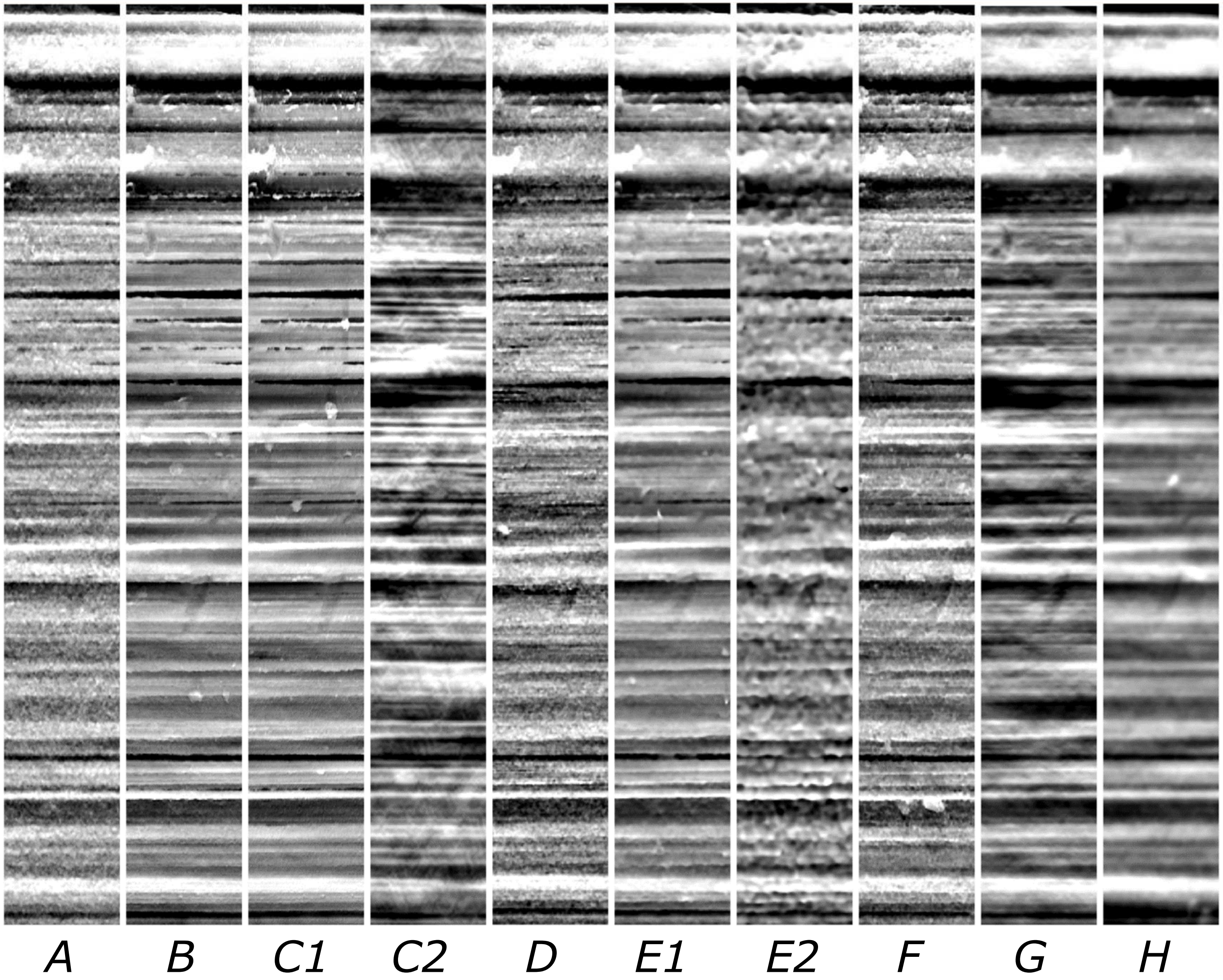

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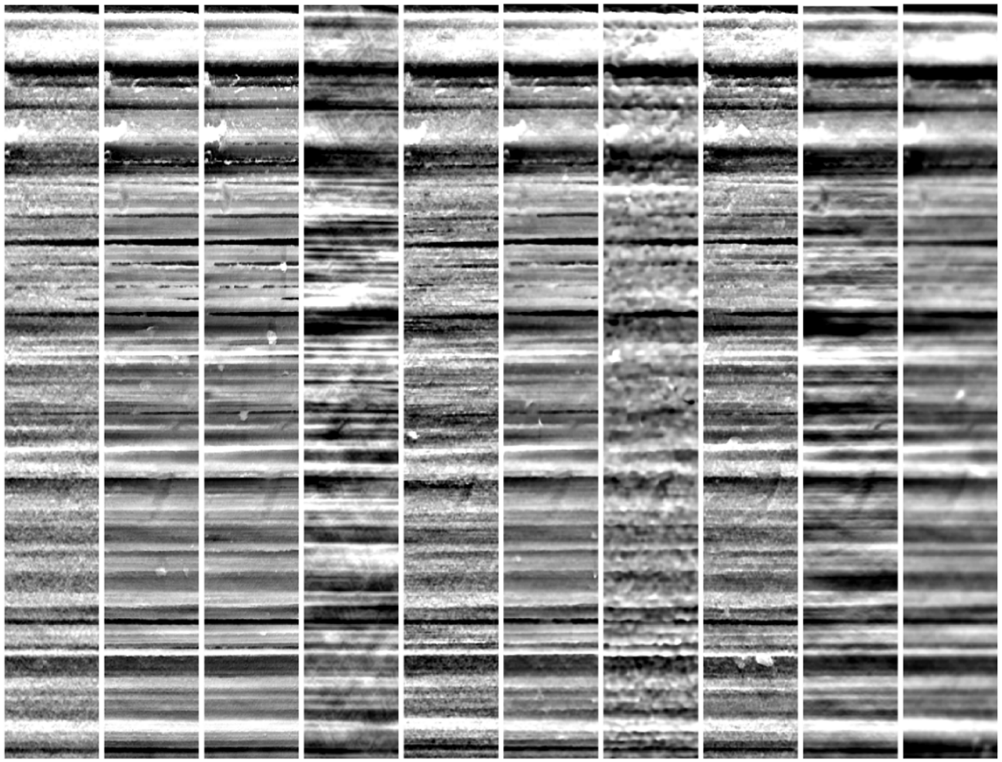
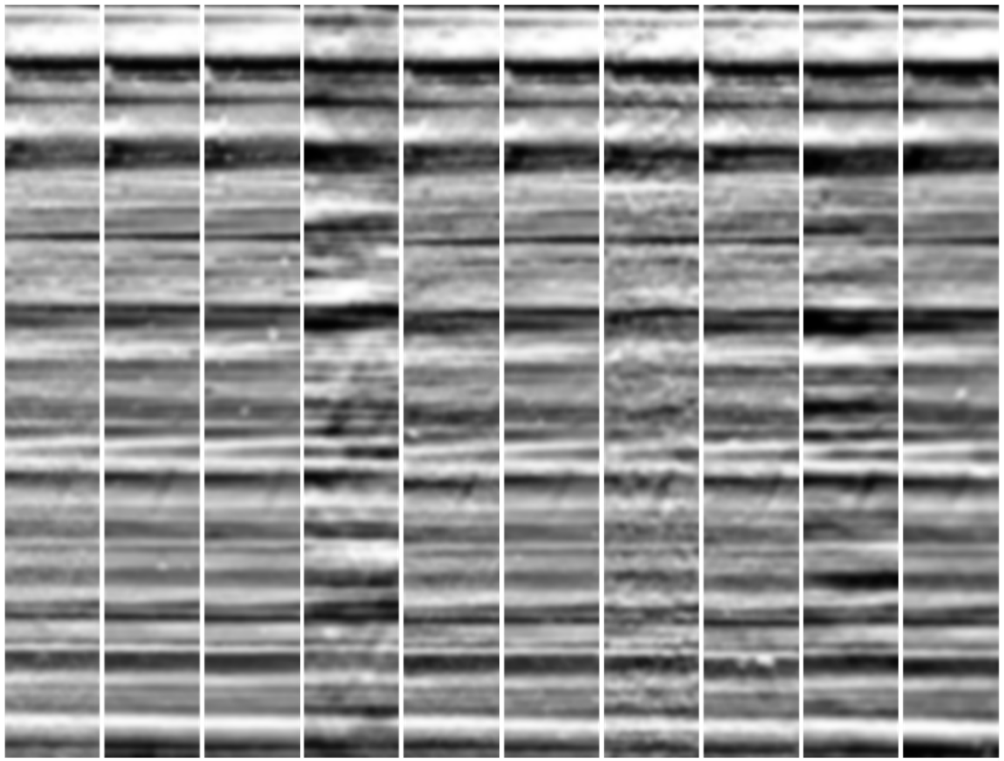
