BACK TO AUTHOR

BACK TO TOPIC

Utilization of LiDAR Technology for Highway Inventory

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ABSTRACT

Collection of roadway inventory data is a basic task for most highway agencies. Maintaining up-to-date information about roadways is essential for design, planning, maintenance, and rehabilitation purposes. For inventory, highway agencies typically rely on field data collection, which is time consuming and subject to limitations such as adverse weather conditions. Recent availability of new and emerging technologies has led to experimentation with these technologies for collection of roadway inventory. This paper is focused on the use of Light Detection And Ranging (LiDAR) technology for collection of roadway inventory. LiDAR uses the same principle as RADAR for collection of information. The LiDAR instrument transmits light beams towards a target and a receiver collects some of the reflected light. The time for the light to travel to the target and back to the receiver is used to determine the distance to the target. Placement of the LiDAR equipment onboard an airplane and directing the light beams at the surface of the Earth allows collection of the Earth's surface profile. The resulting data can be used in obtaining information on certain roadway inventory elements. This paper describes experimentation with LiDAR data collected for Iowa 1 highway, passing through Linn and Johnson Counties, Iowa. Aerial imagery and LiDAR data for the study corridor were merged and analyzed to extract information on highway grade, side slope, and contours as well as stopping and passing sight distances. The results were verified in the field for accuracy by comparing information obtained from LiDAR to the ground truth. These comparisons showed that the information obtained from the LiDAR data closely matched conditions in the field. Overall, this research indicates that where available, LiDAR data can be effectively utilized to obtain certain elements of the roadway inventory. LiDAR is a relatively new and costly source of transportation data. Therefore, additional applications useful to transportation agencies must be developed to justify investment in LiDAR data collection.

Key words: data collection—infrastructure—inventory—lidar—sight distance

INTRODUCTION

All transportation agencies maintain some type of roadway inventory, which is used for a variety of purposes. Maintaining up-to-date information about roadways is essential for design, planning, maintenance, and rehabilitation purposes. Inventory data are collected in different ways depending on the inventory element; the typical methods are field surveying using electronic distance measurement and photogrammetry. Although accurate, these methods are time consuming and labor-intensive. With the availability of new technologies, there is potential for finding more efficient methods of collecting roadway inventory data.

This study focused on evaluating the applicability of Light Detection And Ranging (LiDAR) technology in collection of certain roadway inventory data. LiDAR is a technology that can be used to collect information about a surface by sending and measuring the return time of thousands of light beams per second, which are directed at and then reflected from the surface. Measuring the return time of the light beams allows calculation of distance between the LiDAR instrument and the target. By collecting a great number of reflected light beams, the surface profile of the target can be obtained in the form of a "digital signature." Collection of information on the surface profile of Earth in the form of elevation data is one of several LiDAR applications. The main objective of this study was to utilize LiDAR data to obtain information on certain roadway elements. These elements included: 1) stopping sight distance; 2) passing sight distance; 3) side slope; 4) highway grade; and 5) contours.

A literature review focused on highway inventory, LiDAR technology, and the five inventory elements mentioned above follows this introduction. A section explaining the research methodology and the data used in this research follows the literature review. The next section presents the analysis of the LiDAR data and field validation of the results. The paper concludes with the authors conclusions based on the research results and acknowledgment of research sponsorship.

LITERATURE REVIEW

Highway Inventory

Highway management is a process that deals with several highway-related activities involving planning, design, construction, and operation maintenance (*1*). These activities are associated with maintaining, rehabilitating, and reconstructing/replacing highway assets in an efficient manner. These activities require accurate and up-to-date inventory data on the various roadway elements. Common inventory data include roadway geometry, signs, signals, pavement markings, pavement quality, roadside objects, bridges, and driveways. Roadway inventory data are distinct from other type of data handled by highway agencies in that 1) they are collected on each roadway or a large sample of roadways, rather than being collected for specific projects; 2) they pertain to the roadway and the right-of-way, but not to the surrounding buildings and areas; and 3) they pertain primarily to describing the identity, function, and physical features of the roadway and right-of-way (*2*).

