Forensic Study of Bullet Cartridges

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Introduction

Ballistics is an area of study that examines the flight path of projectiles. The examination focuses on the projectile as it leaves the firearm and strikes a target. Many items are collected such as firearms, cartridges, casings, bullets, live ammunition, trace materials, and any material damaged by a projectile. Firearm investigation is a type of toolmark examination. The firearm examiner compares items found at a crime scene to a known item. Cartridges and casings are analyzed to search for individual characteristics. Comparison microscopes are used to identify a potential match. The firearm causes the characteristics on the breechface area of the casing. Ballistics experts may also input information found on spent cartridges and bullets into a number of ballistics databases.

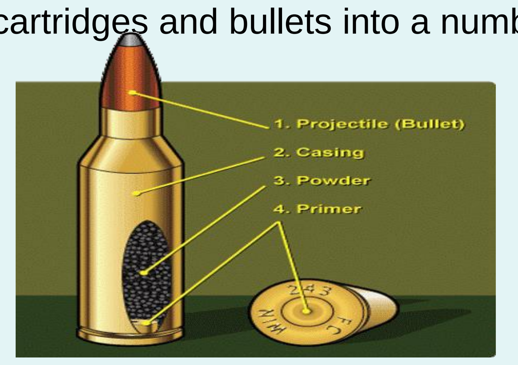


Figure 1: Gun cartridge

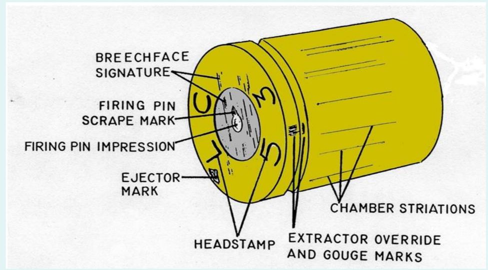


Figure 2: Casing

Thomas Fadul Study

The Miami-Dade Police Department Crime Laboratory conducted a research study on the repeatability and uniqueness of the impressions of a cartridge casing that was fired from 10 consecutively manufactured 9mm Ruger slides. The foundation of the firearm and toolmark identification is that each firearm/tool produces a signature of identification that is unique to that firearm/tool through the examination of the individual striations and impressions. With that the signature can be positively identified to the firearm or tool that produced it.


Figure 3: 9 mm Ruger


Figure 4: Ruger slide

What are Pixel Values?

The word "pixel" means a picture element. Every photograph, in digital form, is made up of pixels. They are the smallest unit of information that makes up a picture. Usually round or square, they are typically arranged in a 2-dimensional grid. For a grayscale image, the pixel value is a single number that represents the brightness of that pixel. The most common pixel format is the byte image, where this number is stored as an 8-bit integer giving a range of possible values from 0 to 255. Typically zero is taken to be black, and 255 is taken to be white. Values in between make up the different shades of gray.

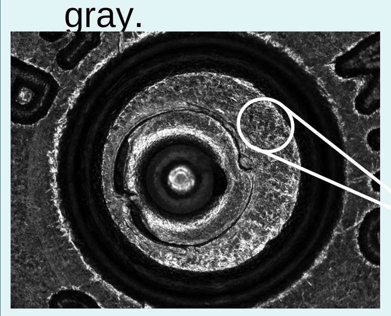


Figure 5:Fadul casing

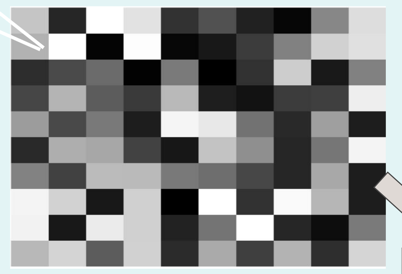
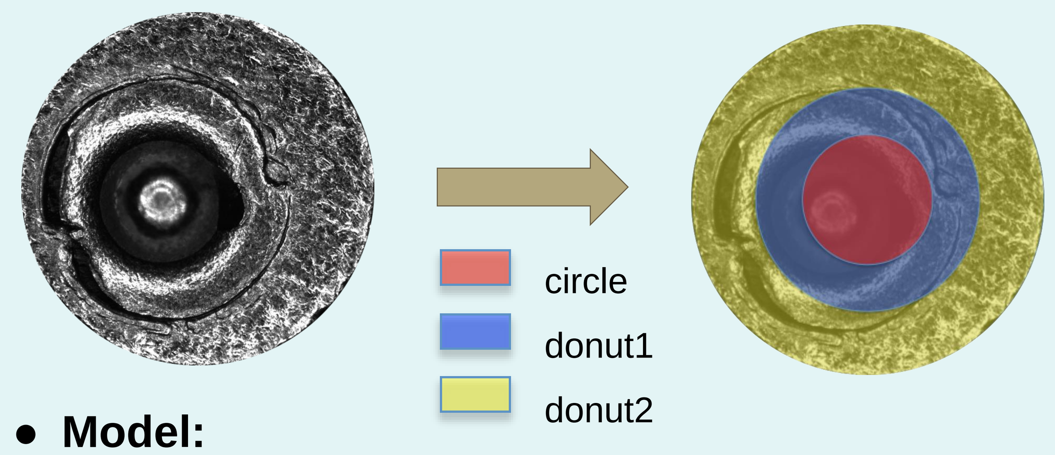


