Statistical Evaluation of Features used for the Comparison of Bullet Evidence

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Introduction

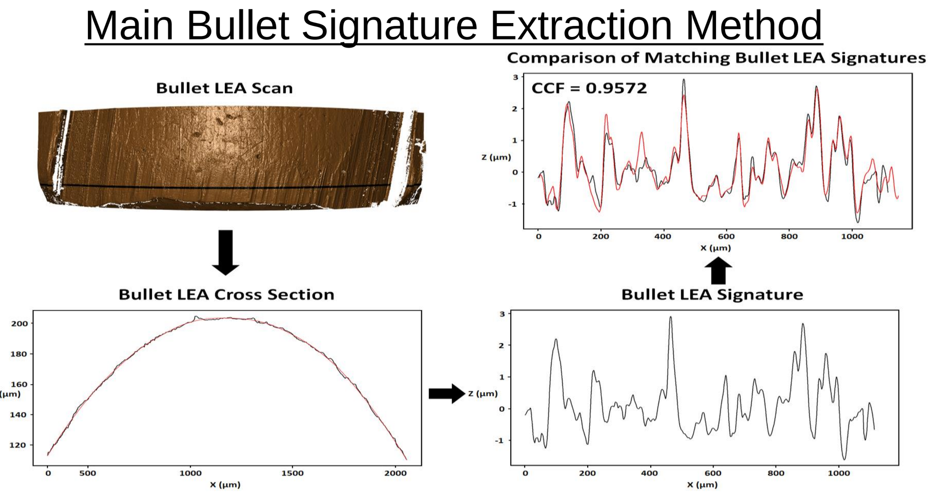
Firearms examinations is one of the more common feature comparison methods found in crime labs across the country, whether in small county labs or larger metropolitan cities. If during the initial examination the class characteristics of the bullet are matching between the known and unknown samples, the examiner moves onto the individual characteristics of the bullets. When a bullet is fired from a gun, the gun barrel itself has unique markings on the spiral rifling pattern of the lands that are engraved into the barrel as land engraved areas and will leave that same pattern on the bullet. The current method of comparing and finding matches in bullet evidence is using a comparison microscope, and an examiner will line up striations on the bullet to see if there's enough correlating toolmarks between the known and unknown bullets. Current requirements for comparison of surface features through Association of Firearm and Toolmark examiners is "sufficient agreement" as defined as exceeding the best agreement demonstrated between toolmarks known to have been produced by different tools [1].

In the last decade, there has been two landmark reports from the National Research Council [3] and the President's Council of Advisors on Science and Technology [4], that identify weaknesses in our current knowledge regarding the information experts utilize when performing examinations and question foundational validity for these methods, effectively restricting usage in court testimony [5]. One of the best ways to obtain the repeatability, accuracy, and consistency required to build a stronger foundational validity [4] is to support firearms examination with objective algorithmic approaches. At present, the innovation of 3D microscopy has been proposed to decrease the potential errors within firearms examinations, as it has allowed for the visualization of the land engraved areas (LEA) and individual characteristics from the firearm to be clearer. The National Institute of Standards and Technology is currently leading the initiative to further foundational validity of firearms through development of objective and quantitative algorithmic methods for comparisons [2]. Their algorithm focuses on one small section of the bullet that has been deemed as the most well marked and contains the crosscuts with the optimal striations as determined by the Center for Application and Statistics in Forensic Evidence.

This project looks to expand upon these algorithms by assessing the occurrence of features across the entirety of the bullet surface, rather than from only a single cross section, and characterize the significance of identified features. Resultant feature maps will further the understanding of features present on fired bullets to further the foundational validity of firearms examination and will guide examiners to the most useful areas for comparison on the bullet's surface.

