GEOMETRIC VERIFICATION OF A LIDAR SIMULATOR

Minsoo Son[1] , Seongjoon Kim[2] and Impyeong Lee[*3]
[1]MSc Student, [2]PhD Student, Department of Geoinformatics, The University Of Seoul,
Seoulsiripdaero, Dongdaemun-gu, Seoul, 130-743, Korea; Tel: +82-2-2210-5422;
Email: 88monkee@hanmail.net

[3]Associate Professor, Department of Geoinformatics, The University Of Seoul,
Seoulsiripdaero, Dongdaemun-gu, Seoul, 130-743, Korea; Tel: +82-2-2210-5638;
E-mail: iplee@uos.ac.kr

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ABSTRACT

Many kinds of LIDAR systems have been developed according to their specific purposes. Also, the system simulation studies have been conducted simultaneously to predict its performance and to determine optimal system parameters. However, the validation of simulation systems in previous studies was not fully satisfactory, since most of researchers focused on simulation techniques only without considering validation. In this study, we propose verification techniques for a simulation algorithm in geometric aspect. This method is to analyze the geometric similarity by comparing the simulated results with real point cloud. We developed the LIDAR simulation software in our previous study. The simulator, which can generate the point cloud with given parameters, is based on comprehensive studies including geometric, radiometric, optic and electronic models. It can also deal with the geometric errors, radiometric, and electronic noises. To verify our simulation algorithm, we first created a simple miniature, and constructed the model data with its geometry, formatted in B-rep. We then generated the simulated and real point cloud on the same targets, and compared both data sets. The experimental results showed that the geometry of the simulated point cloud was similar to the real data. We expect that our method will be useful to validate and improve the LIDAR simulation to resemble the real system, more closely.

1. INTRODUCTION

LIDAR (Light Detection and Ranging) transmits laser pulses to targeted surface or object and measures the distance by detecting the reflected signal. The system is so fast, accurate and stable that today it has been used for diverse applications including DEM (Digital Elevation Model) generation, three-dimensional city modeling, tree height measurement, change detection and contour extraction. To develop a commercial LIDAR system, sensor hardware and involved parameters are needed to be adjusted to optimize for predicting and improving the performance. However, it is not efficient in terms of cost and time to test these aforementioned processes using the actual systems. Thus there are many simulation system studies that have been actively taking place to determine the optimal parameters of the system concurrently with the sensor development. A LIDAR simulator is designed based on the physical characteristics of real system and the most realistic data should be obtained. Due to the environment and systematic inaccuracy, however, the discrepancies between real data and simulation data cannot be avoided. As a result, it is necessary to verify and improve a simulation algorithm by comparing and analyzing the differences between these two data sets.

Most previous studies on LIDAR simulation aimed to visualize the real and simulated data for their verification, but some studies attempted to verify with more reasonable and quantitative methods. Kukko A. *et al.* (2007) generated simulation data for the ground model based on multi-strip point data acquired from the actual LIDAR system, TopoSys Falcon. The simulator was designed to consider the characteristics of two LIDAR systems, TopoSys Falcon and Optech ALTM 3100, and qualitative comparison was conducted by visualizing the data color-mapped with its height values. Carlsson T. *et al.* (2001) carried out a verification using the distance images and waveform data generated from their simulator. The results showed that there were differences between received signal power of real and simulated data because the waveforms were filtered and amplified in laser radar device while the shapes of received waveforms for each pixel were sufficiently similar. They also compared simulated and actual distance image with a perfect distance image in aspect of target figure. O'Brien M. E. *et al.* (2005) designed a LIDAR simulator, using Geiger mode APD detector, and verified its performance through a direct comparison test of measured and simulated data. They also noticed the differences using a statistical histogram, depending on the height values of all points, and compared the accuracy of ICP (Iterative Closest Point) registration with the CAD model, generated from real object. In the second case, those used as measures of the accuracy are the number of data points connected with CAD model and the average squared separation distance between the two data point sets.

In the previous studies, obtained waveforms or images are simply visualized. The work from O'Brien *et al.* present reasonable results, but there are still a lot of differences in the histogram as well as matching error with CAD model because of that complex target object, difficult to accurately model, and wide ground data are used.

In this paper, we propose an efficient method to verify the performance of a simulation algorithm. The purpose of this study is to apply a quantitative data comparison method based on statistical / mathematical techniques and to derive the reliable experimental results. We create a simple miniature to define the exact geometry in order to reduce the error and obtained measured and simulated data using the same environment variables. For both point clouds, we then calculated the range from the origin of the scanner and evaluated the differences through histogram visualization. In addition, by calculating the mean separation distance between the planar-approximated object model from real data and simulated point cloud data, we could evaluate statistically how well our simulator can produce outputs similar to the real system.

