Methods for Automatic Groove Identification in 3D Bullet Land Scans

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1. Background

One new avenue for automated comparisons of bullet marks is based on high-resolution 3D scans of bullet lands. In order to fully automate a comparison process, an algorithm has to be able to detect the location of the edges of the lands, which we refer to as ***grooves***.

Bullet lands have a naturally curved shape. Automated methods need to first remove that global structure in order to extract more detailed information about the remaining deviations. The accurate removal of the global structure can be significantly affected by the extra data (outliers) contained in the grooves.

Failure to correctly identify these groove locations and remove extraneous data leads to an increase in error rates down stream in automated algorithms. Current solutions are susceptible to numeric instabilities [1]. We propose methods based on ***robust*** statistical procedures. Robust methods are less affected by outliers within a data structure.

2. Data

Data Source

Hamby (2009) Barrel Set 44 [2].

- Ten consecutively rifled Ruger P-85 barrels
- 210 individual bullet lands (6 lands each from 35 bullets)
- 3D scans gathered from confocal light microscope at Center for Statistics and Applications in Forensic Evidence (CSAFE)
- Resolution: 0.645 μm/pixel

Data Structure

Each bullet land is represented as a 3D matrix

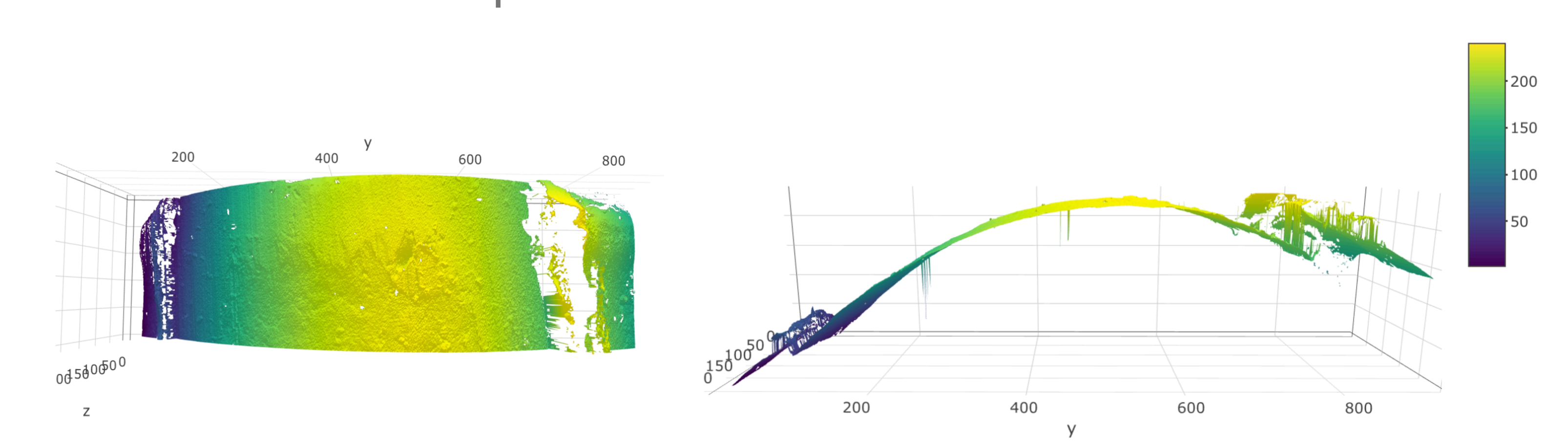

Figure 1. Two views of a high-resolution 3D scan of a single bullet land. When viewing the scan from above (left), striations can be seen along the surface of the land. When viewed from the side (right), the global curved structure of the bullet land can be seen.

Data analysis focused on ***profiles***, slices across the bullet land that were averaged over 10 different locations across the land.

