Validation studies for an automated bullet matching algorithm

Heike Hofmann, Susan VanderPlas and Alicia Carriquiry, Iowa State University

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

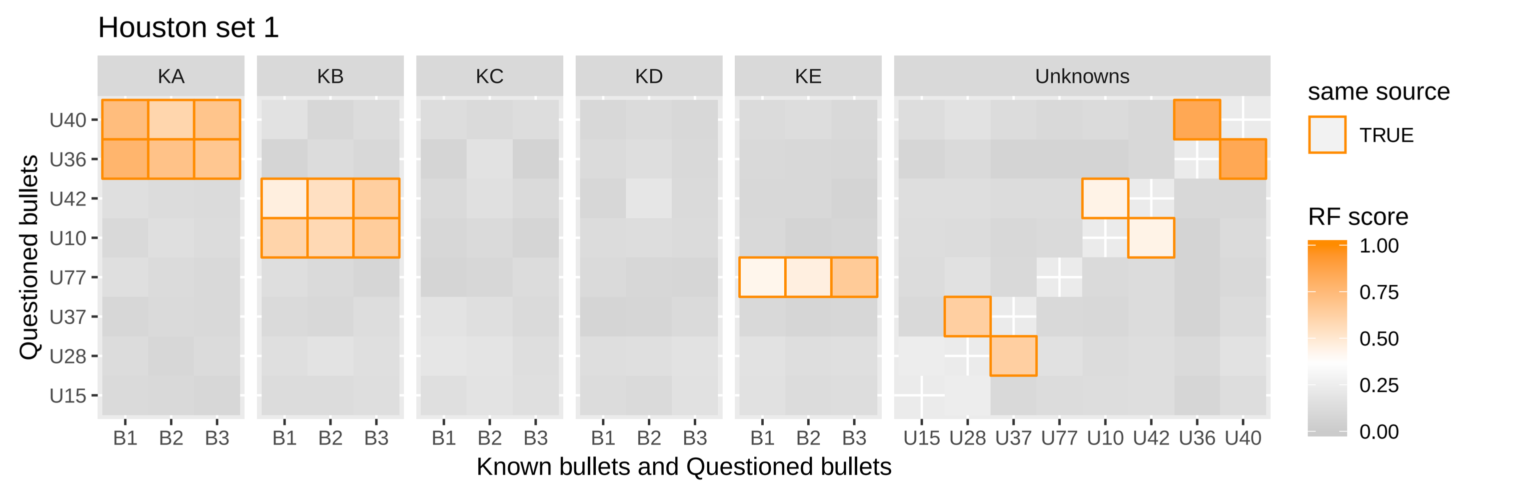

Fig. 1: Overview of matching scores for all pairs of questioned bullets to known bullets (left) and questioned bullets (right).

