POINT DENSITY SIMULATION FOR ALS SURVEY

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ABSTRACT:

Important information can be derived from Digital Elevation Model (DEM) such as deformation monitoring and disaster reduction planning. Airborne Laser Scanning (ALS) is commonly used to generate the DEM. And, the quality of DEM is positively correlated with the density of the point cloud. From the Quality Assurance (QA) perspective, it would be beneficial to know the point density of a ALS survey before the survey is been conducted. This paper proposed to simulate point density through a laser scanning simulator, HELIOS. The point density was calculated and analyzed by adjusting the flight lines and the ALS scanning parameters in HELIOS. The 20m DEM model of Taiwan was employed for simulation. However, computation time becomes a critical issue when the ALS survey covers a large area, i.e., a large portion of Taiwan Island. In order to reduce the simulation time, the downsampling process was conducted by reducing the pulse frequency in HELIOS followed by compensating for the reduction factor. The results showed that with different parameter settings of the scanning flight lines with different downsampling rate to show the effect of downsampling process. As a result, we can further use HELIOS for QA process and improve the simulation efficiency.

1. INTRODUCTION

Digital Elevation Model (DEM) plays an important role in many aspects of application such as deformation monitoring, disaster reduction planning and analysis of environmental changes due to a natural disaster. High-resolution DEM data can also be used to derive important topographic and hydrological parameters such as basin relief and the flow path (Xie, Pearlstine, and Gawlik 2012). Thus, the accuracy of DEM is crucial. Traditional methods such as field surveying and photogrammetry can yield high-accuracy terrain data, but they are time consuming and labor-intensive (Liu 2008). Airborne Laser Scanning (ALS), which also referred to as Airborne Light Detection and Ranging (LiDAR) is widely used to gather the accurate and dense topographic point cloud data. One of the features in the ALS system is that the data output is the direct availability of 3D coordinates of points in the object space (Habib et al. 2005). ALS data have become a major source of digital terrain information (Raber et al. 2007). Actually, ALS is the most effective data acquisition technology for the production of high resolution, high-quality DEM (Forlani and Nardinocchi 2007). Thus, the quality of terrain modeling has been focusing on ALS data acquisition. The denser the ALS point cloud data is, the higher quality of the derived DEM will be. Thus, evaluating the point density in advance is essential for ALS data collecting mission.

Quality Assurance (QA) implies to ensure the manufacturer or company to follow the standard operating procedure or guidelines in the data collecting process. An example of a LiDAR QA activity is gaining prior knowledge of the area to be surveyed in terms of its extent in order to set up the appropriate flight specifications (Habib and Rens 2007). In addition, evaluating point density becomes the way to ensure the point cloud quality. Prior to ALS data collection, a flight planning is needed. However, it is difficult to know whether the flight mission plan meets the requirement of the point density in a varying terrain. This paper proposed to simulate point density through a laser scanning simulator, HELIOS. HELIOS is a laser scanning simulator implemented as a Java library. Through HELIOS, it might be possible to replace the operation of a real laser scanner with a simulation, resulting in a massive reduction of costs and effort (Bechtold and Höfle 2016). In this research, the 20m DEM model of Taiwan was employed for simulation. In this research, the downsampling process was applied to reduce the simulation time. The effect of the downsampling process was shown in the end.

2. METHOD

2.1 HELIOS

HELIOS is a laser scanning simulation framework, which is an abbreviation of Heidelberg LiDAR Operations Simulator implemented as a Java library and multiple extension modules. Extensible Markup Language (XML) is used to define scanner, platform and scene models and to configure the behaviour of modules (Bechtold and Höfle 2016). HELIOS can be used to simulate surveys with different scanner platforms such as ALS and terrestrial laser scanning (TLS), which shown in Figure 1.

The simulation assets were set up such as scene, platform and scanner definitions from XML files to start simulation. HELIOS provide real-time 3D visualization so that the simulation process can be checked in time. Moreover, HELIOS support the scenes with 3D geometry which is an essential requirement for realistic ALS and TLS simulation.