Figure 6: Grayscale image

194	5	253	...	...	201
156	252	...	...	...	...
12	...	...	...	...	...
...	...	...	...	...	...
187	...	...	...	...	25

Centered Regions

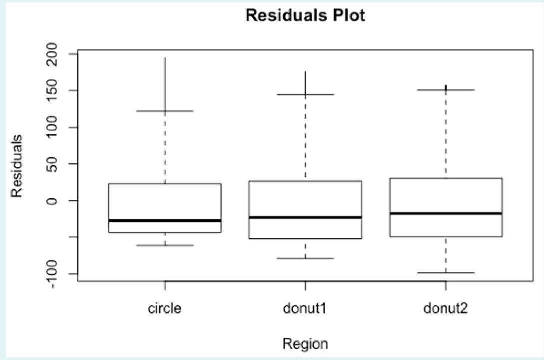
- Started with predetermined, centered regions.



- **Model:**

$$pixel(i,j) = \beta_1 circle(i,j) + \beta_2 donut1(i,j) + \beta_3 donut2(i,j) + \epsilon(i,j)$$

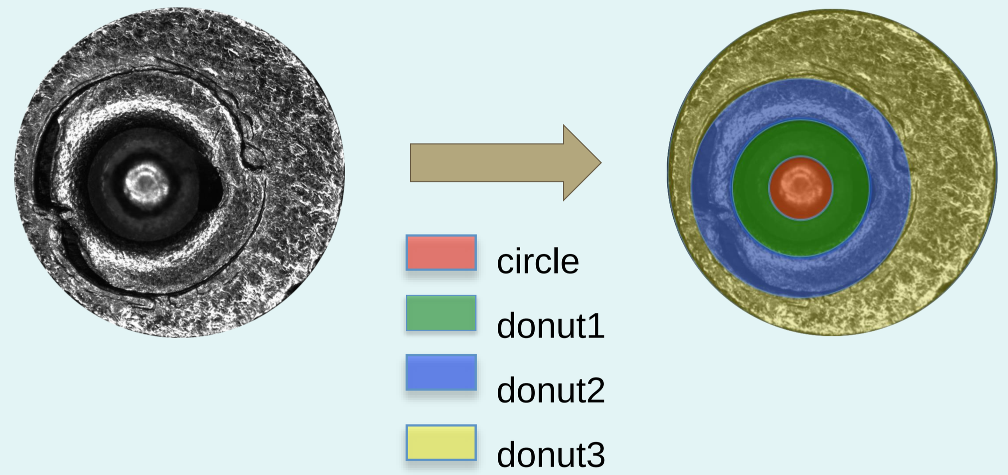
```
Coefficients:
              Estimate Std. Error
regioncircle  61.32892    0.15202
regiondonut1  79.24925    0.11245
regiondonut2  98.55382    0.06831
```



- The spread of the residuals on the Residuals Plot was fairly large, and the medians of the residuals were below zero.

Adjusted Centers

Use the center of the firing pin impression as the center of the regions inside of the breechface, and the center of the image as the center of the breechface region.

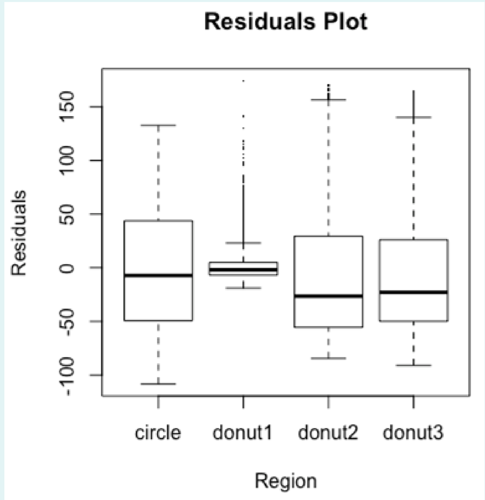


- **Model:**

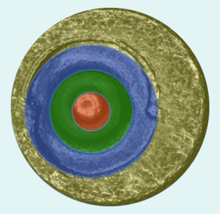
$$pixel(i,j) = \beta_1 circle(i,j) + \beta_2 donut1(i,j) + \beta_3 donut2(i,j) + \beta_4 donut3(i,j) + \epsilon(i,j)$$

