Sources of Variability in Surface Measurements

NIST workshop on Error Management

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Outline

- Study setup
- Similarity measures
- Sources of variability
- Other measures of similarity

Study Setup

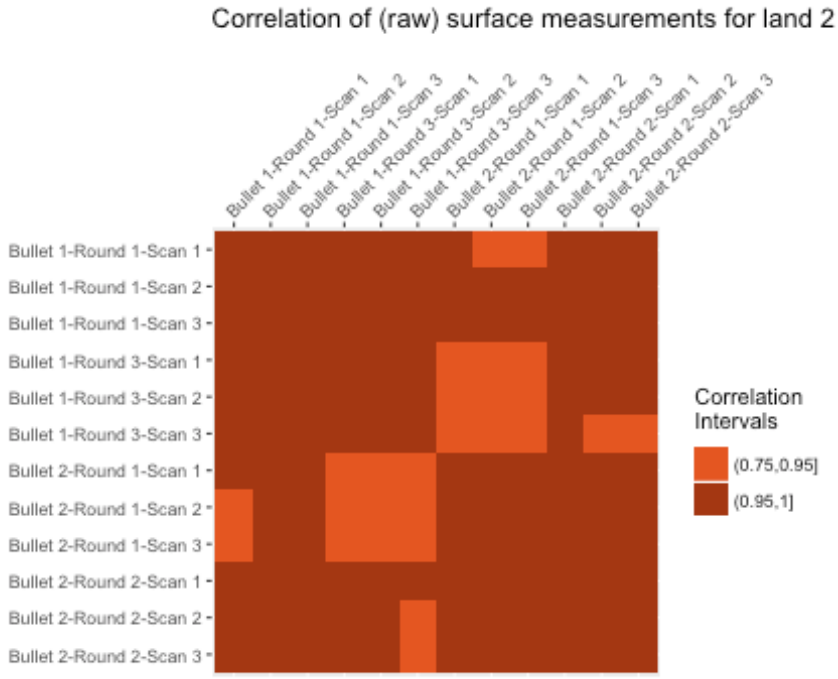
- Goal: quantify sources of variability of surface measurements
- Here: focus on bullet lands
- Study setup:
  - two operators (A, F)
  - scanning three bullet lands (`land`)
  - from two different bullets (`bullet`)
  - on two separate days (`round`)
  - using three immediate acquisitions (`scan`) for each land
- Sources of variability: machine, staging, bullet and lands, operator
- Scans taken with Sensofar CLM microscope at Iowa State

Why measure variability?

- Ideally, we would like to measure *error* - but we don't know ground truth
- Measuring sources of variability will/should inform
  - standard operating protocol,
  - results from machine calibration and
  - same-source analysis

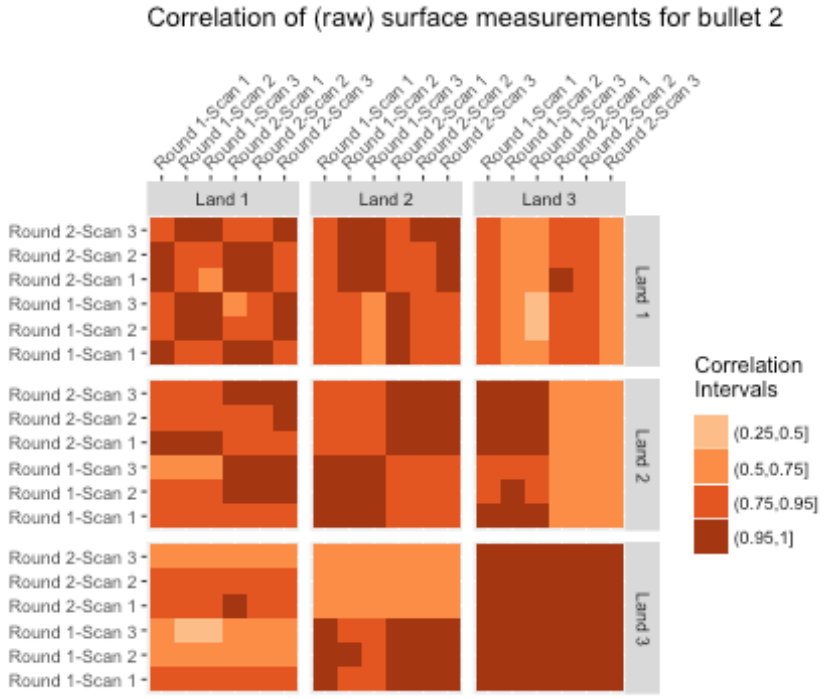
Measuring similarity

- often, (cross) correlation is used ...
- here: one operator, one land - all cross-correlations should be high



