EXTRACTION OF GEOMETRIC INFORMATION ON HIGHWAY USING TERRESTRIAL LASER SCANNING TECHNOLOGY

Jin-Soo Kim [a,] *, Jong-Chool Lee [a], In-Joon Kang [b], Sung-Yeoul Cha [c], Hyun Choi [d], Tack-Gon Lee [e]

[a] Division of Civil Engineering, Pukyong National University, Busan, Korea - (pksurveying, jclee)@pknu.ac.kr
[b] Department of Civil Engineering, Busan National University, Busan, Korea –(ijkang)@pusan.ac.kr
[c] Department of Civil Engineering, Yangsan College, Yangsan, Kyungnam, Korea –(sycha)@yangsan.ac.kr
[d] Department of Civil Engineering, Kyungnam University, Masan, Kyungnam, Korea –(hchoi)@kyungnam.ac.kr
[e] Busan Metropolitan City Facilities Management Authority, Busan, Korea –(kh5246)@daum.net

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ABSTRACT:

Laser scanning technology with high positional accuracy and high density automation will be widely applied in vast range of fields including geomatics. Especially, the development of laser scanning technology enabling long range information extraction is increasing its full use in civil engineering. The purpose of this study is to extract accurate highway geometric information taking the advantages of scanning technology. Fulfilling this goal, the information of target highway's three-dimensional data was obtained through terrestrial laser scanning technology (TLSs). In accordance with the result from target highway's geometric information extraction using the information above, laser scanning technology showed faster speed and better accuracy on highway geometric information extraction with reduced cost compared to traditional methods.

1. INTRODUCTION

After mid 1990's, with the increasing of interests in target's three-dimensional reproduction and modeling in various fields, laser scanning technology has been developed as a new surveying technique with photogrammetry. Laser scanning technology is very economical with faster information processing speed and automation procedures as well as the aspect of information precision compared to other technologies with the same purposes. Supplying this laser scanning technology promoted the concepts of inspection and reverse engineering in the manufacturing industry and has been leading various applicable fields and beyond. Especially, as the interest in building digital archive for native cultural properties is getting higher world wide, its application and digital photogrammetry are also becoming highly practical in the cultural property restoration field (Kadobayachi et al. 2004). Moreover, the application of laser scanning technology limited in interpretation of relatively close range target configuration, is getting larger applicable ranges in civil engineering fields such as structure, construction & management, and pavement through supplying high density middle and long range terrestrial laser scanners in the early 2000's (Shih and Wang 2004; Jaselskis et al. 2005; Su et al. 2005; Park et al. 2007).

The application of laser scanning technology for highway geometric information extraction was mainly adopted for either grade and cross slope information extraction or highway territory's auto partition study using LiDAR information (Hatger and Brenner 2003; Pattnaik et al. 2003). However, general point density and accuracy of LiDAR information show severe difficulties not only for the accurate extraction of highway's geometric information but for gaining highway centerline information that is the most critical element to analyze highway geometric information. The purpose of this study is to make full use of laser scanning technology for more accurate geometric information extraction from HGIS (Highway Geometric Information System) that is still in its developing stage at Geomatics lab in Pukyong National University. Details of this research have following procedures.

1. Being prompt to get large amount of three-dimensional data from highways using TLS.
2. Transmitting the data gained through socket network method by USB modem to lab servers in real-time and processing it (registration and georeferencing).
3. Evaluating the accuracy of geoferenced information, and proving the potentiality of TLS's practical use on highway.
4. Extracting highway geometric information (horizontal and vertical alignment, cross section elements, and superelevation) more accurately using processed data.

2. TERRSTRIAL LASER SCANNING TECHNOLOTY

The advantages of laser scanning compared to existing techniques systems from the high rate-of-capture and density of three dimensional data (Boehler et al. 2001). The greatest difference between Laser scanning technology and photogrammetry is each technology adopts active sensor and passive sensor. Different sensors support different way of getting and processing information as well as the form of information. TLSs allows a large amount of three-dimensional data including colors and intensity information and their rapid process.