Effect of difference noise filter settings





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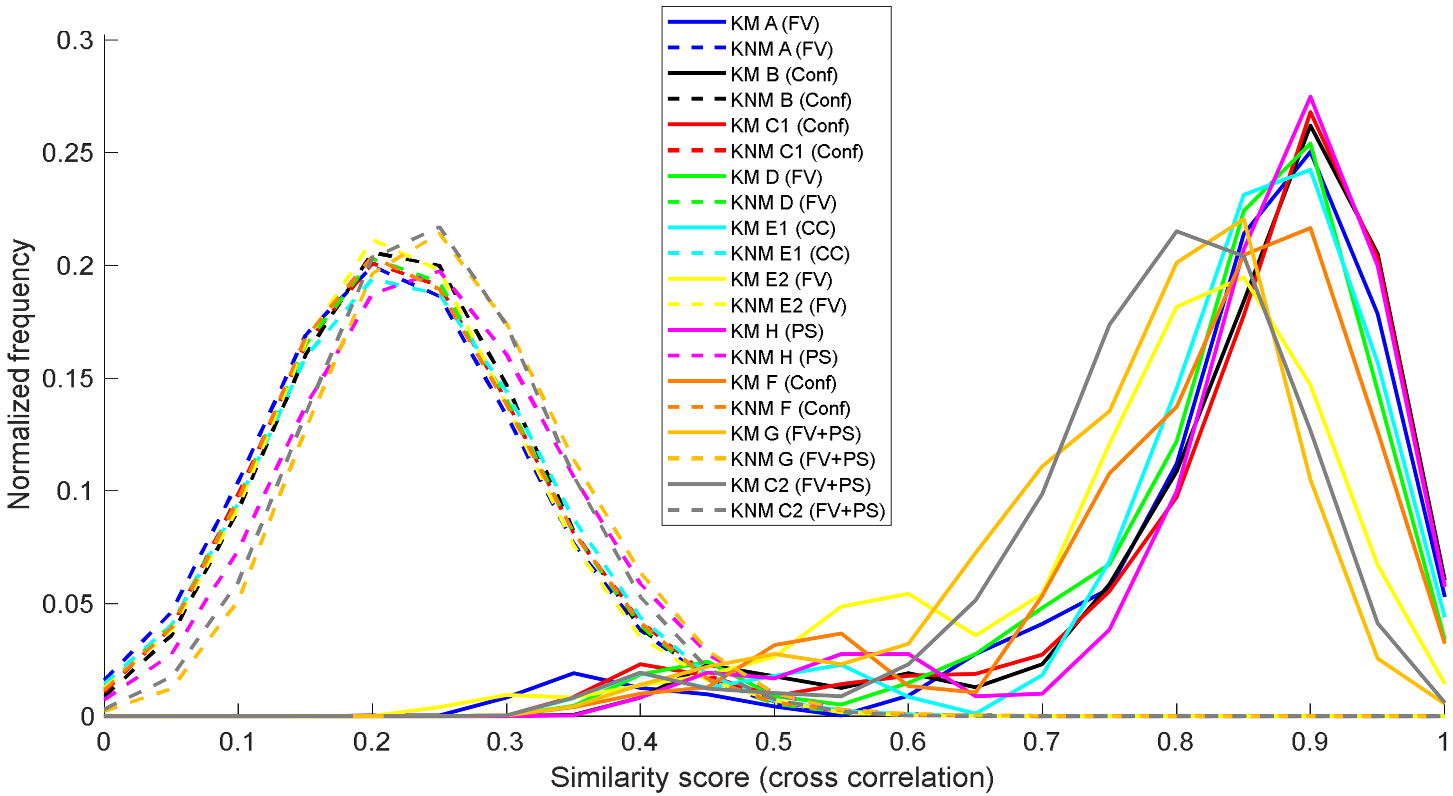
KM and KNM score distributions, noise filtered at 50 μm



