Reproducibility of High Resolution 3D Bullet LEA Scans

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Background

High resolution 3D microscopy has, in recent years, been the primary technological development which has advanced image-analysis algorithms for automated comparison of bullet land engraved areas (LEAs).

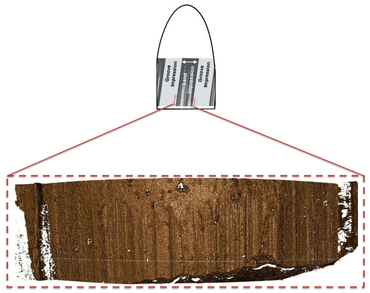
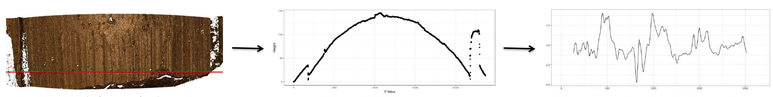


Figure 1: An example of a high resolution 3D scan of a bullet land engraved area (LEA). Often, a single bullet will have 6 LEAs in total.

LEA comparison algorithms such as the one developed by Hare et. al. [1] use 2D signatures extracted from 3D scans.



Stage 1: High resolution LEA scan | Stage 2: 2D profile | Stage 3: Extracted 2D signature

Figure 2: The process of extracting 2D data from a 3D scanning object, as Hare et. al. [1] describe.

We designed a **Gauge Repeatability and Reproducibility (Gauge R&R)** study of the high resolution 3D scanning process as it applies to bullet LEAs.

Data Description

Data presented here are from a pilot study of repeated LEA scans from a Sensofar Confocal Light Microscope:

- *Six* lands from one barrel (Hamby set 44, Barrel 6) [2]
- *Two* bullets fired from the same barrel
- *Four* microscope operators
- *Three* repetitions per bullet-operator combination

This resulted in *24* scans each for the six **barrel-lands**.

Data Analysis

Figure 3: Two example LEA scans of the same barrel-land from the same bullet.

We investigate variability in the extracted 2D signatures and quantify the impact of differing environmental conditions on pairwise automatic matching scores.

Extracted Signature Data

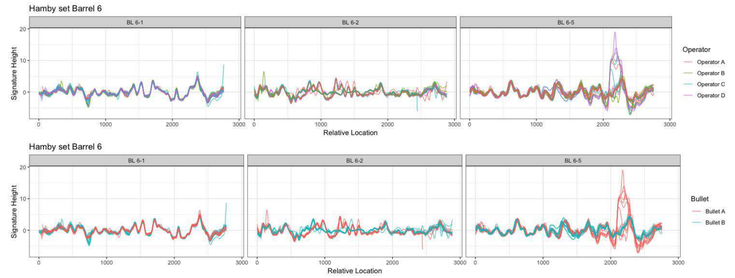


Figure 4: The characteristics of each individual bullet LEA appear to dominate the signal present due to operator. However, clear operator differences appear for certain LEAs.

Pairwise Automatic Matching Scores

Do differing environmental conditions have an impact on automated matching?

We fit an effects model derived from traditional R&R on scores from same-source pairings.

Model 1:

$$\begin{aligned} s_{p,p'} = {} & \text{Random Forest score comparing Signature p, Signature p'} \\ = {} & \mu_{BL} + \beta I[\text{Same Bullet (within source)}] \\ & + \omega I[\text{Same Operator}] + \beta\omega I[\text{Same Bullet and Operator}] \\ & + \epsilon \end{aligned}$$

Description	Parameter	Estimate
Fixed mean for Barrel 6-Land 1	μ_{6-1}	0.997
⋮	μ_{6-2}	0.821
⋮	μ_{6-3}	0.995
⋮	μ_{6-4}	0.976
⋮	μ_{6-5}	0.895
Fixed mean for Barrel 6-Land 6	μ_{6-6}	0.999
Same bullet random effect	σ_β	0.090
Same operator random effect	σ_ω	0.00001
Bullet-operator interaction rand. eff.	$\sigma_{\beta\omega}$	0.000
Residual error	σ	0.118

Table 1: The estimated parameters from Model 1. Operator variability is minimal, and mean scores for Barrel-Lands 6-2 and 6-5 are lower than the others.

Pilot Study Insights

1. The biggest differences in pairwise automatic matching scores are due to:

- individual bullet characteristics
- breakoff
- operator capture of breakoff

2. Future work should focus on:

- microscope differences
- multiple barrel types
- three bullets per barrel
- developing a framework for reproducibility studies

Future Data Collection

We are in the process of collecting an expanded set of scanning variability data:

- *Six* lands each from three barrel types
  - Hamby set 224
  - Houston
  - CSAFE Persistence
- *Three* bullets fired from each barrel
- *Five* microscope operators
- *Two* Sensofar Confocal Light microscopes
- *At least three* repetitions per bullet-operator-machine combination

This will result in at least *90* scans for each **barrel-land**.

References

[1] Hare, E., Hofmann, H., and Carriquiry, A. (2016). Automatic matching of bullet land impressions. *The Annals of Applied Statistics*, 11:2332-2356.

[2] Hamby J. E., Brundage D. J., Thorpe J. W. (2009). The identification of bullets fired from 10 consecutively rifled 9mm Ruger pistol barrels: A research project involving 507 participants from 20 countries. *AFTE Journal*, 41(2):99-110.

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