Validation studies for an automated bullet matching algorithm

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Automated Bullet Matching

Background Automated bullet matching algorithms utilizing 3D scans have been described in many studies [1, 2, 3, 4], using features such as cross-correlation [5, 6, 4] and consecutive matching striae [7, 8].

The **Random Forest** [9] **matching algorithm** combines features derived from 3D topographic scans of land engraved areas [10], using the following steps:

1. Identify an area with expressed striae
2. Discard degraded areas
3. Remove bullet curvature
4. Align signatures
5. Calculate features: cross-correlation, striae depth, # matching striae, CMS, Euclidian distance, and more

The RF model was fit to two Hamby sets (252, 173) from NBTRB scanned with a resolution of 1.5625 microns [11]

Goal

- Validate [10] on external test sets
- Assess sensitivity to distributional changes
- Examine limitations due to training data parameters

Valid Scores should fulfill the following two criteria:

(R1) **Monotonicity:** a higher score is indicative of higher similarity between a pair of bullets, in particular, similarity scores of same-source pairs of bullets are higher than different-source pairs.

(R2) **Stability:** the same score leads to the same conclusion.

Validation Sets

3 sets, increasingly different configurations and test materials:

- **Hamby 44**[12] 2×10 known, 15 question, Closed
  10 Ruger P85 barrels, Winchester 9mm Luger 115 Grain FMJ
- **Phoenix PD** 3×8 known, 10 question, Open
  8 Ruger P95 barrels, provided by Tylor Klep, Phoenix PD, scanned by Bill Henderson (Sensofar)
- **Houston FSI** 3 sets: 3×5 known, 8 question, Open
  10 Ruger LCP barrels, Remington UMC 9mm Luger FMJ; provided by Melissa Nally and Kasi Kirksey, FSI Houston

Validation sets scanned with a Sensofar confocal light microscope (20x, 0.645 microns) - finer resolution than the training sets.

Bullet-To-Bullet Comparisons

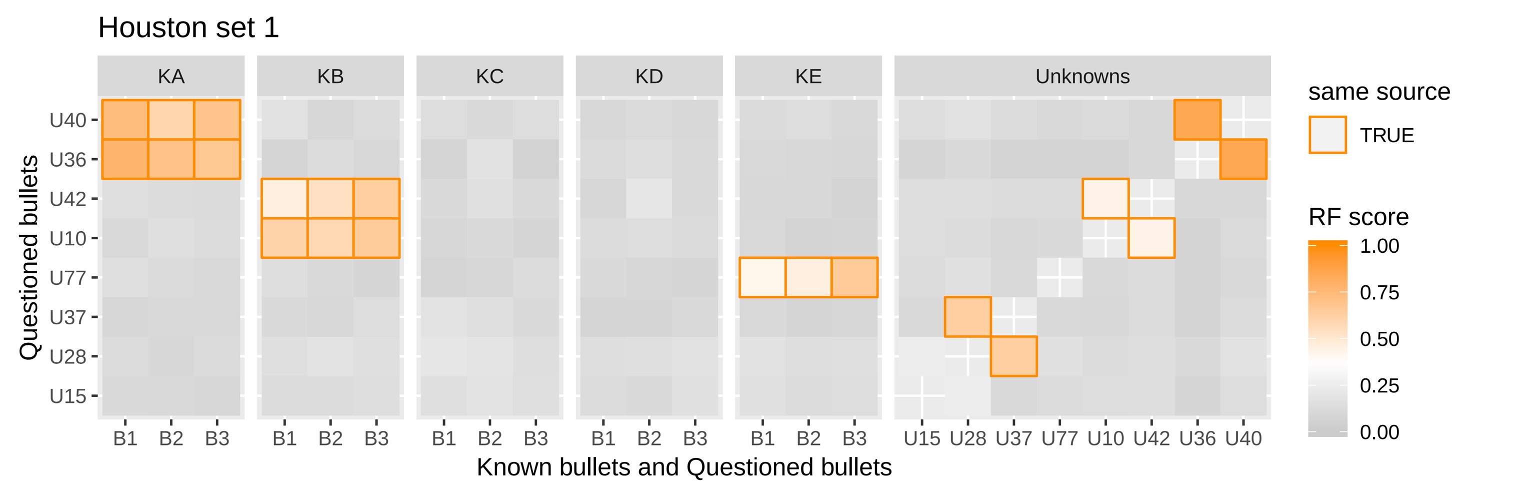

Fig. 1: Overview of matching scores for all pairs of questioned bullets to known bullets (left) and questioned bullets (right).