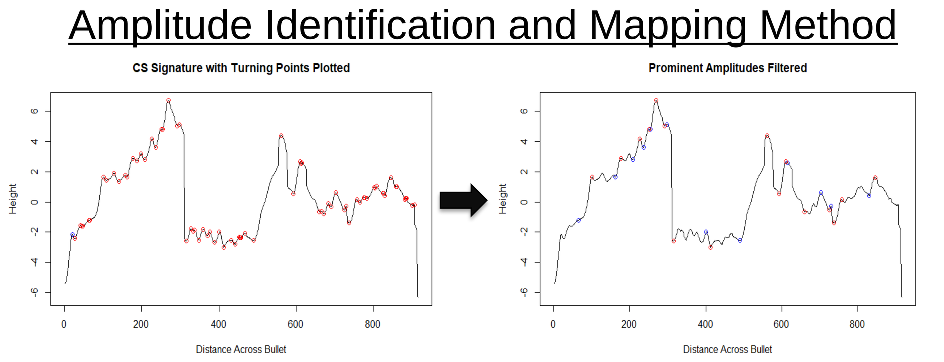
Methodology

Main Bullet Signature Extraction Method



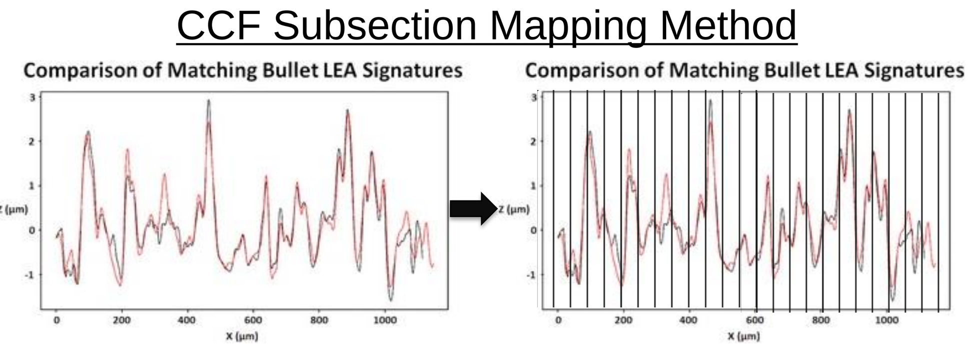
- ❖ Illustration of LEA processing from raw topography to correlation of two matching LEA signatures

Amplitude Identification and Mapping Method



- ❖ Amplitudes were separated into bins by determining average mean and standard deviation across all 6 lands of the bullet to determine their designated mapping color

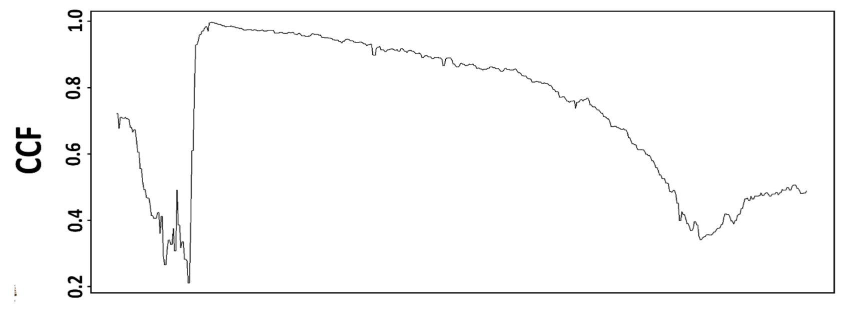
CCF Subsection Mapping Method



- ❖ Aligned signatures divided into 20 sections along cross section and a CCF score was calculated for each section
- ❖ All CCF scores were collated, and the 50% and 75% quartiles were calculated to determine bins for their designated mapping color

