VISUALIZING LASER SCANNER DATA FOR BRIDGE INSPECTION

Guzide Atasoy
Carnegie Mellon University, Pittsburgh, PA, USA
guzide@cmu.edu

Pingbo Tang
The Ohio State University, Columbus, OH, USA
tang.238@osu.edu

Jiansong Zhang
Carnegie Mellon University, Pittsburgh, PA, USA
zhangjiansong@cmu.edu

Burcu Akinci
Carnegie Mellon University, Pittsburgh, PA, USA
bakinci@cmu.edu

Abstract

Laser scanners are being used for the geometric assessment of bridges due to their ability of capturing dense point clouds about an environment very quickly. As important as the geometric data collection, is the timely and intuitive interpretation of such point cloud data (PCD) enabled through effective visualization techniques. In this study, using PCD of a highway bridge, we evaluated different 3D visualization techniques to support a variety of bridge inspection tasks. The visualized geometric items include a) points, b) lines, and c) surfaces. The visualization techniques evaluated for these items include: a) wireframes for visualizing surfaces, b) cross sections for visualizing 2D profiles, c) colours for visualizing values of interest from virtual inspection point of views (e.g., deviations), d) lighting directions for rendering 3D scenes, and e) contours for visualizing statistical data patterns. The evaluated techniques show differences in supporting the visualization of geometric data through better utilization of the raw data. This paper discusses these differences in visualizing geometric items to support a variety of inspection requirements of bridge inspectors.

KEYWORDS: Bridge Inspection, Laser Scanner Data, Visualization Techniques

INTRODUCTION

Geometric information is critical for evaluating the conditions of bridges. In the United States, the National Bridge Inventory program (Federal Highway Administration, 2009) requires bridge inspectors to bi-annually collect 27 geometric data items for over 600,000 bridges all over the country. Examples of these geometric data items include “minimum vertical under-clearance” and “cross section losses of bridge components”. Using conventional surveying instruments (e.g., measuring tapes, rods, total stations), bridge inspectors need to take measurements on bridges (e.g., 3D points on the bridge), and calculate the results (e.g., calculate point-point vertical distances and obtain the minimum value) for obtaining these geometric data items. Such manual geometric data collection and interpretation approach is tedious, and usually requires blocking the traffic to enable bridge inspectors to access to the inspected bridge components (Velinsky and Ravani, 2006). Therefore, there has been a desire for more efficient geometric data collection and interpretation in order to provide timely information to support bridge maintenance.

High precision, high speed laser scanners are instruments that enable fast, non-contact, and efficient geometric data collection about infrastructure systems. A 3D laser scanner can deliver dense 3-D measurements of bridges in minutes. Jaselskis et al. (2005) used detailed 3D as-built models generated from laser-scanned point clouds to extract geometric information to assess the beam camber, surface elevation, and smoothness of bridges. With such detailed information captured in dense laser-scanned point clouds, identifying the ways in which the captured information can be effectively delivered to bridge inspectors becomes an important issue. In a case study focusing on a highway bridge, we found that depending on the geometric information requirements of bridge inspectors, the effective data visualization techniques could vary. Such techniques influence the time spent and insights gained in performing geometric measurements and interpreting the data.

Several software tools are currently being used to process (e.g., aligning and integrating multiple scans, cleaning noise, generating wire-mash representations, and assigning colour) and visualize the point cloud data (PCD). The research described in this paper focuses on the assessment of different visualization techniques provided by three of such tools to display the geometric information captured in PCD and measurements taken on PCD. Specifically, this paper presents discussions on the geometric information requirements of bridge inspectors, a review of available visualization techniques, and assessments of the effectiveness of these techniques in terms of their impacts on the users in terms of time that they spend on performing the measurements and the insights that they gain by visualizing the results.

BACKGROUND INFORMATION

Laser scanners are used for geometric assessment of bridge structures, such as monitoring the clearance of bridges (Kretschmer et al., 2004) surface conditions and elevation of pavements (Jaselskis et al., 2005). Tang et al., (2007) showed several advantages of using a laser scanner for bridge inspection in terms of higher accuracy of the data and enabling identification of unexpected bridge deformation patterns.

