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Pilot Study on Laser Scanning Technology for Transportation Projects

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ABSTRACT

This paper describes the results from a pilot study to investigate the use of laser scanning for the Iowa Department of Transportation in delivering projects in a safer and more efficient manner. Laser scanning is a terrestrial laser-imaging system that quickly creates a highly accurate three-dimensional image of an object for use in standard computer-aided design software packages. Included in this paper is a description of the technology, discussion of the pilot tests, lessons learned, and results. It appears that laser scanning technology may be an alternative tool for design and construction of transportation projects. Based on results from the study, laser scanning can be used cost effectively for preliminary surveys. It also appears that this technique can be used quite effectively for construction measurement in a safer and quicker fashion compared to conventional approaches. Laser scanning technology would be quite beneficial for determining volume calculations.

Key words: computer-aided design—data collection—laser scanning—preliminary survey—three-dimensional image

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INTRODUCTION

As transportation projects become more complex to design and build, it is important to take advantage of appropriate innovative technologies for reducing project cycle time. Laser scanning is one such technology that has potential benefits over standard surveying techniques such as aerial photogrammetry for providing accurate measurements. Laser scanning is a terrestrial laser-imaging system that quickly creates a highly accurate three-dimensional (3D) image of an object for use in standard computer-aided design (CAD) software packages. The laser's visible green beam is moved across a target in a raster scan. The horizontal and vertical angles of the beam are measured for each point, as well as the time of flight of the pulses. Figure 1 shows the Cyrax 2500 system used for the pilot study *(1).* Once an object is encountered, the laser is reflected back to the unit with the time of flight, which generates a measurement of distance. These measurements produce an impact location, which in return displays a cloud of points.

Measurements taken from the "cloud" can be used to do interference detection and constructability studies. Each point has embedded x, y, z data, so it can be directly loaded into a CAD program without any need of digitizing. Less than 6 mm (1/4") accuracy can be obtained using this technology (*2*).

FIGURE 1. Cyrax 2500 Laser Scanning Unit

As an object is being scanned, each 3D measurement appears immediately as a graphical 3D point image on the laptop screen. Exporting scanned data into a CAD application, such as AutoCAD, MicroStation or 3D StudioMax, is also possible. This technology has been successfully demonstrated on numerous projects related to developing bridge as-builts, highway widening, power plant retrofits, refinery expansion projects, water utility construction project archives, rock face surveys, dam foundation surveys, cave scanning, rebar inspection, and visual effects for movies *(1)*. In several cases, field and office time were reduced using laser scanning compared to conventional methods.

PILOT STUDY OBJECTIVES

This study involves a pilot test to investigate the use of laser scanning to assist the Iowa Department of Transportation (Iowa DOT) in delivering projects in a safer and more efficient manner. The objectives are as follows:

1. Learn about how to use the laser scanner and software.
2. Select appropriate pilot projects to test the capabilities of this technology.
3. Determine the benefits and costs associated with using this technology compared to conventional approaches.
4. Provide recommendations regarding the future use of laser scanning for the Iowa DOT.

PROJECTS INVOLVED

In total, there were six test areas involved in this pilot study: (1) an intersection including a railroad bridge, (2) a section of highway including a pair of bridges, (3) new concrete pavement, (4) bridge beams on an unfinished bridge structure, (5) a stockpile, and (6) a borrow pit. These projects were selected because they were of particular interest to the Iowa DOT as areas where greater efficiencies could be attained. Table 1 summarizes the purpose for each pilot project. More specific information can be found from the study report *(3)*. There were some difficulties registering all of the scanworlds associated with the borrow pit pilot test. Consequently, it was decided to discard this pilot project and rely on volume-measuring capabilities using only the stockpile pilot project.

TABLE 1. Purpose of Pilot Projects

Pilot Project	**Purpose**
Intersection and railroad bridge	Learn about the Cyrax 2500 scanner and Cyclone software (training exercise).
Section of highway and pair of bridges	Determine surface elevation of highway and compare to aerial photogrammetry. Also, determine the level of bridge detail available using laser scanner.
New concrete pavement	Determine smoothness of freshly paved concrete.
Bridge beams on unfinished bridge	Assess camber on bridge beams for determining optimal loading requirements.
Stockpile	Determine volume of stockpile and compare to traditional methods.
Borrow pit	Determine volume of borrow pit and compare to traditional methods.

FIELD OPERATIONS AND LESSONS LEARNED

Several lessons were learned during the two week training and field scanning process as they related to the set-up and operation of the equipment.

