Evaluation of 3-D Laser Scanning for Highway Construction Applications

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A research project has been funded by the Illinois Department of Transportation to evaluate the use of 3-D laser scanning technology for highway construction applications. Their primary interest is to use the technology to quickly and accurately determine pay quantities for earthwork. Once the decision is made to invest in the technology, other applications are expected to be developed. The most obvious is to use laser scans to supplement and, where practical, replace traditional surveying methods, so potential highway applications from the initial reconnaissance survey to the final evaluation of pavement roughness will be assessed. As the ability to rapidly collect and appraise data from a wide area is well suited to real-time monitoring of settlement in the vicinity of pile driving operations, this application will be studied in detail. Computer software will be developed and provided as a deliverable so that construction personnel can easily analyze data to generate the desired results. The two-year project began in September 2007. Intensive data collection began in January 2008. Preliminary results from scans covering one mile of existing terrain on a new road construction project are presented.

Key Words: laser scanning, LIDAR, surveying, highway construction, earthwork quantity

Introduction

The use of laser scanning equipment to produce three-dimensional representations of objects and surfaces is a new technology in land surveying and geospatial information technology. The equipment cost remains high in comparison to electronic total stations; however, the scans quickly produce a collection of data points, or "point clouds," which can be processed to provide three-dimensional models, accurate to within a few millimeters, holding the promise of increasing field productivity and improving the integration of design and construction survey data (Gordon and Akinci, 2005). Laser scanning equipment has been used in specialty surveying applications, such as monitoring widespread ground subsidence, disaster recovery operations, landslides, and, more recently, earthwork construction. The technology has significant potential for monitoring highway and bridge construction activities (Jaselskis et al., 2003 and Jacobs, 2007). Examples include: obtaining accurate pre- and post-construction terrain models to determine earthwork quantities, especially in urban areas or on reconstruction projects; monitoring pavement smoothness and adherence to design grade; and monitoring ground movement near excavations, large embankments, or pile-driving operations. However, it is not clear how data obtained using laser scanning technology will compare to results from traditional surveying methods and whether this will significantly change the calculated quantities.

Research is needed to determine whether laser scanning technology can be cost-effectively implemented by Departments of Transportation (DOTs) for monitoring highway construction activities. A research project has been funded by the Illinois Department of Transportation to field test and verify the comparability of laser scans with currently specified construction measurement and quantity determination methodology. Several bridge and highway projects

have been identified to examine ways to integrate design drawings and other geospatial project data with construction measurements and recommend procedures to implement the technology in specific construction applications. Southern Illinois University Edwardsville (SIUE) recently obtained a Trimble GS 200 scanner with 360º scanning at 200m range, real-time video acquisition with 5.5X zoom, scanning speed of up to 5,000 points per second, and efficient data-editing and post-processing software. SIUE will coordinate with the IDOT District Chief of Surveys to evaluate traditional equipment and methodology in comparison with the study technology and methods.

The objective of the research project is to determine cost-effective means to implement laser scanning technology in the construction phase of IDOT projects. The primary goal is to study the use of a laser scanner for evaluating pay quantities for earthwork operations (Objective 1). This will require comparisons between laser scanning and conventional surveying data to evaluate the accuracy (Objective 1a) and to develop procedures to optimize the use of the scanner (Objective 1b); that is, to develop data with the required level of accuracy in the smallest number of crew hours. Scans will be performed on representative sections of road construction projects at all stages of the construction from design to completion. Several different projects will be studied in order to completely evaluate the technology during the period of the research contract. Recommendations for changes to the IDOT Standard Specifications for Road and Bridge Construction will be developed (Objective 1c).

A second objective is to evaluate the use of the laser scanner for real-time monitoring of settlement during pile driving operations (Objective 2). A scanner set up at a stable location can survey the job site periodically and plot changes in elevation. Procedures for employing the technology to provide sufficient accuracy and precision at intervals that will permit timely corrective action must be developed and evaluated.

The data provided by the laser scanner will have other applications in road construction and design. In the course of the research, scan results will be evaluated to determine the feasibility of using a scanner to provide initial survey data for design, for evaluating gravel and pavement thickness, for assessing pavement roughness (Peterson, 2007), and for surveying damaged bridges (Objective 3). Preliminary results with recommendations for further research will be included in the final report.