The typical method for collecting and processing many geometric-related inventory data is a labor-intensive. A person drives along the roadway and takes notes regarding the current situation. This person might need to take measurements along the roadside using, for example, a total station to get readings necessary to find the grade or side slopes of the road. The person also checks the safety of the roadway and the availability of safe sight distances. The necessary information and measurements are recorded in a field book and later transferred to the roadway inventory database (*2*). Though most of this information could be available in the original design plans, roadway elements like sight distance might change with time due to construction and vegetation growth. Thus, there is need to update inventory information regularly.

LiDAR TECHNOLOGY

LiDAR technology utilizes the Global Positioning System (GPS), precision inertial navigation systems, laser-range finders, and high speed computing for data collection. LiDAR systems on airborne platforms (e.g., an airplane or helicopter) usually measure the distance between an object the laser beam hits and the airborne platform carrying the system (*3*). Airborne laser mapping instruments are active sensor systems, as opposed to passive imagery such as cameras (*4*). With LIDAR, it is possible to obtain elevation information on large tracts in relatively short time; elevation data obtained with LiDAR can be up to 6-inch accurate. LiDAR system uses the speed of light to determine distance by measuring the time it takes for a light pulse to reflect back from a target to a detector. A laser emitter can send about 5,000 pulses per second, but due to the high speed of light a detector can sense the reflected pulse before the next one is sent (*5*). Following a data collection flight, the data-tapes are transferred to a ground-based computer where a display of recorded data is immediately available (*6*). LiDAR systems produce data that can be used in digital elevation models (DEM). The high density of elevation points provides the possibility to create high-resolution DEM models (*5*). LiDAR has been effectively used in several applications including highway location and design (*7*) and highway safety (*8*).

HIGHWAY ELEMENTS

Sight Distance

According to the AASHTO's "A policy on geometric design of highways and streets" (*9*) (hereafter referred to as the Green Book), sight distance is "the length of the roadway ahead that is visible to the driver. The available sight distance on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path." Adequate sight distance is needed so drivers can avoid striking objects, or when using the opposing lane to pass a slower moving vehicle, and can comfortably merge with cross traffic at an intersection (*10*). Two aspects of sight distance are discussed below: sight distance needed for stopping and the sight distance needed for passing on two-lane undivided highways.

Stopping site distance (SSD) is the distance a vehicle needs to come to a complete stop before hitting an obstruction that a driver sights. SSD should be available for drivers on each lane of the roadway regardless of the type of highway. SSD is the sum of two distances: 1) the distance traversed by the vehicle form the instant the driver sights an object necessitating a stop to the instant brakes are applied, and 2) the distance needed to bring the vehicle to a complete stop after application of the breaks. The computed distances (d) for wet pavements and for various speeds are developed from the following equation:

$$d = 1.47Vt + 1.075\ (V^2/a)$$

where
t = brake reaction time (assumed 2.5 sec)

V = design speed, mph
a = deceleration rate, ft / s^2.

Passing sight distance (PSD) is the distance necessary for a driver on a two-lane highway to see ahead and overtake, pass, and return to the travel lane without interfering with another vehicle. Passing sight distance is considerably longer than stopping sight distance. If passing is to be accomplished safely, the Green Book suggests that the passing driver should be able to see a sufficient distance ahead, clear of traffic, to complete the passing maneuver without cutting off the passed vehicle before meeting an opposing vehicle that appears during the maneuver. When appropriate, the driver can return to the right lane without completing the pass if opposing traffic is too close when the maneuver is only partially completed.

Side Slope

Highway side slope is an important component of the roadway geometry and safety. It's the section of ground that intersects the shoulder and slopes up or down for a certain distance. Side slopes should be designed to ensure roadway stability and to provide a reasonable opportunity for recovery of an out-of-control-vehicle. Providing a flatter slope between the shoulder edge and the ditch bottom, locating the ditch a little farther from the roadway, or even enclosing short sections of drainage facilities will enhance the safety of the roadside, often at a small increase in cost.