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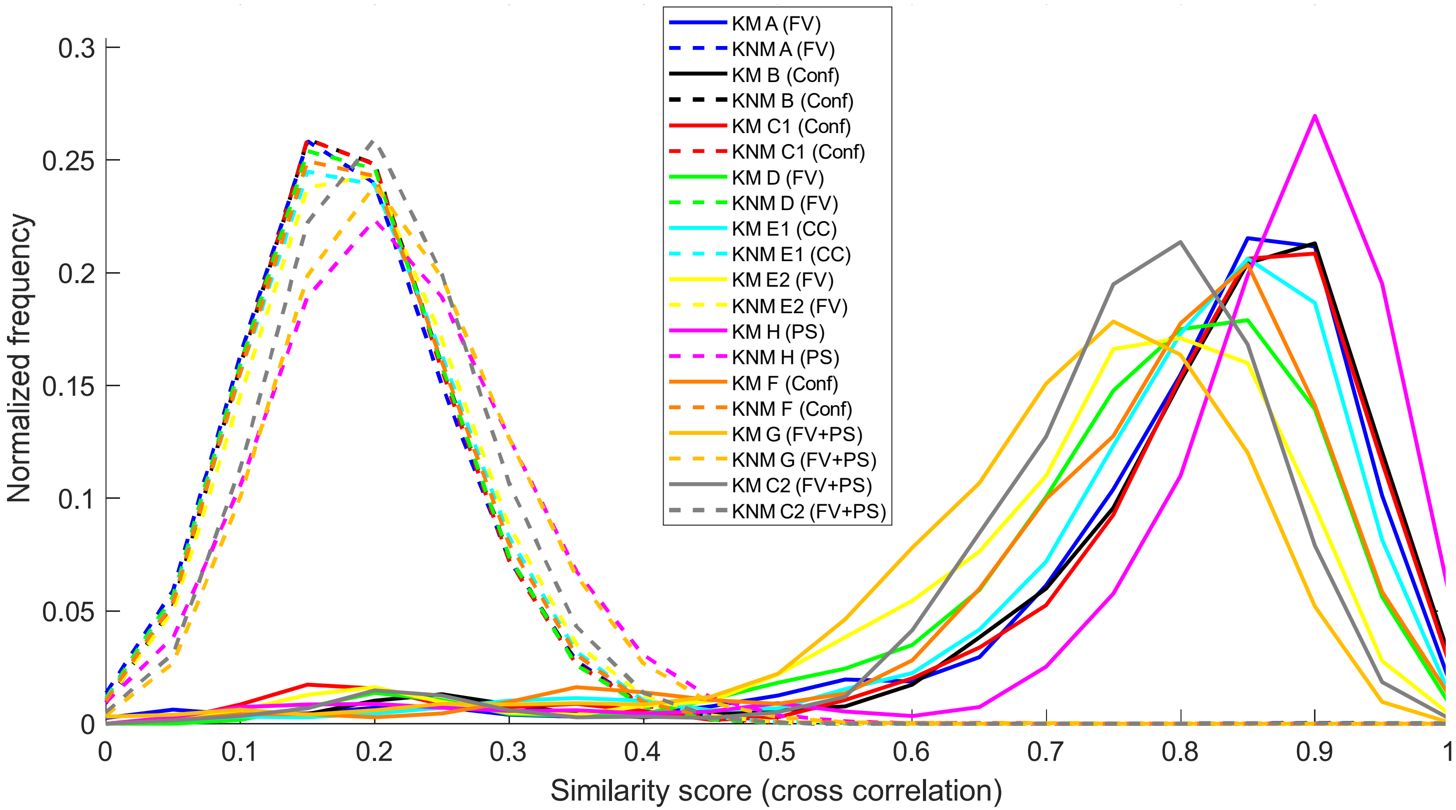
KM and KNM score distributions, all technologies



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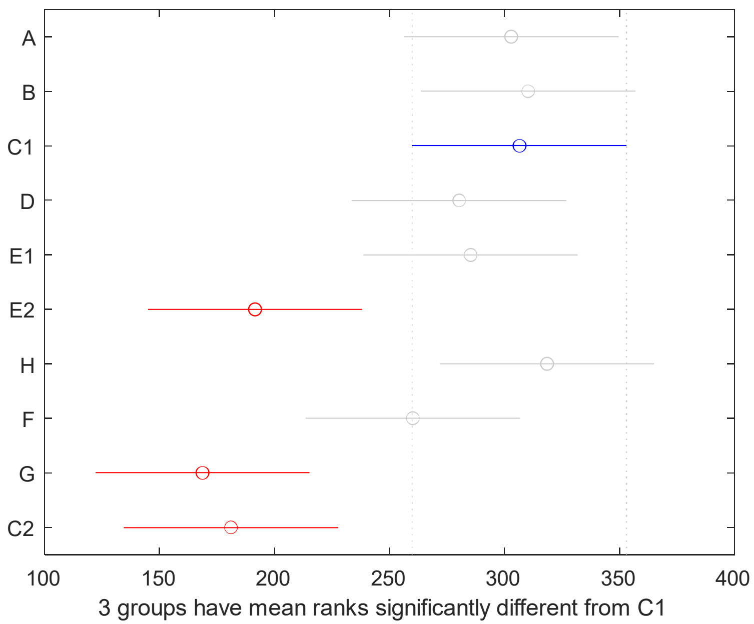
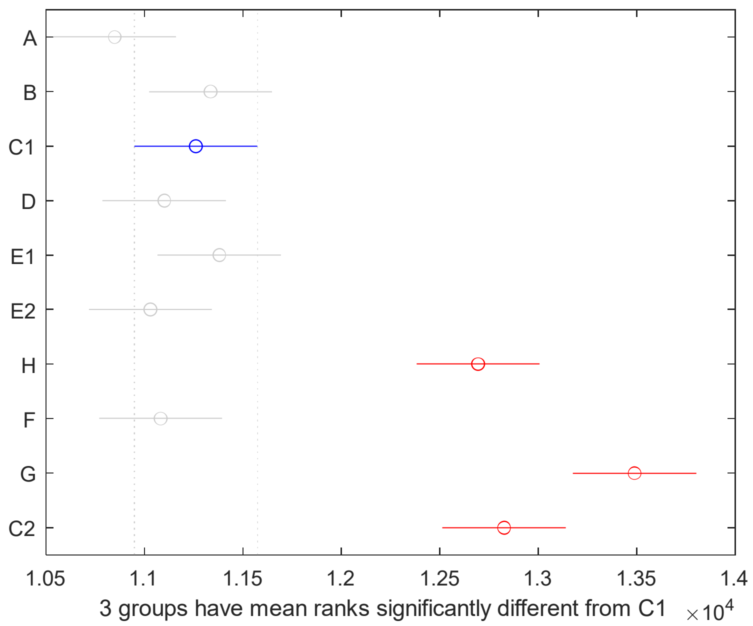


