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Reverse Engineering of a Bobsleigh Structure using LiDAR

Yang, In Tae, Acharya, Tri Dev, Lee, Dong Ha, Shin, Moon Seung *

Lab of GEO-Spatial Information Science, Department of Civil Engineering,
Kangwon National University, Chuncheon, Gangwon, 24341 Republic of Korea
**Corresponding Author*

Abstract

Recent extreme weather events and natural disasters are causing rapid aging of the ancient structures with cultural value. It has threatened the safety and management of civil structures. The construction design documents of old structures are not kept for such long time. Even if they are, they seem to be mismatched with the design structures due to corrosive effects. For these reasons, Korea has been facing difficulties in maintenance, reengineering and safety evaluation. The purpose of the study is to derive the drawings of the existing bobsleigh structure and compare with its original CAD drawing designs. The reverse engineering was done by extracting 3D cloud point data from terrestrial LiDAR system. The comparison results shows minimum error on the reverse engineered drawings, which shows LiDAR can be used for effective reverse engineering tool which takes very short period of time.

Keywords: Reverse Engineering, LiDAR, 3D, Bobsleigh

INTRODUCTION

Recent extreme weather events and natural disasters are causing rapid aging of the ancient structures [1]. Even recent urban structures are undergoing rapid corrosive effect due to causes like acid rain, extreme weather etc. [2,3]. With time these structures are in need of maintenance and safety evaluation. But, the original design documentation are not available, even if they are, the structure seems to have changed. Hence, for the maintenance or safety evaluation, the reverse engineering should be performed. With the continuous development of new sensors, data capture methodologies and multi-resolution 3D representation, it has been increasingly popular in different fields.

Reverse Engineering is the process of discovering information about an object in order to know its technological principles or current status. It is not new engineering method, it has been used in reconstruction of new software's in computer science, applied in design of small mechanical parts to machine works in heavy industries [4]. In real world application, it can be obtained through 3D reconstruction using laser scanners (LiDAR), Synthetic Aperture Radar (SAR) and photogrammetric techniques for various purposes [5-7]. But, in civil engineering works, its application has been limited to safety assessment of structures like bridges and tunnel [8,9]. For these reasons, Korea has been facing difficulties in maintenance, reengineering and safety evaluation.

Hence, the study focuses on application of reverse engineering on a concrete structure. The purpose of this study is to derive information of the existing bobsleigh structure and compare with original design plans with the newly extracted ones. The reverse engineering is done by extracting 3D cloud point data from terrestrial LiDAR system.

LiDAR

LiDAR is a remote sensing technology that measures distance by illuminating a target with a laser and analyzing the reflected light. It is popularly used as a technology used to make high resolution maps, with applications in geomatics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing, atmospheric physics, and airborne laser swath mapping, laser altimetry, and contour mapping.

A ground based LiDAR works on the principle of laser triangulation & time of flight. Triangulation implies between the scanner lens, laser, and object being scanned to obtain accurate 3D data as point cloud. The distance between the scanner lens and laser (parallax base) is known and to find the time of flight/distance between the scanner and the object is by using speed of light and the travel time (figure 1).

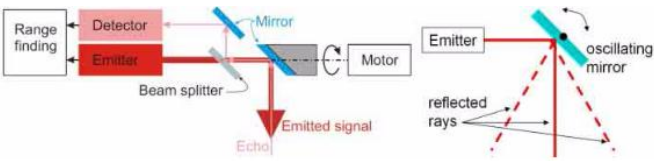

Figure 1 - LIDAR's principles [10].

In triangulating laser scanner, the laser energy is widened in order to form a plane, rather than a beam (figure 2). With the help of a rotating mirror, this plane is swept through object space. All information is provided to obtain x, y, z coordinates of the objects surface. A dense point cloud is then produced through associated software like Cyclone. In recent years, LiDAR has been widely used in reconstruction of complex buildings [11], damage detection and safety assessments of historical building [12,13].

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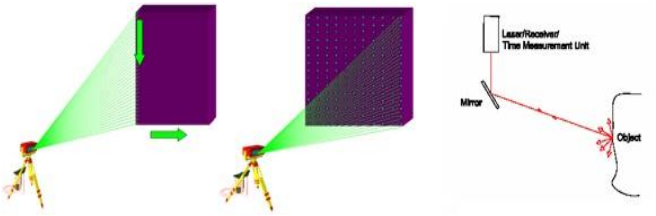

Figure 2 - LiDAR scanning process (Source: Leica-geosystems).