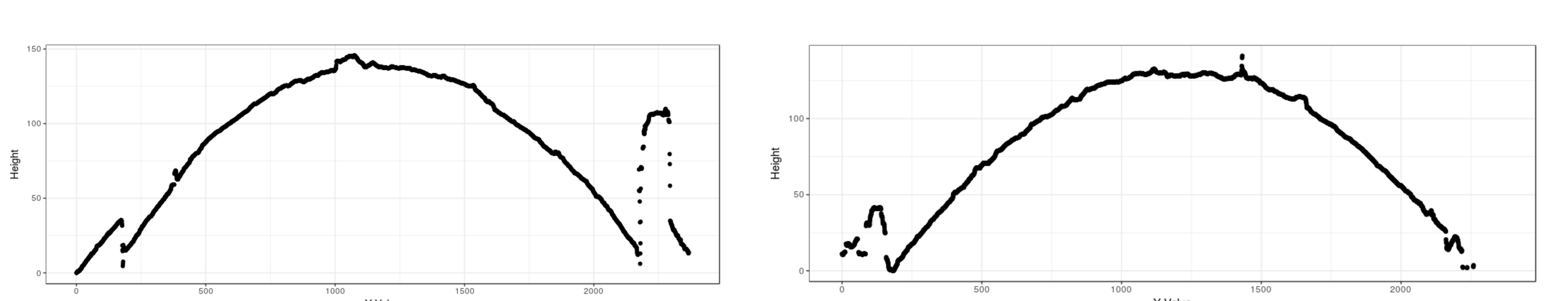

Figure 2. Two examples of bullet land profiles from the Hamby Barrel Set 44 3D scans.

3. Methods

Grooves affect the removal of global structure in bullet land data due to their unusual values in unlikely places. In order to identify and remove these unusual portions of a bullet land, we use two different robust methods that are less affected by unusual values. The steps of the process are outlined as follows:

Step 1. Model the Global Structure

Robust linear models were fit using the `MASS` package in R, and robust LOESS models were fit using the `locfit` package in R. Linear models assume a quadratic structure, while LOESS models are more flexible.

Robust Linear Model | Robust LOESS

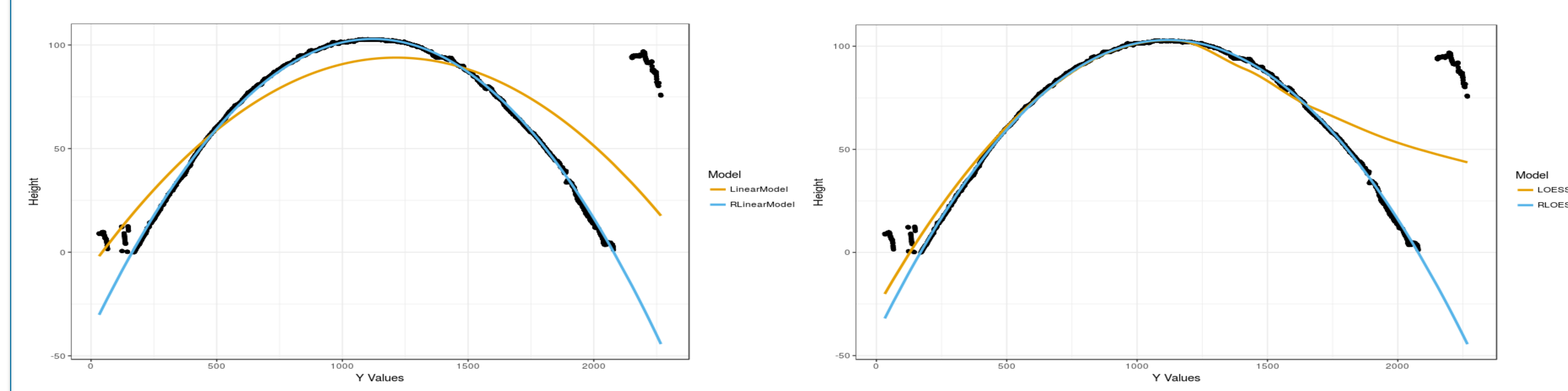

Figure 3. A demonstration of a robust linear fit (left) as compared to a traditional linear model, and a robust LOESS fit (right) as compared to a traditional LOESS fit. Robust methods are developed to be less affected by outliers. This property is clearly demonstrated above.