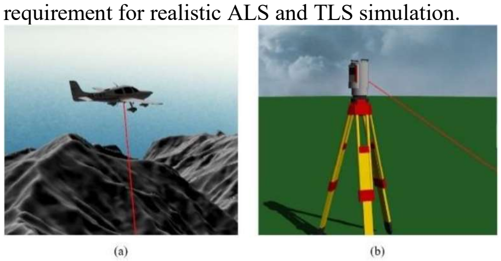

Figure 1. Surveys with different types of scanner. (a)ALS (b)TLS (Adopted from HELIOS)

2.2 Study area and dataset

In this paper, the study area is in Pingtung, Taiwan, where it sits in southern Taiwan (Figure 2). In this study area, it is the southernmost of the Central Mountain Range. The highest altitude is up to 2800 meters contrast to the lowest altitude is about 450 meters. The 20-meter resolution DEM of Taiwan (Figure 3) was acquired for HELIOS simulation process. The 20m resolution DEM is an open data provide by Ministry of the Interior (MOI), Taiwan, which stores the elevation and coordinates in each grid. The generated DEM model shown in Figure 4.

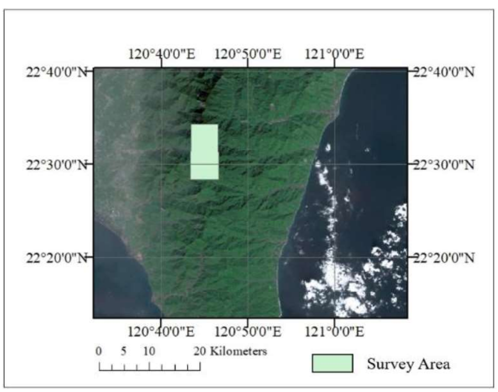

Figure 2. Study area

Figure 3. 20m resolution DEM of Taiwan

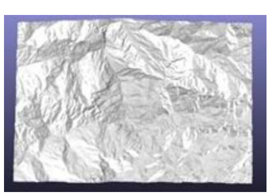

Figure 4. Generated DEM model

The reference point cloud data we use to validate the simulation result is from Leica ALS70. The parameter settings for the flight line scanning such as flying altitude, Field of View (FOV), scan frequency, pulse frequency and flight speed are involved in HELIOS for simulation. Through these parameter settings, the estimated average point density is 1.6 points/m^2. We simulate one flight line through HELIOS to compare with reference point cloud data in this research.

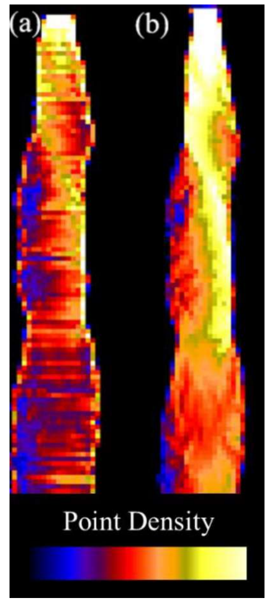

Figure 5. Point cloud color by point density. The yellow color refers to the highest point density, and the blue color refers to the lowest point density. (a) reference point cloud (b) simulated point cloud

2.3 Downsampling of ALS simulation

In order to reduce the simulation time to improve the efficient of QA process, we conduct the downsampling process in HELIOS by reducing the pulse frequency. The side effect is that the point cloud resolution will be increased. The relationship between transverse resolution and point spacing is shown in the equation below:

$$\theta = \text{FOV} \times \text{ScanFreq} / \text{PulseFreq} \quad (2)$$

$$\text{Point Spacing} = h * \tan\theta \quad (3)$$

Where θ = Transverse resolution (deg)
ScanFreq = number of scan lines per second in hz
PulseFreq = number of laser pulses per second in hz
h = Flight altitude (m)

When the point spacing become twice, the point density is half than original simulation result. Through adjusting the pulse frequency to reduce the point density, the simulation time will reduce as well. The downsampling rate is the number indicates that how much we reduce the point density. For example, when the downsampling rate is 2, which means the point density will be half of the original simulation point cloud data. We need to restore the point density after doing downsampling process so that we can compare with the reference data. If we use downsampling rate of 2 to simulate, the simulated point cloud will be multiplied by two. Hence, the down sampled point cloud data can be used to evaluate point density in the end, meanwhile we can save large amount of time on simulation process.

