Collecting Road Inventory using LIDAR surface models

Mr. Sitansu B Pattnaik*, Dr. Shauna Hallmark, Dr. Reginald Souleyrette

Center for Transportation Research and Education, Iowa State University
ISU Research Park, 2901 S. Loop Drive, Suite 3100, Ames, Iowa 50010-8632
Email: pattnaik@iastate.edu*, shallmar@iastate.edu and reg@iastate.edu
Tel: +1(515)-294-7188*, +1(515)-294-5249, +1(515)-294-0467
Fax: +1(515)-294-0467

Introduction

Grade and cross-slope of the roadway influence the operational characteristics of vehicles. Heavy vehicles operation is mainly impacted by the roadway grade, which affects their stopping and passing sight distance. Emission characteristics are also influenced by the roadway grade. Cross-slope of the road segments influences the drainage across the road pavement and can affect vehicle movement along the roads.

Presently available road inventory databases do not accurately measure the existing grade for it to be useful in analyzing the effect on the issues described above. The grade and cross-slope values are usually grouped into intervals for ease of storage and analysis. The grade and cross-slope of the roadway can change with the use of the facility mainly due to settling of the pavement and structural failures. The grade and cross-slope in a facility could also be different from the design specifications and hence to assess the functionality and the safety of a facility the current grade and cross-slope are important elements of analysis.

Cross slope is often a compromise between the need for a relatively steep cross slope for drainage and a relatively flat cross slope for driver comfort. [1] In Iowa, two-lane highways usually have a cross slope of 2.0%. The outside lanes in multi-lane facilities usually have a cross slope of 3.0%. The cross-slope is varied to allow the water to drain across the pavement. The grade along the roadway is necessary to avoid stagnation of water hence a minimum grade of 0.4 % is required along road sections.

Surface models created from Light Detection and Ranging (LIDAR) can be used to determine the artifacts defining the roadway condition which include the cross-slope, grade and surface roughness. This form of remote sensing can be crucial in rapid data collection and analysis for developing a timely maintenance and inventorying procedure.

The objective of this research is to estimate the roadway characteristics from LIDAR data by developing regression models relating the elevation changes with the grade and the cross-slope of the road segment. Presently, the major concern is to correctly identify the points defining the pavement surface from the point cloud for accurate analysis.

Use of LIDAR data

Road inventorying is a difficult and prolonged process requiring on-site presence. The task of management of these widely spread networks becomes even more challenging due to the weather conditions, which make it difficult for on-site measurements. On-site surveys are time consuming and are a safety risk, as data collectors have to be very close to the vehicles using the facility. Surface models created from LIDAR data are useful in visualizing the entire study area and can potentially minimize ground survey for road inventorying.

Data Description:

LIDAR data and 12- inch resolution orthophotos were collected for the Iowa highway 1 corridor in October 2001. In addition to the LIDAR dataset and 12-inch orthophotos, a set of 6-inch resolution orthophotos was available with the DOT. A commercial vendor for the project collected data. The density of LIDAR points in the dataset was 1 every 27 square feet. The vendor also provided the gridded DEM of the area with 5 feet postings.

A GIS street database was also available from the Office of Transportation Data, Division of Planning and Programming at the Iowa DOT. GIMS dataset contains roadway characteristics for all public roadways in the state of Iowa, such as lane width, grade, traffic volume, surface and shoulder type (CTRE final report, May 2001).

Methodology:

Ten test segments were selected along the Iowa 1 corridor as shown in figure 1. Seven straight segments were selected which avoided horizontal or vertical curves. Two segments were chosen along locations with a vertical and horizontal curve and one segment was chosen along a vertical curve. Figure 2 shows the location of the road segments selected for the analysis.