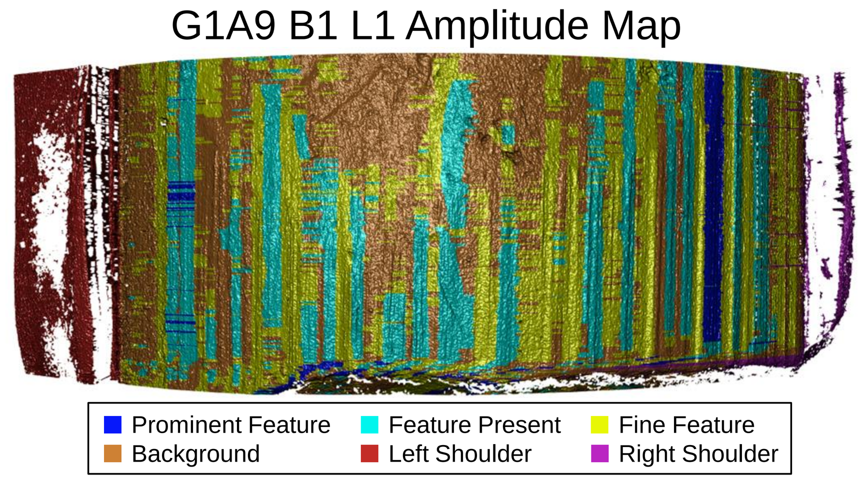
Results

Full Cross Section Heat Map
Intra-Comparison Correlation Values



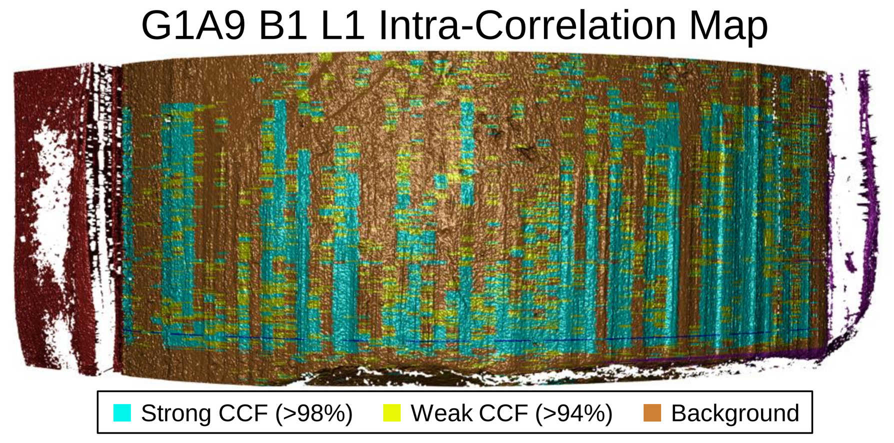
- ❖ CCF scores obtained from intra-comparing each cross section to every cross section in the bullet LEA, and taking max score for the cross section
- ❖ Plot uses CCF score from the comparison of cross section 78 to all other cross section
- ❖ Answers the question: Where do the striations occur that match the closest with the CSAFE identified optimal cross section?

G1A9 B1 L1 Amplitude Map



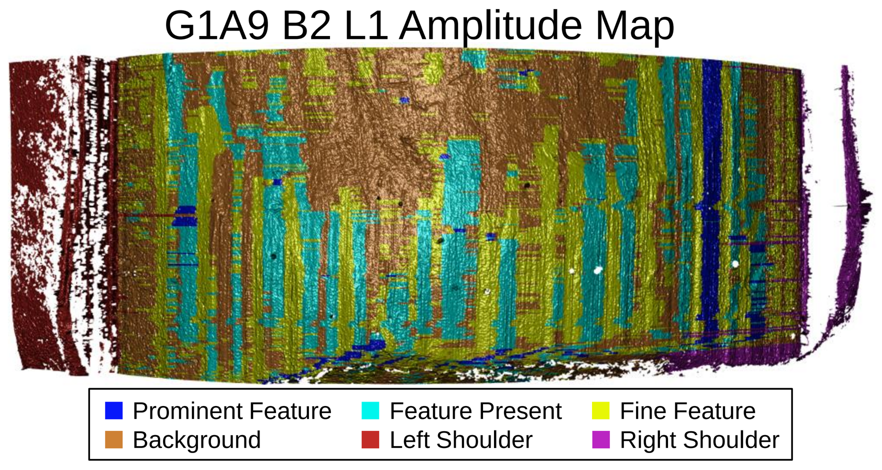
- ❖ Amplitude maps depict the significance of the features
- ❖ Answers the question: Where are the largest striations and where are there areas the provide with the best comparisons?