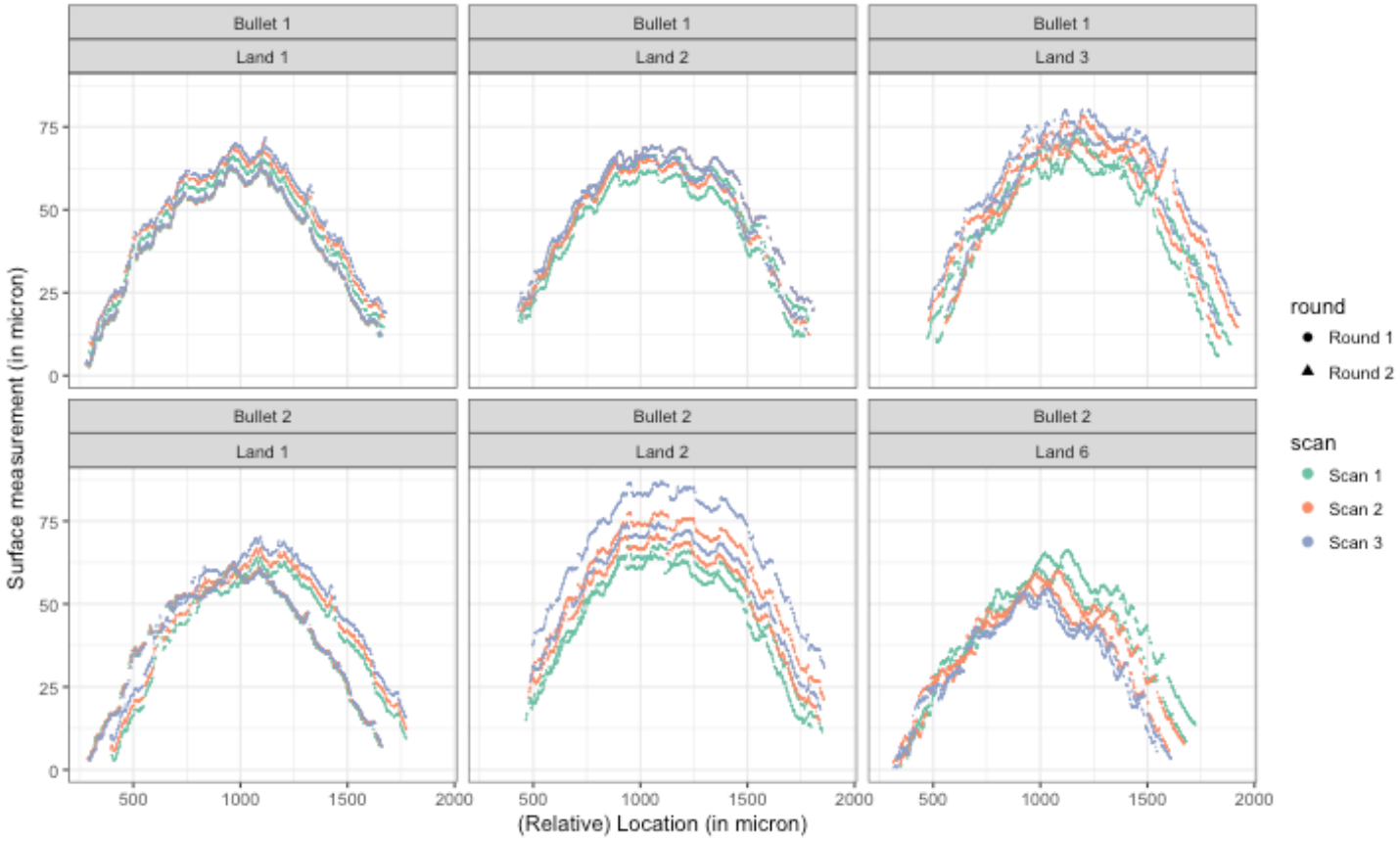
Measuring similarity (cont'd)

- here: one operator, different lands - cross-correlations are still relatively high