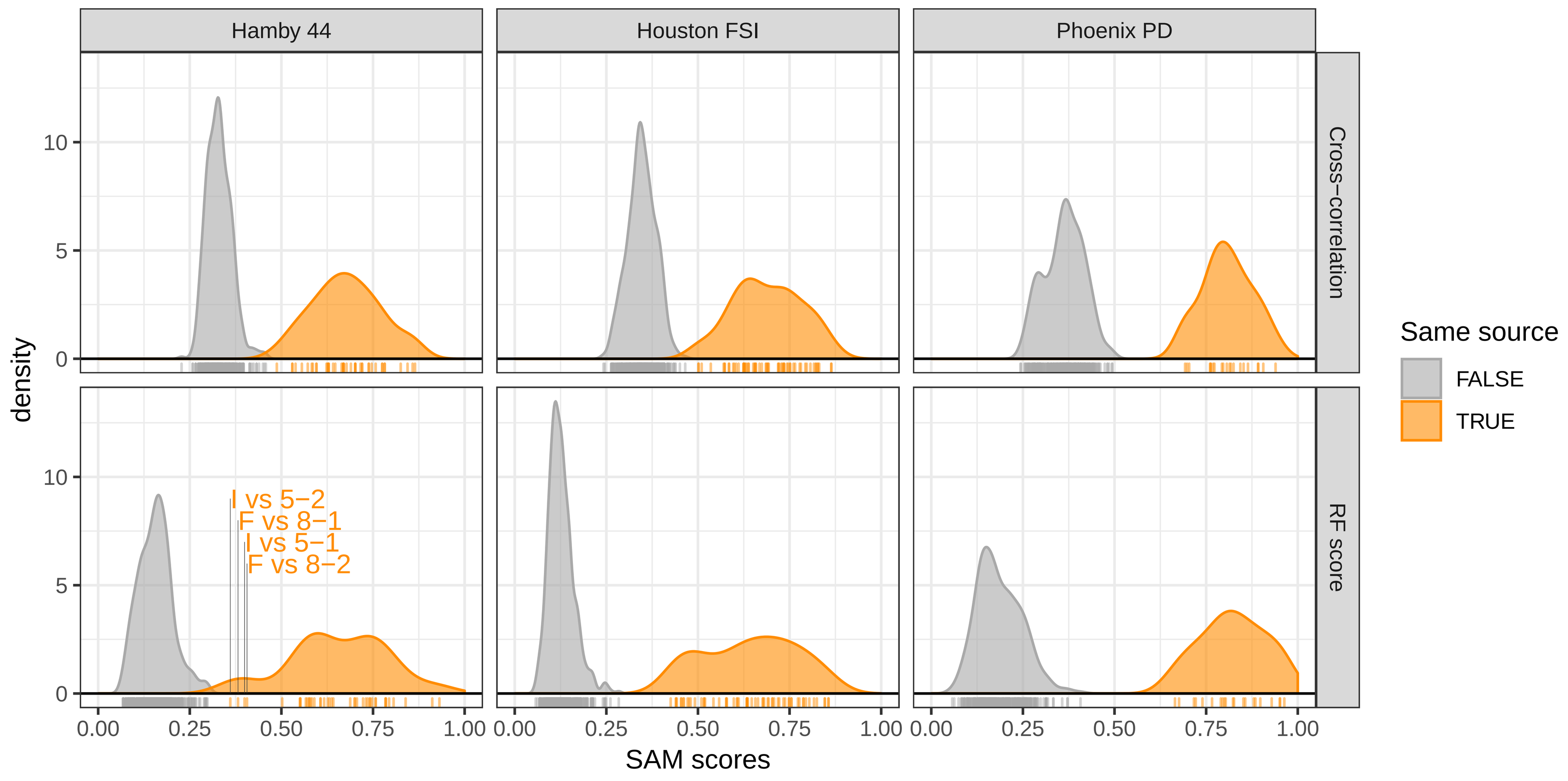

Fig. 2: Density curves of similarity scores from cross-correlation (top) and RF scores (bottom). Ideally all scores of different source pairs should be much lower than scores for same source pairs.

Measurements

Let $z(t)$ describe a signature. $z(t)$ forms a spatial process with location indexed by t for $t = 1, ..., T$, where T is the number of pixels.

The Random Forest score, Cross-correlation and Consecutively Matching Striae are evaluated for each pair of signatures:

Cross-correlation: for two signatures $x(t)$ and $y(s)$ the cross-correlation is defined as $\arg\max \rho_{XY}(\tau)$ with

$$\rho_{XY}(\tau) = \frac{1}{\sigma_X, \sigma_Y} E[(X_t - \mu_X)(Y_{t+\tau} - \mu_Y)]$$

Consecutively Matching Striae (CMS) defined by [8]. Generally, CMS of 6 or above is considered 'a match'.

