Three-dimensional data of wirecut surface scans under the confocal microscope (110 character maximum, inc. spaces)

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ABSTRACT

Update later: max of 170 words: describe the study, the assay(s) performed, resulting data, and reuse potential

Wire cut data is important in forensic investigations but lacks a systematic way of analyzing the data. We created a data set of 120 scans of aluminum wire cut in `x3p` format, using 5 wire cutters and 3 locations along the 4 blades, with 2 replicates for each combination. A systematic pipeline with multiple analysis plots was developed to analyze the data and draw conclusions based on numerical measures.

1 Background & Summary

Wire cut data is a type of forensic tool mark data used to identify the source of a wire cutter based on the striations left on the surface. There have been cases where the evidence and testimony on wire cut evidence played a crucial role in the criminal investigation and conviction of a defendant.

However, there is a lack of a standardized method to analyze it except for visual comparison. Although the Association of Firearm and Toolmark Examiners (AFTE) developed the Theory of Identification[1], which outlines the process of comparing tool marks, it is still subjective and relies on the examiner's experience, making results hard to reproduce and validate. Several reports, such as those from the National Research Council[2] and the President's Council of Advisors on Science and Technology[3], pointed out the abovementioned issues and called for more objective and reproducible methods to analyze tool marks. Early research by Ma et al.[4] and Zheng et al.[5] has focused on collecting and distributing datasets for this purpose and providing a foundation for future advancements in tool mark analysis. Studies such as those by Chu et al.[6] and Vorburger et al.[7] have demonstrated the efficacy of using numerical methods to improve accuracy and consistency in tool mark analysis. Hare et al.[8] and Ju et al.[9] have explored methods for quantifying the similarity between representative signals, but alignment remains a major hurdle.

In this study, we would like to follow the same path and provide a data set of wire cut scans, and also discuss a systematic pipeline to analyze the data and draw conclusions based on numerical measures. Here, we provide a data set containing multiple files, as described in Table 1.

breakable table, cannot cross-reference inside table

For the reproducibility of all our data and alignment results, we introduce in detail in Cutting wires (cross-reference not working without section number, number-sections: false not working) how we cut the wire and collect the 120 scans with 5 tools on 3 locations, in Extract profiles how we extract profiles from the scans, in Filtered signals how we filter signals from the profiles, in Align signals how we align signals from different scans and optimize the alignment with the cross-correlation function (CCF) values. In Data Records, we discuss where our data is held. Then, in Technical Validation, a technical validation was conducted to further compare signals from different sources also match our assumption, together with visual aids for drawing conclusions. Finally, in Usage Notes, we provide available codes for creating the data set and conducting technical validation, as discussed in Methods and Technical Validation. Code availability discusses where these codes can be found online. We hope this pipeline developed using this data set can be further generalized and applied to real crime scenes

Table 1. Structure of available data and files.

	Description	Section
Raw data		
`scans/`	folder containing 120 topographic 3d scans of aluminum wire cuts in x3p format	Cutting wires
`meta.csv`	meta information for each cut with tool, blade, and location information (csv format)	Cutting wires
Manual derivatives		
`profiles`	folder of files with manually extracted profiles (csv format)	Extract profiles
Computational derivatives		
`signals`	folder of signals, processed from corresponding profile (csv format)	Filtered signals
CCF values	CCF values of all pairwise aligned signals in 1 CSV	Align signals
Image files		
`aligned-signals`	pictures of pairwise aligned signals from same sources in PNGs	Align signals

to help investigators draw conclusions based on real wire cut data.

2 Methods

In this study, aluminum wire was used to create an optimal scenario where the most amount of information could be transferred from the tool to the substrate, despite the wire in some real cases being made of lead. The physical property of aluminium wire make it an excellent candidate for keeping marks while being relatively easy to bend and non-toxic.