* Corresponding author.

TLSs operate on one of three principles: time-of-flight, phase shift, or triangulation. A proper scanner for general use of large scale applications is time-of-flight or phase shift methods using timed pulse (Mills and Barber 2004). Triangulation scanners are mainly used to close scan for cultural property restoration, inspection, and reverse engineering fields.

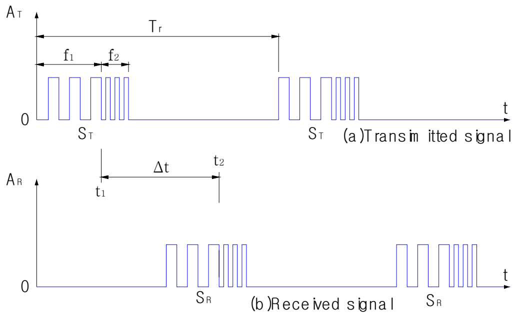


Figure 1. Principle of distance survey using transmitted and received signals in the time-of-flight method

Since this study has selected longitudinally long range highway as a target, time-of-flight type scanners with relatively long observation length were used. The Transmitted and received signals are shown in Figure 1. S_T is the transmitting signal from scanner. It has two frequencies f_1 and f_2 . T_r is the period of S_T . S_R is the received signal corresponding to the transmitted signal. The way of measurement is to calculate the distance using the time gap in the reflection of the transmitted laser from the surface. The time elapsed for transmitting Δt is, $\Delta t = t_2 - t_1$. t_1 is the time elapsed for transmitted frequency changed from f_1 to f_2 , and t_2 indicates the time elapsed for received frequency changed from f_1 to f_2 . Therefore, the distance toward target can be determined by applying the light velocity c . Continuous point clouds from one target pass through registration related to relative position merging in three-dimensional space and georeferencing related to target's absolute coordinate conversion.

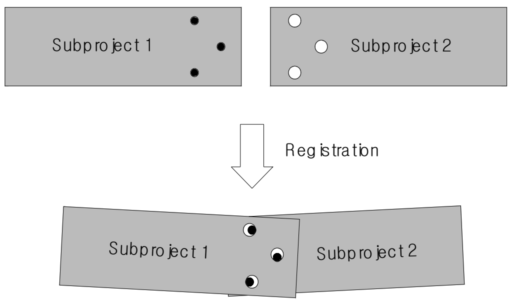


Figure 2. Principle of registering point clouds measured from different locations

As shown in Figure 2, registration is a process that calculates point clouds from different positions, which is calculating relative positions that makes the gap between configurationally common parts close to zero theoretically.

This is the procedure of point clouds' coordinate conversion to form the same coordinate system, and it is determined by movement and rotation elements in three-dimensional space. The point clouds that have formed the same coordinate system through registration is converted to target's absolute coordinate merging with control point by georeferencing as shown in Figure 3.

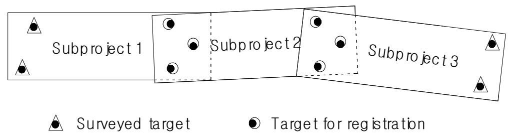


Figure 3. Principle of georeferencing point clouds passed through a registration process

3. DATA ACQUISITION AND PROCESSING

3.1 Data Acquisition

National highway of 1km that connects Duwang-ri and Mugeo-ri located at Nam-gu Ulsan-si is selected as target highways for scanning. Target highway section contains straight lines, transition curves, and circular curves and its alignment is in proper condition. Moreover, because target highway was constructed using rigid pavement as shown in Figure 4, it has better laser intensity than that of using flexible pavement and as a result, it increases the information intake rate.