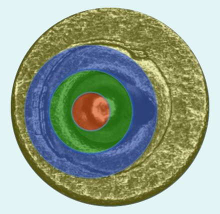
```
Coefficients:
               Estimate Std. Error
regioncircle  122.24267    0.37096
regiondonut1   18.90312    0.14127
regiondonut2   84.54042    0.09356
regiondonut3   90.89980    0.07384
```

RSS = **6,636,073,296**



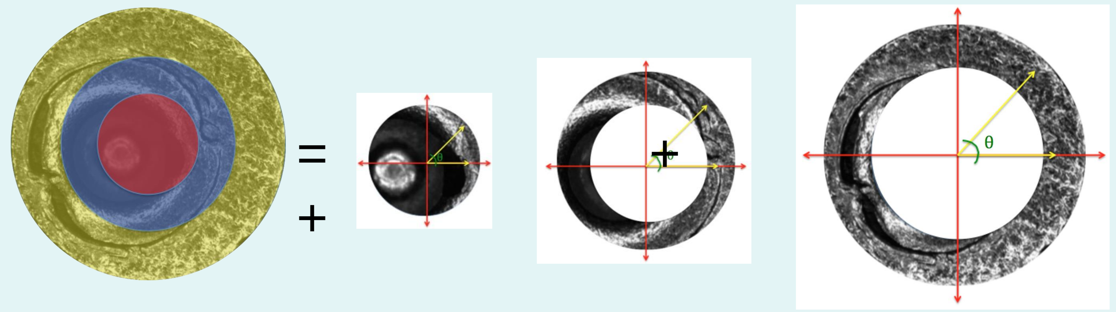
Running this model on other images:


RSS for image of bullet shot from the same slide = **0.963×(original RSS)**


RSS for image of bullet shot from a different slide = **1.257×(original RSS)**

Using Angle As A Predictor

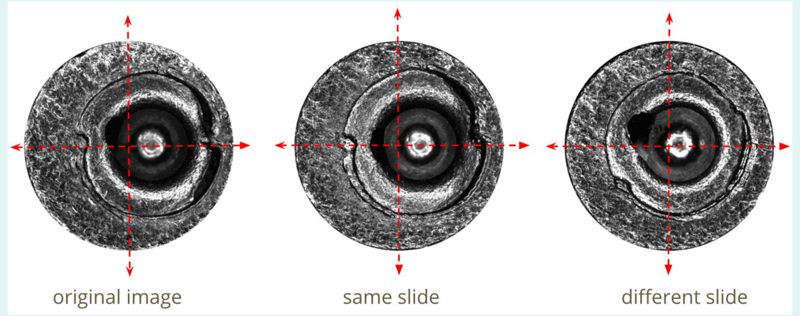
- Use the angle from the center of the image as a predictor.
- Run separate nonparametric regression models for each region (the regions are the same as those used in the "Centered Regions" section).



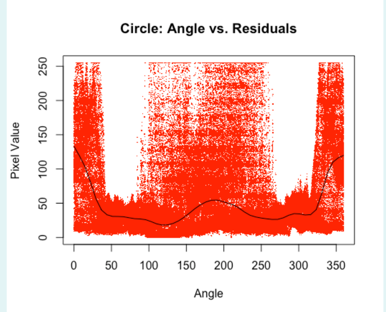
- Concern: What if the bullets in the database are not rotated the same way?
Solution: Rotate the images.

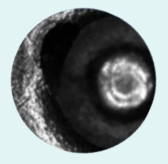
Rotated Images

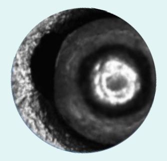
- Rotate the images so that the center of the firing pin impression has an angle value θ = 0 degrees.