2.1 Cutting wires

The aluminum wire used was 16 Gauge/1.5 mm, anodized. In order to cut the wire, 4-inch pieces were unspooled and cut using Kaiweets wire cutters, model KWS-105, as shown in Figure 1(a), for 1 blade location, either inner, middle, or outer, which gives us 1 replicate. Each piece was then cut into half to create 2-inch pieces for each side, AB and CD, with a sharpie line marking the cut ends, giving us 4 samples. Here, we are showing AB sides only in Figure 1(b) (remove the tent figure), and the CD sides are similar from the other side of the cut, with the back of A being C and the back of B being D. Both AB and CD sides form tent structures on the tips of the wire, and we can separate each side of the tent into 2 pieces along the bending position, resulting in 8 scans. We repeated this process for all 3 locations along the blade and 5 wire cutters, with 2 replicates for each tool-edge-location combination, resulting in 120 scans. Each piece was labeled with the naming conventions, T(ool) 1/2/3/4/5 (Edge) A/B/C/D W(ire) - L(ocation) I(nner)/M(iddle)/O(uter) - R(epetition) 1/2, with T1AW-LI-R1 being the piece cut by tool 1 on the A edge at the inner location for the first repetition. Then, we can use the standard scanning protocols for the confocal microscope, shown in Figure 1(c) (need an extra pic of the very tip), to scan the wire tip surfaces. The scanned surfaces are saved in a resolution of $0.645\mu m \times 0.645\mu m$ per square pixel in an `x3p` file format.

XXX figure 1 - generally, zoom into these images - we do not want to have a hand in the image, nor a view of the crafting aluminum :) - what are the exact rules on visuals in Scientific Data ? XXX hard to put the full requirements here, see https://www.nature.com/sdata/publish/submission-guidelines#figures

put into quarto layout with (a) (b) (c) on the top left, no tent, add blade C & D (Do later after decide on using qmd or Overleaf)

2.2 Extract profiles

Numerical comparisons between 2 replicates cannot be done directly on the `x3p` files. We need to extract representative functions from the scans first. A representative function with the most information is considered as a signal for one scan, which can be used for comparison later. To obtain this function, we first need a profile of the scan, which is a sequence of values along a user-drawn line on the surface. The profile should capture most features of the scan, and be orthogonal to the striation marks of the scan, which are formed by ups and downs of grooves. So, we draw the line across the wide region of the scan to maximize the feature captured, as shown in dark blue in Figure 2(a). We can then investigate the values under this profile line. The profile function is along the line is plotted in Figure 2(b).

2.3 Filtered signals

With the profile extracted, we can then obtain the signal. Two Gaussian filters are applied to these resulting profiles. In particular, we first used a large low-pass filter with bandwidths of 400 microns to remove large trend, as it can overwhelm the signals, and then used a small high-pass filter of 40 microns to average across noise and remove spikes, as shown in Figure 2(c). Cleveland et al.[10] (add reference: W. S. Cleveland, E. Grosse and W. M. Shyu (1992) Local regression models. Chapter 8 of Statistical Models in S eds J.M. Chambers and T.J. Hastie, Wadsworth & Brooks/Cole.). Finally, the extreme tail values are removed.

2.4 Align signals

Signals extracted from different scans can be put together for comparison, and we maximize the corss-correlation function (CCF) values between the signals to numerically find the best alignment. For example, we compare T1AW-LI-R1 to T1AW-LI-R2, T1CW-LI-R1 to T1CW-LI-R2, and so on. That is comparing each row in Figure 3. We know that signals from two replicates with the same tool-edge-location combination should yield similar signals as in the first and second column of Figure 4, which will give alignments of massive overlapping and high CCF values close to 1. The alignments and values we got in the rightmost column of Figure 4 fulfill our expectations.

3 Data Records

The complete data set is available on the ISU DataShare repository at https://iastate.figshare.com/, which is public and open access for every interested researcher. The data set consists of 120 scans in the `x3p` file format with the naming convention as described before. (Explain the x3p header info?)