2. LIDAR SIMULATOR

In our previous work, we developed comprehensive LIDAR simulation software mainly composed of three modules (geometric, radiometric and visualization module). The each module is organized by modeling sensors, object and beam profile, etc. The geometric module is to determine the relationships between a LIDAR sensor and targets geometrically (Kim *et al*, 2009). We navigated to the target surface where the beam intersects and calculated the geometric distance from the optical focus to the intersection point. The radiometry module computes the incident energy, corresponding to each detector pixel, of both the transmitted laser pulse and the noise and also generates the waveform data which means the energy detected in time domain for each pixel. Finally, the visualization module is designed to provide the input/output data, such as targets and background models, 3D point clouds, range images and waveform of each pixel, for users. The detailed models of the modules are shown in Table 1.

<table>
<tr><th>Geometric module</th><th>Radiometric module</th><th>Visualization module</th></tr>
<tr><td>Detector model</td><td>Pulse model</td><td>Model view</td></tr>
<tr><td>Scanning model</td><td>Beam profile model</td><td>3D points view</td></tr>
<tr><td>Vehicle motion model</td><td>Receiver model</td><td>Image view</td></tr>
<tr><td>Beam ray model</td><td>Noise model</td><td rowspan="3">Signal view</td></tr>
<tr><td>Object model</td><td rowspan="2">Waveform model</td></tr>
<tr><td>Intersection model</td></tr>
</table>

Table 1. Geometric / Radiometric / Visualization modules

3. METHODOLOGY OVERVIEW

A LIDAR simulator is used for system development and improvement by providing a test data based on adjustable environment parameters and the output data should be verified. In other words, a validation process should be conducted through the analysis of the quantitative similarity of these actual LIDAR data assumed to be true and simulated data. The simulation data is generated from the simulator designed to have same conditions with real LIDAR system's characteristics and environment parameters. The obtained data sets are basically made in the form of point cloud. Therefore, those can't be directly compared because the identity of the individual points certainly does not match. So, in this study, 1) the range distribution of points in the two sets of data is confirmed, 2) the mean distance between the planes, approximated with the real data, and simulated points are calculated. (Figure 1)

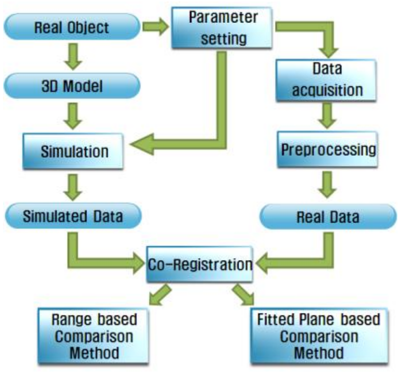

Figure 1. Study flowchart

3.1 Range based method

In accordance with the methodology in Figure 2, distances from the origin of the scanner to the target for every point have been computed and then according to the frequency distribution histogram of distance values are written. Similarly the number of points in each distance interval versus the total number of acquired points, which means that the ratio, is normalized to create normal histogram. In addition to the number, the ratio of data points is being analyzed and we can verify whether similar results to actual ones can be generated from the simulator.

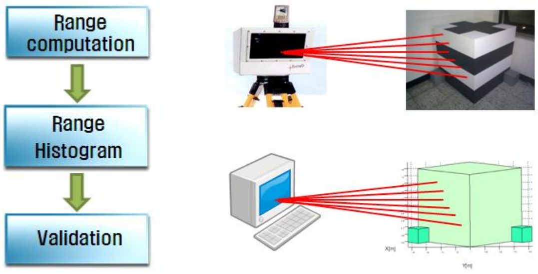

Figure 2. Range based methodology (left) and Range calculation (right)

3.2 Approximated-Plane based method

Object model estimated from the actual data is assumed to be true and compared with the simulated data. As shown in Figure 3, segmentation of measured and simulated point cloud data and extraction flat patch points as the object surface are done and three-dimensional plane equations applied differently by each of the patch. With such a way, coefficients of the planes, approximating the measured data points that make up each patches, is estimated. The process is accomplished through least squares estimation using a Gaussian-Markov model. Finally, an average distance between the planes and the simulated / real data points (x_i, y_i, z_i) are calculated and thus used as a measure of tolerance.