G1A9 B1 L1 Intra-Correlation Map

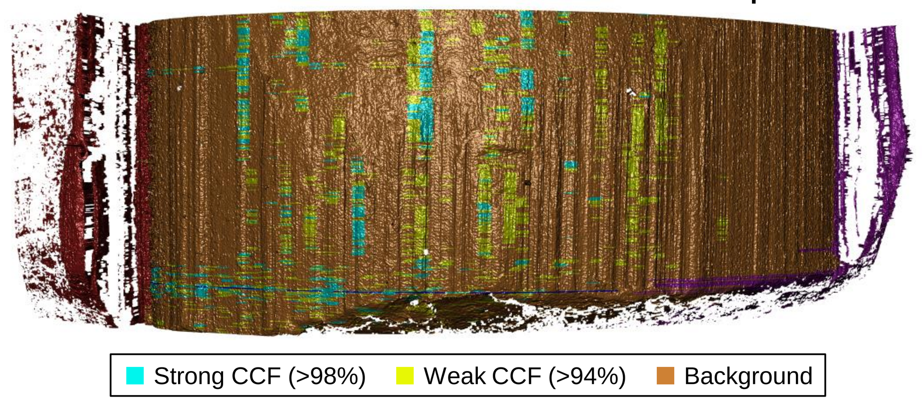


- ❖ Sub-sectioning the CCF values provides a clearer depiction of where on the bullet is each striation found
- ❖ Answers the question: How valuable and consistently marked is this striation along the surface?