Step 2. Calculate Residuals

Robust Linear Model | Robust LOESS

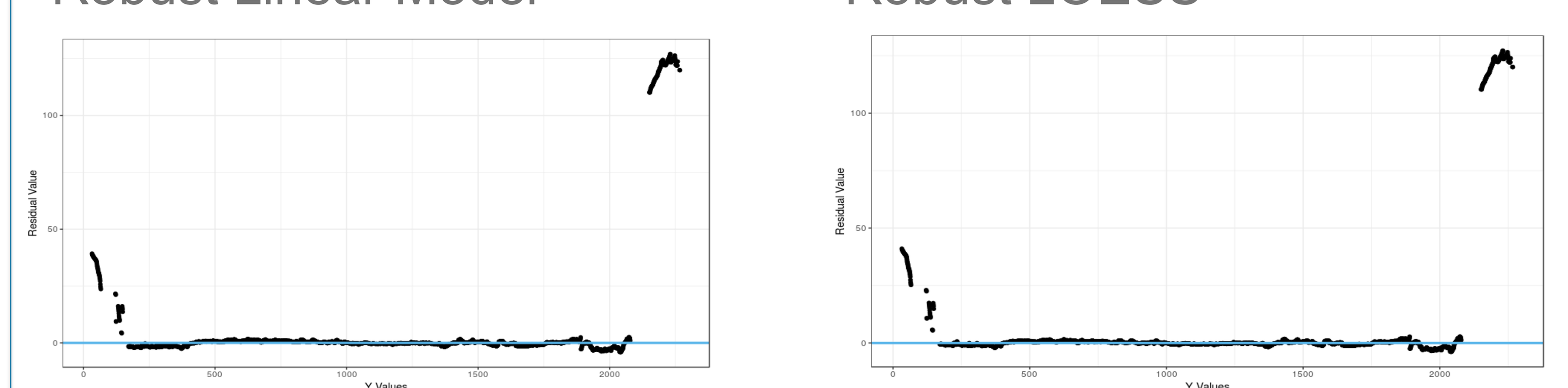

Figure 4. Residuals from the two robust fits; the robust linear model fit (left) and the robust LOESS fit (right). In this case, the residuals for the two models are very similar.

Step 3. Remove Extreme Residuals

Remove any data point that corresponds to an extreme value in the residuals. This "cutoff" value is different for the two models:

<u>Robust Linear Model</u>:
- 4*Median Absolute Residual

<u>Robust LOESS</u>:
- 2*Median Absolute Residual

The range of remaining values after removal of extreme values is the range of the "land". Values outside of this range are considered part of the "groove".

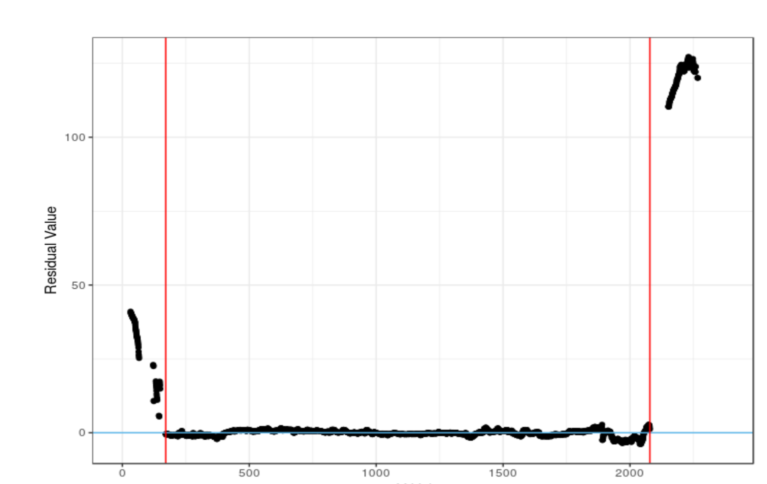

Figure 5. Residuals from a robust loess fit overlaid with predicted groove locations.

4. Results

To assess the methods, we compare predicted grooves to manually identified grooves ("ground truth"). We do this by finding the range of values between the "ground truth" groove and the predicted groove, and summing their residuals. We can refer to this as an ***accuracy score***. A smaller accuracy score represents a more accurate prediction.