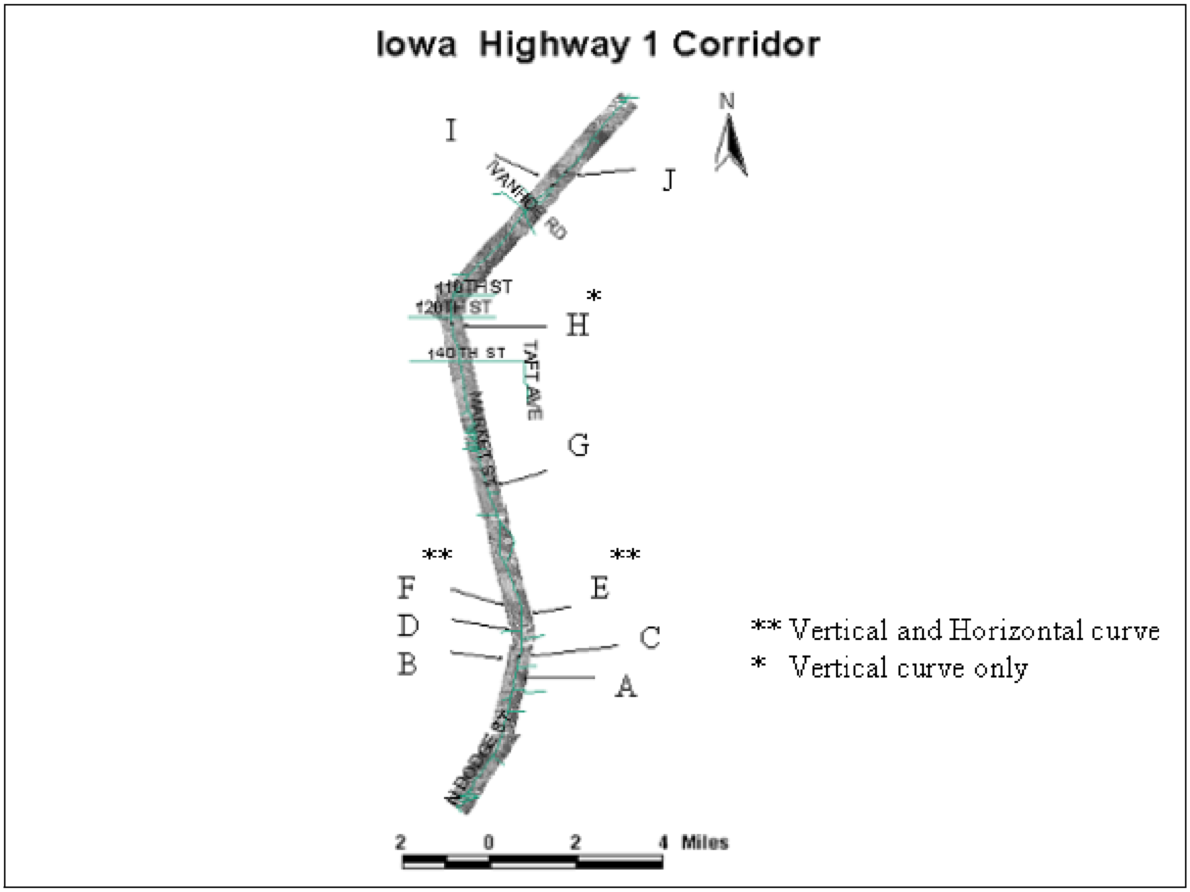

FIGURE 1 Location of the test segments along Iowa Highway 1

Least squares regression was used to calculate grade and cross-slope. Using regression analysis, a plane was fit to the dataset in question. It was theorized that grade and cross-slope could be determined by fitting a plane to LIDAR data from roadway sections with constant grade and cross-slope (lane-groups). As a result, each 2-lane roadway segment was defined by two planes delineated by the center of the roadway crown and the edge of pavement. Shoulder sections were evaluated separately, since cross slopes are frequently different than the roadway cross slope. Consequently four sections were analyzed on each roadway segment.

The LIDAR data consisted of a randomly spaced point cloud with average point density of 1 point per 27 square feet. In order to satisfy the minimum number of LIDAR points for assuming a normally distributed dataset for least square regression analysis, each section was 120 feet in length. This length was determined by considering the average density of LIDAR points throughout the corridor and the lane width allowing adequate number of points to be used for regression analysis.

Length = 30 / (Minimum width * density)

The number 30 is the minimum data points required for assuming normal distribution. (Rule of thumb) Longer sections would be preferred as the number of points for regression analysis will increase, but the increased length of the segment may be unsuitable as only monotonously increasing or decreasing sections can be estimated by using linear regression.

Delineation of Road Sections:

The lateral extent of each roadway section boundaries of each roadway section (2 lane sections and 2 shoulder sections for each segment) were necessary to determine which of the LIDAR data points corresponded to a particular section. In order to define lane and shoulder regions, the location of the edge of pavement, centerline, and edge of shoulder was necessary. The four individual sections for each segment included:

- northbound shoulder (NS)
- northbound pavement (NP)
- southbound pavement (SP)
- southbound shoulder (SS)

Roadway boundaries were defined using each of three different datasets including the 6-inch resolution orthophotos, 12-inch resolution orthophotos and a surface model. The surface terrain model was created from the LIDAR data. The point cloud from randomly spaced LIDAR for Iowa Highway 1 corridor, which had an average point density of 1 point per 27 square feet, was used to develop a triangular irregular network (TIN) using the Spatial Analyst module in ArcView 3.2®. The surface model was tested since it is a direct product that would be available with any LIDAR data collection effort. Aerial images are frequently taken in conjunction with LIDAR data collection and can be planned to meet desired resolution requirements for final orthophotos, but add to the cost and require additional processing. Therefore, the ability to use the surface model alone to determine roadway boundaries would be the ideal situation.