KM



KNM

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G	Brand 5, Model I *FV + Photometric Stereo*
H	Brand 6, Model I *Photometric Stereo*

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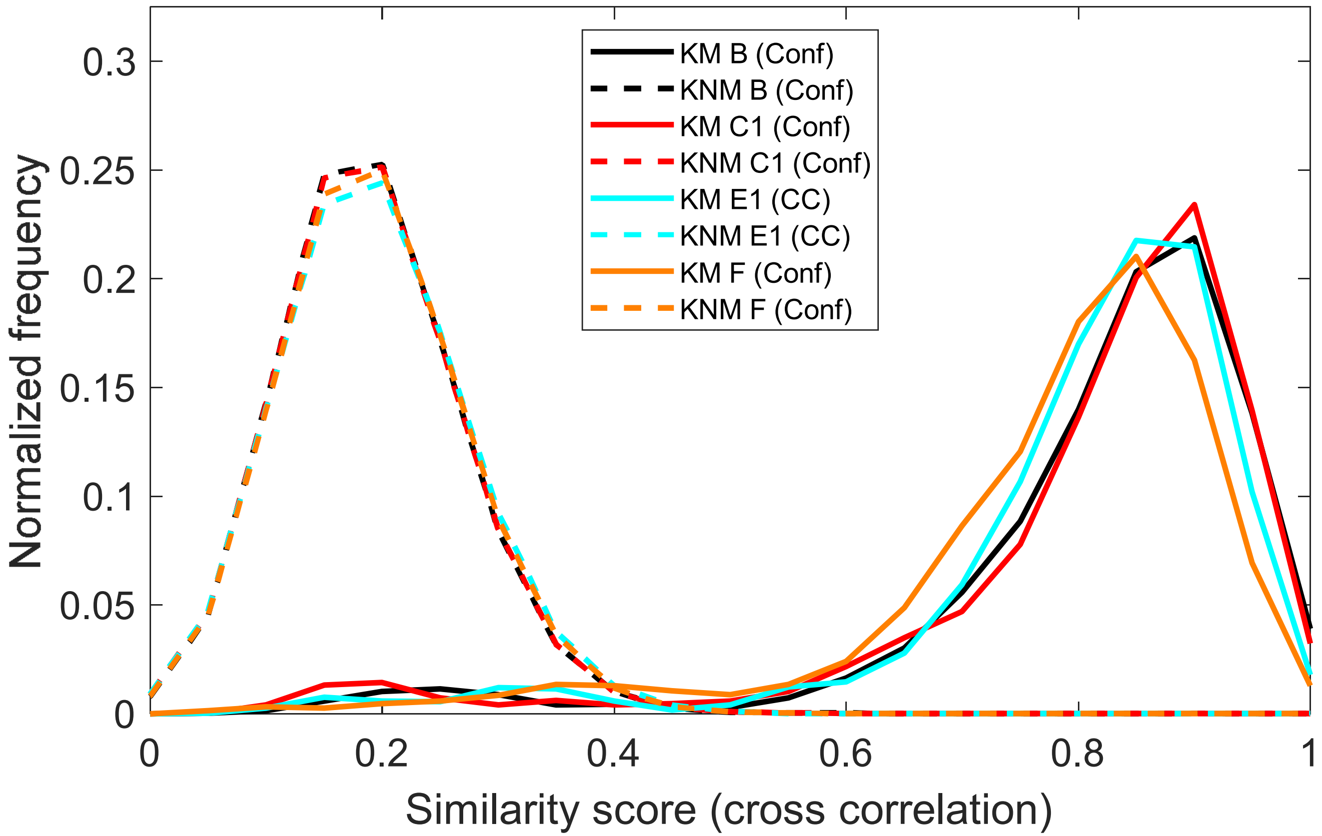
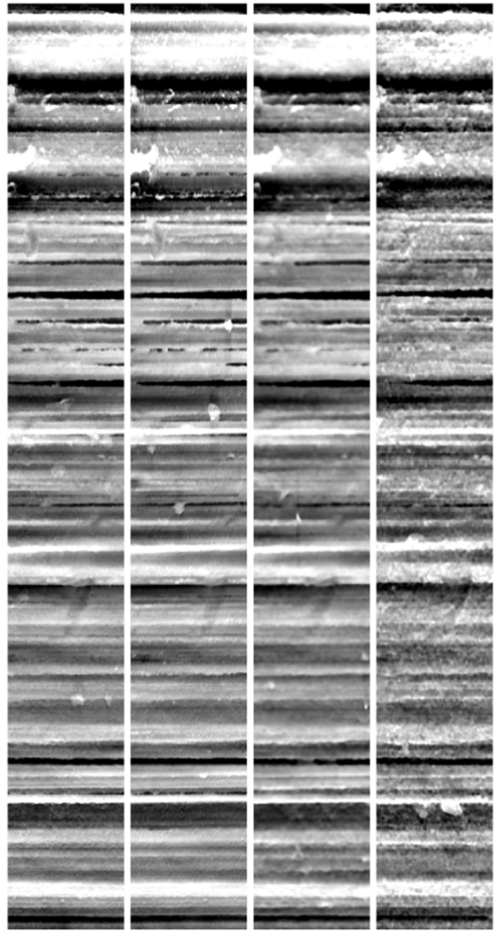
Comparison Confocal microscopy