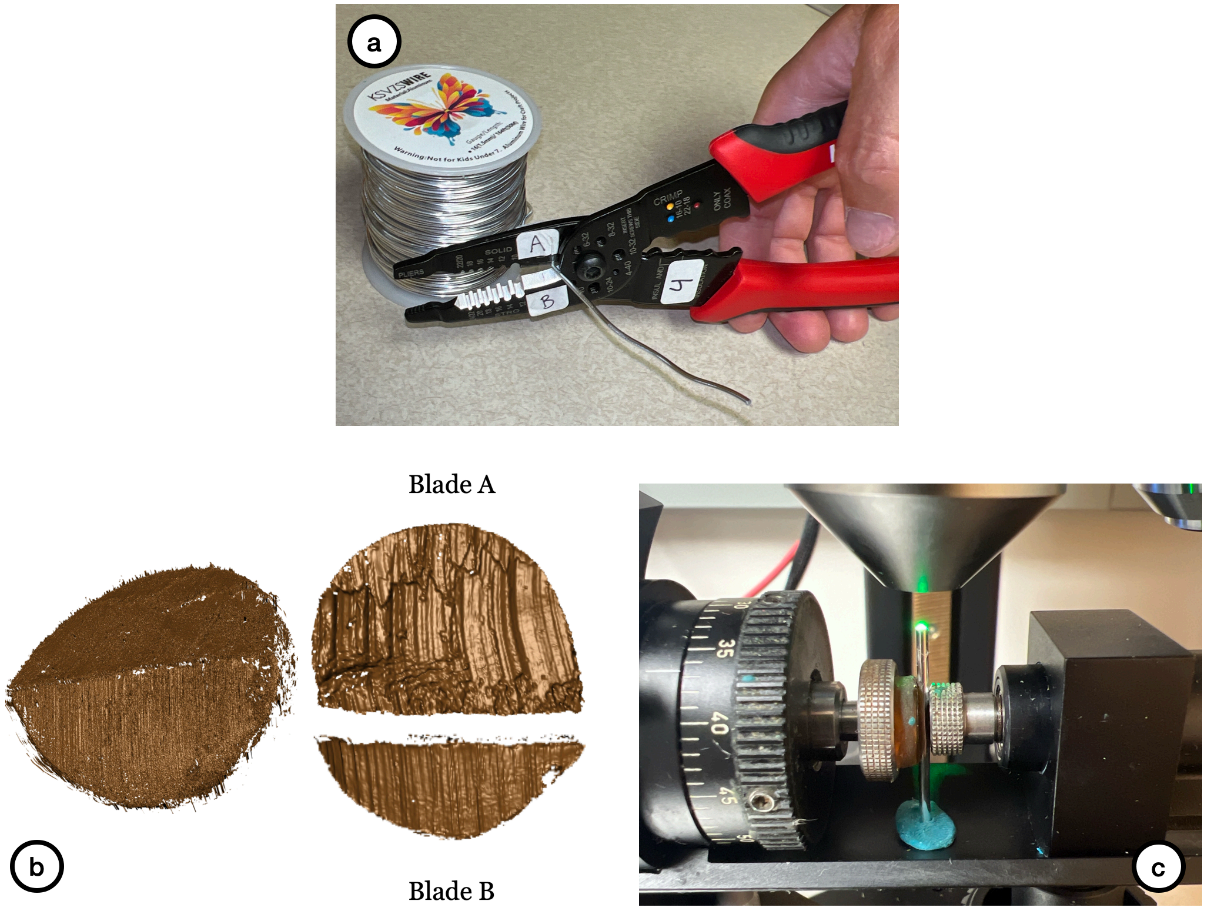

Figure 1. (a) A Kaiweets wire cutter of model KWS-105 was used to cut the wire. (b) A tent structure created by blade AB. After separating 2 tent structures by the connecting position, we obtained 2 samples - 1 sample from blade A and B. (c) A confocal microscope was used to scan the wire surfaces.

4 Technical Validation

a picture of alignment with ccf from different sources to show if different source, our evaluation returns small ccf, which matches what we thought.

For the data collection process, two team members did the cutting and labeling together, then one person did the scanning and named according to the naming convention above. The scanning was done in a specific order to ensure consistency across all scans. The data was saved in a consistent format to ensure they could be easily accessed and analyzed. A third person then checked the data to ensure that the data was consistent in naming and accurate.