Previous research studies exploring the adoption of laser scanners in the construction management domain have mainly focused on investigating approaches for data collection (e.g., Gordon et al., 2003), object recognition (e.g., Bosche, 2008), edge detection (e.g., Tang, 2009), and as-built model generation (e.g., Cheok, 2000). Fabio (2003) claimed that creating realistic 3D models (e.g., mapping colour to the points) provide better visualization of the final results, but unfortunately, studies focusing on understanding the visualization aspect of the laser-scanned data is still limited. Abmayr et al. (2004) studied augmenting the laser scanner data with colour information collected by digital cameras. Currently, several commercial laser scanners provide the option of integrating a calibrated high-resolution digital camera for collecting colour information. Some recent research studies implemented and tested systems integrating digital cameras and laser meters (Ordonez et al., 2008).

In the domain of 3D data visualization, Fabio (2003) explored three visualization modes of displaying 3D models: (a): *Wireframe mode* consisting of points, lines and curves, without texture or shading information, (b) *Shaded mode* representing surface properties in addition to geometric primitives, such as colour, normal information, reflectance, transparency and lighting model, and (c) *Textured mode* using the mapping of colour gained from the image of the object. However, so far, there are no detailed studies about the impacts of different visualization techniques on the effectiveness of geometric information interpretation and the efficiency of extracting required information from 3D data.

RESEARCH METHOD

This research focuses on exploring the effectiveness of different visualization techniques on data processing and interpretation, and studying how the efficiency of geometric information retrieval vary across different geometric information items that need to be extracted by the bridge inspectors (e.g., location, distance, etc.), characteristics of the collected data, and the applied visualization techniques. The particular visualization techniques explored include: (a) geometric representation techniques of PCD in the forms of points, lines, cross sections and surfaces, (b): techniques for augmenting PCD with intensity, colour, and lighting condition and rendering, and (c): techniques for visualizing measurements of geometric items through tabulations, annotations, colour maps and contours.

To test the above mentioned visualization techniques, we selected a highway bridge as our test bed. This single-span girder bridge has a span size of 30m. According to (Tang, 2009), about 43% of bridges in the NBI data base are similar to this bridge in terms of structure type. In order to capture the whole span of this bridge, we took scans from 11 different locations. Then, we cleaned the noise in the PCD, aligned and integrated them to reconstruct a 3D as-is model of the bridge. The scanner used in this research generates PCD containing x, y, z coordinate information and gray-scaled intensity of each point (reflectivity).

Identification of Bridge Inspection Requirements

Tang (2009) conducted requirements analysis on the national bridge inspection (NBI) standards and identified that 27 geometric data items are required by the NBI program in the US. He categorized these required data items into seven categories: 1) location; 2) object dimension; 3) area 4) space clearance; 5) distance; 6) angle; and 7) deviations from a reference location, line or surface (Tang, 2009). We observed that three of these data items, namely, the space clearance, the distance and the deviations from a reference are related to the measurement of a space dimension between an object and either another object or a reference datum. Hence, we combined these three categories into one category, space measurement, and ended up with five categories of NBI geometric data items including location, object dimension, space dimension, area, and angle.

In order to assess the effectiveness of different visualization techniques, we selected five representative geometric data items from each of the five categories mentioned above. These geometric data items are the measurements of three different types of geometric primitive including:

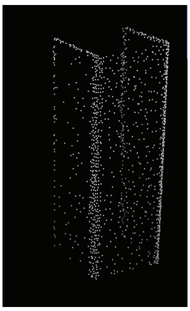
1. Points for indicating measurements of object locations: Elevation of deck (location);

2. Lines for indicating measurements of object dimensions and space clearance: the deck width (object dimension) and vertical under-clearance of a bridge (space clearance);

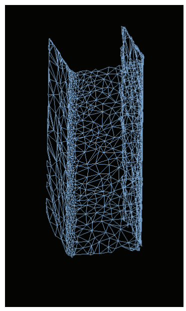
3. Surfaces for indicating measurements of areas: cross-sectional loss of piers (area).

Overview of Visualization Techniques

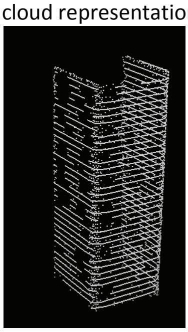
Fabio (2003) identified 12 reverse engineering software tools that are widely used for visualizing 3D models. Getting access to 11 of them, we reviewed the software tools in terms of their functionalities for taking and visualizing measurements on a 3D data model. Based on our review and experiences with a number of these 3D reverse engineering environments, we found that it is possible to visually represent the 3D model of a bridge in four generic forms. These geometric representation forms refer to: PCD as the raw data form, polygonal wireframe representation generated by triangulating PCD, cross-sectional profiles generated based on PCD, and surface representation of triangulated PCD. Figure 1 shows these 4 forms of a pier including: (a) point cloud: Figure 1.a, (b) polygonal wireframe: Figure 1.b, (c) cross-sections: Figure 1.c, and (d) surfaces: Figure 1.d.