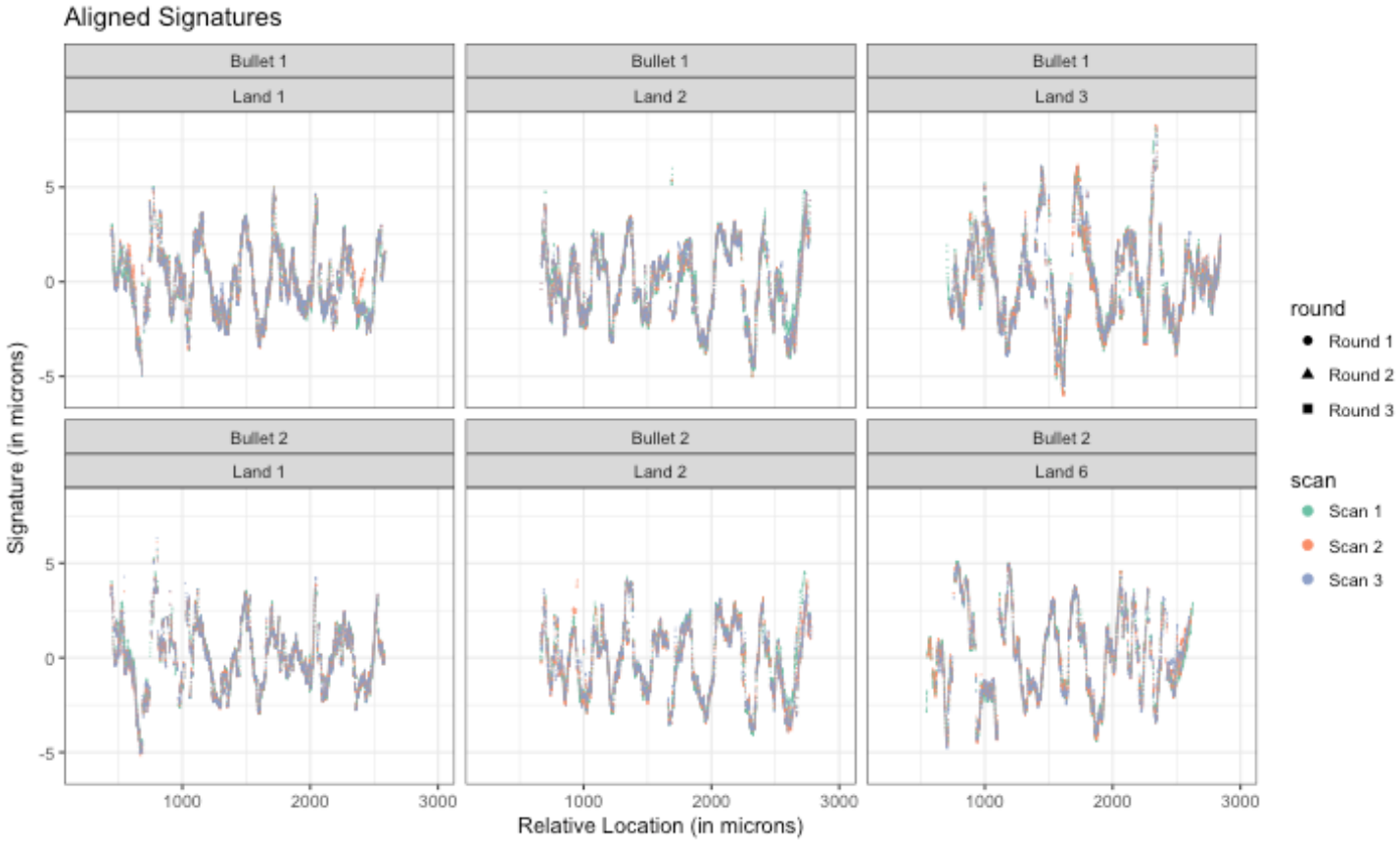


Raw surface values

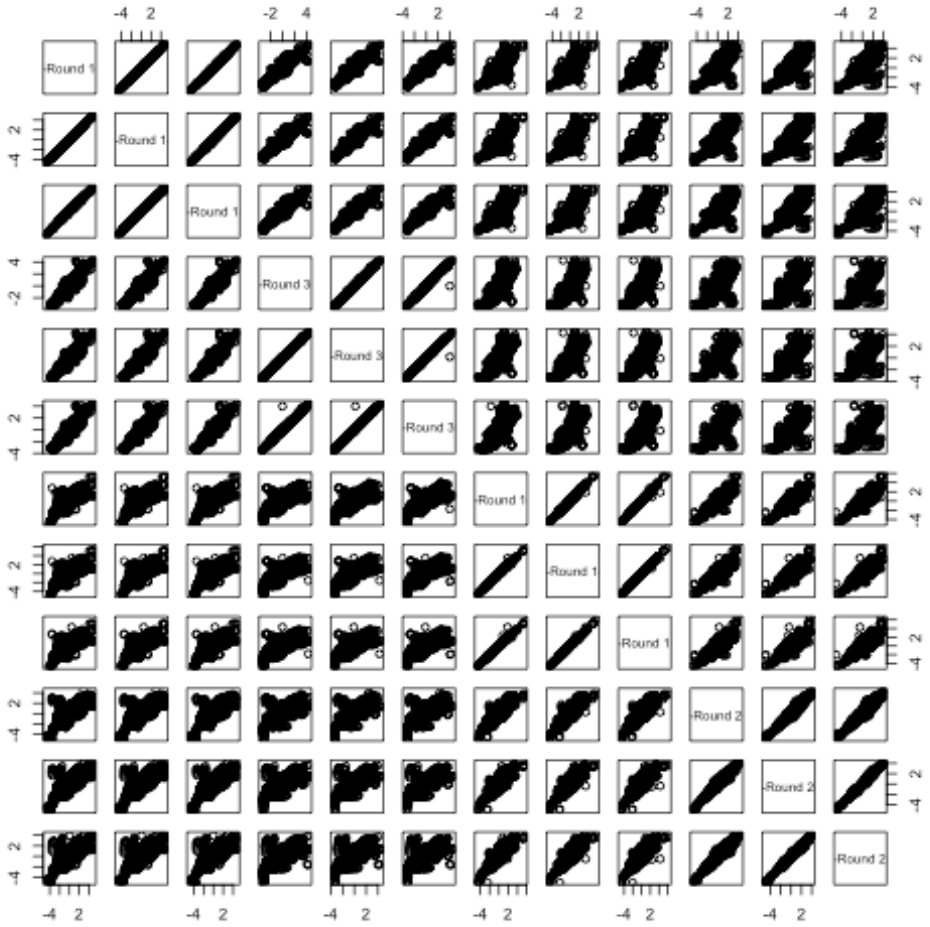
- (cross)-correlation captures 'bullet-shape' rather than similarity of lands
- But: similarity measure should reflect study setup