B *C1* *E1* *F*

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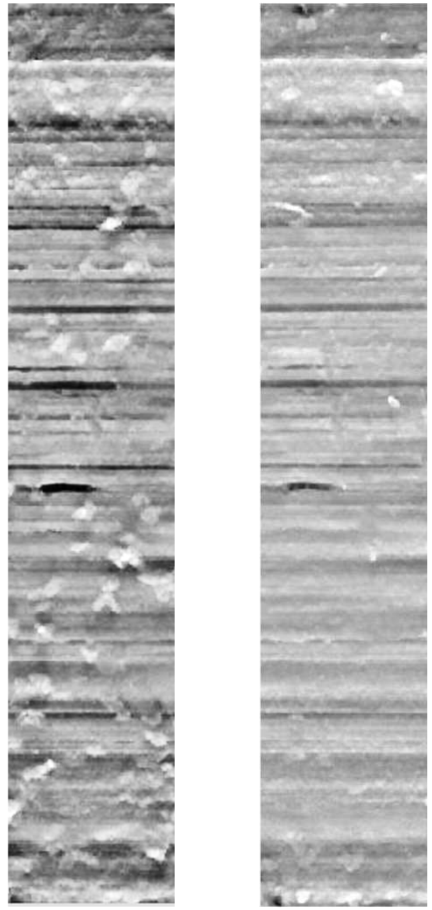
Comparison Confocal microscopy

- *Lab F:*
  - *Older model*
  - *Dusty samples*



Before *After*

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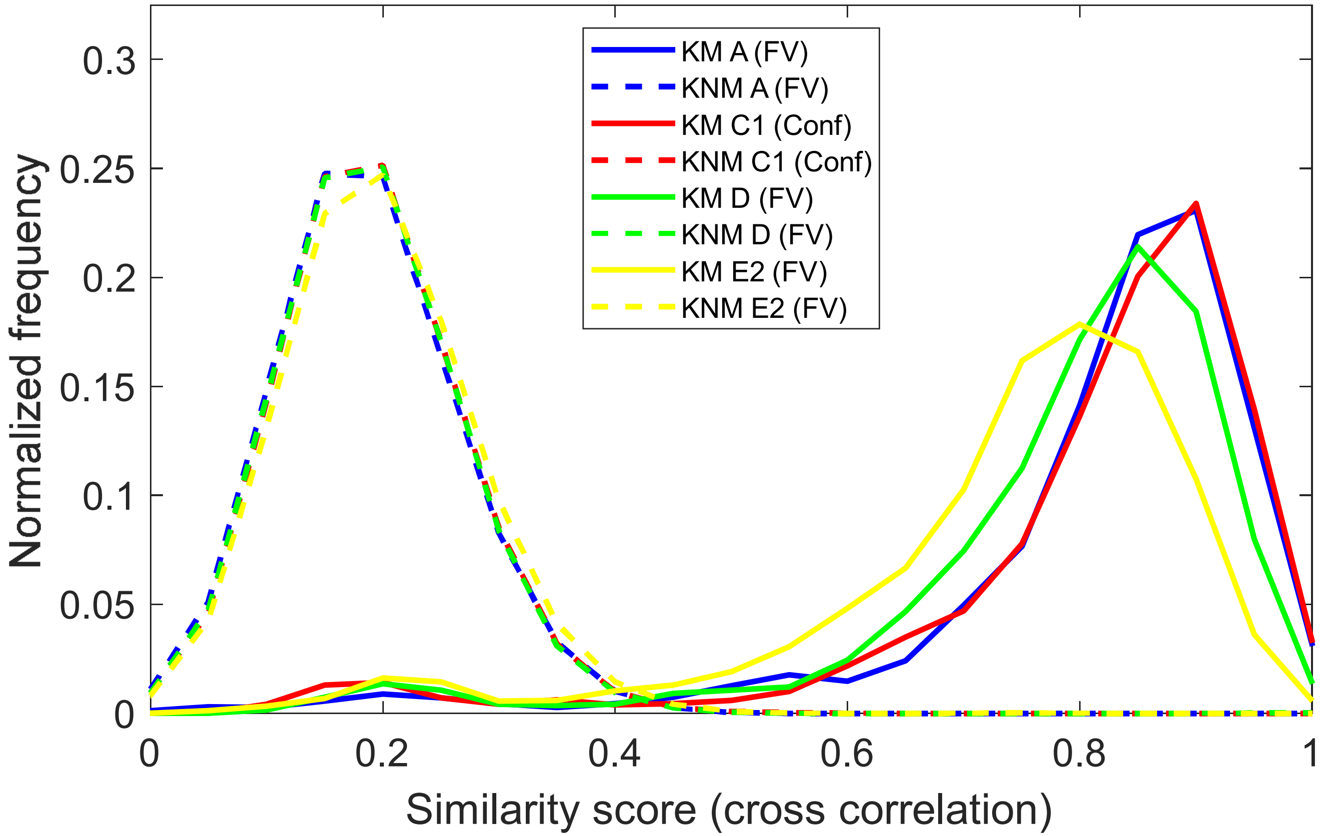
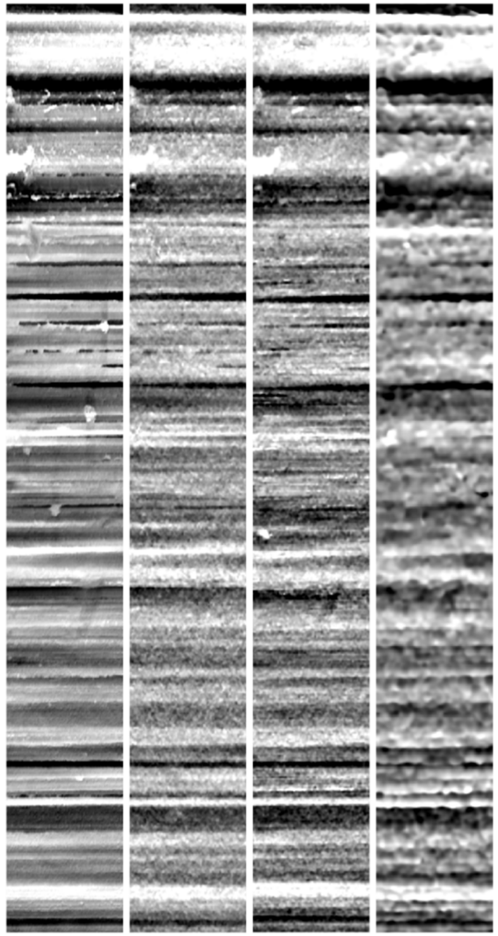
Comparison Focus Variation microscopy