Figure 4. Photo view of test-field area

3.2 Control Surveying

As a critical element for georeferencing, control survey is a procedure that requires extremely close observation. A Sokkia SET230RK3 reflectorless total station was used for control survey and this equipment has the range measurement accuracy of ± (3mm+2ppm) in prism mode and ± (2mm+2ppm) in relectorless mode (Sokkia 2006). Observation was made at each four control points in beginning point and the ending point of target highway. 33 check points were also observed to analyze the accuracy of finally processed three-dimensional information.

3.3 Terrestrial Laser Scanning

Laser scanning of target highway was performed using a Trimble GS 200 scanner by Trimble Inc (Trimble 2004). This scanner uses time-of-flight measurement technology that is based upon the principle of sending out a laser pulse and observing the time taken to reflect from an object and return to the instrument. Advanced electronics are used to compute the range to the target. The distance range is combined with angle encoder measurements to provide the three-dimensional location of a point. It has the field of view of horizontal 360° & vertical60° and maximum 3mm standard deviation in the distance of 50m. Since it uses 532nm visible band laser, RGB information is also available.

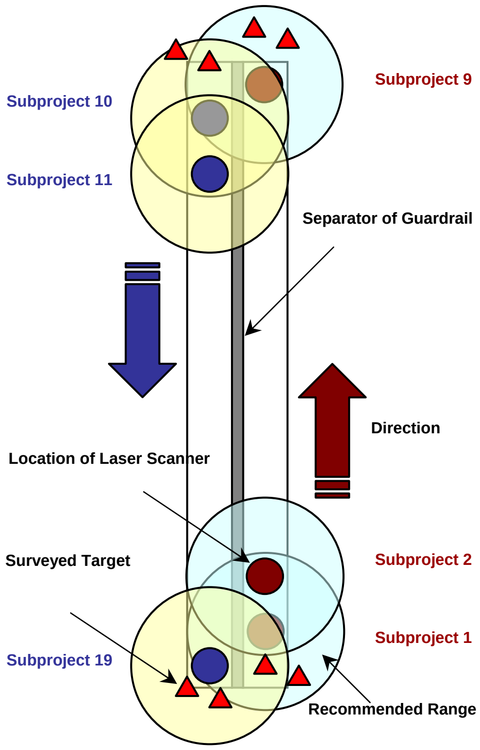


Figure 5. Constituent diagram of laser scanning for registration and georeferencing to involve overall cross section elements in the object highway

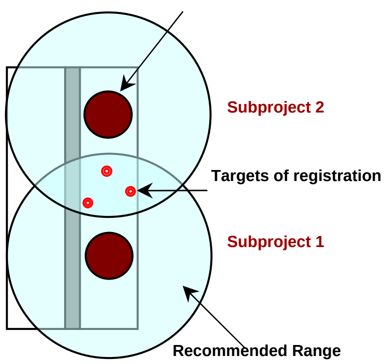


Figure 6. Plan view of target arrangement for the registration of continuous point clouds

Because median barrier and traffic headlight barrier of guardrail form were set up on target highway as shown in Figure 4, it is difficult to contain all the highway cross section elements in one subproject. Therefore, as shown in Figure 5, total 19 separate subproject scannings were performed to duplicate into both sides centering a median barrier.

Three targets were set up at duplicated places as Figure 6 and close scannings were performed for continuous point cloud registration at each subproject procedure. Figure 7 is a point clouds illustration from procedures in one subproject.

Figure 7. Illustration of point clouds obtained from a tangent section

3.4 Data Transfer and Process

As shown in Figure 8, acquired information (point clouds & control points) is sent to and saved real-time in the lab server through socket network method using USB modem.