Research Approach

Six tasks have been identified to achieve the project objectives. These will be completed during a two year period. Two new road construction projects will be under construction in the area near SIUE during this time. One urban reconstruction project has been selected, and several projects requiring pile driving under varying soil conditions will be available for the research.

Evaluate / Analyze / Model Proposed Projects

The research team will evaluate design documentation for selected projects to develop a plan for performing the required scans. Three dimensional terrain data will be analyzed to develop a plan to scan representative sections, roughly one mile long, of each project to ensure accurate

coverage of the affected areas with the least number of scanner setups. Planning will include the incorporation of existing survey control points and the placement of additional points to be able to register overlapping scans and control the accuracy of the scans.

Develop Planning Software

A computer program, ScanPlan, is under development using Visual Basic 2005 to aid in the planning of laser scanning operations for road construction. The program will import 3D files of existing terrain from various popular CAD programs and Triangulated Irregular Network (TIN) files. Then, given the required accuracy, the range of the laser scanner, the instrument height and the limits of the vertical angles, the software will highlight all regions that are in the line of sight of the scanner from a proposed location. The planner can add stations until the entire project area is covered. After adding the locations of established control points, the software will identify scanner positions that cannot be adequately located to allow the planner to add control points to set in the field. The software will be designed to account for scanners with different capabilities; for example, some scanners can be located accurately over a known point while others require three or more known points for location. The software developed and tested during the course of this project will ensure efficient use of the scanner on the construction site. The software will be included as a deliverable on the project.

Develop Volume Calculation Software

Data from laser scanners can be output in various standard formats. These provide the X, Y and Z coordinates of all points relative to the scanner. Some scanners provide gray scale intensity values while those equipped with cameras list the red/green/blue (RGB) values of color at each point. Points from overlapping scans are "registered" given the location of known points in the scan. The first project objective is to determine the quantity of earthwork. This can be calculated by comparing scans performed at the beginning and end of the project or at intermediate phases. Software will be developed and tested to read point cloud data from any scanner along with the coordinates of known points in the scans and calculate volumes between two scans taken at different times in the project. This software will be used to complete the research project and provided as a deliverable so that DOT personnel can evaluate earthwork quantities without the need to purchase multiple, expensive licenses for general-purpose commercial software that is difficult to learn and to maintain proficiency.

Scan Projects

The research team will coordinate with IDOT and construction company personnel to scan the selected projects at critical times. A representative section of each project, up to one mile long, will be identified for study. A detailed scan will be completed of at least one project at each of these six phases: reconnaissance survey, design survey after light clearing, after clearing and grubbing, after final grading, after base course, and after pavement. The timing of the research project relative to the design/construction schedule will determine which scans are performed on which projects. Targets will be scanned on all control points along the route, and additional targets will be installed based on the planning conducted using the ScanPlan software. In

addition to the project control points, a more detailed array of points will be located using conventional surveying methods to verify the accuracy of the scans along the route.

Data from these scans will be thoroughly evaluated to determine and document the accuracy for determining earthwork volume, layer thickness and pavement roughness. The time required to complete the scans will also be evaluated to document productivity. Finally, methods to convert final scans to as-built models will be studied.

Evaluate Feasibility for Design

Scans conducted along a proposed route for new road construction before clearing and grubbing will assess the effect of natural vegetation on the usefulness of laser scanning data for design. This data will be compared with the results of subsequent scans after removal of grass and small trees and again after clearing and grubbing at the beginning of construction. We will evaluate the ability of traditional design software to import extensive point cloud data from a laser scanner and use the data for design operations.

Study Settlement Monitoring During Construction

Two construction projects will be monitored during pile driving operations to evaluate the ability of the laser scanner to monitor settlement. The scanner will be set up in a stable location, and scans will be conducted at regular intervals. The results will be immediately processed to display elevation changes between scans. These results will be further evaluated to determine the accuracy and precision of the data and its usefulness in identifying settlement problems in real time that require corrective action.