Field Operation

Field operations involved two major tasks: (1) set up survey control points and targets (i.e., globe targets mounted on tripods) and (2) scan the desired objects and acquire targets. The research team consisted of two separate crews, surveying crew and scanning crew, for these two activities. The scanning operation involved several activities related to properly using the Cyclone software such as creating a database, operating scan control window, and target acquisition.

The survey crew consisted of five surveyors and one coordinator. The survey crew used traditional methods to set up targets and tie them into the Iowa state plane coordinate system. Thus, different scans could be registered and matched to each other with a high degree of accuracy. The surveying time was not specifically tracked but should be similar to the scanning time. This is because the surveyors worked the same hours as the rest of the team.

The scanning crew consisted of two operators. Table 2 shows the basic information related to the number of scans and duration of each scan. Scanning time defines the difference between start and end times of scanning. Start time is when the scanner begins to take the point cloud image while end time is when the computer is disconnected from the scanner. Scanning times varied per scan primarily because scans were performed using different resolutions.

TABLE 2. Field Scanning Information for Pilot Projects

Pilot Project	**No. of Scans**	**Total Scanning Time (hrs.)**	**Average Scanning Time (min.)**
Intersection and railroad bridge	—	—	—
Section of highway and pair of bridges	30	14	28
New concrete pavement	3	1.6	32
Bridge beams on unfinished bridge	5	2.9	34.8
Stockpile	3	1.5	30
Borrow pit	17	4.4	15.5

Lessons Learned

Since the research team had adequate control on each target, it was not necessary to have common targets in every scan. Overlapping targets are necessary when there is no knowledge of the x, y, z coordinates for each location. To obtain proper registration, at least three targets need to be common in each scan when control is not established on the targets.

Target acquisition is a critical issue for scanning and registration later. During the scanning process a few different types of mistakes were made that created additional work in the field and office. Some of the more common examples are listed below:

1. Targets were completely missed during the initial scan, reducing the number of targets in the scanworld and causing difficulty during the registration process.
2. Failure to scan the correct targets. This is typically detected during the acquisition process and requires the operator to reacquire the correct target.
3. Paired targets were mislabeled (switched). This could be corrected during the registration process.
4. Targets with labels that do not exist in the control files. This could be corrected during the registration process by including the correct coordinates.
5. Targets without labels. This lead to difficulties during the registration process because it is hard to tell which target is being used.
6. Targets with double labels. This is happens because the same two targets were acquired during the acquisition process using different labels. This problem is corrected during the registration process.

It was found that vibrations or scanner movement during the scanning operation makes it very difficult to align images during the registration process. This is because the scanned image becomes distorted once the scanner is moved from its initial position. Thus, it is important that the laser scanner be mounted on a stationary, nonvibrating surface.

DATA PROCESSING AND CONCERNS

The primary procedures involved with analyzing the scanned data from the field include importing coordinate data, registration, image fitting and editing, mesh editing, contouring, and using the virtual surveyor routine *(4)*. Not all of the projects required each of these steps as the requirements were dependent upon the desired outcome. Sometimes special steps were necessary in order to meet the unique requirements of the pilot tests. Details related to the image processing for each of the pilot projects (except for the intersection and railroad bridge training exercise) can be found in the research report *(3)*.

Registration Concern

The project of Highway and Pair of bridges was the first one that the research team did on its own after training. As a result, there were many mistakes related to correct target acquisition, which made the registration process more time consuming. A total of nine targets in eight scanworlds had target problems. It was found that checking and measuring target locations and distances between targets in the control space is an efficient and effective way to identify the problems once large errors appear in the registration window. The correction action, however, was performed in model space and then a new control space was created from model space. Because some mistakes were made with the first few scanworlds, extra work was required to minimize the registration errors. After registration and related cleanup work had been successfully finished, there were still some targets with errors slightly larger than the original tolerance of 0.009 meters. Most of targets with errors ranged from zero to 0.007 meters. Those errors could be caused by either a physical setting deficiency of targets or distortion of the laser beam but not by the targets labels. Because the greatest errors were in pairs of targets with distances greater than 50 meters, distortion is most likely the reason.

Fitting and Editing Concern

The process of removing the noise and modifying the registered scanworlds went smoothly for I-235 and primarily involved removal of superfluous data representing traffic on the roadway surface. Because the scanned images are 3D objects, different perspective views had to be checked in order to make sure the traffic noise was completely removed. Although the research team expended a significant amount of effort on mesh editing the point cloud file, this step was not really necessary since elevations could be measured directly using the virtual surveyor routine.