REVERSE ENGINEERING

Reverse Engineering is a concept of engineering in which the produced object is detail studied of its construction and composition through analysis of its structure, function and operation. It is also referred as re-engineering, retro-engineering or reverse-analysis. It somehow contracts the main principle of the engineering concept in dissembling as primary step and analyzing a moving part in detail for archiving a plain duplicate or modification for better ones. The process can be of software program, mechanical or electronic device, and also artistic models, cultural monuments or buildings. It is often done because previous documentations of the object is never written, no longer available or changed over time.

In Civil works, it can be obtained from various processes, but the basic approach is to recreate the 3D model and make measurements over it. Reverse Engineering takes widely advantageous in the field like Cultural Heritage Conservation, the motor industry, aviation industry, medical device, game, animation industry. Figure 3 shows the concept of reverse engineering of a concrete bobsleigh structure and CAD design.

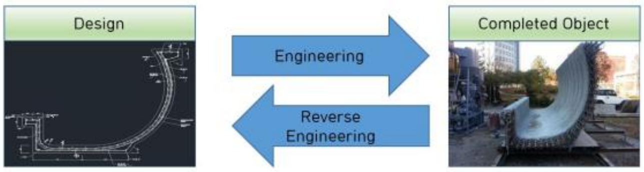

Figure 3 - Reverse Engineering concept.

METHODOLOGY

Basically, reverse engineering contains two parts, first digitizing the object and 3D modeling of the digitized object. Here, the study focuses to derive the complete 3D model through laser scanning of an object and different measurement will be carried out to create the construction plans and drawings of the object. The study object selected in this study is a concrete bobsleigh track of is 6m x 2m x 2m dimension (figure 4). It was constructed using shotcrete by civil engineering structure lab of Kangwon National University and was completed on July, 2013.

Figure 4 – Concrete bobsleigh structure.

Laser scanning has been very robust technology in creating 3D structure through points cloud. In this study, Topcon GLS-1500: a long range high speed precise scanner has been used for the scanning of the object (figure 5). In the scanning process, after the selection of the object, scanning as well as target scanning points has to be very carefully determined. Each scan face should have targets for tying the alignment and merging of the surface so that all dimensions are covered without obstacles. It is recommended that, the number of target must be at least 3 in number with min two in one scan. Figure 6 shows positions of the object along with LiDAR scan and target stations.

Figure 5 – Topcon GLS-1500.

For better result, the scan and target positioning while merging, the points were surveyed using Sokkia GRX2 GPS. Also, LiDAR uses its relative coordinate system while obtaining of the position of the points in object. It is essential to either provide absolute coordinate system or transform the cloud point to it. The GPS used in the measurement of the coordinate is recorded in Transverse Mercator (TM) system. The coordinates of the target points are as shown in Table 1.

Table 1. Coordinates of the target

Point	X	Y	Z
Target-1	585784.452	265083.550	108.000
Target-2	585779.487	265058.405	108.022
Target-3	585772.127	265065.617	108.043

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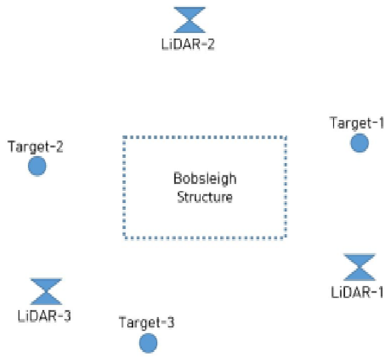

Figure 6 – Layout of the scan and target control point around bobsleigh structure.

Topcon ScanMaster software was used for processing of the LiDAR point cloud and the drawing and comparison were done in AutoCAD. In creating the cloud point in Topcon ScanMaster, the scan were aligned, and merged based on target and control points. The unnecessary background were trimmed and mesh was created for the smooth surface of the object. Similarly, after exporting the edited final point cloud in CAD, line and polygons were drawn for the surface.

RESULTS

Data processing

The scan resolution of the LiDAR was 5mm x 5mm which has resulted in large amount of cloud data. First of all, the cloud data were thinned through filtering for the processing and cleaned for the required structure only. The scans were registered according to the common targets and control points. Scanning resulted in many data with relative 3D coordinate due to scanning from many sides. Those scans were combined for creating a common surface based on same coordinate system through registration (figure 7).

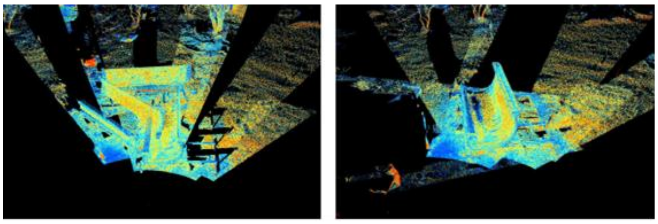

Figure 7 – Registration of scans.