Anticipated Results

The project deliverables include reports documenting the results of the research and software to enable DOT personnel to utilize the technology. The final report will include chapters on the following key topics: 1) Verification documentation 2) Process design 3) Proposed revisions to specification 4) Settlement monitoring capability and 5) Feasibility for design. Two computer programs will be developed using Visual Basic 2005 and provided along with user instructions with the final report: 1) ScanPlan will import 3D terrain data in a format acceptable to IDOT and allow the user to graphically input control point locations and scanner locations to develop a plan to adequately cover the route with laser scans 2) CalcVol will import point clouds, register them given the coordinates of known points in the scans, and calculate and display the volumes of cut and fill between the “before” and “after” terrain surfaces. The sponsoring DOT will be given unrestricted license to use the software.

Preliminary Results

Extensive laser scanning was conducted on a one-mile section of the Governors Parkway extension currently under construction in Madison County, Illinois. The scanning was completed in January 2008. The objective was to document the terrain profile before excavation. Tree clearing had been completed prior to scanning. A second set of scans will be generated upon completion of the excavation in order to determine the actual earthwork quantities.

The scanned region was relatively flat with one significant ditch requiring about 20 feet of fill. It includes a proposed intersection between the new three-lane road and the extension of an existing two-lane road. The region around the intersection will also require significant earthwork.

A Visual Basic computer program, ScanPlan, was developed to plan scanner locations in order to ensure adequate coverage of the construction zone with the fewest number of scans. A TIN file was available for the project area to provide data on the existing terrain. The ScanPlan software shows a plan view of the terrain and plots the coverage area for a scan at a location designated by the mouse. The mouse is clicked to save the selected locations. A print out is provided for the scanning team with the station and offset of each scan. Figure 1 shows the plan for the east half of the Governors Parkway project. Note that the red border shows the limits for which topographic data was available not construction limits. Scan locations are numbered, and the covered area is color-coded. Small white areas indicate regions that may be missed in the scanning. These results are based on a contour map constructed from aerial photos with vegetation in place, so they provide a preliminary plan but the actual data must still be evaluated to ensure complete coverage. Small circles show the location of existing control points.