Aligned signatures

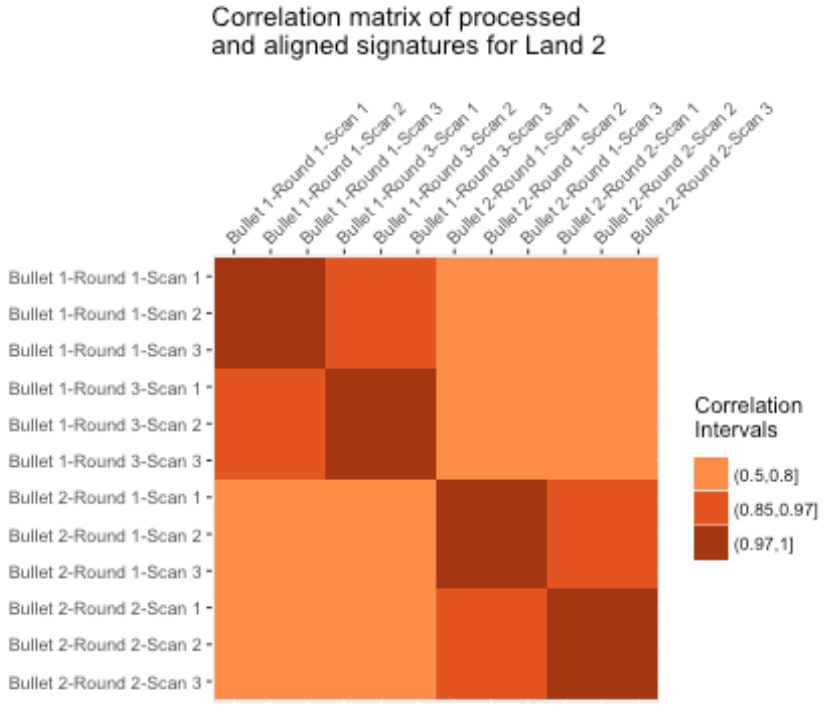


Comparison of aligned signatures



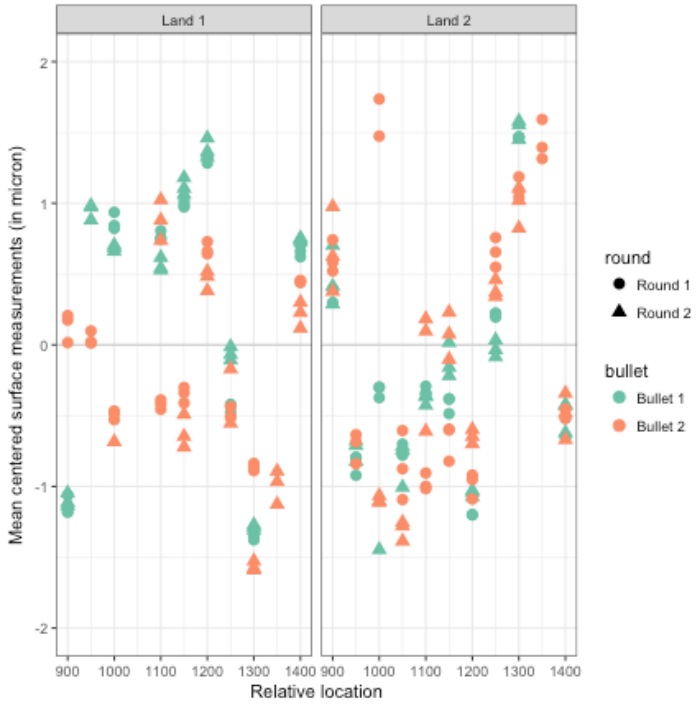
Comparison of aligned signatures

- Correlation drops (b/c main structure is removed)
- ... but now reflects study structure



Sources of variability

- measurements from different bullets (color) show large differences,
- the two lands seem to exhibit similar variability,
- scan repeats are typically very close



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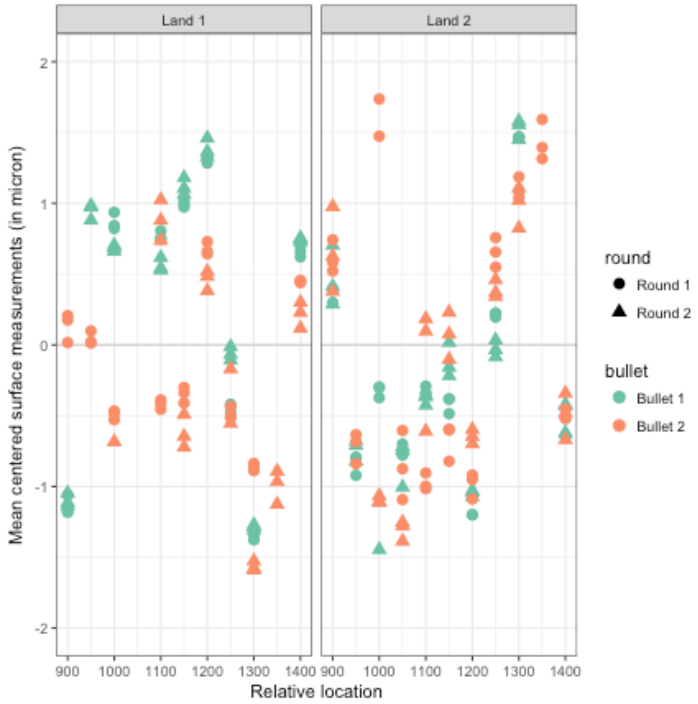

For each location x we set up the following model with $n = 12$ observations ($12 = 2 \times 2 \times 3$):

$$y_{ijk\ell} = \mu + b_{ij} + r_{ij(k)} + s_{ij(k\ell)}$$

Modelling variability

$$y_{ijk\ell} = \mu + b_{ij} + r_{ij(k)} + s_{ij(k\ell)}$$

- μ is average surface measurement in location x,
- b_{ij} is effect for bullet/land ($i, j = 1, 2$),
- $r_{ij(k)}$ is round ($k = 1, 2$) nested within bullet/land and,
- $s_{ij(k\ell)}$ are scan repeats within each round ($\ell = 1, 2, 3$)

Results

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Results

Operator A

Source	Variance	Std.Dev.
location	2.6726	1.6348
bullet	0.3243	0.5695
land	0.0047	0.0689
staging	0.1529	0.3910
scan	0.0264	0.1623

