Some approaches for analysis of ballistics signatures using cross-correlation functions

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Introduction

- Goal: Demonstrating approaches to analyzing and modeling similarity scores for forensic identifications
- The approaches are demonstrated on the NBIDE (NIST Ballistic Identification Designed Experiment) breech face impression set analyzed by maximum areal crosscorrelation function
- Tools include graphical representations of the data, and estimating contributions to correlation from various effects

A firing pin topographical image (vertical proportions not drawn to scale)



A breech face topographical image (vertical proportions not drawn to scale)



Areal Cross-Correlation Function

• A similarity measure is

$$\mathsf{CCF} = ACCF_{\max} = \frac{\sum \sum \sum n \sum (A_{mn} - \overline{A})(B_{mn} - \overline{B})}{\left[\sum \sum n \sum n (A_{mn} - \overline{A})^2 \sum \sum \sum n \sum n (B_{mn} - \overline{B})^2\right]^{1/2}},$$

where A and B are registered at the maximum correlation position

- Areal correlation of one surface to another
- After requisite trimming of areas, drop-outs, and outliers, and filtering for form and waviness

CCF properties

- CCF is brute force in being global and un-weighted (and computationally intensive)
- CCF is especially appropriate for NIST SRM bullets and cartridge cases (each surface was manufactured to be virtually identical)
- There are more "clever" strategies for identification: Consecutive matching striae for bullets, Congruent matching cells (NIST), application of multivariate pattern and discrimination methods by Petraco, et al.

NBIDE (NIST Ballistic Identification Designed Experiment)

- 12 new guns: 4 Ruger, 4 Smith-Wesson, 4 Sig Sauer
- Each gun fired 9 times: 3 times each of ammunition brands: Winchester, Remington, PMC
- $3 \times 4 \times 3 \times 3 = 108$ cartridge cases
- CCF of each casing to every other casing measured
- Experiment Design by J.Filliben; casings were fired at OLES facility, and were given random ID before measurements and correlations
- Note: Certain commercial equipment may be identified in this presentation in order to specify certain experimental procedures. This does not imply recommendation or endorsement by NIST, nor does it imply that the equipment are the best available for the purpose.

The NBIDE Guns



Mechanical firing of NBIDE guns



CCF values for correlations of breech faces of match and non-match cartridge cases



Graphical depictions of CCF data

- Exploratory data analysis: always graph the data!
- The figure on the next slide partitions the match and non-match CCFs by Reference Casing (Matches, lower triangles; Non-matches, upper triangles).
- The plot following that is a color/intensity depiction of a CCF matrix
- (These may not be so easy for much larger sample size, or if you don't have round-robin comparisons.)

Non-match and Match CCFs by Casing

		0.2 0.6		0.2 0.6		0.2 0.6		0.2 0.6	
	Sm-W 401 1 3	Sm-W 401 1 46	Sm-W 401 1 63	Sm-W 401 2 110	Sm-W 401 2 84	Sm-W 401 2 9	Sm-W 401 3 44	Sm-W 401 3 51	Sm-W 401 3 76
Non-Match	444444		400000					400000	
Match	225 ZAS		<u>~~</u>					20200	<u>~~~</u>
	Sm-W 314 1 112	Sm-W 314 1 127	Sm-W 314 1 85	Sm-W 314 2 116	Sm-W 314 2 36	Sm-W 314 2 39	Sm-W 314 3 117	Sm-W 314 3 29	Sm-W 314 3 6
Non-Match									
Match				^ ~~~				~ ~	
Materi									
	Sm-W 306 1 26	Sm-W 306 1 7	Sm-W 306 1 71	Sm-W 306 2 106	Sm-W 306 2 121	Sm-W 306 2 131	Sm-W 306 3 13	Sm-W 306 3 143	Sm-W 306 3 41
Non-Match									
Match	2 86	_ 	~ 26		<u></u>	△		_ <u></u>	
	Sm-W 305 1 57	Sm-W 305 1 64	Sm-W 305 1 97	Sm-W 305 2 103	Sm-W 305 2 137	Sm-W 305 2 24	Sm-W 305 3 4	Sm-W 305 3 5	Sm-W 305 3 59
Non-Match						-			
Match	△ △ △ △ △		20000	~~~~~		^ &	~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~		~ 25 ~
	Sig 33 1 23	Sig 33 1 66	Sig 33 1 99	Sig 33 2 141	Sig 33 2 32	Sig 33 2 34	Sig 33 3 128	Sig 33 3 61	Sig 33 3 79
Non-Match									
Match	2 20 -220-		20 2 8 2 6	~ ~ 2260				280-2 0 A	
	Sig 32 1 87	Sig 32 1 90	Sig 32 1 91	Sig 32 2 115	Sig 32 2 12	Sig 32 2 25	Sig 32 3 100	Sig 32 3 42	Sig 32 3 56
Non-Match									
Match		△ 280 △	△ <u>▲</u> △ △		~///	~ ^~		180000	a <u>aa</u> assa
	Sig 31 1 114	Sig 31 1 27	Sig 31 1 48	Sig 31 2 15	Sig 31 2 65	Sig 31 2 92	Sig 31 3 119	Sig 31 3 20	Sig 31 3 62
Non-Match									
Match	~~ ~~	A 4808	△ ▲☆▲	~ ~	<u>~</u> 280	2900	~ ~~	~ ~ ^^	2000000
	Sig 30 1 40	Sig 30 1 60	Sig 30 1 89	Sig 30 2 10	Sig 30 2 17	Sig 30 2 8	Sig 30 3 135	Sig 30 3 21	Sig 30 3 30
Non-Match									
Match		~~~~	12200.	△ ☎ ☎△		△ △ ∞△	2 20 2	20000a	2020 55. 12
	Ruger 48 1 31	Ruger 48 1 80	Ruger 48 1 96	Ruger 48 2 130	Ruger 48 2 138	Ruger 48 2 22	Ruger 48 3 139	Ruger 48 3 49	Ruger 48 3 55
Non-Match					240000X				
Match		<u>~~</u> 285		~ ~ ~ ~ ~ ~		۵۸	~~~~		22000-222
	Ruger 46 1 120	Ruger 46 1 125	Ruger 46 1 95	Ruger 46 2 1	Ruger 46 2 67	Ruger 46 2 82	Ruger 46 3 136	Ruger 46 3 19	Ruger 46 3 53
Non-Match						2 441110 20.		4 	
Match		A AXXXX	2000-C	△ <u>▲</u>		∆ 26×2 ×		20000 2000	
	Ruger 42 1 28	Ruger 42 1 43	Ruger 42 1 75	Ruger 42 2 2	Ruger 42 2 35	Ruger 42 2 50	Ruger 42 3 16	Ruger 42 3 54	Ruger 42 3 72
Non-Match							2		
Match	~	//20025.	△ △66		△ ▲	2000		A A	
	Ruger 41 1 102	Ruger 41 1 111	Ruger 41 1 78	Ruger 41 2 134	Ruger 41 2 45	Ruger 41 2 94	Ruger 41 3 118	Ruger 41 3 129	Ruger 41 3 142
Non-Match									
Match		~~ ~~ ~			48 00	<i>2</i> 386		~ ~	12
	0.2 0.6		0.2 0.6		0.2 0.6		0.2 0.6		0.2 0.6