For the validation of the scans and their processing we investigate the correlation scores of pair-wise aligned signals. For signals from scans of wires cut with a different tool, we would expect a low correlation score. Large scores between signals are indicative of being made by the same tool. Show boxplots and roc curve.

For the validation of all other tools and locations of scan replicates, see Github repo.

5 Usage Notes

The `R` package `x3ptools` (available from `CRAN`) supports working with files in x3p format.

Sample scripts in R for processing scans from x3p format to their signal are available from ... github.

Further analysis can be conducted with the `GitHub` `R` package `wire` and the `GitHub` `R` shiny app `wireShiny` (citation?). We already conduct between-replicate comparisons in the technical validation section, and we can also conduct across-replicate comparisons to establish error rates threshold and produce other analysis plots.

Suppose we put the CCF values in a tilemap with different tool, location and edge combinations. In that case, we expect only the diagonal to have high CCF values, close to 1 and marked as orange in the tilemap, as the diagonal represents the same

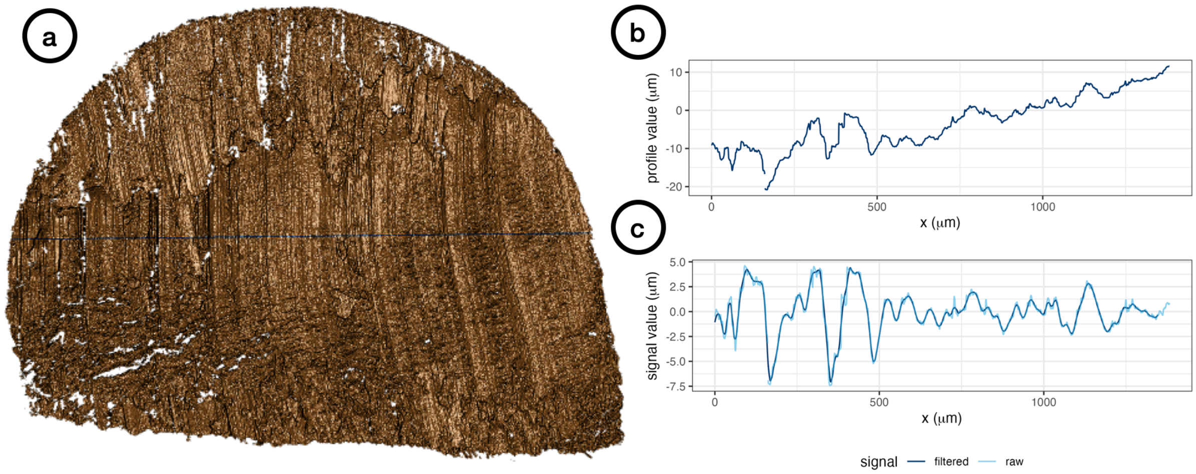

Figure 2. (a) A profile line in dark blue was drawn across the striations of the scan. (b) The profile function extracted along the profile line in (a). (c) The raw signal in light blue is obtained by using the low-pass filter on the profile function in (b) and the filtered signal is obtained by using the high-pass filter on the raw signal.

source, and the rest of the matrix to have low CCF values, close to 0 and marked as gray. In Figure 5, the behavior is consistent with our expectation overall, except for some rare cases with tool 5 edge D, which is caused by ?????. We also put the resulting CCFs in the boxplot, as in Figure 6. We can see that the CCF values for the same sources are close to 1, while the CCF values for different sources are much lower than expected. This difference can be used to establish a threshold for CCF and help us draw conclusions about the similarity between wire cut scans numerically, which can be used in real crime scenes. The density plot in Figure 7 shows the distribution of the CCF values with the same sources and different sources. The overlapping points between the tails of these two distributions can be a rough threshold. Furthermore, the receiver operating characteristic (ROC) curve in Figure 8 shows the sensitivity / true positive rate against the false positive rate (FPR) (1 - specificity). The curve is very close to the upper left corner, which is excellent for classification and drawing conclusion. It gives us a true threshold of 0.589 to control the FPR to be less than 0.05 with false negative rate (FNR) to be 0, (false positive rate (FPR) / false discovery rate (FDR) -> define the H0 or call it false identification rate (FIR)???), and 0.658 to control the FPR to be less than 0.01, with FNR to be 0.02.