Grade

Grading is an important aspect of cross section design. Highway grade differs depending on the terrain and the topography of the ground. The degree of slope affects the appearance, safety and maintainability of the roadside. When designing a highway, designers choose the grade of the road in accordance with the geometric design standards for the type of road (11). The topography of the land traversed has an impact on the grade chosen for that highway. Maximum and minimum grades depend on the design speed of the highway and on the type of terrain.

Contours

Understanding the ground's contour map is a key element to designing highways. A good contouring plan allows the designers to better understand the topography and geometry of the site and help engineers make a better decision on where exactly to locate the route and what difficulties the might be encountered due to rough topography of an area. It also helps in increasing the likelihood of achieving natural looking slopes and drainage facilities (12). During the initial stages of route planning and with the need for enough ground information designers needs to go back and can consult with the existing records of contour maps that are probably the most important source of preliminary information.

RESEARCH METHODOLOGY AND DATA CHARACTERISTICS

Figure 1 presents the methodology adopted in this research. LiDAR data were merged with geocoded aerial imagery in a GIS to obtain a composite database. This composite database was then analyzed to extract pertinent information. The extracted information was compared to "ground truth" for validation.

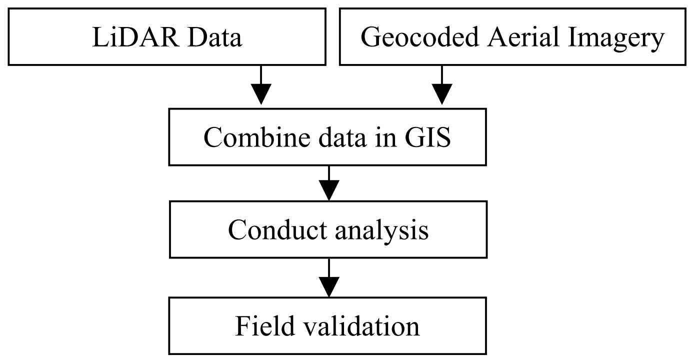

FIGURE 1. Research Methodology

Site Description

The study corridor, passing through Linn and Johnson Counties, Iowa, consisted of the Northern section of IA 1 Solon Bypass (Figure 1). Part of the study corridor is rural in nature; cornfields are viewed on both sides of the road. Some parts have clusters of trees and shrubbery while others have scattered acreages along the route. A small section of the highway is urbanized and passes through the Village of Solon. The corridor receives significant traffic during morning and evening due to its proximity to the University of Iowa.