Each of the three datasets was used individually to create polygons that defined each region of the roadway segment. The polygons were then used to select the LIDAR points that corresponded to each section by polygon overlay to be used in the regression analysis. Figure 3 illustrates the use of each dataset to create boundary polygons.

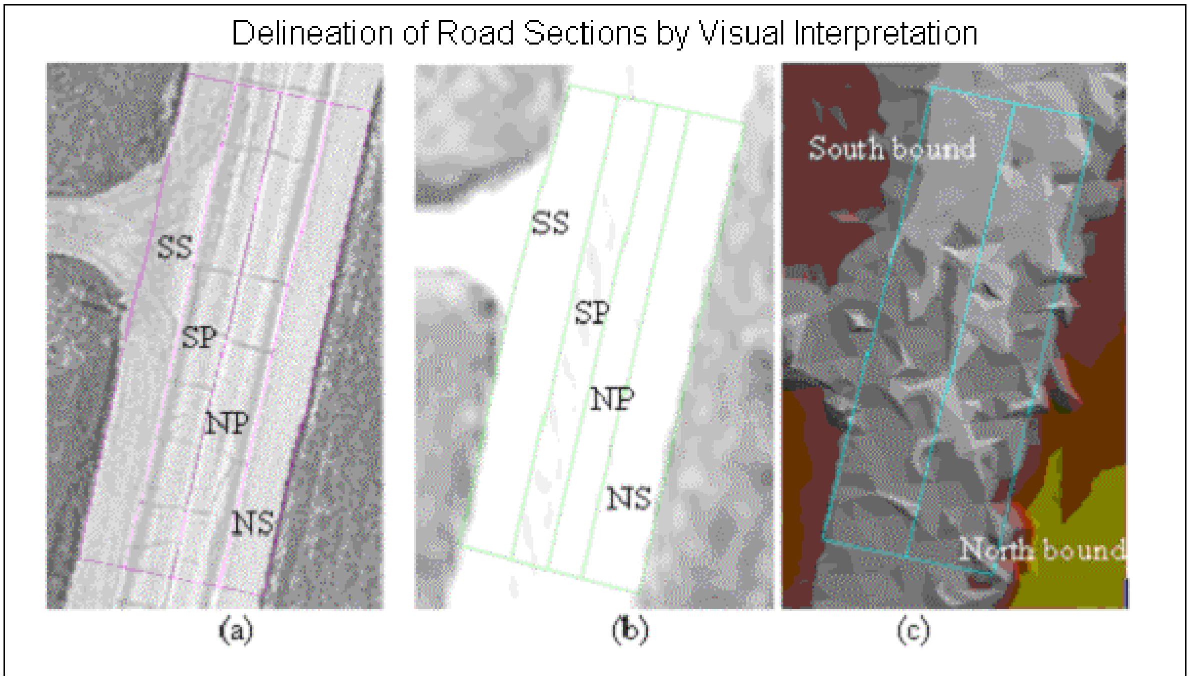

Figure 3: Roadway delineation from: a) 6-inch Orthophoto b) 12-inch Orthophoto c) TIN from LIDAR

With the surface terrain model, the outer edge of the shoulder was the only feature that could be visually determined. As shown in Figure 3(c), only a rough outline representing the entire roadway was available using the TIN. The outer edges of the shoulders were established as the outer edges of the outline. The centerline of the road was determined by finding the midpoint of the area enclosed by the outer edges of the shoulder. Information relating to the lane width and the shoulder width were queried from GIMS database for each of the 10 test segments. Once a centerline was established, pavement edges were determined by adding the lane width for each section from the GIMS. The centerline and pavement edges defined the polygon for the northbound pavement and southbound pavement sections.

In the 12-inch resolution orthophotos, the shoulder edges could be determined for all 10 segments, but the centerline could not be consistently identified in the images. When the centerline was not readily identifiable, it was estimated by finding the midpoint from the delineated outer edge of the shoulders. Each of the four roadway sections was determined for each segment using the 12-inch resolution orthophotos. The edge of pavement, centerline, and edge of shoulder were clearly visible for each of the 10 segments in the 6-inch resolution orthophotos. Consequently for the 6-inch orthophotos, the boundaries of each of the four sections (NS, NP, SP and SS) were defined using the images alone.