Land-To-Land Comparisons

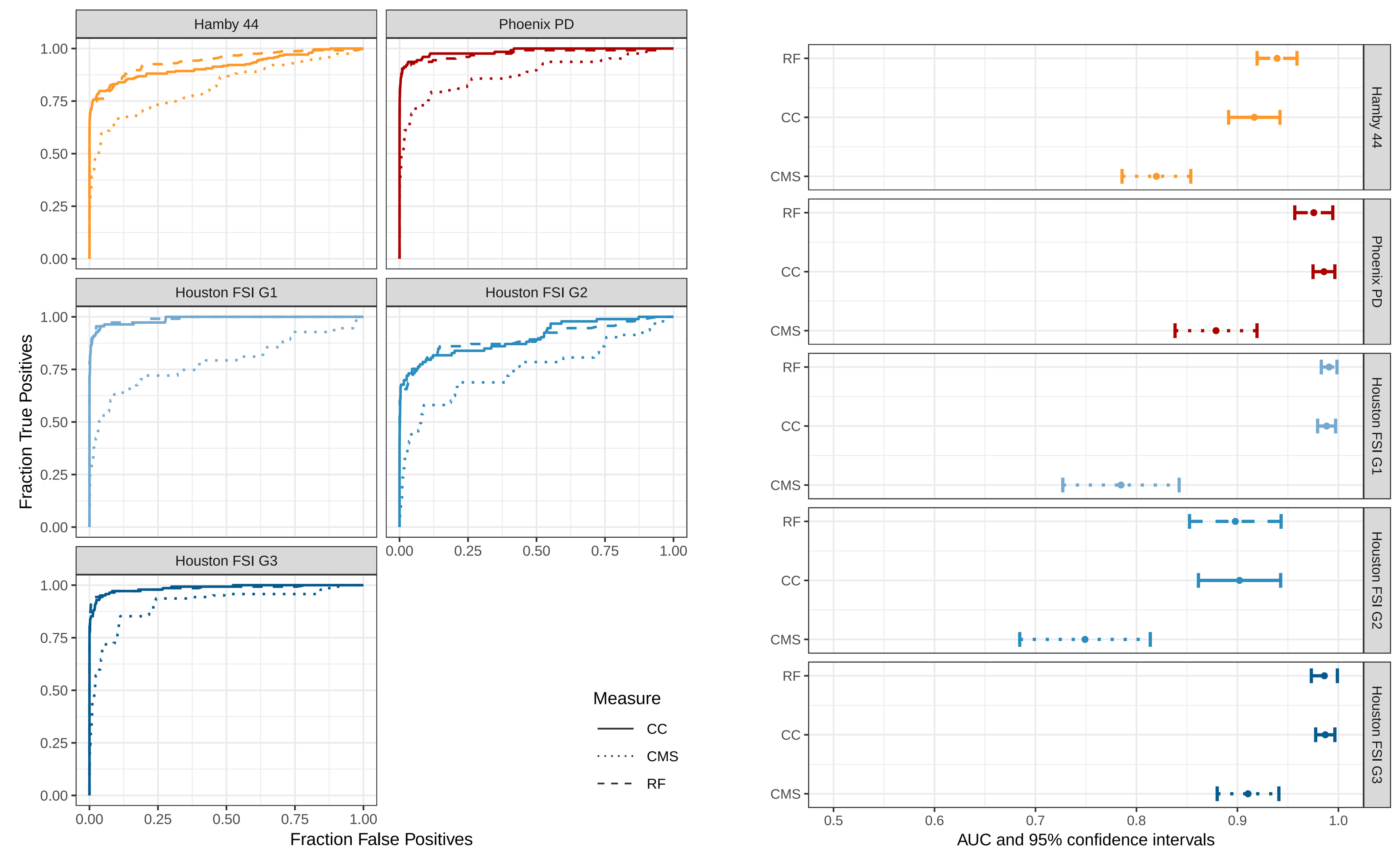

Fig. 3: ROC curves and AUC values for each test set using cross correlation (CC), consecutive matching striae (CMS), and the random forest score (RF).

Future Work

- Re-fit the random forest with sets of different resolutions, barrel make, manufacture, and ammunition types.
- Improve the ability to utilize partial signatures from bullets with tank rash and other damage
- Investigate algorithm performance with more diverse barrels

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