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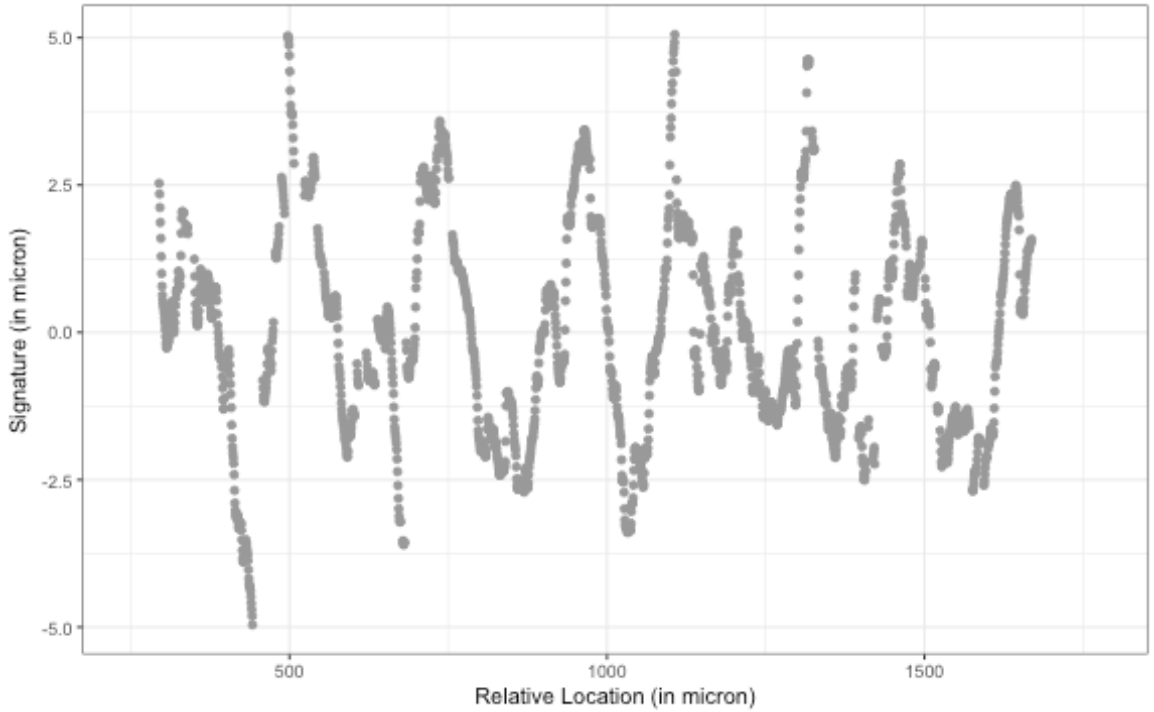
Operator F

Source	Variance	Std.Dev.
location	4.9805	2.2317
bullet	0.2629	0.5128
land	0.0030	0.0554
staging	0.1713	0.4138
scan	0.0191	0.1380