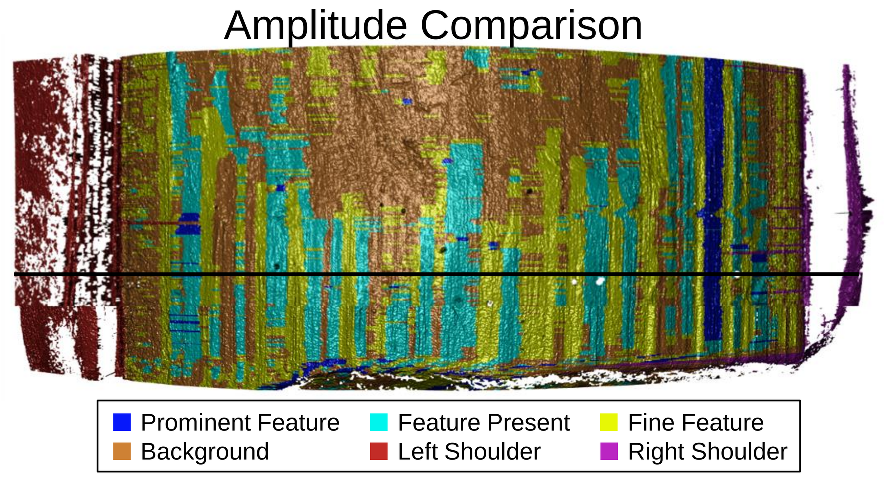
G1A9 B2 L1 Amplitude Map



G1A9 B2 L1 Intra-Correlation Map

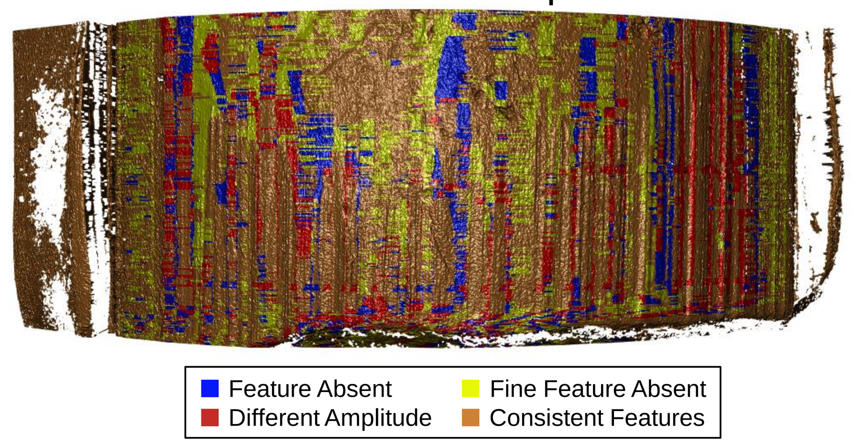


G1A9-B1-L1 and G1A9 B2-L1
Amplitude Comparison



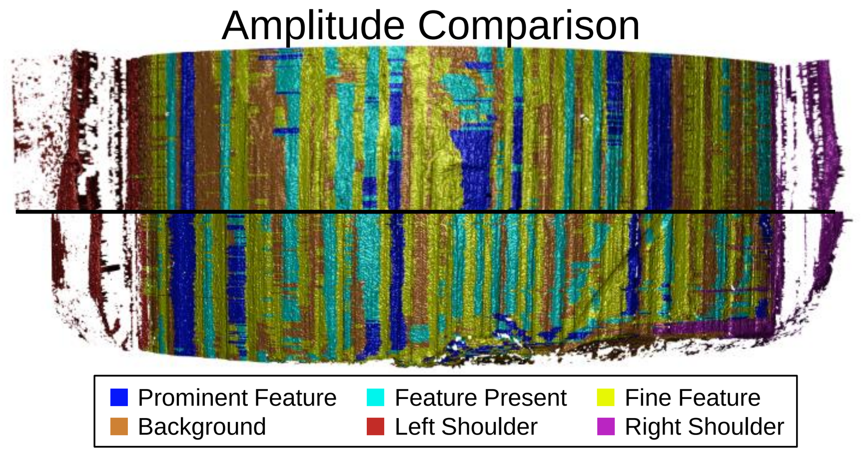
- ❖ Dividing line delineates the comparison between Bullet 1 (bottom) and Bullet 2 (top)
- ❖ Correlation of significant striation location is apparent which supports a common origin conclusion

G1A9-B1-L1 and G1A9 B2-L1
Difference Map

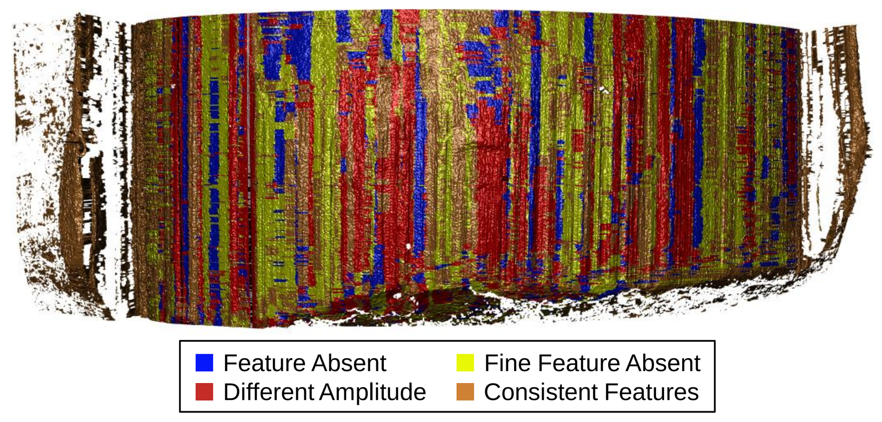


- ❖ Corresponding values subtracted
- ❖ Illustrates variability of features across matching LEAs
- ❖ Total variation between B1-L1 and B2-L1 was 47%
- ❖ Total variation between B1-L2 and B2-L2 was 61%

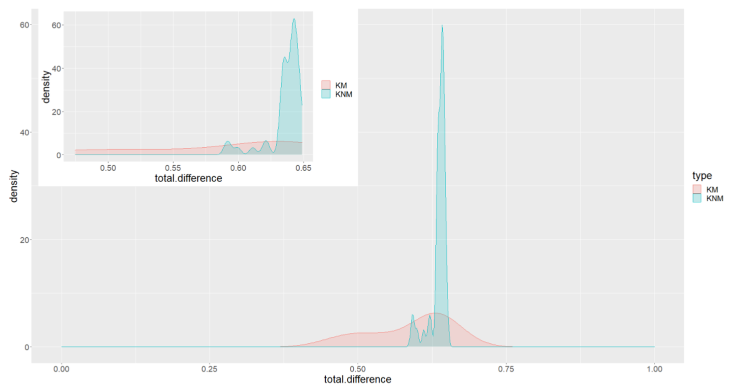
G1A9-B1-L2 and G1A9 B2-L2
Amplitude Comparison