• *CCF* color matrix for topographic images of 108 breech face impressions for 12 BIDE guns. The data are ordered by gun(large groupings) then by ammo within each grouping.

Empirical Modeling of CCF scores

- Average CCF between two casings can *possibly* be modeled as combination of several terms:
 - Average Non-match CCF
 - Increase in average CCF due to casings being from same gun (we hope this increase is large)
 - Increase in average CCF due to same ammunition brand/type?
 - Increase in average CCF due to guns being of same brand/type (for non-matches)?

All the above terms come with their own 'errors' and variabilities.

Estimated empirical effects for NBIDE BF CCFs (only)

- Average Non-match CCF: 0.21 (std.dev. 0.04, std.err. 0.0004)
- Average CCF for Matches: 0.61 (std.dev. 0.14, std.err. 0.005)

Non-match CCFs for NBIDE BF

- Average effect of same gunbrand in non-matches is 0.01 (std.err. 0.001)
- All estimated brand effects and/or interactions < 0.04 in non-match CCFs
- Of the ammunitions, PMC gave lowest CCFs on the average: the lowest effect was PMC-PMC pair
 - So having same ammunition brand may not necessarily increase the CCF for non-match casings
- Tendency: Ruger high, Smith-Wesson low

NBIDE Match BF CCF effects

- Average Match CCF:
 - Ruger 0.70 (std.dev. 0.11, std.err. 0.01)
 - Sig-Sauer 0.62 (std.dev=0.14, std.err. 0.01)

- Smith-Wesson 0.52 (std.dev. 0.09, std.err. 0.01)

- Random effect standard deviation of individual guns (measures variability between guns of each brand):
 - Ruger 0.07
 - Sig-Sauer 0.12 (due to one gun with low match CCFs)
 - Smith-Wesson 0.05

Estimated Ammunition Brand effects in Matches

- Average effect of having Same ammunition in Matches = 0.03 [std. err. (<.01)]
- Highest average ammunition effect for matches is PMC-PMC with .04 (std. err. 0.02)
- Ammunition combination as a random effect has .02 standard deviation

NBIDE BF Points about CCF

- Manufacturer effects much more evident in matches than non-matches
- On the average, Ruger yields higher CCF, Sm-W lower CCF, for both matches and non-matches
- PMC-PMC combination yields (slightly) higher CCF for matches , lower CCF for non-matches
- Estimated gun brand effects are smaller, and ammunition effects are much smaller, than the (Match vs. Non-Match) effect on the CCF score

Final Points

- These patterns may NOT be true for human examiners or other automatic systems
- Specific conclusions do not necessarily hold in other ballistics scenarios (different guns, different ammunition, etc.)
- However, these or similar methods of analyses can be useful for a variety of ballistics and other forensics applications