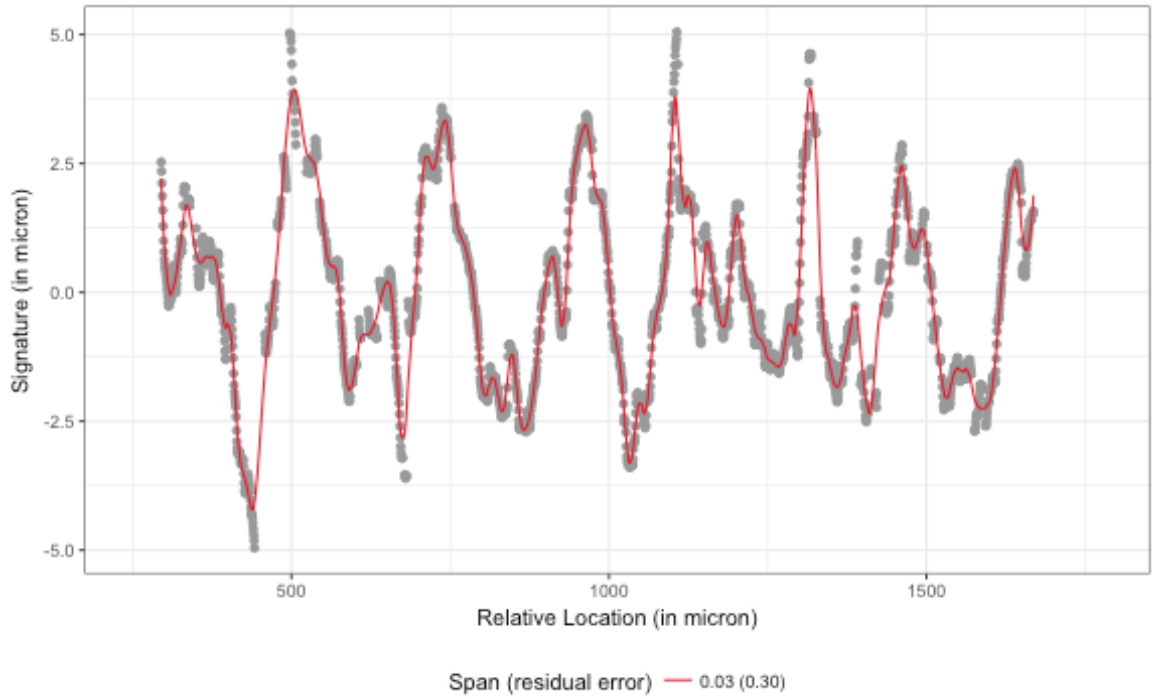
Impact on analysis

- definition of peaks and valleys: match residual error of smooth to variability expected across bullets



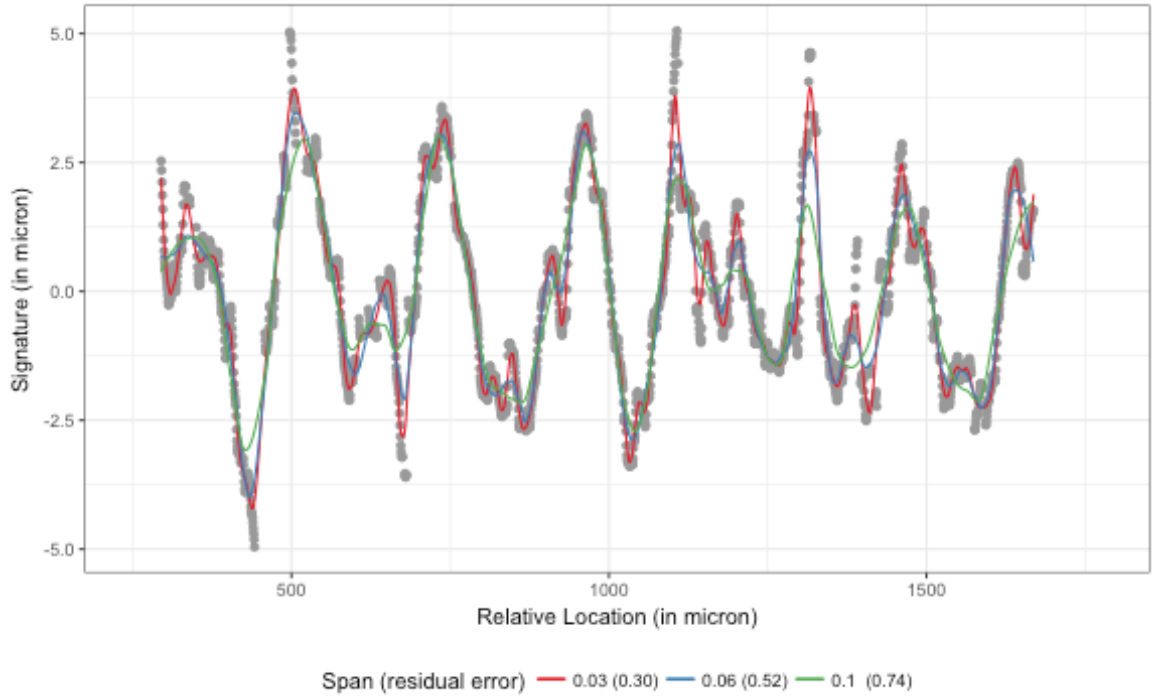
Impact on analysis

- definition of peaks and valleys: match residual error of smooth to variability expected across bullets
- smooth with span of 0.03 is too close to values (residual error of 0.30)