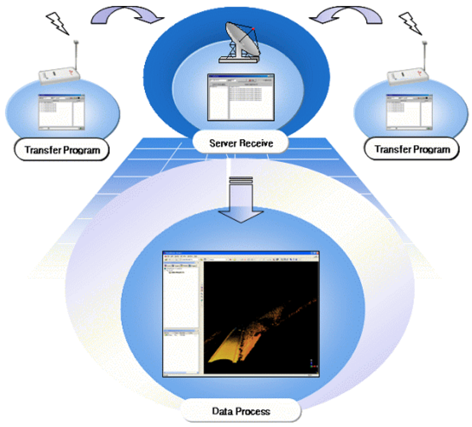


Figure 8. Constituent diagram of real-time socket network method developed in the study

Generally, in the case of transmitting binary files in a subproject might give effects on transmitting speed and cause frequent errors. Hence, files must be conversed to sam(seauential access method) file for the faster transmission of small amount of data. Transmitted sam files are convertible to binary files through file merging system.

As Figure 9 and Figure 10 show, in the process of performing continuous subproject, three targets for registration were set up in duplicated locations and targets were closely scanned in each procedure of subproject.

The center of a target is automatically determined from closely scanned point clouds of targets and registration among continuous point clouds is available through the center of predetermined three targets. The examples for registration of two continuous point clouds from each direction are shown in Figure 11. Point clouds that form the same coordinate system through the registration process, turn into absolute coordinates of target objects by merging with control points. Figure 12 shows point clouds of 1km section in highway as the final georeferenced result.

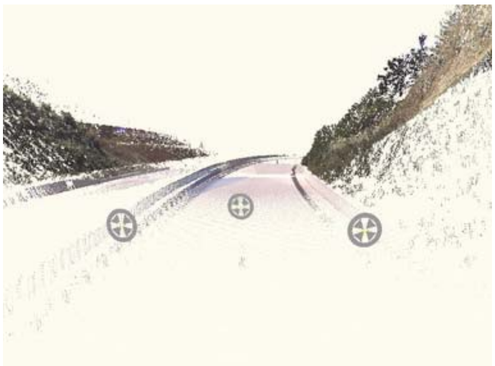


Figure 9. View of precisely scanned targets and point clouds data obtained from the preceeding subproject

Figure 10. View of precisely scanned targets and point clouds obtained from the following subproject

Figure 11. Result of registration from two continuous point clouds measured from each direction

Figure 12. Result of final georeferencing of overall point clouds

3.5 Analysis of accuracy

Point clouds rotate and moves in three-dimensional spaces through registration and georeferencing. To analyze the accuracy of ultimately determined three-dimensional information, the result of 33 check points by control survey was compared to that of laser scanning.

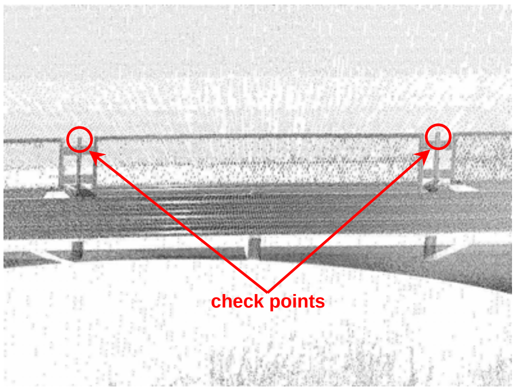


Figure 13. View of check points in point clouds

As shown Figure 13, traffic headlight barrier prop on highway center lines was used as check points. As the results, directional errors are indicated as Figure 14; -0.068~+0.066m in direction X, -0.096~+0.079m in direction Y, and -0.007~+0.090m in direction Z. RMS Error shows ±0.041m to X, ±0.041m to Y, and ±0.025m to Z. Compared to the results from traditional methods, these values show the developments of new method of survey and practical applications in various measurement fields are highly expected.