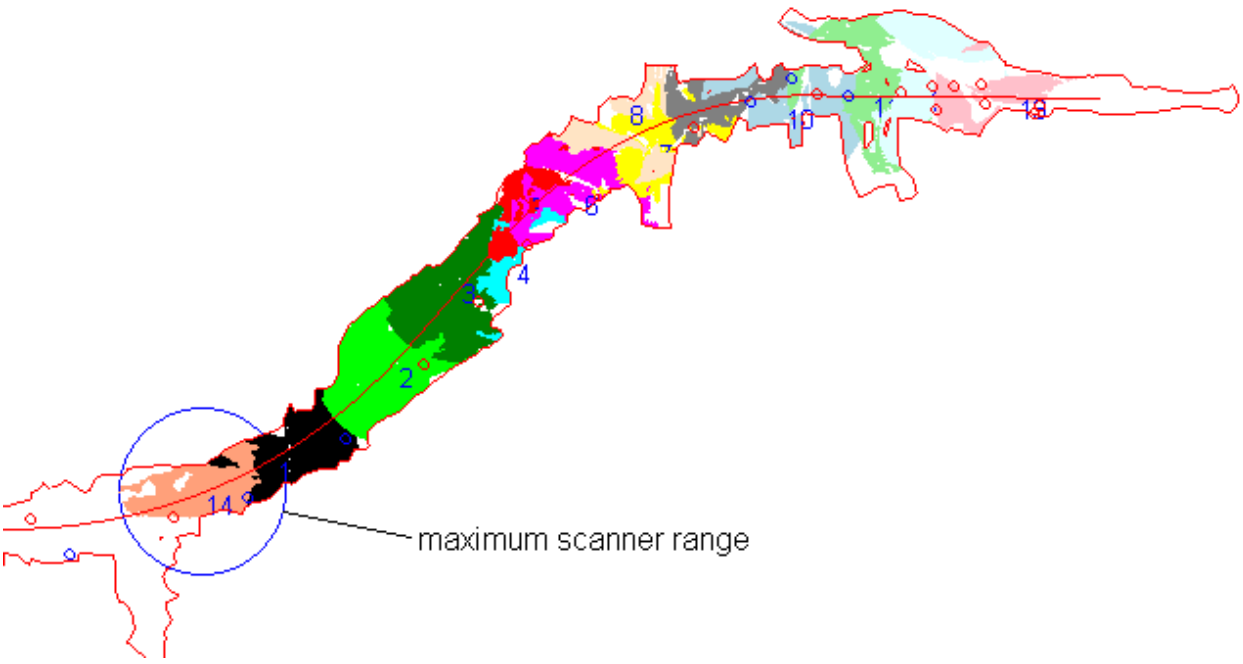

Figure 1. ScanPlan results for Governors Parkway

Laser scans were completed over a one-mile region near the center of the project. Planned scans were conducted first. After evaluating the data, three more required scans were identified and completed in order to adequately cover the region. The ScanPlan software will be updated based on experience gained from this exercise. Figure 2 shows the points clouds from the scans. Figure 3 is a zoomed view showing the actual points in overlapping scans.

We are currently evaluating data and refining our procedures for future scanning. The surveyor for the project provided their point data that will be used to create 50-foot sections to determine pay quantities using the conventional average end area method. This raw data will be compared to the laser scanning data as well as the calculated earthwork quantities.

