LiDAR-Based Assessment of Roadside Slope Hazards: Enhancing Safety on Rural Roads

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Abstract

A significant proportion of motor vehicle fatalities occur across the United States, especially among road users in rural areas. This study focuses on identifying potentially hazardous roadside slopes along secondary roads in rural regions, aiming to mitigate risks and enhance transportation infrastructure safety. Utilizing existing topographical survey data from the North Carolina Department of Transportation (NCDOT), aerial Light Detection and Ranging (LiDAR) scans were used to develop a methodology for analyzing roadside slopes. Three-dimensional LiDAR point clouds were rasterized into two-dimensional, top-down images of a roadway scene. The image was processed using variable reconstruction techniques and the roadway was segmented by multiple edge detection methods. Then, slope-fitting was tested for LiDAR points adjacent to road segments, using the R-squared value as a metric, with variable length and width to determine the optimal dimensions. The optimal segment found was 3 edge pixels (2.4 - 3.4 ft) long with lateral measurement areas extending 7 pixels (5.6 ft) from either road edge. We were able to identify roadside slopes adjacent to 92.0588% of roadway edge pixels.

Background and Objective

- 68% of US road miles (> 6 million miles) are in rural areas[1].
- 40% of motor vehicle traffic fatalities in 2021 occurred in rural areas, with a 5% increase from the previous year[2].
- Roadsides and shoulders are the most common location for single-vehicle crashes causing death or injury[2].
  - 50.2 % of crashes resulting in fatality
  - 43.5% of crashes resulting in injury
- **The objective of this study is to identify stretches of roadway with potentially hazardous side slopes on rural, secondary roads.**

LiDAR Data

- Light Detecting and Ranging (LiDAR) is a remote sensing technique that uses pulsed light to measure distances[3].
- The aerial LiDAR data are extracted as a three-dimensional point cloud consisting of (x, y, z) coordinates.
- Federal and statewide initiatives have emerged to extend LiDAR coverage across the entire country, including the North Carolina Department of Transportation.

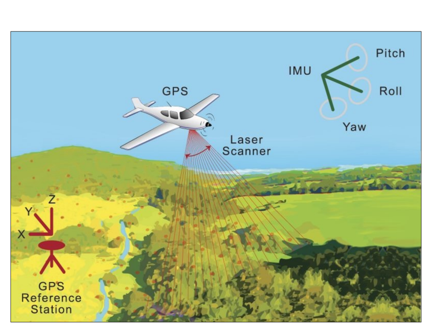


Figure 1. Depiction of how aerial LiDAR collects data from lasers to produce point cloud data[4].

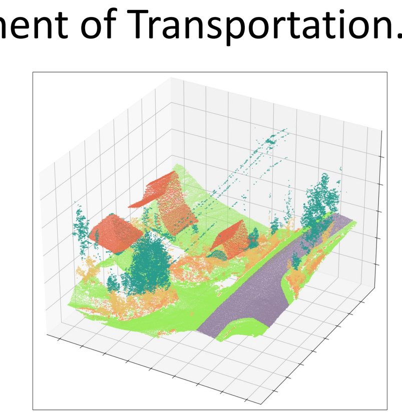


Figure 2. Aerial LiDAR data extracted and plotted as 3D point cloud.

Development Scene

- Buncombe County, NC
- 409.6 ft x 409.6 ft (0.8 ft/pixel)
- 1,057,670 LiDAR points

<u>LiDAR Rasterization</u>

- Pixel classified from LiDAR class frequencies
- Road classification assigned if any road points present
- Empty pixels filled with nearest-neighbor interpolation

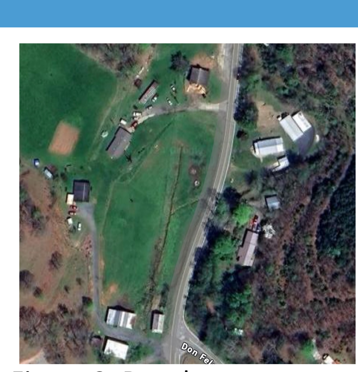


Figure 3. Development scene from Google Maps.