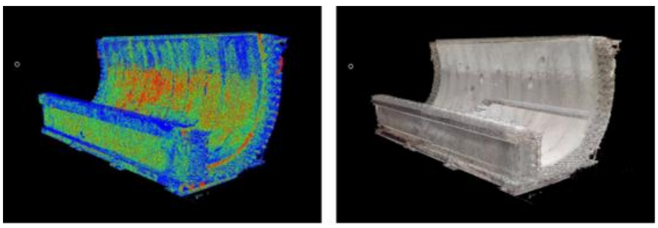

Figure 8 – Complete point cloud and image in 3D.

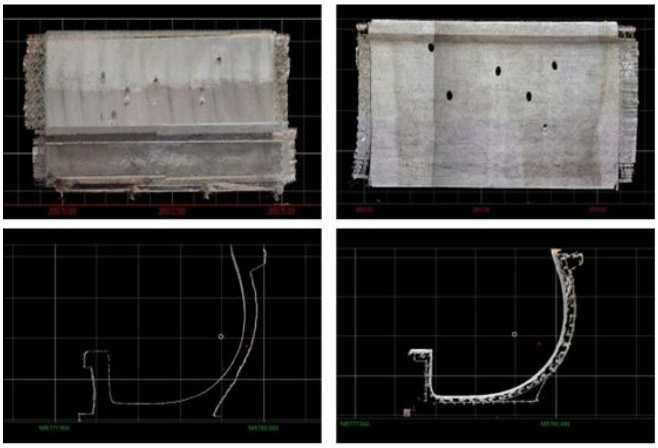

Figure 9 – Front, back and cross sections views.

Most of the work form scanning to 3D cloud point filtering, registration and 3D model generation is done in Topcon ScanMaster software. The RGB scans are shown in the figures 8 and 9, where colour represents the reflected intensity. The final 3D structure was exported to AutoCAD in different views, front, back and cross sections (figure 9). In figures 10-12, left images show the images simple exported image whereas the right one is viewed in vector views in AutoCAD. All the export images were derived from ScanMaster to AutoCAD.

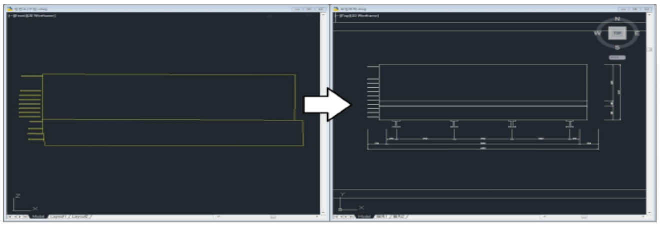

Figure 10 – Measurements of front view export.

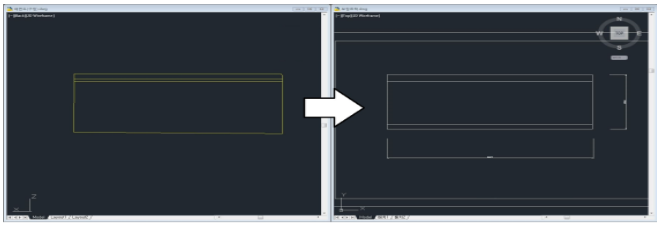

Figure 11 – Measurements of back view export.

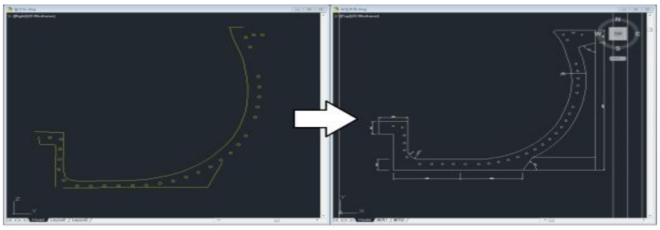

Figure 12 – Measurements of front cross-section export.

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Comparison

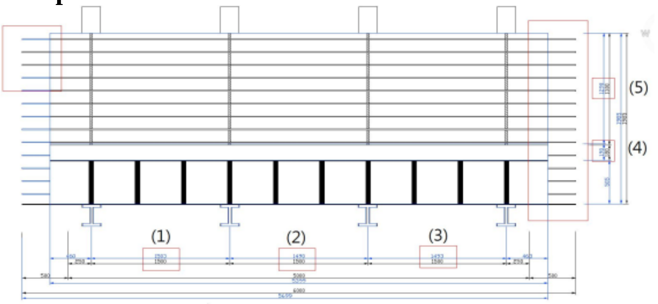

Figure 13 – Front view comparison.