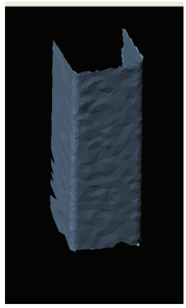
1.a: Point cloud representation of a pier



1.b: Wireframe representation of a pier



1.c: Cross-section representation of a pier

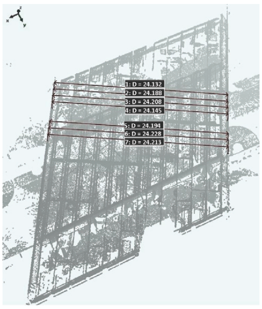


1.d: Surface representation of a pier

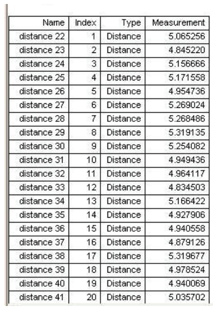
Figure 1: Geometric Representation forms

Some scanners can deliver data sets with additional information (e.g, RGB colour of every point), and such additional information may benefit different geometric representations. For instance, the above three geometric primitives, -points, lines and surfaces-, can be augmented with intensity information of the objects in a scene. Another example is that applying lighting from different directions can enhance the contrast of particular parts of a 3D model. Such rendering can aid users to recognize geometric features of interests for a specific inspection task. To evaluate various visualization techniques in terms of their effectiveness in enabling users to perform and interpret measurements more quickly and insightfully, we performed measurements of 5 geometric data items utilizing two commercial reverse engineering tools out of the 12 presented by Fabio (2003). The reason for the selection of these tools, which will be referred as Tool 1 and 2 from here on, is their capability to utilize all categories of geometric representations and the augmentation techniques mentioned above.

On a 3D model, the measurements performed on geometric data items can be visualized not only by geometric primitives and the numbers depicting the property values of them (e.g., length of a line), but also through colour-coding these property values, as well as methods for visualizing the elevation or deviation patterns of surfaces. We identified four techniques that can be applied in order to display the measurement results, as shown in figure 2.

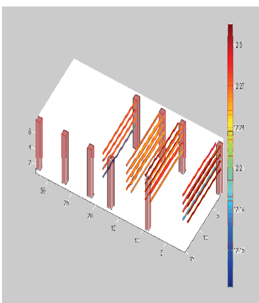


2.a: Visualization using annotations

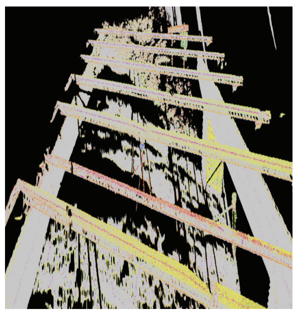


Name	Index	Type	Measurement
distance 22	1	Distance	5.065256
distance 23	2	Distance	4.845220
distance 24	3	Distance	5.156666
distance 25	4	Distance	5.171558
distance 26	5	Distance	4.954736
distance 27	6	Distance	5.269024
distance 28	7	Distance	5.268486
distance 29	8	Distance	5.319135
distance 30	9	Distance	5.254082
distance 31	10	Distance	4.949436
distance 32	11	Distance	4.964117
distance 33	12	Distance	4.834503
distance 34	13	Distance	5.166422
distance 35	14	Distance	4.927906
distance 36	15	Distance	4.940558
distance 37	16	Distance	4.879126
distance 38	17	Distance	5.319677
distance 39	18	Distance	4.978524
distance 40	19	Distance	4.940069
distance 41	20	Distance	5.035702

2.b: Visualization using tabulation



2.c: Visualization using colour map



2.d: Visualization using contours

Figure 2: Measurement visualization techniques

These four measurement visualization techniques are: (a) *Annotation*: Figure 2a shows lines representing deck width measurements on a 3D model and each line has text on it to indicate its length, (b) *Tabulation*: Figure 2b shows a table listing the lengths of these lines as part of a measurement report, (c) *Colour Map*: Figure 2c shows colour-coded lines for visualizing horizontal clearance measurements between two rows of columns and such colour-coded approach can visualize the spatial distribution patterns of large number of measurements to help bridge inspectors to interpret the data, and (d) *Contours*: Figure 2d shows contours to visualize the elevation difference of the meshes created from PCD on bridge deck. Contours can also be used to show surface deviations. The effectiveness of such techniques in conveying measurement results is explored by using the selected two commercially-available systems and a prototype system developed by Tang (2009). As discussed in detail later, the advantage of the prototype is the colour-coded maps generated depending on the values of the measurements, which is a functionality that has not been implemented by the two software systems explored in this study.