Vegetation removal on the stockpile was the most difficult part of the editing process. After numerous trials, a set of parameters was determined as a best solution to remove the brush and vegetation with minimal disruption to the stockpile. After applying the region growing routine, some leftover target tripods still required removal using a manual approach. This usually also deleted some of the stockpile but did not influence the final result because the density of the point cloud was sufficiently high. Figure 2 shows the point cloud after final point cloud cleaning.

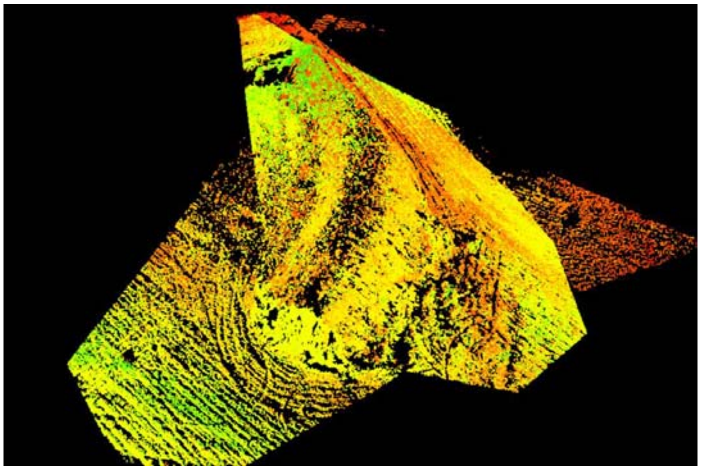

FIGURE 2. Cleaned Up Point Cloud Image of Stockpile

Special Concerns

A few new special features were applied to the Hardin County Bridge because the beams were not parallel to the reference plane axis, and establishing the true top of beam surface was challenging because of the protruding steel reinforcing loops present on the top surface. To be able to use the virtual surveyor routine along the beam, a new coordinate system was created by drawing a line on the beam, which was set as a new x-axis instead of the default system. Also, one end of that beam was set as the new origin. The new x-z plane was used as new reference plane to cut the beam into slices. By defining a proper thickness of each slice, the top boundary line can clearly be determined by the front view of the beam slice. After this step, the normal virtual surveying process can be applied.

To measure the volume of stockpile correctly, the mesh volume had to be measured taking into consideration the sloping ground below the stockpile. Since it was not possible to establish a curved reference plane that follows the upward sloping stockpile, it was necessary to create two separate meshes with one reference plane. The top mesh is based on the entire cleaned point cloud. The bottom mesh is based on the surrounding area of this point cloud. The desired volume of the stockpile is calculated by taking the volume difference between the top mesh relative to an arbitrary reference plane and bottom mesh relative to the same reference plane. The reference plane can be randomly chosen but must be below the top of the bottom mesh in order to simplify the calculation.

PILOT STUDY RESULTS

The results include information related to the technical results from the pilot tests, time expended to perform the pilot tests, and a cost comparison between aerial photogrammetry and laser scanning.

Technical Results

Elevation measurements were taken of the I-235 roadway centerline, lane edges, and shoulders using the Cyclone virtual surveyor. The measured results were exported into an ASCII format file. To determine the accuracy of those data points and to compare them with those from other surveying methods such as helicopter aerial photogrammetry, an ASCII file was converted into a MicroStation and GEOPAK file to create the plan views of I-235. While the difference between those methods can be clearly seen from the

MicroStation file, a detailed accurate comparison was also conducted. The average difference for measuring elevation at the lane edges between traditional surveying and Cyra laser scanning ranged from 0.001 meters to 0.009 meters, while the difference ranged from -0.006 meters to -0.023 meters between aerial photogrammetry and Cyra laser scanning. This comparison demonstrates that much more accurate measurements can be obtained from Cyra laser scanning technology than from the photogrammetry method.

The stockpile volume is calculated assuming that the reference plane is established at 300 meters. Using this assumption, the top and bottom mesh volumes are 2,176.849 and 1,669.78 cubic meters, respectively. Thus, the stockpile volume is 507.07 cubic meters. The volume of this stockpile was calculated using a traditional surveying approach and GEOPAK software and was found to be 512.96 cubic meters. It can be seen that the results of both surveying methods are fairly close to one another (1.2 percent difference, or 6 cubic meters).