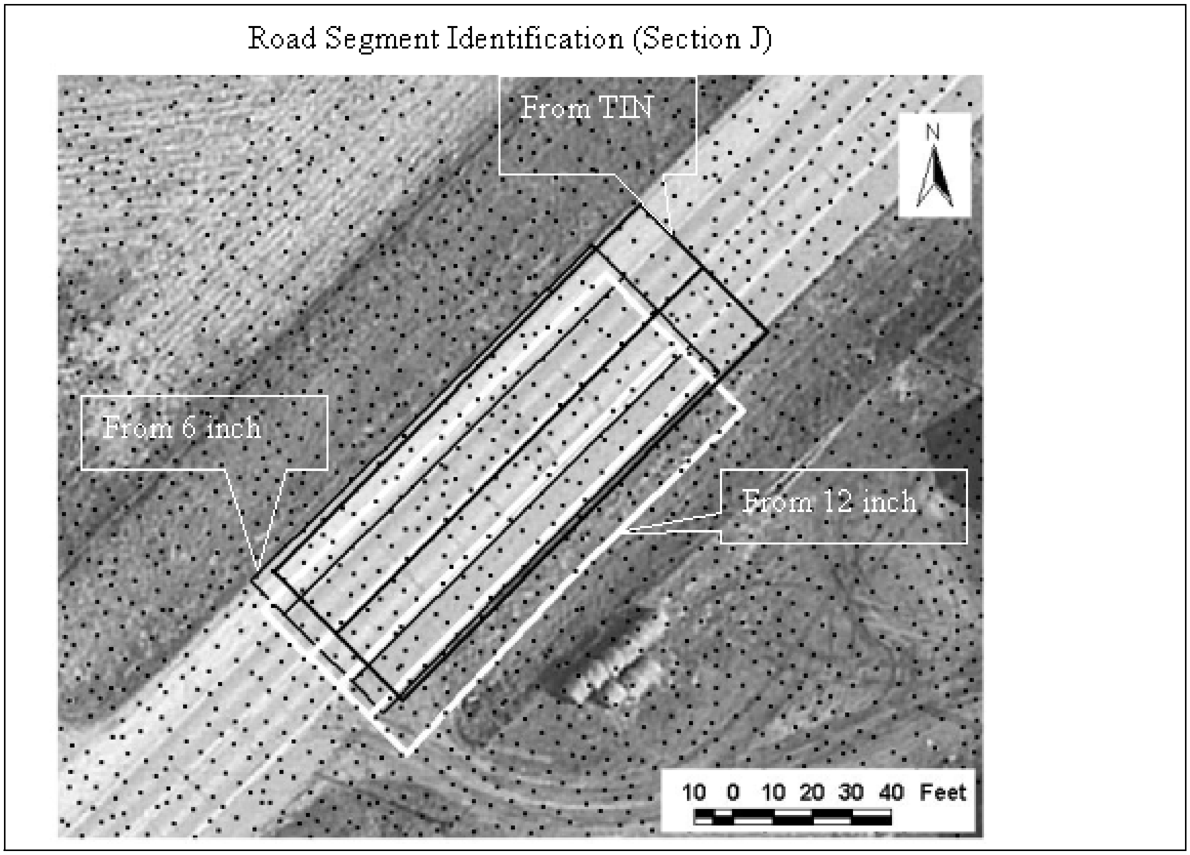

Figure 4 Comparison of road segments derived by using the three baselayers

Utility of Remote Sensing and GIS:
Road inventorying is a difficult and time-consuming process requiring on-site presence. The task of management of these widely spread networks becomes even more challenging due to the weather conditions, which make it difficult for on-site measurements. Data collection by remote sensing has made it possible to

The results from the regression analysis from the LIDAR points identified interactively will be compared to the results by using the GIMS metadata for pavement and shoulder width while using the centerlines derived interactively.

Regression Analysis

There exists a very high correlation between the points in the LIDAR point cloud even though in absolute terms the LIDAR measurements have 15 inches of RMSE. [3] The correlation between the LIDAR points is suitable for determination of cross-slope and grade as these are relative measures of the elevation at different points on the roadway.

The elevation values are regressed with distance from the centerline and the distance along the segment is used for analysis. The co-efficients of these independent variables give the cross-slope and the grade.

