# 1 Introduction

2 Methods

In order to best identify the GEAs we first want to diminish noise in the image. This can be achieved by converting each scan into an image gradient, which signifies where there are directional changes in the color of the image. This approach loses most of the detail of the three dimensional scans, but it better highlights the differences between LEAs and GEAs. Once an image gradient is obtained we select only edges we consider to be "strong", meaning they have a magnitude above the 99th percentile. Our reason for not fully carrying out a Canny Edge detection algorithm before using a Hough transform is that the Canny Edge algorithm increases processing time by about 35 seconds per image and actually highlights more striae and breakoff.
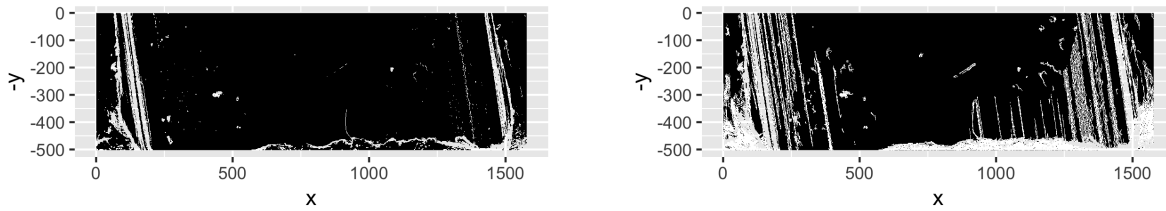

(a) Edges with magnitudes in the 99th percentile (b) Edges improved with Canny edge detection

Figure 1: Side-by-side comparison of Hamby 252 Bullet using both magnitude thresholding and Canny edge detection

As shown in Figure 1 the striae in the LEA are much more pronunced than in the image with only strong edges. We wish to focus on only detecting GEAs, so detecting an increased number of striae through Canny edge detection is not useful for our algorithm. Once we obtain the image gradient with only the strong edges we can then utilize our Hough transformation to obtain generally reasonable estimates of image boundaries. For the Hough transformation we utilize the function " `hough_lines`" from the imager package with the number of bins set to 100. While changing the number of bins does not seem to effect the processing time of the Hough transform, having a larger number of bins increases the number of extraneous detected lines in the image. For example in Figure ??a we can see that the Hough transforms with 100 bins does a perfectly aedequate job of picking up the suspected grooves of the bullet. Therefore the extra detected lines in ??b are not used in our analysis so we chose to limit our bin number as a result.

Once Hough lines are calculated we select only the lines that have scores greater than the 99.9^{th} percentile to try and ensure that we are dealing with only the strongest edges and do not accidentally pick up on any particularly strong striae on the LEAs. We also make the
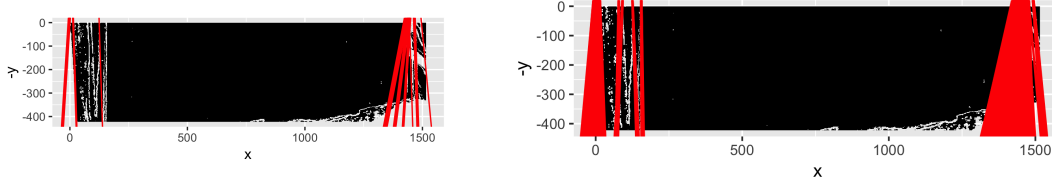
(a) Hough Transform with 100 bins

(b) Hough Transform with 900 bins

Figure 2: Side-by-side comparison of Houston Barrel F Land 1 Hough Transformation. Hough lines are filtered by having scores in the 99.9th percentile, and having central angles less than $\frac{\pi}{4}$.

assumption that scans are oriented properly and as such, most Hough lines that correlate to the GEAs will be roughly vertical with some deviations in angle based on scanning technique. Therefore we select only the Hough lines that have angles from the positive x-axis less than $\frac{\pi}{16}$ and greater than $\frac{-\pi}{16}$. The parametrization outputted by " `hough_lines`" is of the form:

$$\rho = x \ cos(\theta) \ + \ y \ sin(\theta)$$

Where ρ represents the length of the normalized vector between the detected line and the origin of the image, and θ is the angle between the positive x-axis and the normalized vector. In Figure 3 we see an example of how Hough transforms parametrize a line.
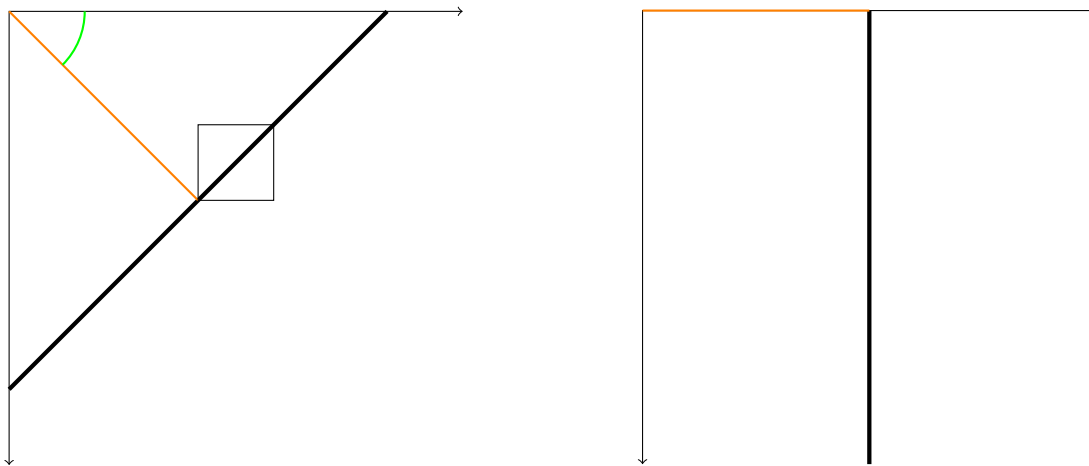

Figure 3: Diagram of Hough transform parametrization oriented for image origin.

We note that when θ is equal to 0, the x-intercept is given by ρ, when θ is not 0 we utilize the above equation to find that the x-intercept is equivalent to $\frac{\rho}{\cos(\theta)}$. We then calculate the slope

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and the y-intercept in a similar fashion. To determine which Hough line is the boundary of each GEA we rely on the assumption that the middle two thirds of each bullet scan is often part of the LEA. Therefore, we find the x-intercept of the lower and upper one sixth of our bullet scan then compare these boundaries to each Hough Line. It is important to note at this point in the explanation that when we refer to x and y, we are the location of the point of interest in microns on the bullet land. With this in mind, we then find the x-intercept of each Hough line at both the top of the land (defined to be y = 0) and the bottom of the land (y = the height of the bullet land in microns) as shown in 4.
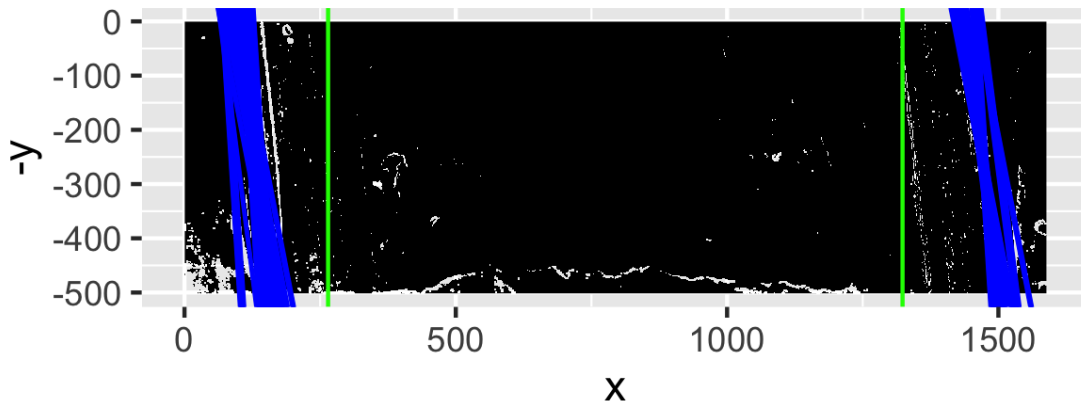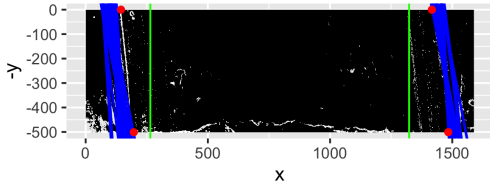

Figure 4: Hamby 252 Bullet 1 Land 1, Hough line estimates shown in blue, middle six-thirds of land shown in green.