3. RESULT

We input the parameter settings of scanning flight lines same as the reference flight mission plan. Figure 5 (a) shows the reference point cloud, while Figure 5 (b) shows the simulated point cloud. In order to compare the reference and the simulated point cloud data, the point density was calculated in both data, we set 10000 square meters in each pixel to calculate point density. Then RMSE was derived from the equation below:

$$\text{RMSE} = \sqrt{\frac{\sum(Ei-Oi)^2}{N}} \qquad (1)$$

Where E_i = simulated point cloud density (points/m^2)

O_i = reference point cloud density (points/m^2)

N = total pixels

Through this equation, a value of 4.962 points/m^2 RMSE was observed between the reference and simulated point cloud data. This numbers implies that there is a system bias between simulated data and reference data. By comparing both point cloud data with 2D scatter plot. In Figure 6, x-axis present the point density of the reference point cloud, and y-axis present the point density of the simulated point cloud. It was found that point cloud data are positively correlated.

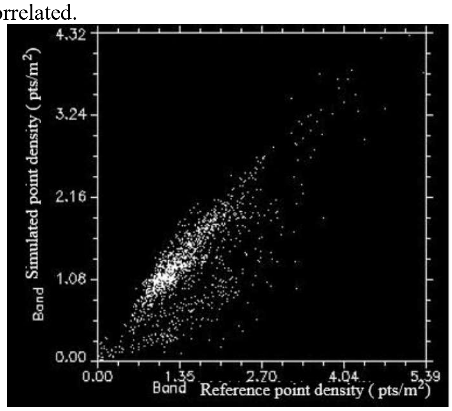

Figure 6. Comparison of reference and simulated point cloud.

Only single flight line was simulated in this experiment. However, there are some problems occur while simulating a large survey area with large number of flight lines. The most critical issue is that it cost too much time for simulation, such as two hours of simulation with one flight line which is 10 km long for this experiment. In addition, there are 7000 km long flight lines in each survey area on average for survey company to conduct a survey project each time, which means there will be 3500 hours for simulation. In case of using HELIOS for QA of ALS flight mission plan, waiting time is too long for simulation result. Furthermore, when survey company find that their flight mission plan needs to be modified, then they need to adjust the scanning parameters and conduct simulation process again. This will cost more time so that the QA process became very inefficient.

Different downsampling rate have been experimented to reduce the simulation time and compare with the reference point cloud. Finally, the RMSE and simulation time was calculated as shown in Figure 7.

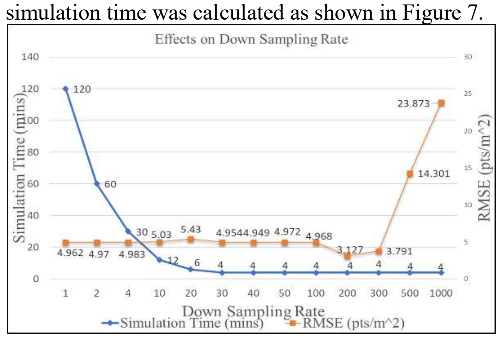

Figure 7. RMSE and simulation time of HELIOS with different downsampling rate

It was found that the RMSE remained stable (4.97 – 4.968 points/m^2) for the downsampling rate of 2 to 100. And, the lowest RMSE value occurred at the downsampling rate of 200 (Figure 7), and then dramatically increased when the downsampling rate was higher than 300.

The computation time showed an asymptotically decreasing pattern with increasing downsampling rate. When the downsampling rate was 2, the simulation time was half of the simulation without downsampling. When the downsampling rate was 4, the simulation time became a quarter. When the downsampling rate was greater than 30, the simulation time stopped decreasing. As a result, the simulation time was decreased from 120 minutes to 4 minutes, a 30 fold increase of computation time was achieved.