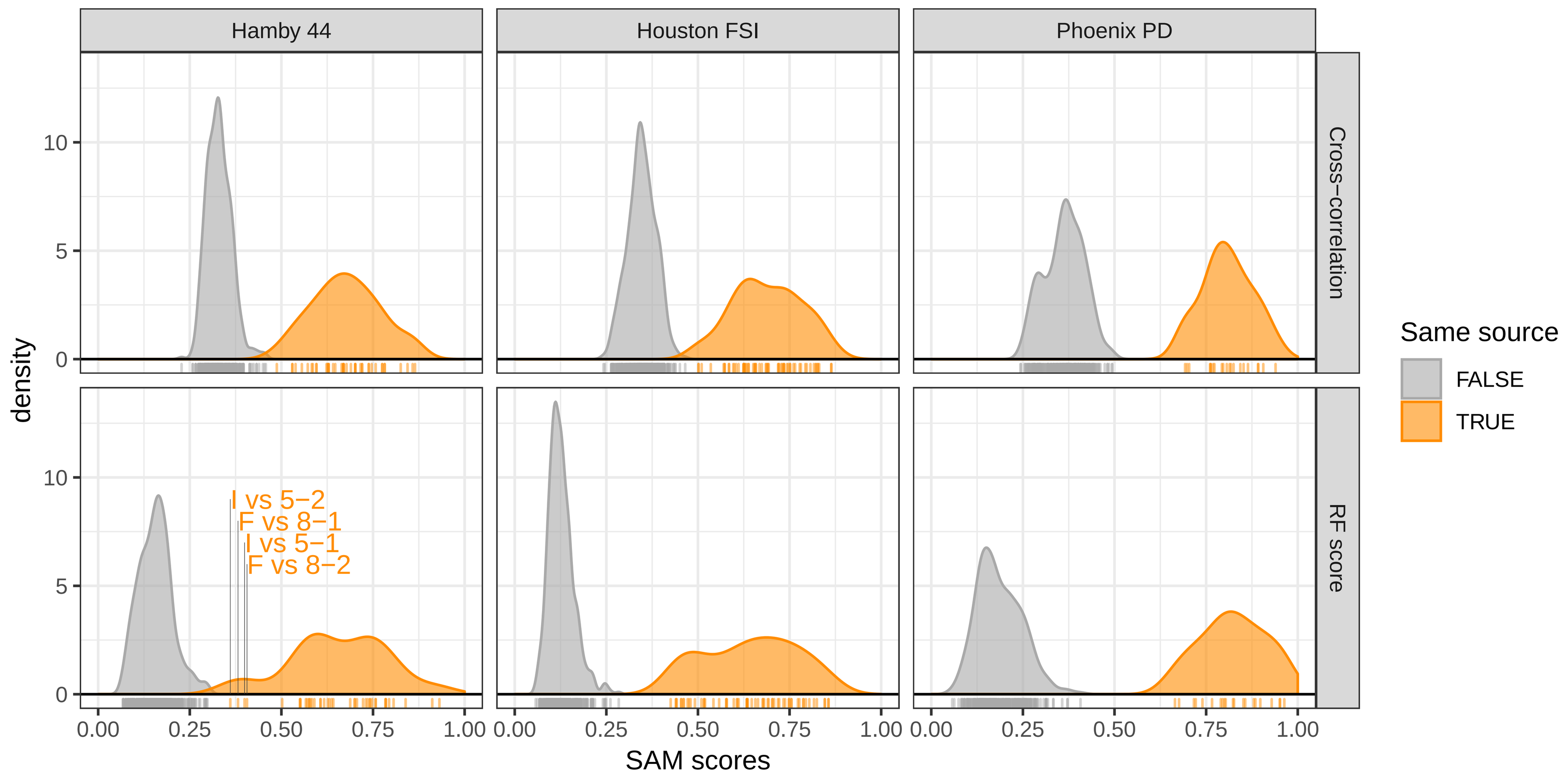

Fig. 2: Density curves of similarity scores from cross-correlation (top) and RF scores (bottom). Ideally all scores of different source pairs should be much lower than scores for same source pairs.

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

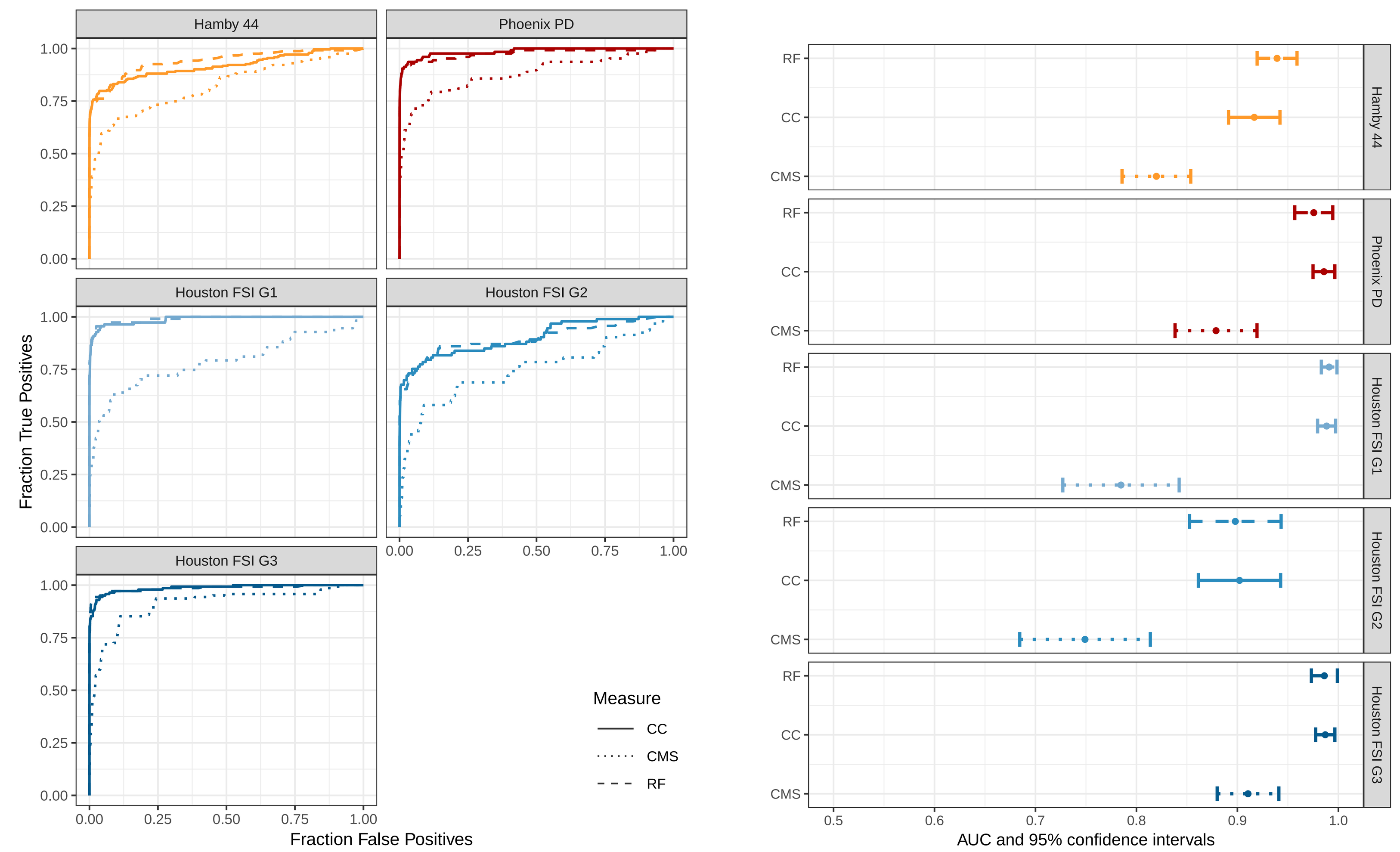

Fig. 3: ROC curves and AUC values for each test set using cross correlation (CC), consecutive matching striae (CMS), and the random forest score (RF).

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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