C1 A D E2

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Comparison Focus Variation microscopy

- *Lab D:*
  - *Student operators*
  - *Relative large variation in positioning*
  - *Filtering with 50 μm causes KM distribution to be on top of the one from labs A and C1*
- *Lab E2:*
  - *Relatively more noise compared to other measurements*

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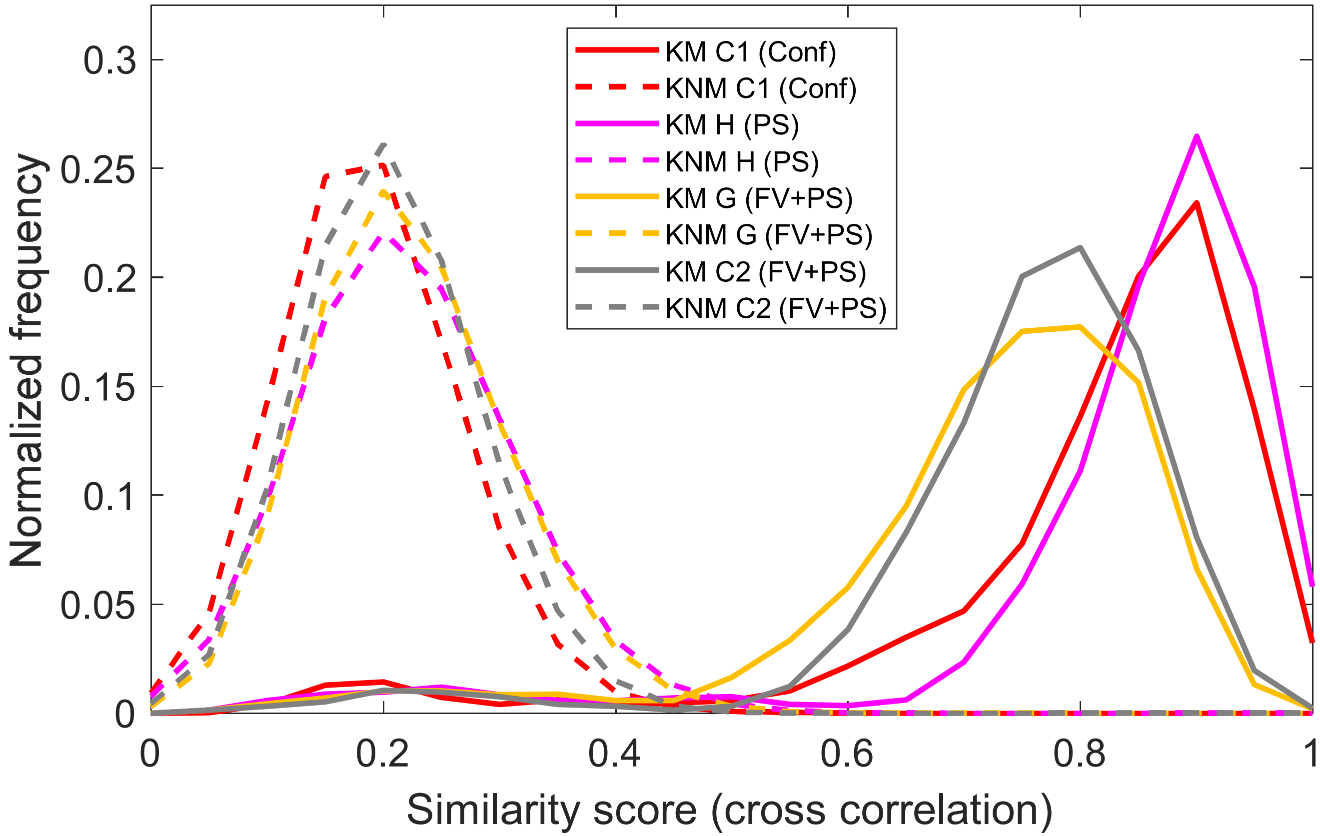
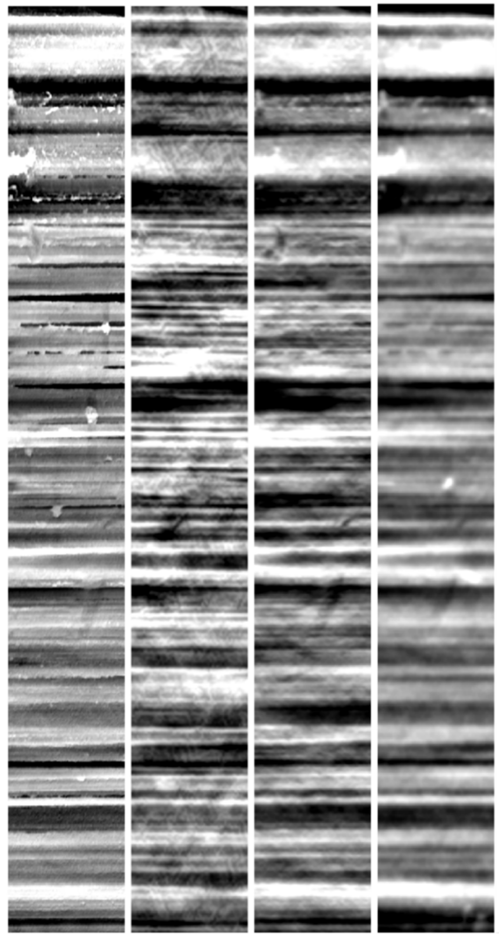
Comparison Photometric Stereo (+ FV) microscopy