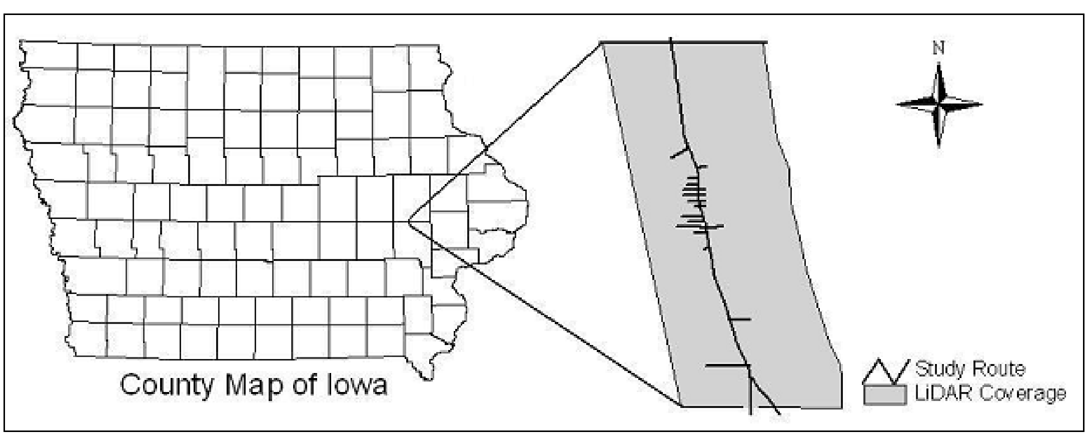

FIGURE 2. Study Corridor

Data

The aerial imagery and LiDAR data for the study corridor were collected on different days. The LiDAR data consisted of both the First-Return and the Last-Return. The former constitutes x, y, z readings for points that LiDAR hits first (e.g. tree canopy), while the latter constitutes last hits of the LiDAR (e.g., returns that penetrate through tree canopy). Aerial images were in Geo-tiff format with a spatial resolution of 2 meters while the LiDAR data were in ASCII comma delimited text file format with an accuracy of 6 inches. The LiDAR point Shapefiles were converted to 3-dimensional Shapefiles by incorporating height information in ArcView and finally to Triangular Irregular Networks (TIN). TIN is a vector data model that uses triangular elements to store surface information. Considerable time was needed for these conversions due to the high density of the LiDAR data.

Data Merging and Compilation

The study area consisted of 12 aerial images and 69 LiDAR bounds. Because all the images combined with all LiDAR bounds would create a large ArcView file that required significant time to retrieve, the aerial images were not joined in one project. Twelve smaller projects were created based on each aerial image. Each project was then overlaid on the appropriate LiDAR bounds.

To superimpose the 69 bounds of LiDAR data correctly on their 12 corresponding aerial images in ArcView, all LiDAR bounds in the text format were converted to Shapefiles and a trial and error procedure was used. The LiDAR bounds were overlaid on the image to see which files corresponded to the opened image.

DATA ANALYSIS AND VALIDATION

The five elements of interest consisted of: 1) stopping sight distance; 2) passing sight distance; 3) side slope; 4) grade; and 5) contour generation. Each element was analyzed separately using the same methodology and dataset. A description of the analysis of each element follows.

Stopping Sight Distance

Given a TIN, ArcView GIS software has a tool to identify any object obstructing the line of sight of an observer. A line of sight is a 3D graphic that is drawn from an observation point to a target on an active TIN in ArcView. The line of sight not only indicates that the target is visible; it also shows which parts of the terrain along its length lie within the observer's field of view (13). With this line of sight tool, it was possible to identify the sections of the route where a driver's line of sight was obstructed. The approximately 15-mile highway stretch under study was divided into 200 ft increments. The stopping sight distance was tested for adequacy at each station along the route. Using the line of sight tool, the line would start at the station and it would be extended along the road for the adequate sight distance needed. The height of the observer's eye and the object were obtained from the Green Book. The height of the driver's eye is estimated to be 3.5 ft and the height of the object to be seen by the driver is 2 ft, equivalent to the tail light height of a passenger car.

Using ArcView, a line of sight between the station and the expected location of the object was drawn. Green line segments indicated visible terrain while red line segments indicated terrain that was not visible. If the target was visible, a blue point (dot) was placed on the line of sight at the obstruction point. Following this method, stopping sight distance was obtained along the whole stretch of IA-1 and the blue points placed on the map would indicate an obstruction. Since the LiDAR data and the aerial images were obtained at different times, it was difficult to identify, after drawing the line of sight, whether the obstacle appearing was an object or it was a vehicle on the road. For this reason all the blue points that appeared on the road were eliminated and the focus was on blue points generated off the road. Figure 4 illustrates the blue points appearing due to an obstruction.