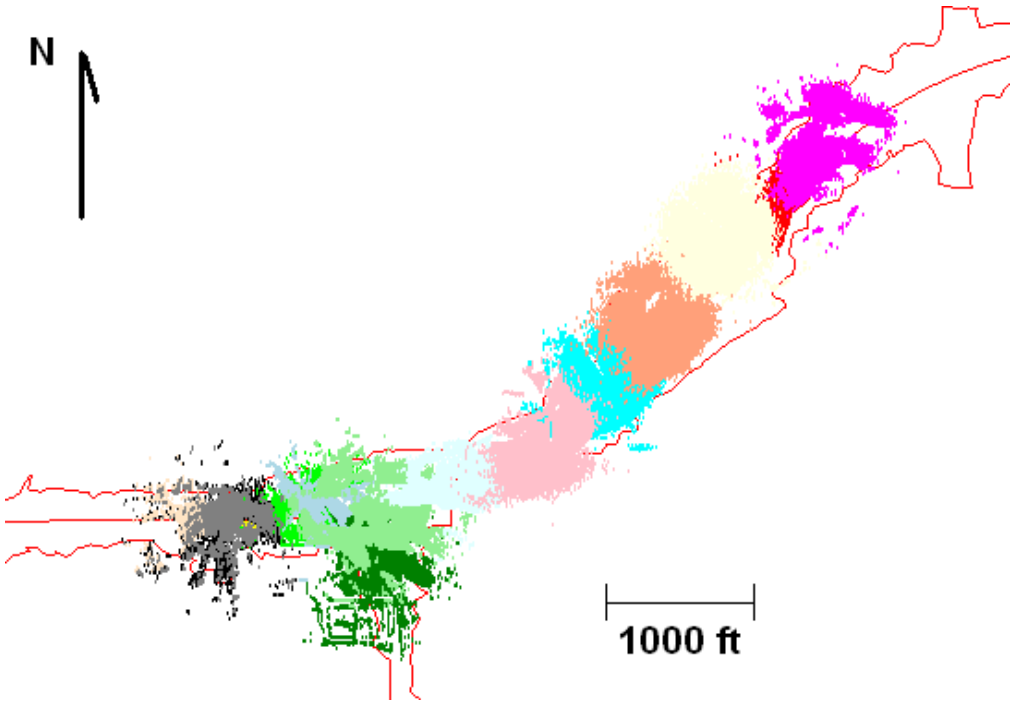

Figure 2. Scan coverage

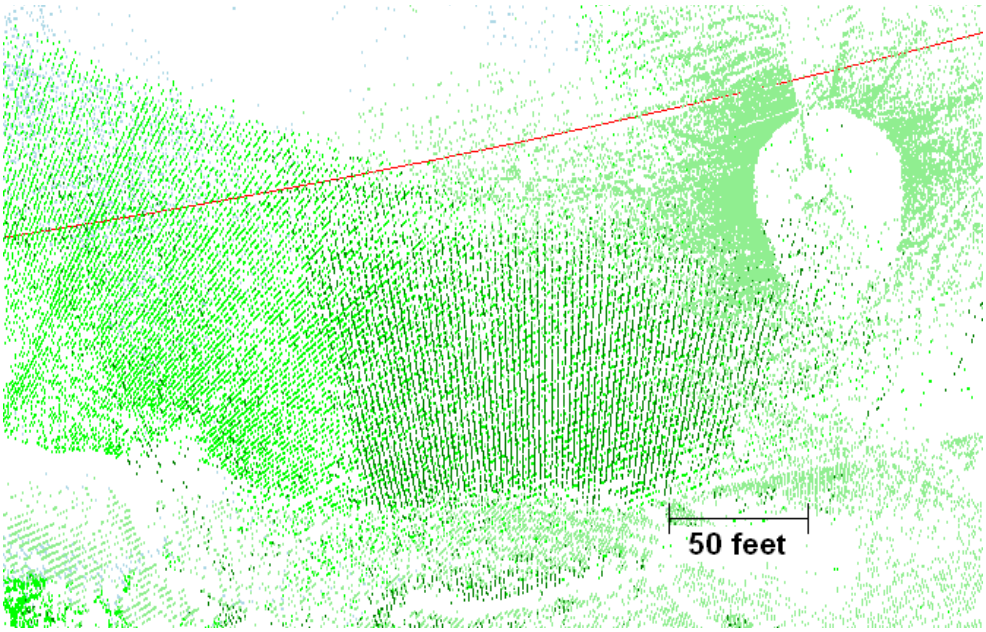

Figure 3. Scan coverage (zoomed in).

Figure 4 shows a cross section through the scan data. The plot displays all points in a 10-foot band (e.g. from Station 194+20 to Station 194+30) and includes the traditional survey points designated by black squares. A solid line is plotted through the lowest scan points. Tall grass and other objects are visible above this line. Algorithms to automatically ignore these points are being refined in order to fully automate the data reduction process to create a "net surface" to develop contour data for earthwork calculations.

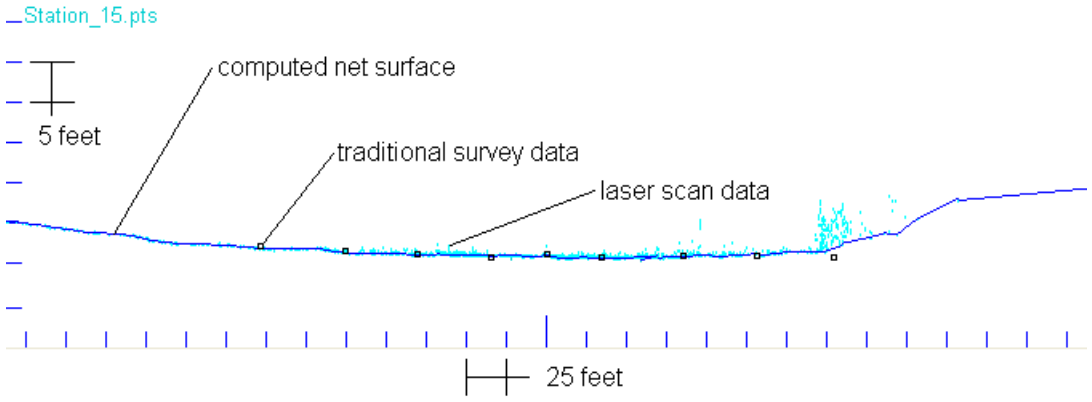

Figure 4. Cross-section plot of points with net surface and superimposed traditional survey point data.

Applicability of Results to the Practice of Departments of Transportation

The research will result in a detailed procedure and the necessary software to import standard point cloud data files from any laser scanner and perform earthwork volume calculations to determine earthwork pay quantities for construction. Procedures and software will also be provided to plan scanning operations in order to optimize crew time. The intent is that personnel

responsible for project monitoring will have the capability to view and evaluate scan results. These results will provide much greater accuracy than the current Average End Area method for determining earthwork quantities ensuring accurate costs for construction activities. This capability will also allow the DOT to quickly determine actual quantities when the contractor disputes the engineer's estimates. The evaluation of other uses for the technology such as settlement monitoring and design surveys will provide IDOT with information necessary to evaluate the cost effectiveness of investing in this technology.

Conclusions

Preliminary results indicate that it is feasible to use laser scanning technology to accurately map terrain prior to road construction. Efficient procedures and software are required to optimize this process in order to demonstrate that it is a cost-effective approach for determining earthwork quantities. Current off-the-shelf software may require adaptation to provide a product that is sufficiently friendly for the casual user.

Acknowledgements

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