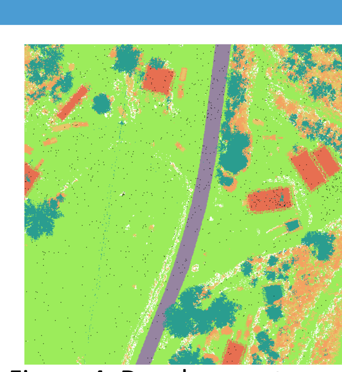


Figure 4. Development scene from LiDAR point clouds.

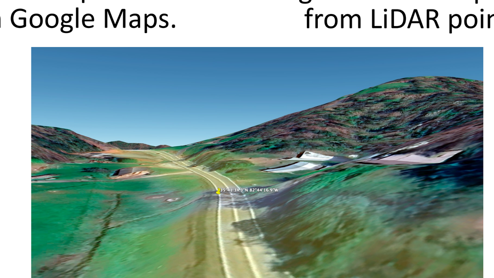


Figure 5. Overhead angle showing elevation (Google Earth)

Methods

1. Finding Road Edges

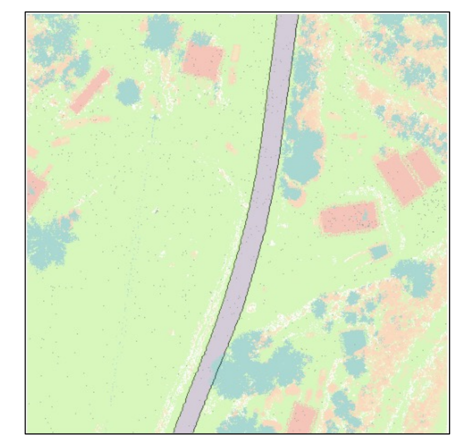


Figure 6. Results of Sobel edge detection.

- Three approaches were tested for road edge detection: Canny edge detection, Sobel Edge Detection, and Contours.
  - Contours contain endcaps at the end of the roads, making it less effective.
  - Sobel and Canny results are identical +/- 1 pixel.

2. Calculating Midline

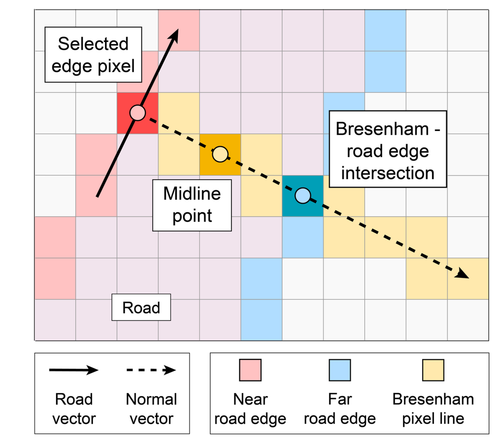


Figure 8. Explanation of Bresenham's line algorithm.

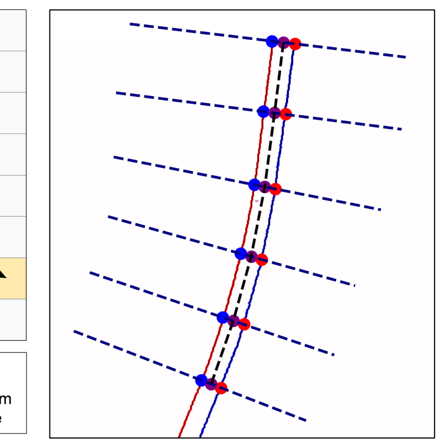


Figure 7. Results of spline calculation method.

- Points sampled on shorter edge and slope calculated between points.
- Bresenham's line algorithm used to determine intersection of normal line with longer edge.
- Midpoint of segment calculated and connected to find spline.

3. Determining Shoulder Regions

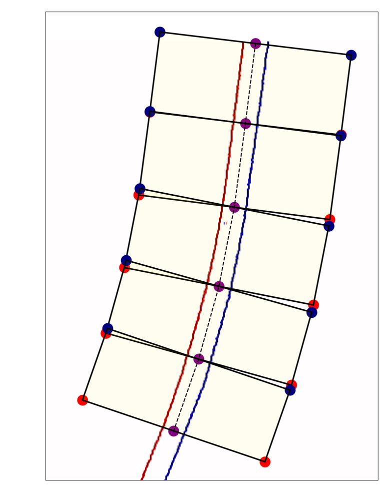


Figure 9. Results of shoulder region calculation.