6 Code availability

table of codelist files with short explanation, similar to table 1

no, we can't use the website as a place for more detailed procedures. This paper is the detailed procedure.no more README, scanning procedures in another HTML

We put together the cutting and the standard scanning procedures mentioned in Section 2.1 cross-ref not working with more pictures for each step into a README of the GitHub repository `heike/Wirecuts` (High-res pics needed in the README).

The data set can be easily accessed with the `CRAN R` package `x3ptools`. Further analysis can be conducted with the `GitHub R` package `wire` and the `GitHub R` shiny app `wireShiny` (citation) .

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Author contributions statement

hh{Let's follow the Elsevier definitions: https://www.elsevier.com/researcher/author/policies-and-guidelines/credit-author-statement}
Y.L.: Methodology, Software, Validation, Data Curation, Writing - Draft; H.H.: Conceptualization, Methodology, Validation, Writing - Review & Editing; C.M.: Lab supervision; E.A.: Physical Specimen, Scanning; J.S: Forensic advice; A.C.: Funding acquisition.
All authors reviewed the manuscript.

Competing interests

(mandatory statement)

H.H. is a technical advisor to AFTE (Association of Firearms and Toolmarks Examiners), fellow of the ASA (American Statistical Association), and committee member of the ASA Forensic Science Committee. H.H. has testified as court witness on behalf of judge April Neubauer, NY State Supreme Court Criminal Term in New York City. other competing interests - Alicia?