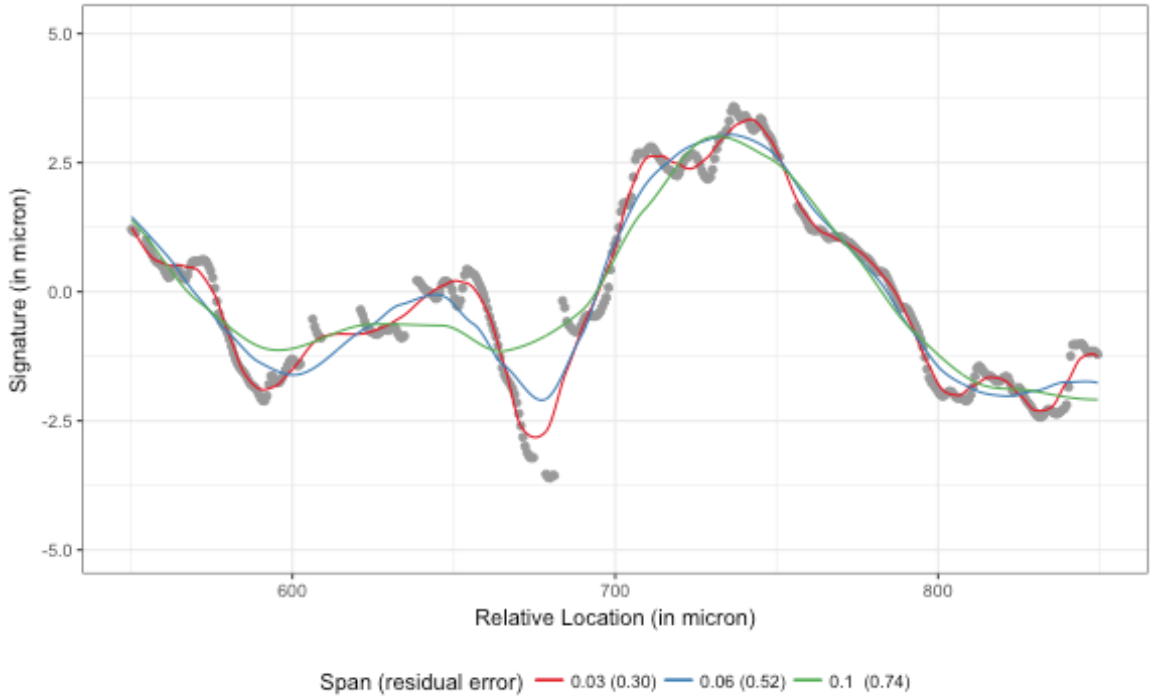
Impact on analysis

- definition of peaks and valleys: match residual error of smooth to variability expected across bullets
- smooth with span of 0.1 oversmooth, span of 0.06 seems best (blue line)



Impact on analysis

- zoom-in
- span of 0.05 corresponds to about 90 micron Gaussian filter

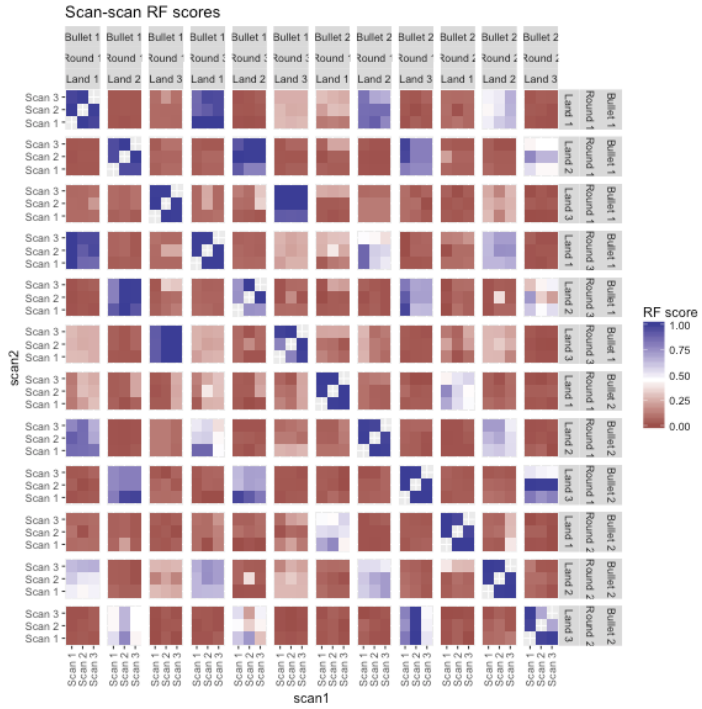


Conclusions/Future work

- variability results likely machine dependent (Sensofar CLM) and dependent on machine settings: resolution of 0.645 microns/pixel, light, internal threshold
- ammunition: Remington UMC 9mm Luger Full Metal Jackets
- gun barrels: Ruger LCP
- Thanks to Allison Mark and Francesca Spencer for providing the scans
- Thanks, as always, to our advisors and collaborators at NIST!

Other measures

- besides correlation we can use other measures of similarity, e.g. matching scores
- use RF score (Hare et al. 2017)



Other measures

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- use RF score (Hare et al. 2017)
- this is what the previous matrix ideally looks like