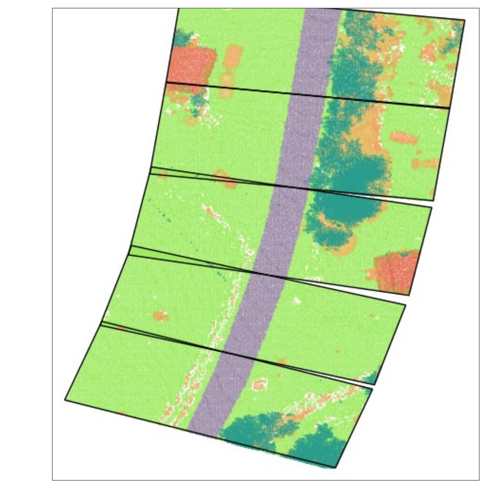


Figure 10. LiDAR ground points filtered within the shoulder regions.

- Rectangular shoulder areas formed using normal to a desired distance from edge.
- Variables to optimize:
  - Length of road segment
  - Distance from edge

4. Finding Optimal Region

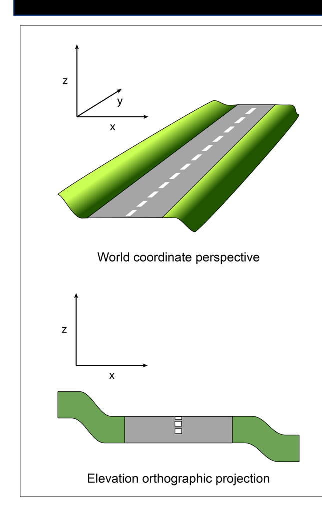


Figure 11. Depiction of orthographic projection axes change.

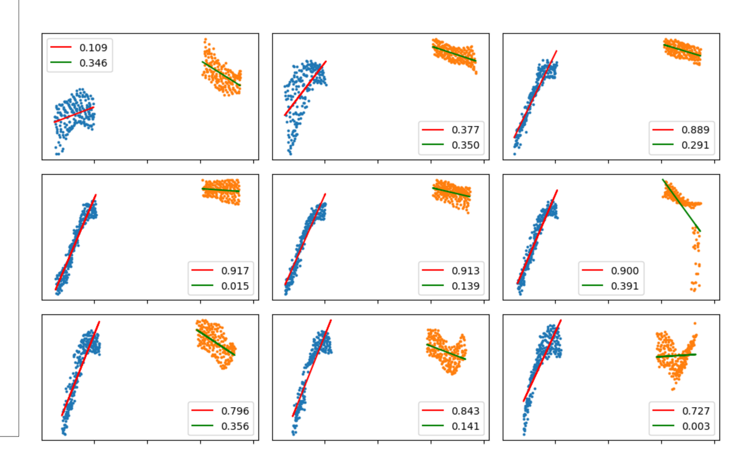


Figure 12. R-Squared values calculated for each shoulder region along the road.

- Orthographic projection was implemented to change axes.
  - The x-axis is seen from the center in feet, and the new y-axis is the elevation in feet, or the original z-axis.
- Tested every combination from 3 to 30 pixels in either dimension
- R-squared used as a metric for fit accuracy
- Optimal bounding region:
  - 3 pixels (2.4 - 3.4 ft) in length
  - 7 pixels in width (5.6 ft)

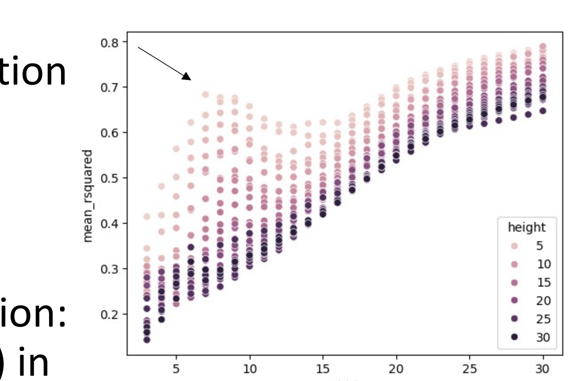
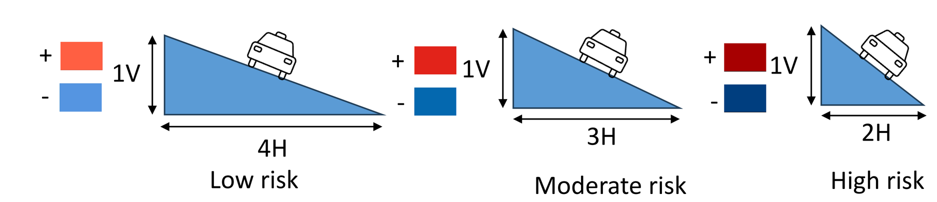


Figure 13. Graph of shoulder region widths against the r-squared values to determine the optimal size.