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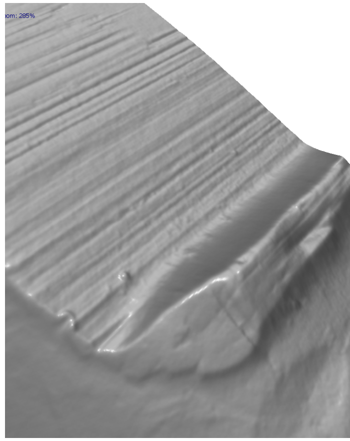
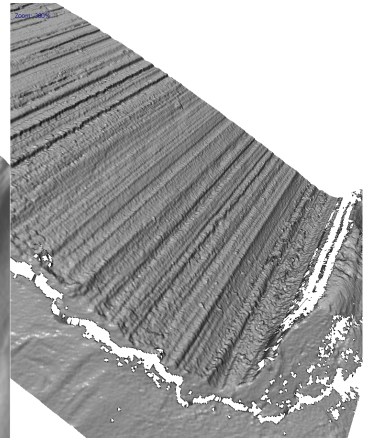
Comparison Photometric Stereo (+ FV) microscopy

- *Lab H:*
  - *System requires gel pads for acquisition*
  - *Gel pads 'smooth' the data (remove noise and reduce strong reflections)*
  - *Gel at times doesn't contact the full LEA*



H



C1

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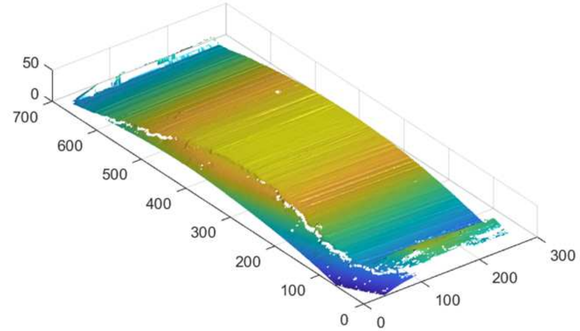
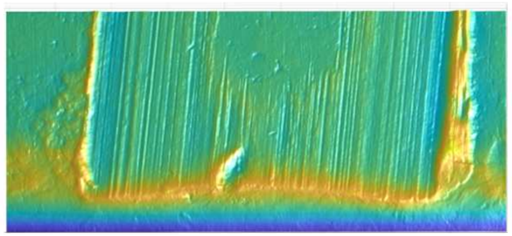
Comparison Photometric Stereo (+ FV) microscopy

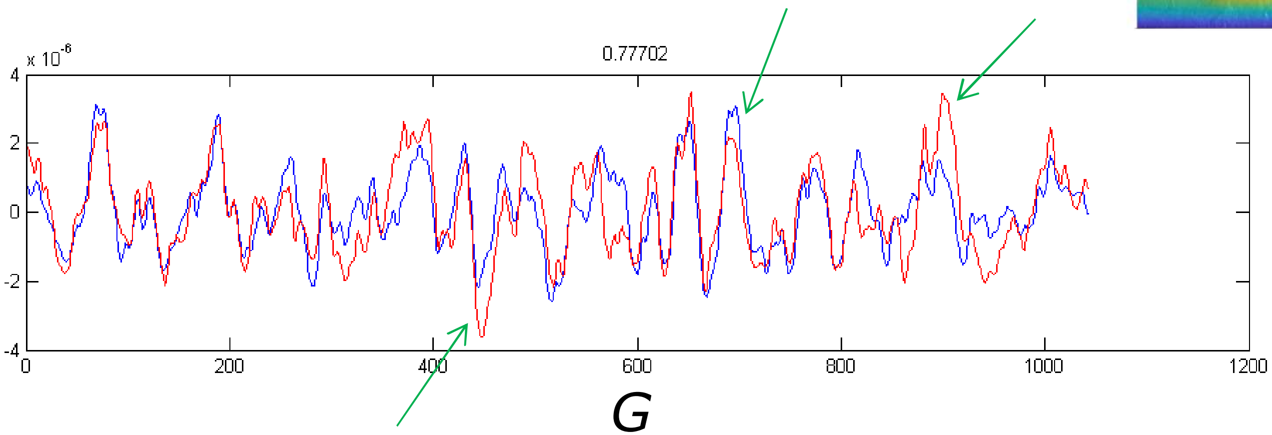
- *Lab C2 and G:*
  - *Profile amplitude accuracy might be affected by strongly reflective areas*
- *Lab G:*
  - *Filter artefacts at the onset of the mark*
  - *Small local 'feature shift'*



C1



G



G

Blue: Lab C1 (Confocal)

Red: Lab G (FV + PS)

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Comparison Photometric Stereo (+ FV) microscopy

- *Systems C2 and G:*
  - *(Very) Fast and easy data acquisition*
  - *Systems targeted at database retrieval*
  - *Profile amplitude measurements might be affected by highly reflective marks surface*

Note: The shape of marks is removed by the system for C2 and G, whereas for the other systems the shape is removed by software