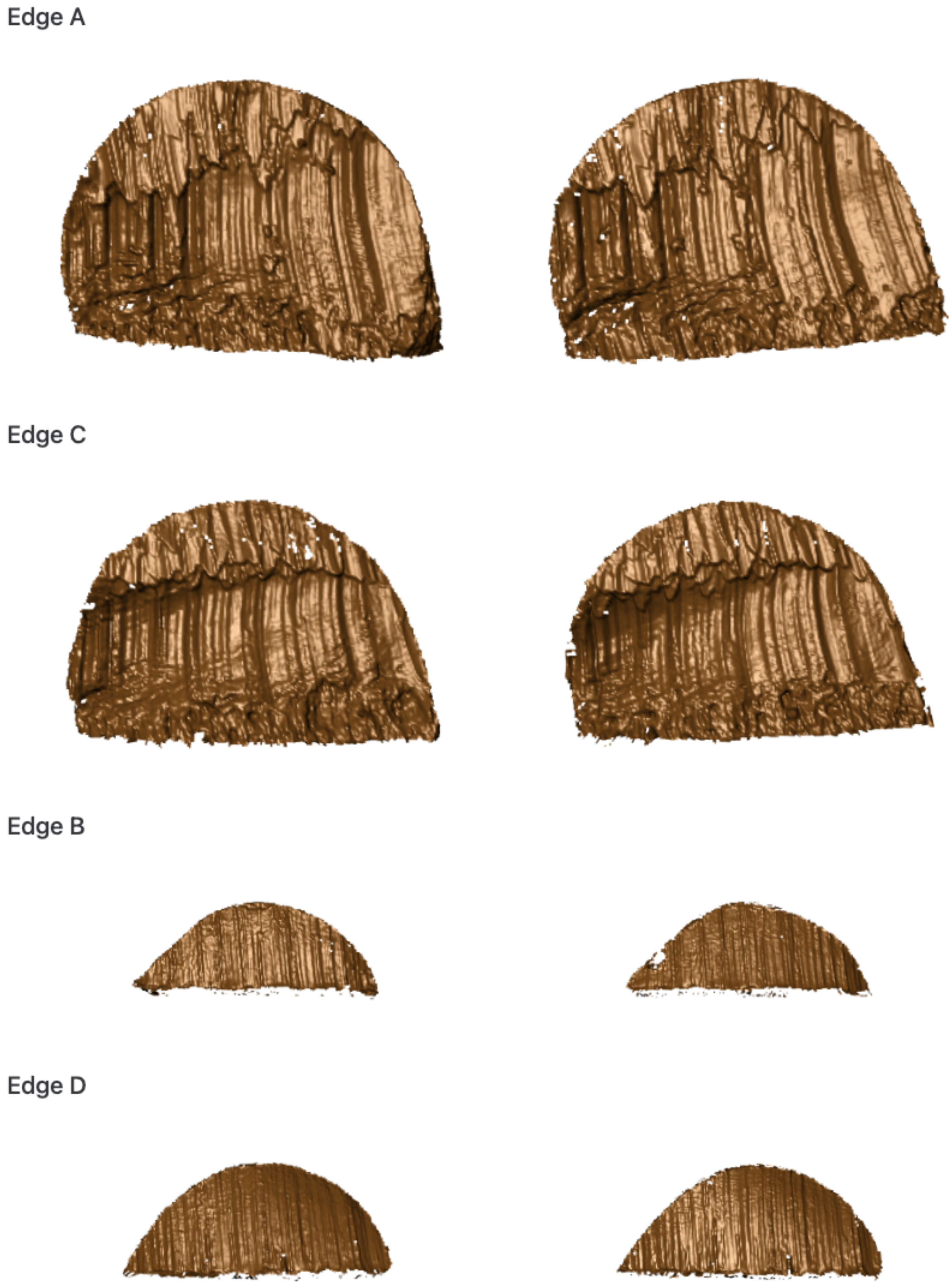

Figure 3. Scans from different sides of tool 1 at the inner location.

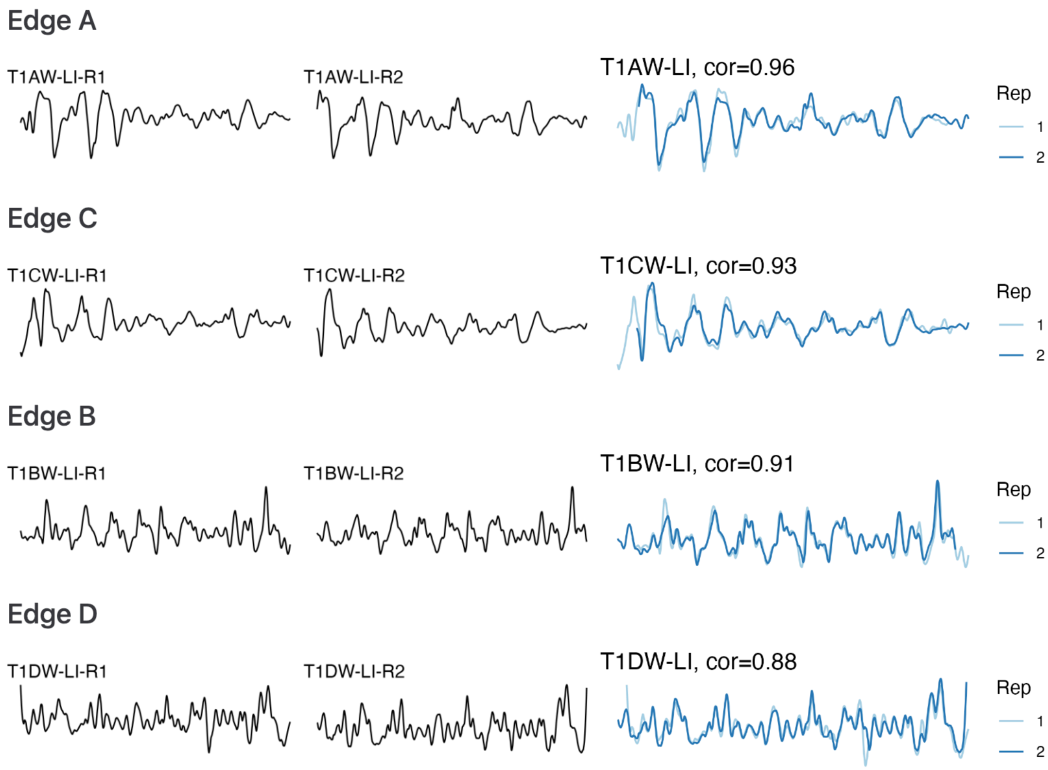

Figure 4. The first and second columns show the signals extracted from Figure 3, and the third column shows the alignments and CCF values between pairs of signals.