5. Fitting Slopes

- The slopes were divided into established hazard categories vertical (V) to horizontal (H) grade ratios[5]



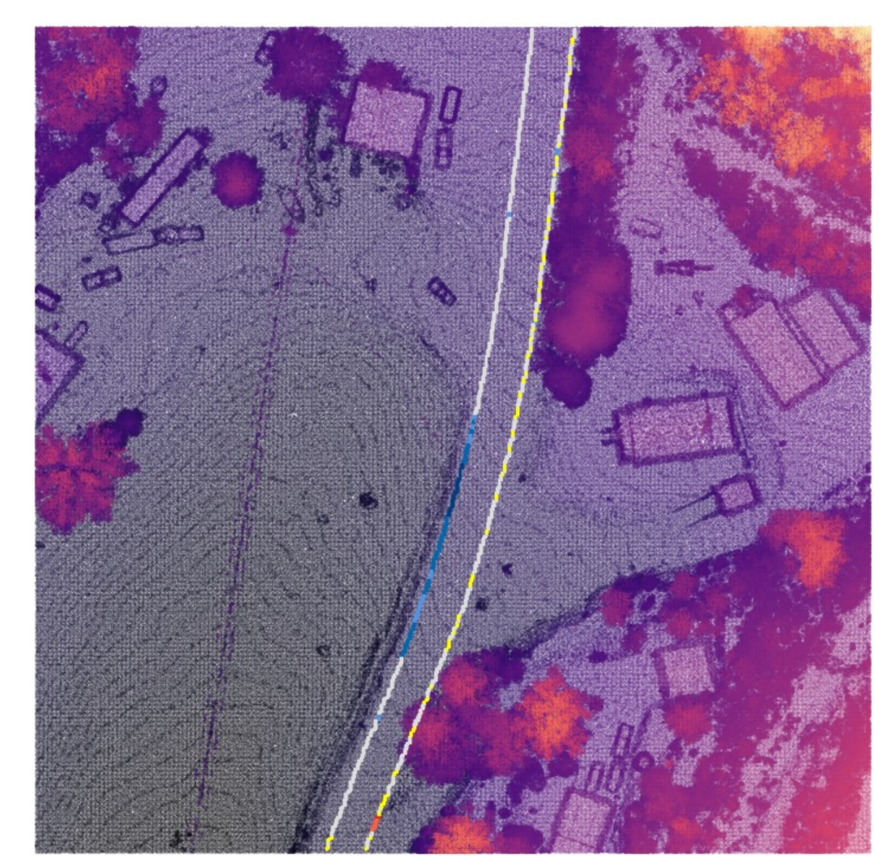
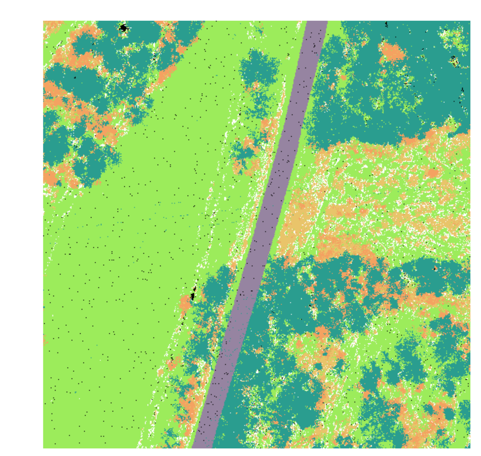
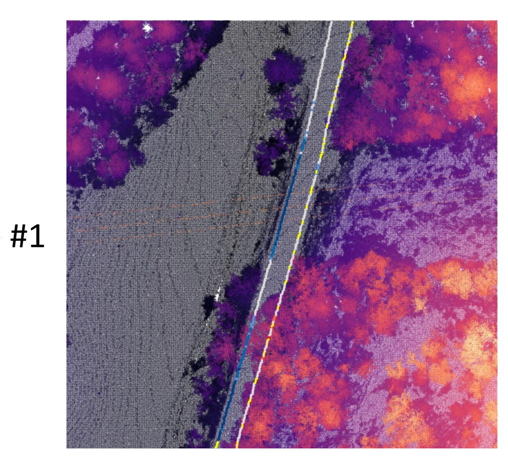