The structure of bobsleigh construction was based on the original track design guidelines of Fédération Internationale de Bobsleigh et de Tobogganing (FIBT). The original CAD drawings were used to compare with the reverse engineered outputs. The comparisons were done on AutoCAD in different view. Figures 12-15 show the measurements that were done in front, back and cross-section view of the object.

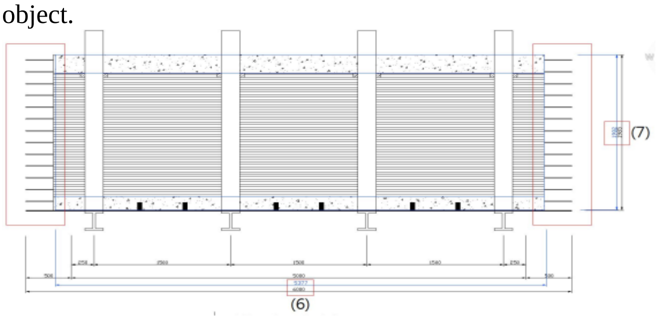

Figure 14 – Back view comparison.

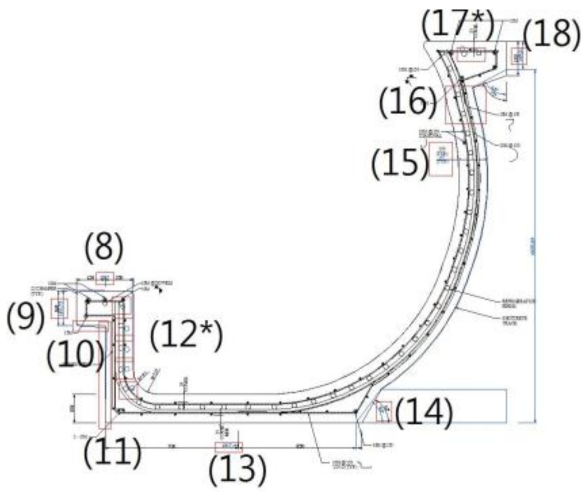

Figure 15 – Cross-section comparison.

Table 2. Comparison analysis

S. No.	Original data (m)	LiDAR data(m)	Error (m)	Side
1.	1.500	1.503	+0.003	Front view
2.	1.500	1.490	-0.010	Front view
3.	1.500	1.493	-0.007	Front view
4.	0.180	0.190	+0.010	Front view
5.	1.300	1.290	-0.010	Front view
6.	5.400	5.377	-0.023	Back view
7.	1.985	1.982	-0.003	Back view
8.	0.300	0.297	-0.003	Cross-section
9.	0.180	0.184	+0.004	Cross-section
10.	0.125	0.158	+0.033	Cross-section
11.	0.505	0.495	-0.010	Cross-section
12.	0	0.031	+0.031	Cross-section
13.	1.350	1.317	-0.033	Cross-section
14.	0.202	0.221	+0.019	Cross-section
15.	0.150	0.147	-0.003	Cross-section
16.	0	0	0	Cross-section
17.	0	0.030	+0.030	Cross-section
18.	0.180	0.150	-0.030	Cross-section
Mean error			0.01456	
RMSE			0.018753	

First of all, the corners were matched for the matching of the two different sources. In the above figure, random lines were selected across the outline of the structure, which can be seen as numbers in brackets. Front, back and cross-section view were sampled at 5, 2 and 11 lines respectively. In the front view, the error was found to be -0.023 to -3.003m. In back view, error ranged from -0,023m to +0.003m. Similarly, the cross section has error ranged from 0m to + 0.033m. The total RMSE is ±0.018753m. The detail of the displacement error can be seen in table 2.

CONCLUSION

The purpose of the study was to derive the drawings of the existing structure and compare with the original. The reverse engineering was done by extracting 3D cloud point data from terrestrial LiDAR system. After comparing the reversed engineered structure and original design drawing, the displacement has been found from 1mm to 33mm in different from lack and lateral view. The RMSE was found to be ±0.018753m. These error might be result of error while control point establishment and error due to construction. From the study, it can be concluded that, LiDAR can be used for effective reverse engineering tool which takes very short period of time. Further works, will be more focused on the complex historical monuments, volumetric analysis and automation of the CAD designs.

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