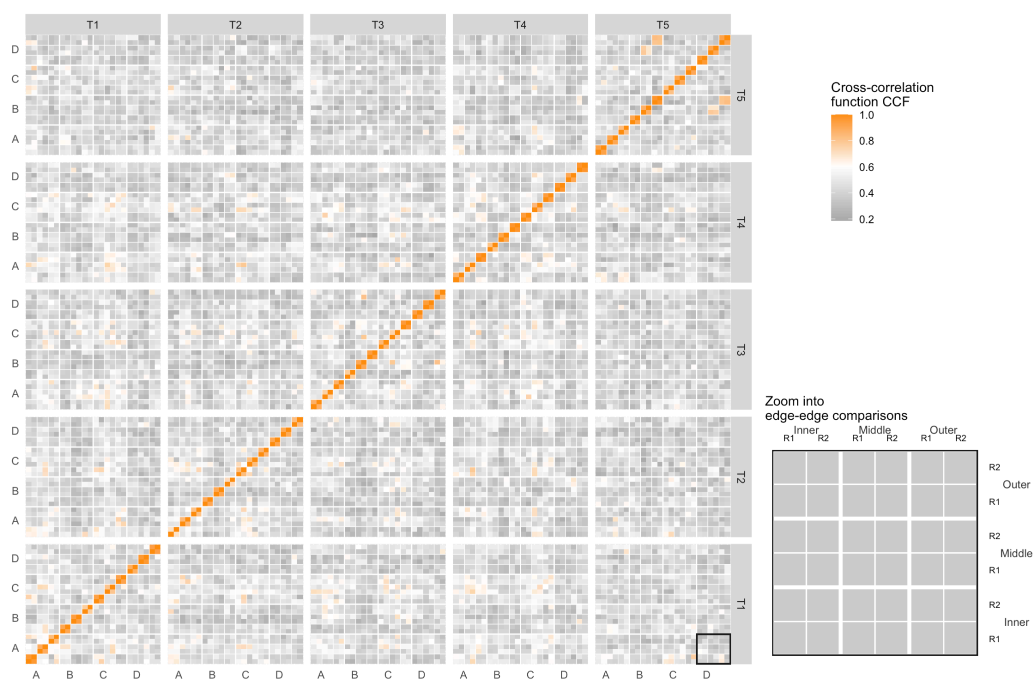

Figure 5. The tilemap shows signals from the same source have CCFs close to 1.

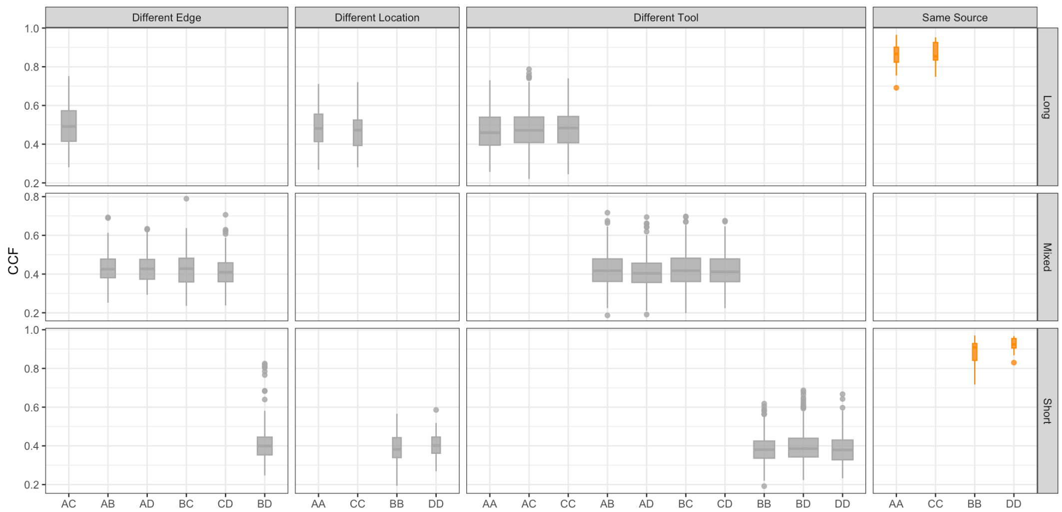

Figure 6. The boxplot shows that signals from the same sources have higher CCfs than those from different sources.