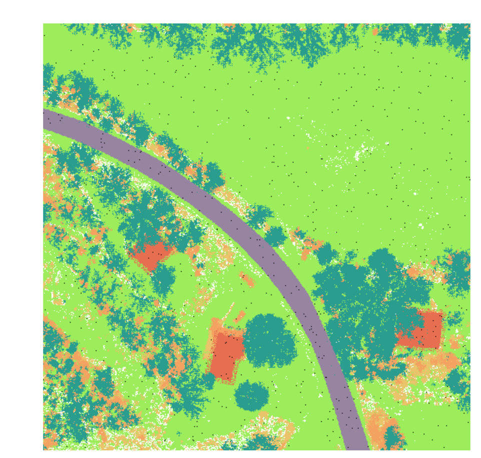
Figure 14. Slope grades are plotted, highlighting areas with hazardous slopes.

6. Other Tests

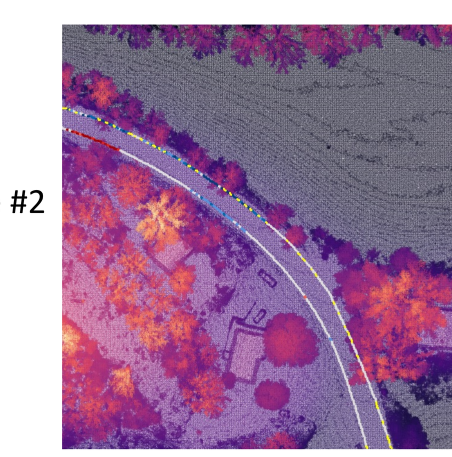


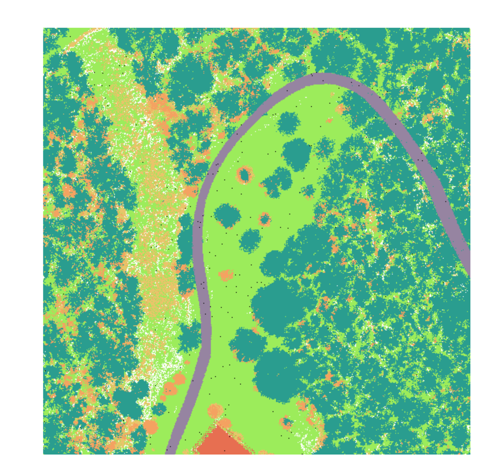
Scene #1



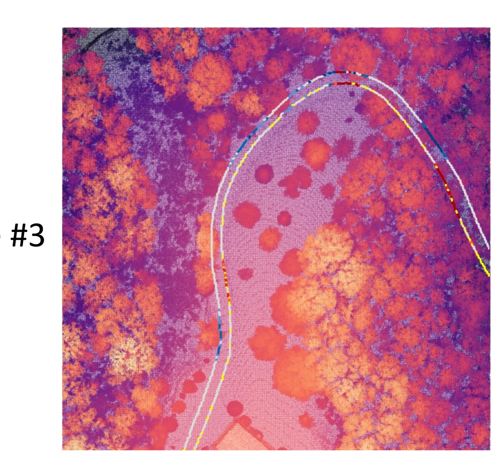


Scene #2





Scene #3



Conclusion

- We used aerial LiDAR data to determine shoulder slopes for roads in rural areas. This method has potential to identify areas of concern for the NCDOT without additional resources.
- Limitations:
  - Roads with complex shapes (e.g. roundabouts)
  - Density of foliage in immediate proximity to the road can limit the data available for fitting.
  - Dependent on the availability of LiDAR classification data
- Future goals are to extend the application of this method to scenes with different road geometries (like intersections) and cover as much of the state as possible.

References

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