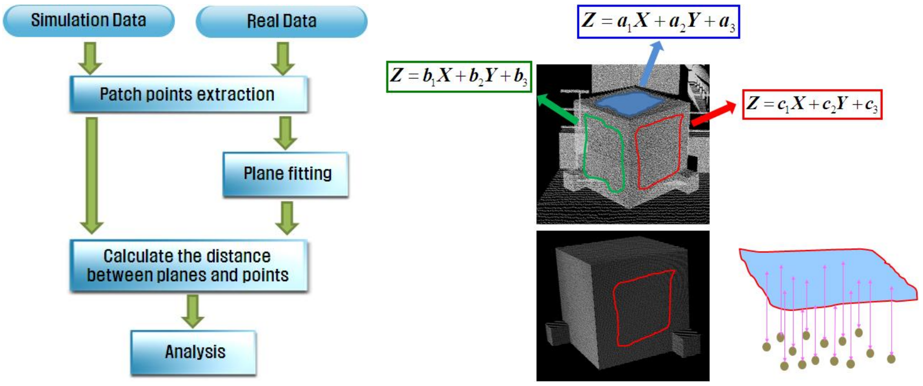

Figure 3. Approximated-plane based method (left) and approximation of each surface point to a plane, and the distances between the planes and the corresponding simulated data points

4. EXPERIMENTS

4.1 Actual data acquisition and preprocessing

We needed to obtain actual data to validate the developed simulation algorithm. It is a simple cube of the 1m length of each side and two cubes with 20cm length of each side were further combined at the bottom of the model (left picture of Figure 4). An opaque PVC material was used to prevent the beam penetration or inside scattering. The equipment used in the data acquisition is ILRIS-3D, the terrestrial LIDAR system created by Optech corporations, and major specifications of the system are shown in Table 2.

Scanner Performance	
Scan pattern type	Step Stare
Scanning range	3m ~ 1000m
Laser Pulse Repetition Rate	2000 Hz
Raw Range Accuracy	7mm@100m
Beam Divergence	0.00974°(170μrad)

Table 2. Main system specifications of Optech ILRIS-3D system

We scanned at 24.00 m apart from the target, and with point spacing of about 7.0 mm for around the model. In experimental results, a total 118,604 shots were transmitted and 103,704 shots which are reflected from the target have been received by the detector. Using a terrestrial LIDAR system to scan, there are very dense points obtained without the necessary points. Therefore, we removed background points and outliers in received points using commercial software, InnovMetric IMInspect V8.0, and lastly 31,555 points were acquired.

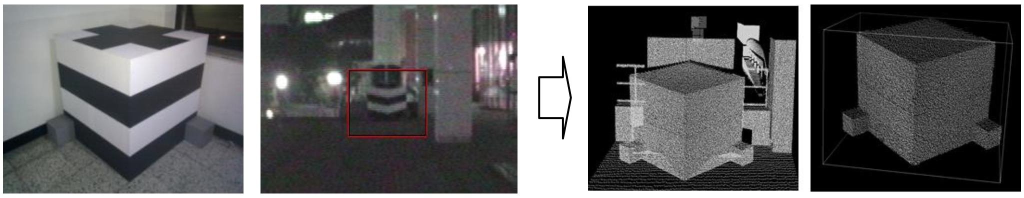

Figure 4. Miniature model and data acquisition area (left), Before/After outlier removal (right)

4.2 Simulation data generation

We adjusted simulation parameters to achieve the same environmental / systematic conditions, scanning mechanism, etc, with the real system as possible and generated simulation data. The data structure used as input to the LIDAR simulation has to be represented in a way of boundary representation, B-rep, an individual object is represented by single polyhedral models that make it a list of faces, edges and vertices. We entered the model defined as illustrated in Figure 5 to our simulator and created total 35,159 simulated points as a result.

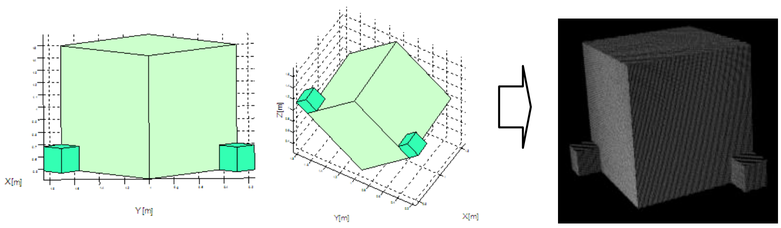

Figure 5. The miniature with B-rep format inputted to the simulator (left) and generated Simulation data (right)

4.3 Co-registration

The two data sets have different coordinate systems as shown in Figure 6. The actual data set have a coordinate system with the origin of laser transmitter as its standard, and the coordinate system of the simulation data is based on center of the object model. Through coordinate transformation, the two data sets can be easily visualized, ascertained with eyes and numerically analyzed to confirm the difference. The three-dimensional transformation was then performed from 5 conjugate points, and set from the intersection of three planes, using commercial software, PolyWorks IMInspect program module.