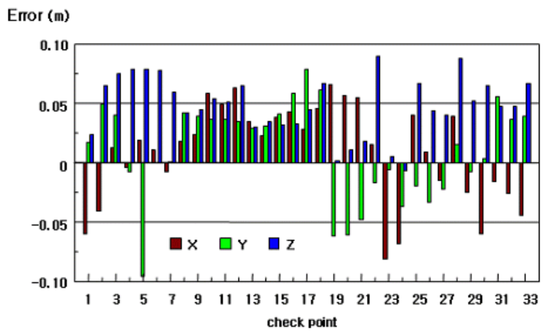


Figure 14. Distribution chart of estimated errors depending on direction

4. HIGHWAY GEOMETRIC INFORMATION EXTRACTION

4.1 Horizontal and Vertical Alignment Elements of Design

As Figure 15 shows, among processed information for horizontal alignment elements of design extraction, 46,280 point data related to the upper part of traffic headlight barrier setting up in median barrier was separately extracted.

Extracted information was divided into straight line sections and curved line sections using simplification algorithm once suggested by Douglas and Peucker (Douglas and Peucker 1973). And horizontal alignment elements of design automatic extraction algorithm developed from the lab in Pukyong National University was also used for extraction (Lee 2001).

In addition, using extracted horizontal alignment elements of design, horizontal alignment was reproduced. 111 elevation data based on accumulative distance was extracted on reproduced highway center lines. Through extracted information, vertical alignment elements of design were automatically extracted and reproduction of elements of design was performed. Comparison between finally extracted horizontal & vertical alignment elements of design and elements of design at the time of making a design is shown in Table 1and Table 2. In Table 1, point of intersection moved 0.001m toward X, and 0.748m toward Y direction and R showed 0.475m gap. This error is estimated by the result of center line construction. Table 2 shows the differences of 3.318m for L, 0.336 for K, and it is recognized as almost the same value considering construction errors.

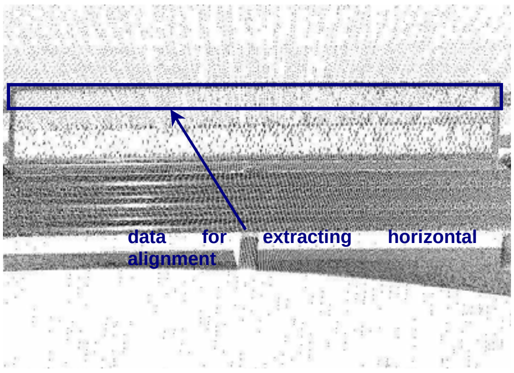


Figure 15. View of measured point clouds for the extraction of design elements in horizontal alignment

	Design values	Extracted values	Differences
PI_x (m)	222676.939	222676.938	0.001
PI_y (m)	226054.609	226053.861	0.748
R (m)	610.000	610.475	0.475
S (m)	1.924	1.869	0.055
L_t (m)	167.869	165.478	2.391
A	320	317.837	2.163

Table 1. Comparison of design elements of horizontal alignment to extracted values

	Design values	Extracted values	Differences
VPI_a (m)	1100.000	1102.038	-2.038
VPI_e (m)	45.920	45.884	0.036
L_v (m)	400.000	396.682	3.318
K (%)	54.795	54.429	0.366

Table 2. Comparison of design elements of vertical alignment to extracted values

4.2 Cross Section Elements

Point data related highway's cross section elements has the contour of cross section elements by the principle of least squares method as it is shown in Figure 16.

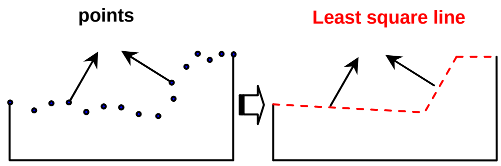
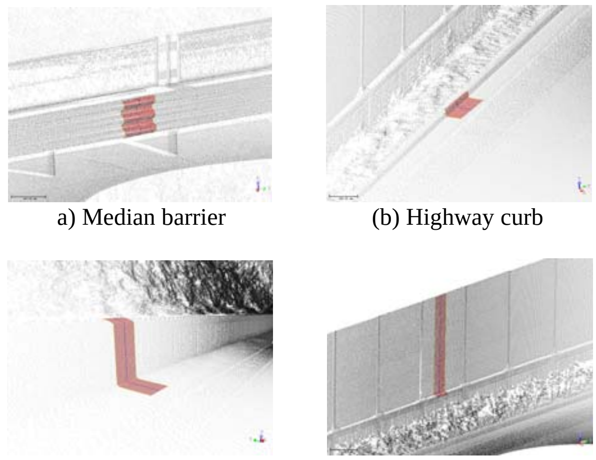