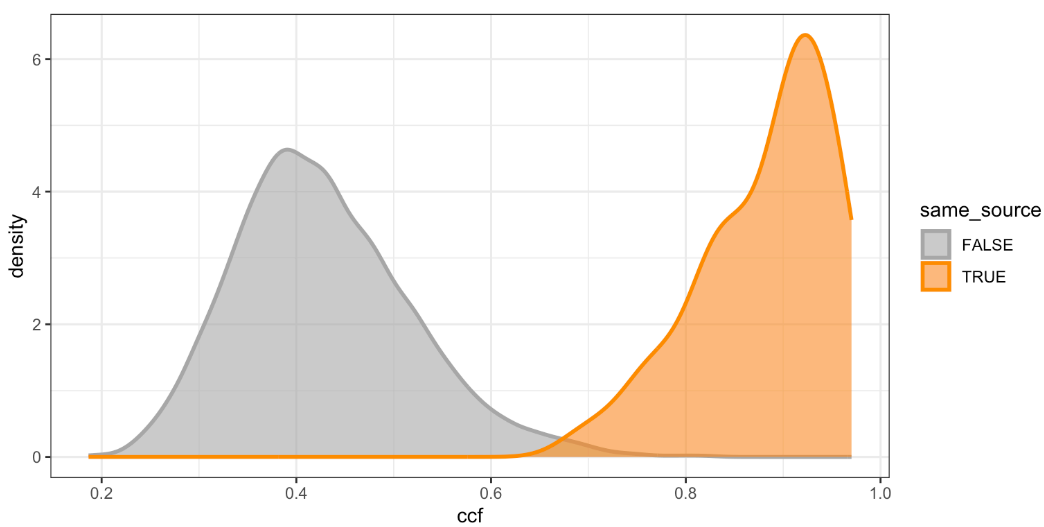

Figure 7. The density plot shows tails of distributions overlap, which can be used as a rough threshold for drawing conclusions.

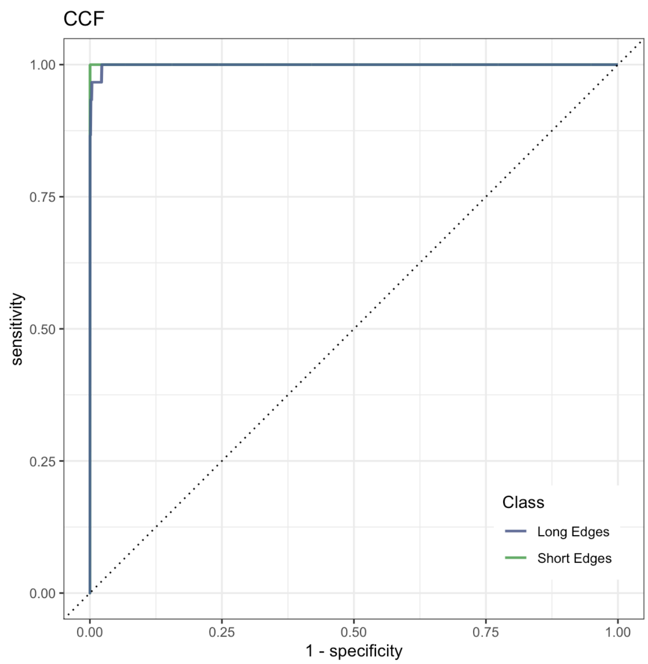

Figure 8. The ROC curve is bending very close to the upper left corner, which means excellent in classification and drawing conclusions.