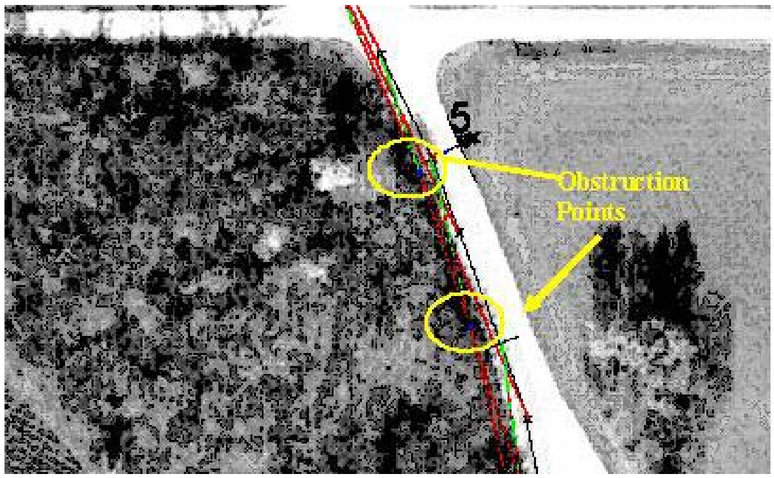

FIGURE 4. Identifying Stopping Sight Distance Obstructions

The analysis of the passing sight distance was similar to the analysis of the stopping sight distance in that the line of sight tool was used. The passing sight distance involved testing the ability of the driver to clearly view a conflicting vehicle on the opposing lane while attempting to overtake a slower vehicle. The line of sight is reciprocal i.e., the driver on the opposing lane should be able to see the vehicle maneuvering to overtake the slower vehicle on the opposite lane. It's very important for both drivers to have a clear view of the opposing lane while going through this process. The passing sight distance is a function of time, acceleration, speed and the difference in speed between the passing vehicle and the passed vehicle. The heights of the observer's eye and the object were obtained from the Green Book For the same reason mentioned in the stopping sight distance analysis, all obstructions appearing on the roadway were eliminated and only the points outside the roadway were taken into consideration.

Side Slope Analysis

In this analysis, side slopes were measured at stations located every 1,000 ft along both sides of the highway. At every station, the elevation of the point of intersection between the outer edge of the shoulder and the ground was found. A horizontal distance of 15 ft was measured from that point and the elevation at that point was measured. Using the identifying tool on the ArcView and with the availability of the TIN files, it was possible to find the elevation on any point on the map.

Grade

LiDAR data are a source of ground elevations and therefore highway grade can be calculated by taking into consideration elevations at different locations along the length of the highway. To calculate grade on IA1, a 500-ft increment was measured along the shoulder of the roadway in each project and the elevation found at both ends of the segment and finally grade calculated by taking the difference between elevations at the two ends of the segment. The segment was considered at the shoulder rather than at the centerline to make field validation easy. Working in the center of the roadway would have involved a high level of risk during the field validation.

Contours

The last highway element of interest was contour generation. Utilizing the Contour tool in ArcView, contour lines at 1.5 ft interval were generated using the available TIN themes.

FIELD VALIDATION AND RESULTS

Approach for Choosing the Field Validation Points

After the analysis was conducted, a set of points was selected for field validation. With the large number of points available, a careful selection of the points was needed. For each inventory element, 10 points were selected for field inspection. The method used to select the points for the side slope, grade, and contours concentrated on choosing points with the highest values in their category to overcome any imprecision caused by the LiDAR inaccuracy that can reach up to 6 inches. The objective was to compare the relative difference between the values obtained by ArcView GIS and between the values obtained in the field rather than checking the exact elevation values. The research team adopted this method due to the difficulty in finding a benchmark with a known elevation along the highway in which all the measurements can refer to.

To validate the results of the highway elements under study, a visit was made to the study area. A team of three persons was equipped with surveying instruments along with a digital camcorder. All five elements were investigated and digital photos were taken to compare and confirm the results obtained from the field. Information about the selected testing points was acquired from the GIS maps and tables were prepared to ensure an easy and quick entry of the collected data.