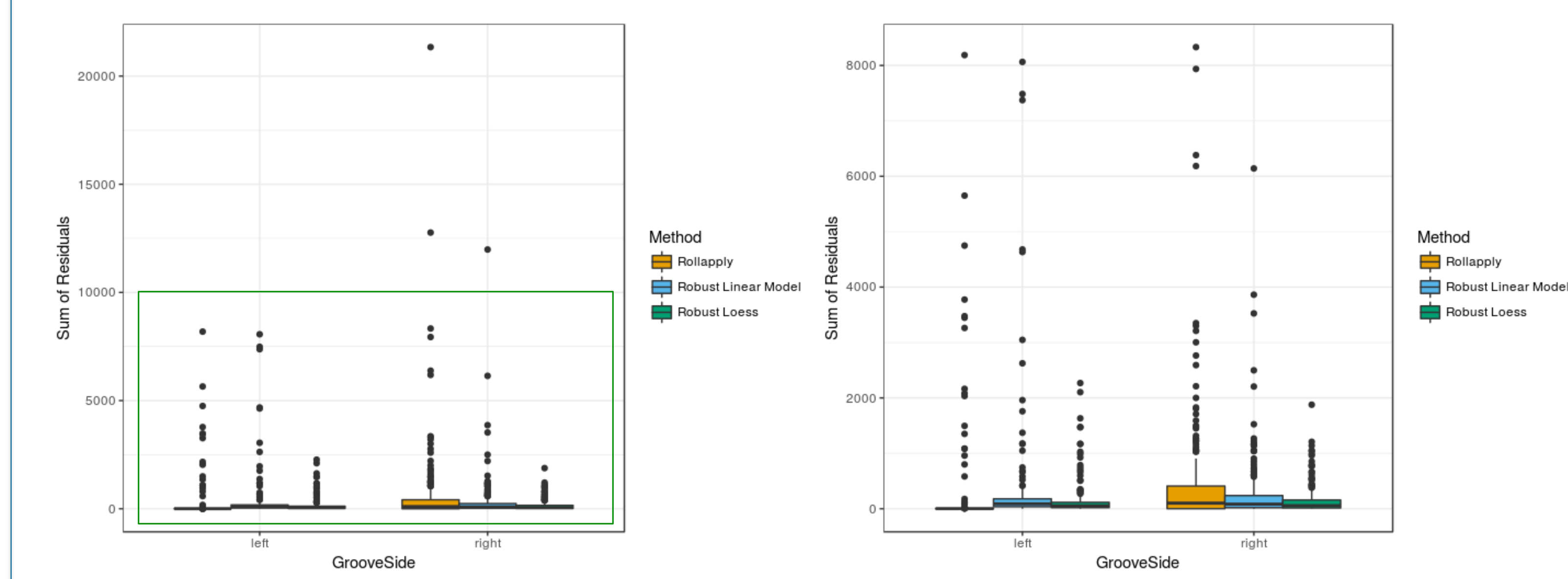

Figure 6. Comparative boxplots of accuracy scores using (1) current method, (2) robust linear models, and (3) robust LOESS. These represent the distribution of accuracy scores over all 208 used lands (left) in the Hamby Barrel Set 44 3D scans, and a zoomed version removing some outlying lands (right). Within each plot, they are split between left groove and right groove.

Discussion

- There is clear improvement in accuracy over current methods by both robust methods on the left grooves
- Clear improvement using robust LOESS on the right grooves, but robust linear models do not perform as well here

Robust linear models are fit with the assumption of an overall quadratic shape. This is not always the case in reality, which leads to poor models for the global structure. This is one reason we have seen a more striking improvement using robust LOESS, a more flexible method that can adapt to scans that are not ideal.

While initial results show great improvements using robust methodologies, further work should be done on validating the cutoff values at which extreme residuals are removed.

5. References

[1] Hare, Eric, Heike Hofmann, and Alicia Carriquiry. 2016. "Automatic Matching of Bullet Lands" *ArXiv E-Prints*, January.
[2] Hamby J, Brundage D, Thorpe J, "The Identification of Bullets Fired from 10 Consecutively Rifled 9mm Ruger Pistol Barrels: A Research Project Involving 507 Participants from 20 Countries," AFTE Journal, Vol 41, No 2, Spring 2009

6. Acknowledgments

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