Figure 16. Principle of determining contours of cross section elements using measured point clouds

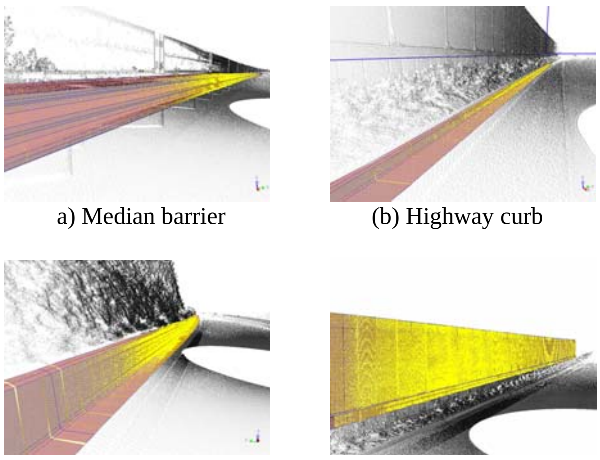
In this study, the contour of median barrier, highway curb on embankment area, L-type roadside barrier on the cut slope area, and roadside soundproofing wall that are all target highway's cross section elements, was extracted at the interval of 0.5m and the contour in the whole section was determined by applying extracted contour to matched section. Figure 17 indicates the results of the contour extraction from point date related to each design of elements and Figure 18 is the results of the extracted contour's application to its matched sections. These extracted contours are saved as dxf format and used to create lateral profiles with 20m intervals.



a) Median barrier (b) Highway curb

(c) L-type roadside barrier (d) Soundproofing wall

Figure 17. Partial contour of cross section elements extracted from point clouds measured at a regularly divided interval.



a) Median barrier (b) Highway curb

(c) L-type roadside barrier (d) Soundproofing wall

Figure 18. Overall contour of cross section elements after applying partial point clouds to the object section

4.3 Superelevation

The result of calculating superelevation in highway with 5m intervals using pre-extracted cross section elements, the superelevation was showed in the range of -5.154% ~ +5.308% . Superelevation profile was created using calculated values of superelevation. It indicates slight gap of ±5%standards. This result tells that target highway's maximum superelevation was established in 5%.

5. CONCLUSIONS

By using terrestrial laser scanning technology, we were able to get target highway's high density three-dimensional information more rapidly and accurately. As the result of processing this information and analysis of its accuracy, laser scanning technology resulted higher accuracy compared to traditional methods. Terrestrial laser scanning technology is expected to be adopted by various fields in the future. Among three-dimensional information, highway center line related information that is automatically divided into straight and curved line sections enabled higher efficiency than traditional manual methods and elements of design can be automatically extracted by newly developed highway alignment algorithm. High density three-dimensional information allows faster and easier highway cross section elements extraction. These extracted cross section elements also enabled extraction of various geometric information such as lateral profiles, superelevation profiles. In conclusion, using laser scanning technology on highway has a great potential for the faster and the more accurate geometric information extraction within highway geometric information system that is about to be developed hereafter.

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NOTATION

The following symbols are used in the paper:

PI = point of intersection;

R = radius of curve;

S = shift;

L = length;

A = parameter of transition curve;

VPI = vertical point of intersection; and

K = rate of vertical curvature.

SUBSCRIPTS

x = x direction;

y = y direction;

a = accumulative distance;

e = elevation;

t = transition curve; and

v = vertical curve.