Sight Distance

Locating the segments of the road that showed an obstruction of the line of sight was the first step in the examination procedure. The station where the line of sight with an obstruction was generated was identified in the field. The team traversed the section starting from the station and driving either the stopping sight or the passing sight distance. The distance was measured using the vehicle's odometer. The digital camcorder was used while traveling the section to help in recording the field conditions and obtaining still images of the obstruction. Two quick on-spot checks were made to verify the passing possibility for drivers traversing that section. The first check was to look for the correct signage in case of a no passing zone. The second check was to examine the road markings and see whether they comply with the results that were obtained earlier. The main purpose was to check whether the obstructions identified through ArcView existed in the field or not. The data obtained from the field confirmed the presence of all the obstructions detected by the line of sight analysis for both stopping and passing sight distances. Results indicated that 100% of the potential and actual obstructions were correctly identified by the line of sight analysis. Table 2 presents the results of the sight distance validation.

Side Slope

Validation of the side slope along the highway was accomplished by using basic surveying. A Total Station was the main instrument used for finding the elevation. The point to be checked was first located using the method mentioned earlier and then the elevation was found at the point where the shoulder intersects the ground and slopes down, the other reading was taken at a distance of 15 ft away. The field results complied with the results obtained from the GIS maps; Table 3 presents the results of the side slope validation.

Grade

Finding the highway grade was done using a Total Station and surveying. The grade was found along the shoulder of the highway and the sections checked in 500 ft segments. Table 3 presents the results of the side slope validation.

TABLE 2. Summary of Results for Sight Distance Analysis.

Section	GIS Results from LiDAR data		Field validation results	
	Sight distance not obstructed	Sight distance obstructed	Sight distance not obstructed	Sight distance obstructed
1		X		X
2		X		X
3		X		X
4		X		X
5		X		X
6		X		X
7		X		X
8		X		X
9		X		X
10		X		X

TABLE 3. Summary of Results for Side Slope Analysis

Point	Difference in elevation	
	Field difference (ft)	LiDAR difference (ft)
1	3.43	3.12
2	4.25	3.60
3	2.6	3.00
4	5.73	3.3
5	5.11	3.43

TABLE 4. Summary of Results for Grade Analysis

Point	Difference in elevation	
	Field difference (ft)	LiDAR difference (ft)
1	25.15	25.61
2	17.77	19.87
3	4.25	4.41

Contours

The main objective was to find the relative difference between the contour elevation on the GIS map and in the field. The points to be checked were placed on the contour map and then located in the field where the elevation was measured with reference to a fixed point chosen in the area and was assumed to be of zero elevation. The difference was then calculated and compared to the LiDAR analysis. Validation results are presented in Table 5.

TABLE 5. Validation of Contours

Point	Difference in elevation	
	Field difference (ft)	LiDAR difference (ft)
1	6.26	6.6
2	-6.26	-6.2
3	2.83	2.60

CONCLUSIONS AND RECOMMENDATIONS

LiDAR technology offers the potential to collect some roadway inventory elements that are difficult to collect by traditional inventory data collection methods. In this study LiDAR data were utilized to obtain specific roadway inventory elements without physically going to the field (except the airplane flight). As an active remote sensing system, LiDAR does not require the extensive use of labor in surveying big tracts of land. LiDAR is a safer way for data collection since data collectors are not exposed to roadway traffic hazards.

Aerial imagery and LiDAR data for the study corridor were collected and analyzed for extraction of highway stopping sight distance, passing sight distance, grade, side slope, and contours. Field validation was undertaken to check the accuracy of the extracted elements. Results from the analysis of the LiDAR data were close to the ground truth. Based on the results, the authors conclude that LiDAR data can be effectively utilized to collect information on stopping sight distance, passing sight distance, grade, sideslope, and contours.

Future recommendations include obtaining LiDAR data and aerial images simultaneously; this can help analysts detect false obstructions such as on-road vehicles and exclude them from analysis. Conducting cost analysis would help agencies understand the real cost of using LiDAR technology. LiDAR is a relatively new and costly source for obtaining transportation data and the cost of collection might not be justified based on the collection of only five inventory elements. Other applications useful to transportation agencies must be developed to off-set the cost of LiDAR data collection.

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