-> Possible differences in shape content, affecting the profiles

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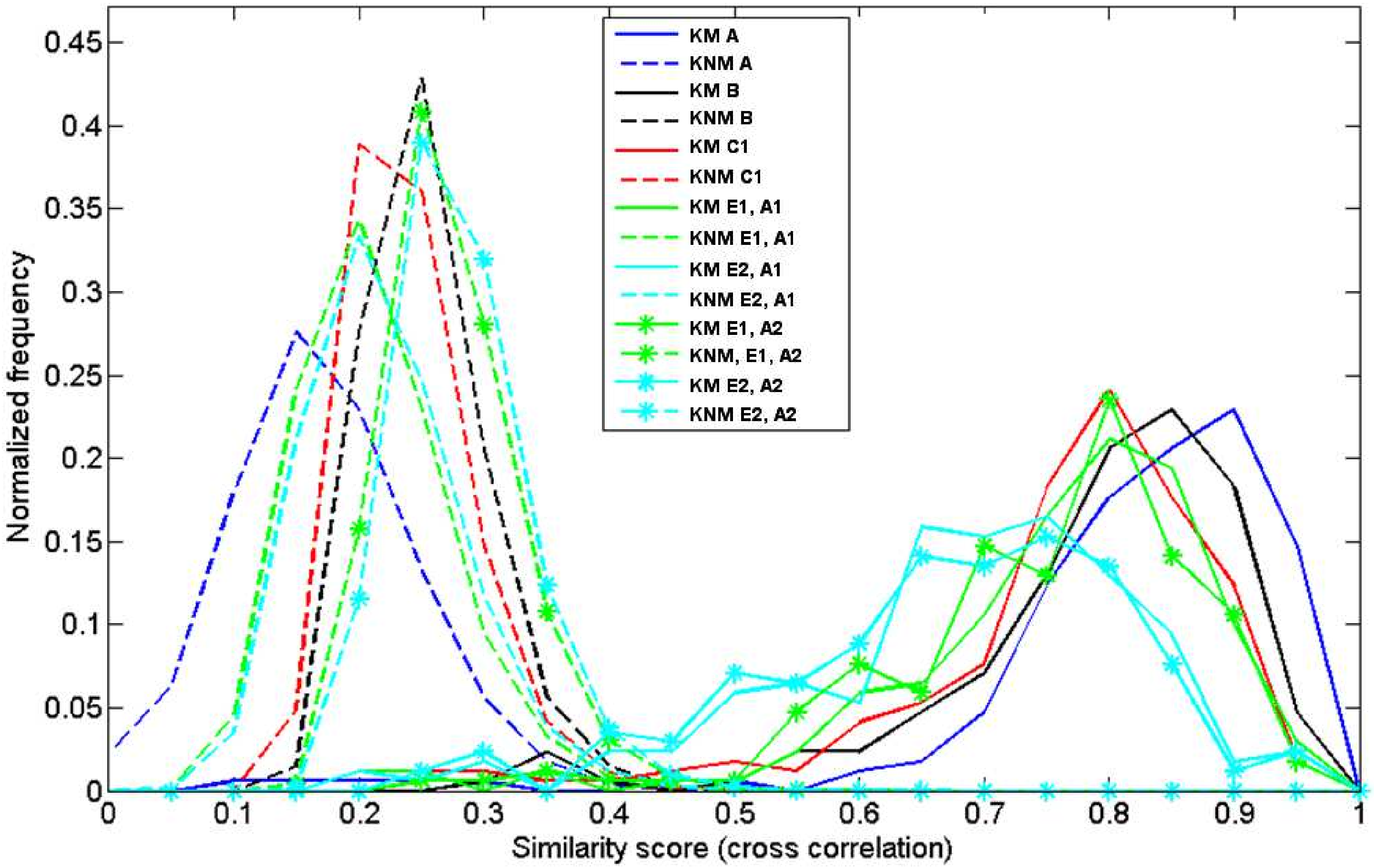
Different methods yield different KM/KNM distributions



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Limitations

- *Limited data (… as always), especially in the tails of the distributions*

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Limitations

- *Limited data (… as always), especially in the tails of the distributions*
- *Only one firearm/ammunition combination so far*
- *Study used one an application specific metric (cross correlation), not a generic surface metric*
  - ➢ *Difficult to generalize results to other mark types/scores*

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Summary

- *Results of using different acquisition methods and different algorithms is like comparing apples to pears, even using the same similarity score*

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Summary

- *Results of using different acquisition methods and different algorithms is like comparing apples to pears, even using the same similarity score*
- *Using the same comparison method yields similar score distributions, despite variation in technology, operator, settings and location*

➢ *(Automated) Interpretation results should be similar*

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Summary

- *Results of using different acquisition methods and different algorithms is like comparing apples to pears, even using the same similarity score*
- *Using the <u>same</u> comparison method yields similar score distributions, despite variation in technology, operator, settings and location*
- *Two categories of influencing factors: 1.) Technology, 2.) Protocol*

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Summary

- *Results of using different acquisition methods and different algorithms is like comparing apples to pears, even using the same similarity score*
- *Using the same comparison method yields similar score distributions, despite variation in technology, operator, settings and location*
- *Two categories of influencing factors: 1.) Technology, 2.) Protocol*
- *Possibility to (partially) address technology and protocol induced variation:*
  - *A: Experienced operator, proper sample alignment, proper cleaning*
  - *B: Automated rotation, unfolding, allowing scaling during alignment*
  - *C: Remove fine details from data by filtering and/or adjusting resolution*

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Summary

- *Results of using different acquisition methods and different algorithms is like comparing apples to pears, even using the same similarity score*
- *Using the same comparison method yields similar score distributions, despite variation in technology, operator, settings and location*
- *Two categories of influencing factors: 1.) Technology, 2.) Protocol*
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  - *B: Automated rotation, unfolding, allowing scaling during alignment*
  - *C: Remove fine details from data by filtering and/or adjusting resolution*
- *Data available in the NIST ballistics database (https://tsapps.nist.gov/NRBTD)*

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Conclusion

- *So is 3D surface data always truly objective?*
  - *Not 'out-of-the-box'*
  - *But differences between systems can be greatly reduced with proper data acquisition protocols*

- *Keep in mind:*
  - *Differences between measurements from the same system in the same lab are expected to be (very) small*

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