Results show that it is possible to measure bridge beam camber using the virtual surveyor routine in the Cyclone software. However, it was not possible to adequately determine the smoothness of the pavement surface. The primary reason is because the laser scanner has an accuracy of two to three millimeters. Most smoothness irregularities will fall within or below the accuracy range of a laser scanner. Therefore, the application of this new technology, in its current state, is not sufficiently sensitive to monitor the smoothness of freshly paved concrete.

Time Requirements

Overall, a total of approximately 870 hours (15.1 hours per scan) were spent on this pilot study, including 403.1 hours for fieldwork, 153.5 hours for lab analysis, and 313 hours for training. Different groups of participants, including a training group, a scan crew, a survey crew, and lab analysts were involved in different phases of the learning process. Some people who attended the training course did not participate further with the project. Also, an assumption was made that the same field time was spent by the scan crew and the survey crew. All of these facts make the time tracking and analysis a complicated process.

Table 3 summarizes time spent on the entire project. In order to evaluate the project more accurately, the time spent by people who attended training but who were not involved in any other tasks was removed from the total hours, yielding the actual hours. Clearly, the learning time is more significant than may be expected.

In order to maximize production and efficiency, the size of the training and scan crew can be reduced to one scanning operator and one coordinator while the survey crew can be reduced to three surveyors and one coordinator (the same person as the scan coordinator) without diminishing work quantity or quality. Therefore, projected hours were calculated based on these crew sizes and are also listed in Table 3. The total hours are reduced to 477.5 from 805.6 (a 40 percent reduction). The field time, lab time, and learning time account for 55 percent, 17 percent, and 28 percent of the total hours, respectively. The total hours above can be converted into hours per scan. The actual hours per scan are 14 (7.0 in the field, 2.7 in the lab, and 4.3 for learning). Learning time is a one-time investment and will have less impact on total time as more projects are scanned and analyzed.

To analyze the project time more meaningfully, the time spent on each pilot project is discussed. For scanning equipment operations, the time per scan over four projects (excluding the borrow pit project) ranges from 3.5 to 4.0 hours with an average of 3.7 hours. For the lab analysis portion, the average time per scan is 2.5 hours for the total project and 0.8 hours for the final trial.

TABLE 3. Summary of Total Time Spent on Pilot Study

Type	Actual Time (hrs.)	Projected Time (hrs.)
Field time	**403.1**	**262.5**
Scanning operation	187.4	121
Transportation	114	75
Breaks	57	37.5
Setup	38	25
Support	6.7	4
Lab analysis time	**153.5**	**80**
Learning time	**249**	**135**
Training course	120	80
Reading and studying	40	20
Watching videos	30	15
Defining procedures	9	10
Discussion	20	10
Meetings	30	0
Total	**805.6**	**477.5**

Cost Comparison

According to the data from the Iowa DOT, helicopter aerial photogrammetry costs approximately $2.66 per linear foot. Based on the I-235 research, laser scanning costs $3.43 per foot. Although the laser scanning cost is approximately 30 percent higher than that for aerial photogrammetry, laser scanning offers advantages in terms of accuracy. Due to this characteristic, it may be possible to use laser scanning as alternative for the initial project planning and design phases. However, scanning would need to be carefully coordinated, as the scan makes no distinction between the differing surfaces involved. Aerial photogrammetry does offer some benefits here because features such as centerlines and shoulders can be visually identified. Laser scanning costs can be reduced if the scanner were to be mounted on platform vehicle, allowing both sides of the divided highway to be scanned at the same time. It is surmised that the costs would then be comparable to those found using helicopter aerial photogrammetry.

CONCLUSION AND RECOMMENDATIONS

Laser scanning appears to have its applications for transportation projects. Applications of greatest benefit using the strengths of this technology appear to be ones where there is a significant amount of detail that needs to be captured and/or applications where safety may be an issue such as providing accurate measurements on an active roadway. Laser scanning performed quite well on determining quantities of soil and rock. Laser scanning was also found to be particularly helpful in measuring bridge beam camber. This technique was able to determine the beam camber quite efficiently and accurately. It was also ascertained that the laser scanner is not suitable for measuring concrete pavement smoothness on newly paved concrete. It seems to take a significant effort to become proficient with this technology and then one needs to continue using it to maintain a level of sharpness. If there are sufficient opportunities to use this technology, then it is recommended that the user purchases the Cyclone software and purchase or rent the scanner. Initially, it may be prudent to rent the scanner. If there are very few occasions, then the user should use more traditional approaches to capturing these data or hire a consulting firm with this expertise to provide the laser scanning services.

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