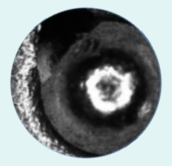


Nonparametric regression model for circle using loess():




RSS for original image = **605,283,770**

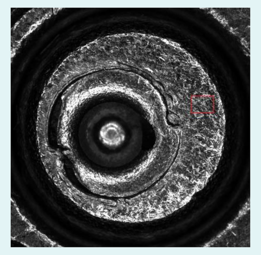
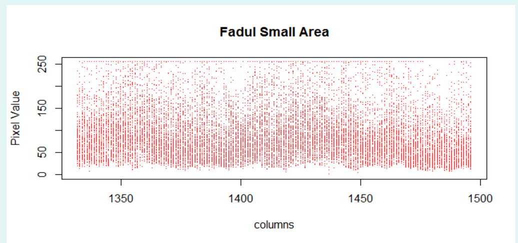

RSS for image of bullet shot from the same slide = **1.151×(original RSS)**


RSS for image of bullet shot from different slide = **1.472×(original RSS)**

Comparing Roughness In Breechface

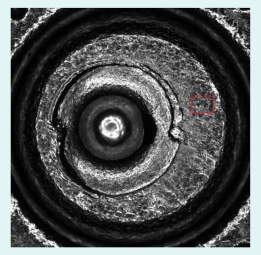
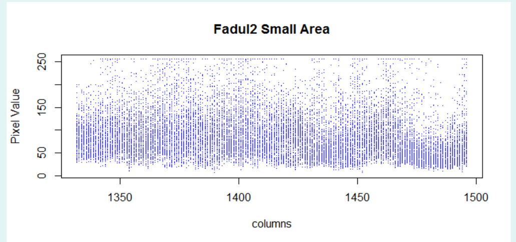
This step consists of studying the roughness of the three images. We selected a small area inside the breechface to study roughness patterns.

Original Image:

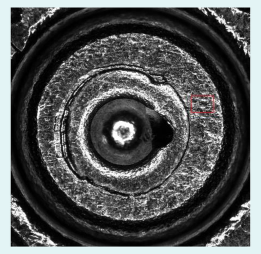
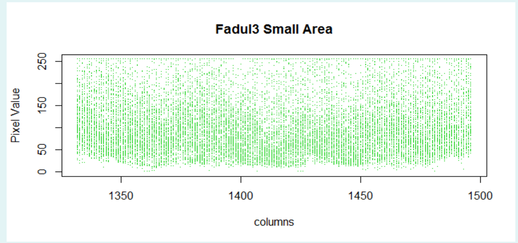
Pixel average: 87.96
Autocorrelation: 0.882

Image from same slide:

Pixel average: 85.00
Autocorrelation: 0.851

Image from a different slide:

Pixel average: 107.87
Autocorrelation: 0.845

For Loop

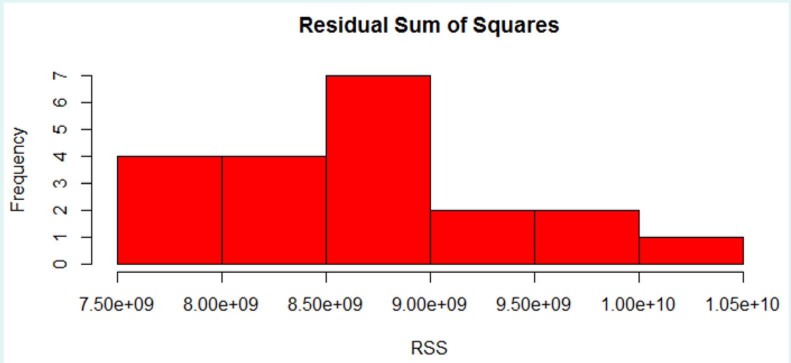
- Created to compute RSS (Residual Sum of Squares) for multiple images at a time using one code.

Finished For Loop

```
nn= 20
for(ii in 1:nn){
  Fadul<- importandcropphoto(Filenames[ii])
  Fadul_dtf<- dataframe(Fadul)
  Fadul_dtf<- regions(Fadul_dtf)
  RSSmod[ii]<- prediction(Fadul_dtf)
}
```

Function Meanings

- importandcropphoto() = crops photo and converts file to matrix
- dataframe() = changes matrix to a dataframe
- regions() = creates the circle and donut regions
- prediction() = predicts the Residual Sum of Squares



As we can see in the histogram the distribution of these RSS values is slightly skewed to the right, with fifteen of their values below 9 billion and just five over it.

Compared to the Original Image, when running the For Loop, the unknown images C and H came out to have the closest RSS values.

Performance Comments

- No two casings will have the same exact characteristics, so the RSS will never be the same but close in relation.
- Factors like the brightness, location of individual markings and picture quality play a role in pixel value.

New Ideas:

- Rotate every image to be in the same position.
- Continue to look at smoothness and roughness of the breechface.
- Create more donuts in the breechface.

For Further Information

Thomas Fadul Study
http://www.nist.gov/forensics/ballisticsdb/fadul-study.cfm

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