By comparing reference and simulation point cloud data in different downsampling rate in 2D scatter plot. When the downsampling rate was 4 and 20, the result was positively correlated, which is shown in Figure 8(a) & (b). When the downsampling rate was 50 (Figure 8(c)), the result showed less degree of positive correlation, with the data gathered up into several parts. When the downsampling rate was greater than 50, (Figure 8(d), (e) & (f)), the simulated point cloud data become uncorrelated and scattered.

Histogram is also used to analyze the distribution of the reference and simulated point cloud. In Figure 9 (a), the distribution of simulated point cloud with downsampling rate of 1, 2 and 4. The distributions are similar to reference point cloud. When the downsampling rate was higher than 10 (Figure 9 (b)), the distribution become irregular. In this case, the simulated point cloud become unreliable. As a result, it can be concluded that when the downsampling rate is too high, the simulated data generates distortion.

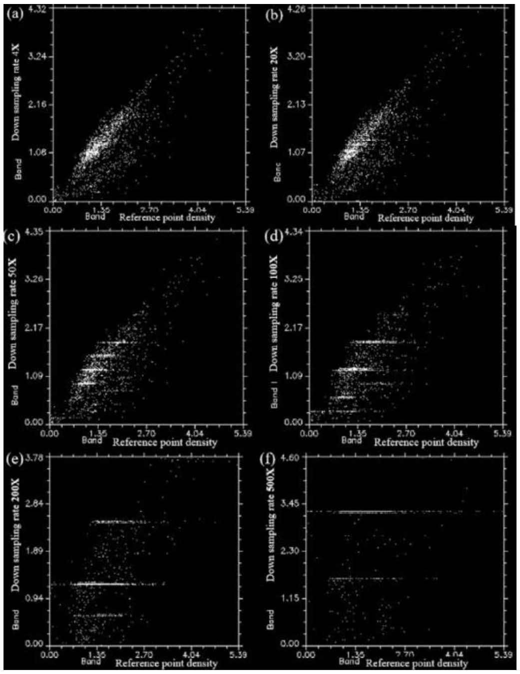

Figure 8. Comparison of reference and simulated point cloud with different downsampling rate by 2D scatter plot (downsampling rate (a) 4 (b) 20 (c) 50 (d) 100 (e) 200 (f) 500

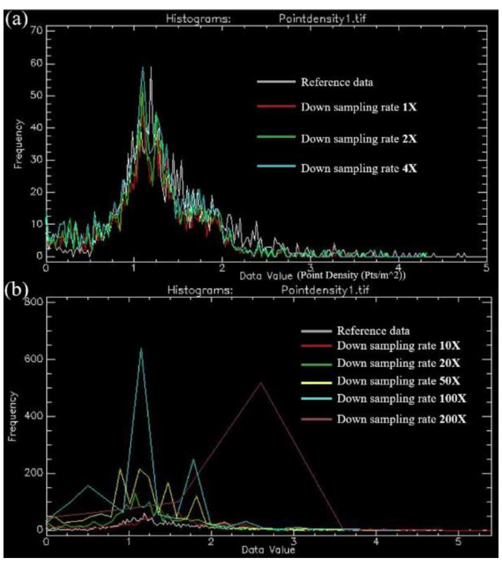

Figure 9. Histogram of reference and simulated point cloud with different downsampling rate

4. CONCLUSION

In this research, we conducted ALS simulation in HELIOS to evaluate the point density produced by a ALS survey. It was found that the simulation of computation time was quite significant so that the simulation of a large survey area was infeasible by a single computer. In order to solve this problem, the downsampling process was applied in HELIOS by reducing the pulse frequency. The experiment in this paper showed the result with different downsampling rate compared with the reference point cloud. And, It was found that the RMSE remained stable (4.97 – 4.968 points/m^2) for the downsampling rate of 2 to 100.

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