In our evaluation, a trained user used all of the software tools to perform the required measurements, and timed all these measurement processes. This user performed the measurements of the geometric data items using the aforementioned visualization and rendering techniques. There is no consensus on the number of measurements required per object to ensure a certain level of accuracy of the measurement results. In our study, we took measurements by sampling geometric primitives with the step size of a meter as a baseline and assessed the time it takes to perform the measurements. With this baseline sampling step size, we compare how different visualization techniques influence the measurement process and the insights attainable through these measurements under different visual representations.

RESULTS

Data Visualization to Perform Measurements

Summary of Findings

In this study, the easiness of manual measurements is evaluated in terms of the time spent per measurement. Results of each of the five geometric items are presented in Table 1 together with their geometric primitive types and the applied geometric representation forms. Since the absolute time spent per measurement by different users varies, our focus is to evaluate the relative differences in the amount of time spent on performing the measurements. Hence, this table does not present the absolute time values, but rather assigns the shortest measurement duration among all results as 1, and presents other measurement durations as a relative scaled value to this shortest duration.

We observed that the point cloud form outperforms the wireframe form in 3 out of the 5 geometric items. There are several reasons behind this observation: (a) the lines and intersections in the wireframe are sometimes misleading because data points not necessarily exist on lines or at intersections, causing repetitions of measurements; (b) the rendering of wireframe after each adjustment of the viewing perspective takes several seconds. The adjustment of viewing perspectives refers to the operations that a user performs to be able to see the right part of the model to perform measurements. These operations include panning, zooming (in and out), and rotation. We also observed that the cross-section generation is necessary in 3 out of 5 geometric items because of its capability of helping users to precisely select points. For instance, in order to identify the minimum vertical under-clearance, the perpendicular distances between the roadway and the bottom surface of the superstructure are needed. It is difficult to pick two points that are perpendicular to each other with naked eye, while two sets of vertical cross sections perpendicular to each other are helpful for a user to locate the corresponding point pairs for vertical clearance measurements.

Table 1 also shows that the fastest operation is the measurement of minimum vertical under-clearance in the point cloud form with cross-sections generated, since picking points on the intersections of cross-section lines is easy and quick. The slowest operation is the measurement of deck width in the wireframe form because of the existing misleading lines, as well as the need for additional operation to adjust the viewing perspective of the model.

Table 1: Performance of measurements with different geometric representation forms

NBI Geometric Data Item	Geometric Primitive	Representation	Duration per measurement	# of measurements
Elevation of deck	Point	Point Cloud	2	118
		Wireframe	6	118
Deck width	Line	Point Cloud + Cross-section	10	7
		Wireframe + Cross-section	22	7
Cross-section loss of pier	Surface	Point Cloud + Cross-section	19	5
		Wireframe + Cross-section	6	5
Vertical under-clearance	Line	Point Cloud + Cross-section	1	135
		Wireframe + Cross-section	5	135
Skew angle of a pier	Surface	PCD (Vector Mthd)	16	1
		Surface (Plane Mthd)	7	1
		Wireframe(Plane Mthd)	10	1
		PCD (Plane Mthd)	10	1

For each measurement, PCD data is visualized within these geometric representation forms, applying different colour and lightning direction configurations. In this study, we found that generally there was no major effect of these two configuration options on the time spent on the measurements, so we only reported the results under default colour and lighting conditions in table 1.

Details on Geometric Data Item Measurements

The time spent on the measurements of the geometric primitives of points and lines in the point cloud form is less than 50% of the counterpart of the wireframe form due to the time-consuming rendering process required by the wireframe form. We also noticed that for the deck width measurements, the time spent on the cross-section generations using the point cloud form is nearly 25% more than those cross-section generations using the wireframe form. Hence, we can deduce that in order to perform the measurements of points (e.g., locations) and lines (distances between points), there is no advantage of triangulating point clouds and generating surface models; however, triangulated model will enable more efficient cross-section generation to save some data processing time.