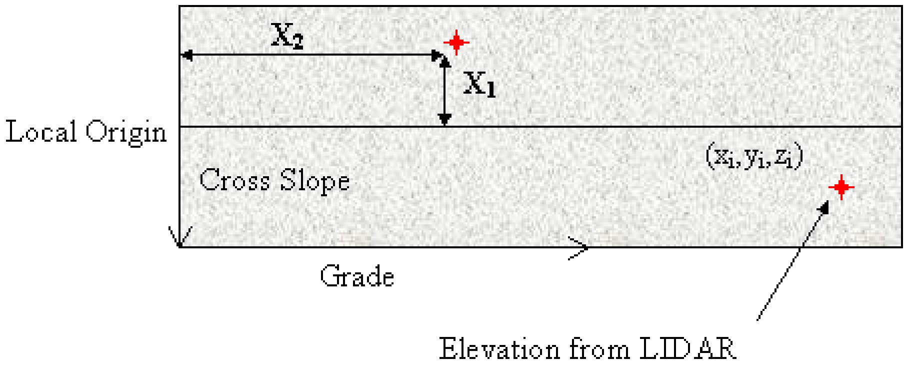

FIGURE 5: REGRESSION ANALYSIS

The form of the regression equation was:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \varepsilon$$

where:

Y = elevation
β_1 = coefficient for cross-slope
X_1 = perpendicular distance from centerline
β_2 = coefficient for grade
X_2 = distance along the roadway

For validation, a slope meter will be used on site to measure the cross-slope and the grade in the road sections analyzed.

Results

The results from regression analysis vary with the points considered for estimation of the cross-slope and grade. Identification of the points defining the pavement and shoulder is crucial for accurate analysis as otherwise the results would be skewed. A cookbook has been prepared for performing the steps for roadway identification and regression analysis.

The residuals for grade and cross-slope estimated using the surface model to create polygons for Segment J are plotted in Fig 6 and 7. As shown, the residuals are within the RMSE value for vertical accuracy of 0.49 feet as denoted by the vendor. This indicates that the relative measurement between points maybe less that the absolute error so that the use of regression analysis is viable.

The goodness of fit of the estimated plane with the LIDAR points is shown in Table 4 for all four roadway and shoulder sections for each segment.

Table 4: Regression results (R^2) For Each Section Calculated Using Surface Model to Define Boundaries(Scenario 2)

	Segment									
Section	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**
Northbound Shoulder	0.454	0.579	0.177	0.923	0.973	0.995	0.479	0.993	0.868	0.853
Northbound Pavement	0.554	0.561	0.27	0.98	0.992	0.993	0.407	0.996	0.898	0.88
Southbound Pavement	0.536	0.642	0.429	0.418	0.997	0.994	0.32	0.997	0.561	0.843
Southbound Shoulder	0.669	0.538	0.772	0.948	0.992	0.992	0.037	0.997	0.664	0.762

Of the 40 observations, 9 are less than 0.5. For only two of the sections (SB shoulder for Segment G and NB Pavement for Segment C) were the results poor enough that they indicate that a plane could not be fit to the data. This could be due to the errors induced while selecting LIDAR points defining the roadway regions or due to abrupt changes in the grade and cross-slope in the road sections or systematic errors in the LIDAR data. However, for the majority of the sections, the R^2 values were greater than 0.8 (20 sections) and 15 of those had an R^2 over 0.9.Therefore for most of the sections, a plane could be fit to the data fairly well.

Issues in Analysis:

Two issues were found to complicate the use of LIDAR to extract grade and cross-slope. First, in order to provide a confident estimate of gradient using regression planes, a minimal number (30) of points are required. However, due to the relative sparseness of LIDAR points falling on paved lanes, it is necessary to use long segments. However, as pavement within long sections can vary in gradient, it is desirable to minimize their length for analysis. A reasonable compromise was reached at 100 feet (30 meters).

Second, partly because spatial accuracy and precision of the LIDAR derived surface model is limited, and partly because we lack breaklines at the edge of the paved surface, data are suspect near the edges and crown of the road. To overcome this problem, we define slightly smaller rectangles of road surface, rectangles for which we have higher confidence in representing actual grade and cross slope measurements (as defined in scenarios 1 and 2 of the following table).

Scope for future work:

- All the sections of the roadway can be estimated by using regression analysis if the centerline is clearly defined.
- Breaklines would be used with the TIN for better identification of the roadway edges. The length of road segment that can be used for analysis and visualization has to be determined for optimal accuracy.
- For visualization, VRML can be used to view the output of the regression analysis.

References:

1. Effects of Roadway Geometrics on Urban Pavement Drainage, Office of Design, Iowa DOT.

2. Eaglescan Documentation for LIDAR data collection.