G1A9-B1-L2 and G1A9 B2-L2
Difference Map

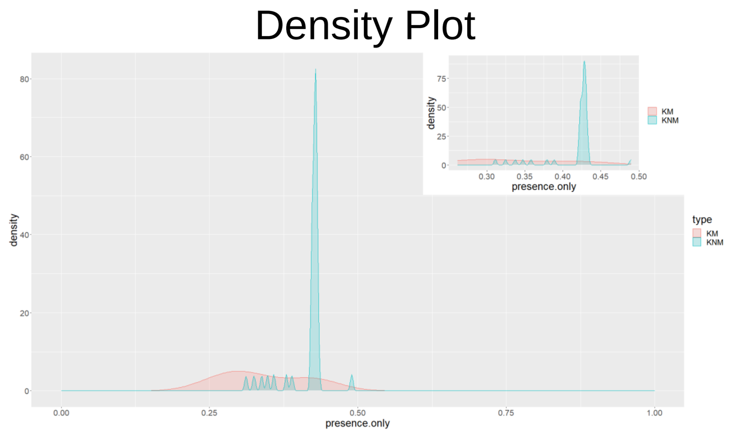


Total Difference Density Plot



- ❖ Examines the distribution of how large the total difference is between lands

Difference in Presence
Density Plot



- ❖ Examines distribution of the difference in presence of features, if a feature is absent on one land

Conclusions

- ❖ Interpreting the Difference Map Plot
  - ❖ The overlap of the values within the difference map plot occur because different lands in the barrel will mark with a different consistency and depth
  - ❖ Overlap may also occur due to the high resolution used, 1.5625 microns, to color the bullets, if the data is smoothed to a larger resolution, it may give a better separation of data
  - ❖ Even with this overlap, using a couple variations of the difference percentages from each map, the matching lands can be extrapolated from the data
- ❖ Comparing matching LEA amplitude maps manually
  - ➢ Evidence indicative of a match is present
  - ➢ Lands compared using this method generally showed at least 2 prominent amplitudes in agreement
  - ➢ This agreement did not occur on any non-matching land inspected in this set of bullets
- ❖ Intra-comparison of the sub-sectioned cross cuts
  - ➢ Valuable insights into what striations occur the most commonly along the surface of the bullet
  - ➢ Provides the ability to locate which cross section presents the best comparison
  - ➢ The optimal cross section will have the most correlation with the rest of the bullet, and will likely have a greater percentage overall of coloration

Deliverables

- ❖ Algorithms that objectively analyze features on the entirety of the surface from a 3D topographical image of bullet lands
- ❖ Improved shoulder detection algorithm over previous methods
- ❖ Amplitude Maps
  - ➢ Inspection of the prominence and significance of the features present on land engraved areas
- ❖ Difference Maps
  - ➢ Quantitative comparison of amplitude maps by calculation of the net difference and inter-variability of features occurrence on matching or non-matching LEAs
- ❖ Intra-correlation Comparison Map of Full Cross Sections
  - ➢ Examination of the intra-correlation of all the cross sections within a given LEA
- ❖ Sub-sectioned Correlation Maps for Individual Features
  - ➢ Subsection of the correlation values to inspect the intra-variability and correlation of specific features on the bullet

Future Directions

Optimizing the data collected though these algorithms:

- ❖ Validation of methods
  - ➢ Calculate inter- and intra-variability of identified features
  - ➢ Optimize resolution for LEA maps
  - ➢ Statistically evaluate variability between known matching and known non-matching LEAs
- ❖ Characterization of more firearms:
  - ➢ Firearms of the same caliber and action
  - ➢ Firearms with different caliber and same action
  - ➢ Firearms with different caliber and different action
- ❖ Explore which characteristics inside the gun barrel transfer the most prominent and consistent marked striations patterns on bullets
- ❖ Further characterize CCF value correlation maps for inter-comparison of feature utility

References

[1] Association of Firearm and Tool Mark Examiners, "Theory of identification as it relates to toolmarks," *AFTE J.*, vol. 30, no. 1, pp. 86–88, 1998.
[2] H. Hofmann, S. Vanderplas, and G. Krishnan, *bulletxtrctr: Automatic Matching of Bullet Striae*. 2019.
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