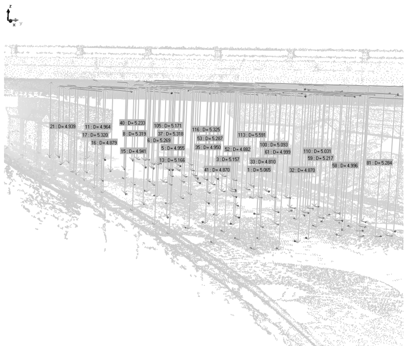
We observed that it is faster to use the wireframe form than raw point cloud form to perform the measurement of the average cross-sectional loss of piers. The main reason is that the cross sections generated in the wireframe form appeared to be smoother and more regular, making the fitting of polygons easier and quicker and helping in preventing failed fitting trials. For measuring the skew angle of a pier, which is the acute angle between the pier and substructure, we used three methods- vector method, plane method and vector plus plane method. In the vector method, we first fit a plane against a side surface of a pier and a vector along the bridge longitudinal direction, then get the normal vector of the side surface plane and performed the angle measurement on the two obtained vectors. In the plane method, we fit a plane against a side surface of a pier (this side surface is perpendicular to the one used in the vector method) and another plane against the side surface of the deck, then performed the angle measurement between these two planes. In the vector plus plane method, we first fit two planes as stated in the description of the plane method, then get the normal vectors of these two planes, and measured the angle between these two vectors. Although the time spent on the measurements is influenced by the varying numbers of planes and vectors generated in each method, we observed that the surface form outperforms the other two due to the easiness of fitting planes using it. Albeit the primacy of point cloud form for the measurement of points and lines, we found that the wireframe and surface forms outperform the point cloud form in terms of surface measurements. As a matter of fact, there is no essential difference between the wireframe and surface visualization forms in terms of easiness of selection of points to perform measurements.

Displaying Measurement Results

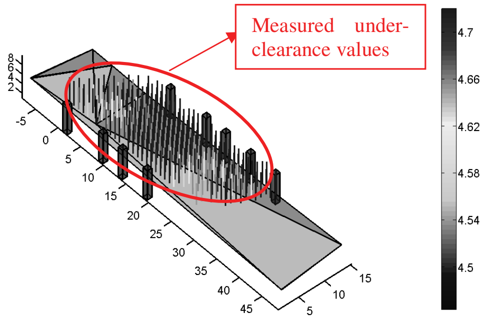
We assessed the four measurement visualization techniques described above, namely tabulation, annotation, colour map and contours, according to their ability to help bridge inspectors obtain insights about the geometric condition of a bridge. For the geometric data items which require only one or a few measurements, it is sufficient to use tabulation; however, tabulation are limited in showing the patterns of the spatial distributions of measured values.

The under-clearance measurement results of the deck with annotation technique are presented in Figure 3a. While there are 118 measurements, only 28 of them can be displayed in the current view because of the fact that the measurements block each other due to the limited screen size and large number of measurements. Moreover, the pattern of the spatial distribution of measurements across the bridge is still difficult to be recognized using this approach. Using the research prototype, as shown in Figure 3b, the vertical under-clearance measurements are colour coded by the measured values. Within the boundary rectangle representing the roadway, the measured under-clearance values are drawn as coloured lines and the spatial distribution of the vertical clearance values can be recognized. The colour scale is determined based on the accuracy expected for vertical clearance measurements (cm level in this case). Since the print form of this paper is black and white, a gray scale figure is used here. Figure 3.b shows that except for the two corners of the bridge, the vertical clearance is larger than 4.6m, which is the minimum vertical under clearance for ensuring safe pass-through of most loaded trucks. Visualizing the spatial distribution of measurement results in such a manner can help bridge inspectors to find that the top right and top left corners of the bridge might require special traffic safety posting, which will state that the vertical clearances at that two locations are less than 4.6 m. Two typical coding modes for colour map are gradient colour and binary colour. Gradient colour coding assign continuously changing colour to the corresponding values while binary colour coding only uses two colours to show whether a value is within a threshold or not. Although the gradient colour method is used in Figure 3b for displaying surface defects deviating from certain thresholds, we found that a binary colour map sufficiently convey the results in this case, since it is only necessary to know a binary answer to highlight regions that have measured values larger or smaller than a particular threshold. The other graphical technique, namely contour, is only applicable for visualizing the elevation variations of a geometric data items.

In this paper, in addition to the geometric data items discussed above, we conducted some analyses on additional visual information captured by some scanners (e.g., intensity values of points). Generally, we found that to detect cracks on a surface, visualizing 3D data with intensity values is more advantageous than point clouds only containing xyz coordinates.