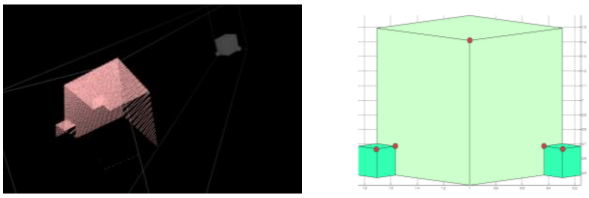

Figure 6. Coordinate difference between two data sets (left) and Extracted five conjugate points (right)

4.4 Comparative study

4.4.1 Result of the range based methodology test

We computed ranges from sensor to target points and analyzed it with histogram. The graphs in Figure 7 show the histogram illustrating the number of points for range intervals and its normalized histogram, respectively.

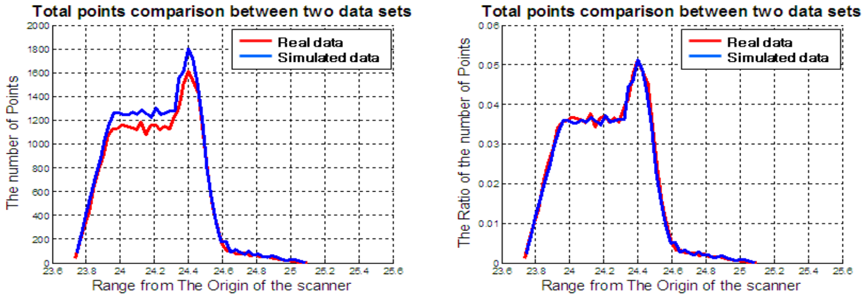

Figure 7. Range histogram (left) and normalized range histogram (right)

In the histogram with the number of points there appeared an average of about 100 differences as many in each interval caused by irregularly distributed noise. However, examining the normalized histogram the distribution differences of actual and simulated data for each interval are within about 0.1% as similarly.

4.4.2 Result of approximated-plane based methodology test

As shown in Figure 8 and Table 3, we extracted points comprising each patch of real data and estimated coefficient of each plane, and then calculated the distance between approximated planes and simulated points. The absolute values of average distance between the estimated planes and the point data sets are shown in Table 4.

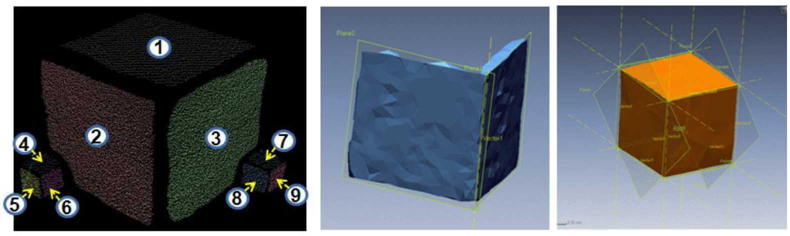

Figure 8. Nine patch configuration (left) and plane fitting procedure (right)

Plane Coefficient		Patch Number								
		1	2	3	4	5	6	7	8	9
$\hat{\xi}$	a	-0.0068	-5.2942	5.3384	0.0043	-3.0086	3.3045	-0.0089	-2.8331	3.9314
	b	0.1758	-5.3171	-5.0953	0.1966	-3.0343	-3.2052	0.1785	-2.9453	-3.6851
	c	-4.6609	127.8994	118.0402	-5.9813	71.5532	77.4906	-5.5369	73.5125	83.8237
$\hat{\sigma}^2_0$		0.000007	0.003285	0.002470	0.000015	0.001084	0.001131	0.000010	0.001153	0.000693

Table 3. The Plane coefficients on each patch ($\hat{\sigma}^2_0$is a variance component estimate)

		Patch Number									Mean Value
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Simulated data	**Average distance**	0.0033	0.0013	0.0017	0.0006	0.0043	0.0035	0.0050	0.0051	0.0032	**0.0031m**
	Standard deviation	0.0023	0.0009	0.0016	0.0004	0.0026	0.0022	0.0006	0.0034	0.0022	**±0.0014**
Real data	**Average distance**	0.0020	0.0060	0.0053	0.0028	0.0060	0.0058	0.0023	0.0067	0.0039	**0.0045m**
	Standard deviation	0.0016	0.0047	0.0041	0.0025	0.0044	0.0041	0.0021	0.0045	0.0028	**±0.0034**

Table 4. The absolute average distance between the nine estimated planes and simulated / real data points

5. CONCLUSION

In this study, we proposed the methodologies to verify the performance of the LIDAR simulation model through quantitative comparison with actual data. We calculated the range values to all points of the two data sets with respect to the origin of the scanner, and confirmed the differences using (normalized) histograms. The result showed that the two data sets were nearly identical in normalized histogram. On the second approach, mean distance between estimated object model from the real data and the simulated / real data points has been calculated in order to examine how similar is the data generated from the simulator to the real one. In future, we will improve the simulation algorithm and verify it using airborne LIDAR data for larger areas. We expect that our method will be useful for improving LIDAR simulator performance.

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