Then each x-intercept for the tops and bottoms of the Hough lines are compared to the x-intercepts for the lower and upper one-sixth boundaries. The Hough x-intercept that is the smallest distance from the upper and lower one-sixth boundaries x-intercepts are selected for groove identification. We then calculate the equation of the line that connects these four sets of points to estimate the borders of the GEAs.

The output of the function get_hough_grooves is thus a list of two groove fits that extend across the entire height of the land. That is to say, the result of the get_hough_grooves process is a set of two functions, where "left.groove.fit" is the equation of the line to estimate the left-hand side groove, and "right.groove.fit" is the equation of the line to estimate the right-hand side groove. The functions for calculating each groove estimate are as follows:

(a) Hamby 252 Bullet 1 Land 1, Hough line estimates shown in blue, middle six-thirds of land shown in green and selected x-intercepts at top and bottom shown in red.
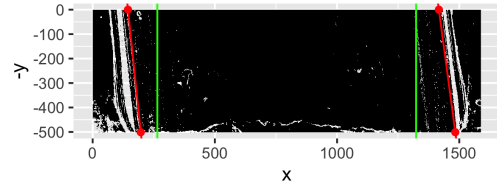
(b) Hamby 252 Bullet 1 Land 1, middle six-thirds of land shown in green and selected x-intercepts at top and bottom shown in red with connecting red lines for best groove fit.

$$slope = \frac{(top.index - bottom.index)}{(height\ of\ the\ image)} \tag{1}$$

$$intercept = ((-slope * top.index) - 1) * resolution \tag{2}$$

Where the resolution is the resolution of the x3p-file scan, obtained by using the bulletxtrctr command x3p_get_scale. While we have estimates of the GEA for the entirety of the land, other methods for detecting the GEAs of bullet lands utilize a single crosscut of the land at a specific y-value where striae are pronounced and the land is free from breakoff. This is accomplished by using the x3p_crosscut_optimize function from bulletxtrctr. We want our method to be comparable to others, so to produce a similar estimate at a single crosscut, we can input the y-value of the crosscut (in microns) into our groove functions to produce a groove estimate of a single crosscut.

The Hough transform process reduces the bullet scan to a two dimensional image, we find that the our estimates extend reasonably well to three dimensions. Below is an example of a three dimensional bullet land with our Hough estimates visualized in red and blue and added as a mask to the x3p of the bullet land.
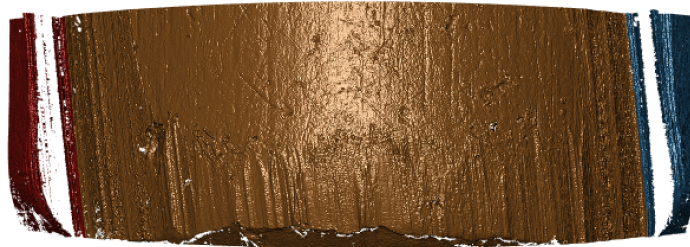

Figure 6: Hamby 252 Bullet 1 Land 1 three dimensional land visualization with Hough estimates shown in blue and red

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The left-hand groove estimate is shown in red and the right-hand estimate is shown in blue. We note that this is a pretty reasonable estimate of the GEAs for this particular land. The estimates appear to be just within the LEA without omitting too many prominent striae. However, Hough estimates are very influenced by the level at which we filter the scores from our Hough estimates and the quality of the land. Below is a three dimensional visualization of another bullet land (land 4) from the Hamby252 Bullet 1 demonstration scans. We see that the land itself is of poor quality without clearly defined grooves or striae and it appears to be relatively flat. These Hough estimates were created by filtering the Hough line scores at the 99th quantile while the good three dimensional visualization is filtered at the 99.9th quantile.
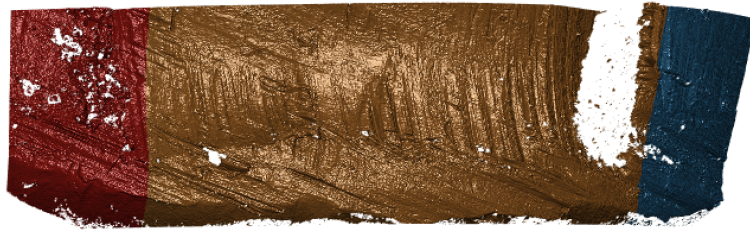

Figure 7: Hamby 252 Bullet 1 Land 6 three dimensional land visualization with Hough estimates shown in blue and red

Here the left-hand groove estimate is able to identify the land just to the right of what could possibly be a groove, but the right-hand groove entirely omitts the groove.

3   Results?