3.a: Visualization of under-clearance using line annotation



3.b Visualization of under-clearance using colour-coded distance values (in meter)

Figure 3: Under-clearance visualization

CONCLUSIONS

In this paper, we evaluated various visualization techniques applied to PCD for extracting the geometric data items required by NBI for bridge inspection purposes. We categorized the NBI geometric data item requirements into five categories and selected representative items within each category to evaluate the effectiveness of visualization techniques in terms of time spent and insights acquired. A trained user performed the geometric measurements using two reverse engineering software tools while adopting different geometric representations of PCD, including raw point cloud, wireframe, cross-section and surface, and augmenting the PCD with colour, intensity, and normal information. We found that: 1) rendering the data with intensity do not provide substantial advantages to support the measurements for extracting NBI geometric data items, but intensity information augmented PCD is effective for identifying surface cracks and patterns of deviations; 2) the raw point cloud form is suitable for measuring points and lines; 3) generating wireframes and cross-sections are required when perpendicular distance measurements are necessary, especially for surface measurements; 4) tabulation and annotation of measurement results are limited in displaying the locations and trends of the defects respectively, and a better display technique for this purpose is the usage of colour-coded error maps to help bridge inspectors to identify the spatial distribution of the defective sections of the bridges.

Comparing the time spent on performing the measurements and the insights attained by visualizing the measurements, we left the accuracy evaluation as a future work. In the next stage of this research, we plan to pursue the collection of the ground truth values of the tested NBI geometric data items and compare the impacts of employed visualization techniques on the accuracy of measurement results. Considering the bias that might arise from the involvement of a single user in performing the measurements, we aim at performing the same geometric item identifications with multiple users, and conducting statistical analyses while comparing different visualization techniques.

REFERENCES

Abmayr, T. Abmayr T., Härtl F., Mettenleiter M., Heinz I., Hildebrand A., Neumann B., Fröhlich C. (2004) Realistic 3D Reconstruction – Combining Laserscan Data with RGB colour Information. 20th ISPRS World Congress, Vol XXXV, Part B: 198-203, Istanbul.

Bosche, F. (2008) Automated Recognition of 3D CAD Model Objects in Dense Laser Range Point Clouds. PhD Thesis, University of Waterloo, Waterloo, Ontario, Canada.

Cheok, G. S., Stone, W. C., Lipman, R. R. & Witzgall, C. (2000) Ladars for construction assessment and update. Automation in Construction, 9(5-6): 463-477.

Fabio, R. (2003) From Point Cloud to Surface: The Modeling and Visualization Problem. International Workshop on Visualization and Animation of Reality-based 3D Models, 24-28 February 2003, Taeasp-Vulpera, Switzerland.

Federal Highway Administration (2009) National Bridge Inventory, Washingtom, D.C., Federal Highway Administration (FHWA).

Gordon, C., Boukamp, F., Huber, D., Latimer, E., Park, K., and Akinci, B. (2003) Combining Reality Capture Technologies for Construction Defect Detection: A Case Study. Proceedings of Europia International Conference, pg. 99-108, Istanbul, Turkey.

Jaselskis, E.J., Gao, Z., and Walters, R.C. (2005) Improving Transportation Projects Using laser Scanning. Journal of Construction Engineering and Managemnet, 131:3 (377).

Kretschmer, U., Abmayr, T., Thies,M., Fröhlich, C., (2004) Traffic construction analysis by use of terrestrial Laser Scanning. Proceedings of the ISPRS working group VIII/2: “Laser Scanners for Forest and Landscape Assessment”; VOL. XXXVI, Part 8/W2, 2004.

Ordonez, C., Arias, P., Herraez, J., Rodriguez, J., and Martin, M. (2008) Two Photogrammetric Methods for Measuring Flat Elements in Buildings Under Construction. Automation in Construction 17(5): 517-525

Tang, P. (2009) Extracting Surveying Goals from Point Clouds to Support Bridge Inspection. PhD Thesis, Carnegie Mellon University, Pittsburgh, PA, USA.

Tang, P., Akinci, B., and James H. Garrett, J. (2007) Laser Scanning for Bridge Inspection and Management. IABSE Symposium 2007, Weimar, Germany.

Tang, P., and Akinci, B. (2009) Extracting Surveying Goals from Point Clouds to Support Construction and Infrastructure Inspection. Construction Research Congress 2009, Seattle, USA.

Velinsky, S. A., and Ravani. B. (2006) Advanced Highway Maintenance and Construction Technology. Available from http://ahmct.ucdavis.edu/index.htm?pg-OtherStructures.