A Preliminary study on Utilizing 3D Vector Terrain Data for Satellite Visibility Analysis in Urban Area

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ABSTRACT: Global Navigation Satellite System (GNSS) has been widely used in the surveying field as well as in other engineering applications. However, how to increase the accuracy of satellite positioning is still a crucial research topic. While the line between a satellite and a receiver on the ground is blocked by obstacles, the signal of satellite will be interfered. It will lead to bad accuracy of satellite positioning. For this reason, the research aims to analyze the satellite visibility, which can simultaneously possess an efficient and reliable data acquisition without wasting time and human efforts. Nowadays, there are multiple data resources that can be used for 3D modeling, such as photogrammetry and LiDAR. The two primary types of spatial data are vector data and raster data. The former has better computational efficiency. Therefore, this research devotes to construct a complete approach to analyze the signal obstructions of GNSS satellites using vector terrain data. The aim is to provide a high efficient and reliable technique so that the quality of a GNSS positioning project can be better evaluated and planned.

KEYWORD: Satellite positioning Technology, Satellite Visibility Analysis, 3D-Model, Topographic Effect

1. INTRODUCTION

Nowadays, one can easily use GNSS to determine the 3D location of any point on the earth's surface. The positioning quality depends on the satellite and the receiver connections. If the line between the satellite and the receiver are shielded, the signal transmission will be disturbed, which will greatly reduce the accuracy of the threedimensional position calculation, affecting the subsequent utilization value, and may make the solution results less than expected. If the satellite visibility analysis is used in advance to determine the visibility of the satellite position, the satellite motion and satellite orbit, one can obtain the best observation period of each station in the day. The reliability of the satellite positioning accuracy would increase. Also, it can effectively improve measurement efficiency, reducing unnecessary time and labor costs.

2. LITERATURE REVIEW

2.1 GNSS positioning quality index

GNSS positioning accuracy is related to the geometric spatial distribution of the satellite and the observation error. The influence degree of the satellite geometric distribution is represented by the Dilution of Precision

(DOP), which is derived from the posterior variance covariance matrix from a least squares solution as following Eq(1):

$$\Sigma = \begin{bmatrix} \sigma X^2 & \sigma XY & \sigma XZ & \sigma Xdt \\ & \sigma Y^2 & \sigma YZ & \sigma Ydt \\ & & \sigma Z^2 & \sigma Zdt \\ sym. & & & \sigma dt^2 \end{bmatrix} \quad (1)$$

The DOP can represent different meanings, such as Table 1.：

Table 1. DOP Definition（Leick, 2004）

Definition	Function
HDOP=$\sqrt{\sigma X^2 + \sigma Y^2}$	Evaluate the horizontal accuracy
VDOP=$\sqrt{\sigma Z^2}$	Evaluate the vertical accuracy
TDOP=$\sqrt{\sigma dt^2}$	Evaluate the time error accuracy between the receiver and the satellite
PDOP=$\sqrt{\sigma X^2 + \sigma Y^2 + \sigma Z^2}$	Evaluate the three-dimensional coordinates accuracy
GDOP=$\sqrt{\sigma X^2 + \sigma Y^2 + \sigma Z^2 + c^2\sigma dt^2}$	Evaluate the three-dimensional coordinates and time accuracy

If the DOP value is smaller, it means that the positioning accuracy is higher. According to the satellite positioning measurement standard in Taiwan, the PDOP should smaller than 10. Therefore, when conducting field observations, it is necessary to analyze first whether the PDOP value of the measurement points conforms to the standard, and find the best measurement period to optimize the positioning measurement.

2.2 Satellite visibility analysis

Since the positioning accuracy determines the DOP value, it is necessary to explore factors that may affect the positioning accuracy, such as satellite position acquisition, maximum visual elevation angle and terrain obscuration, satellite elevation angle, etc., to analyze the satellite visibility on each station. Therefore, the significance of satellite visibility analysis is whether the satellite receivers have access to obstacles.

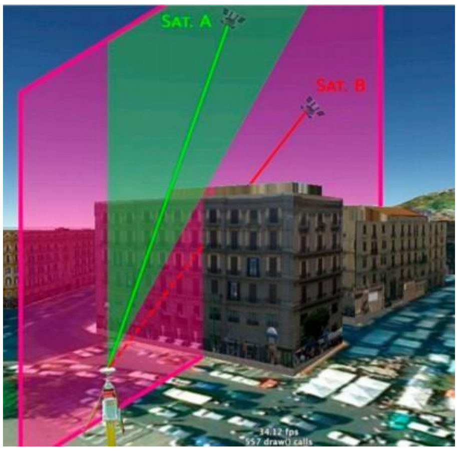

Figure 1. Satellite visibility (Ackermann *et. al.*, 2013)

In Figure 1, the connection between the satellite B and the receiver has a penetrating structure, so the satellite is considered to be invisible to the receiver; conversely, if the connection doesn't touch any obstacles, as the satellite A shown in Figure 1, it will be visible to the receiver. Therefore, it is necessary to obtain the maximum visual elevation angle of each station in each directions in order to carry out subsequent satellite visibility analysis.

2.3 Terrain data analysis

In order to obtain the maximum visual elevation angle, the terrain data has to analyze first. Due to the rapid advancement of science and technology, there are several sources of data for constructing three-dimensional terrain. The two most commonly used methods are raster data and vector data.

i. Raster Data

Raster data use grids or cells to store geometric information, such as aerial photographs, satellite images, DSM etc. The higher resolution will cause larger space to store. In the past, the maximum visual elevation angle is calculated by raster data mostly. It uses equal interval sampling from raster data, and calculate all sampling points to the elevation angle of the receiver, then derive the maximum visual elevation angle. Yet, in practical applications, the large amount of sampling points will cause decrease in computational efficiency, especially when the topographic data resolution is higher, the calculation time will also take longer. Therefore, Han & Li (2010) proposed that the non-equal interval sampling method. If the terrain is more complicated, or the shorter sampling time of the satellite orbit, or the closer the sampling point is to the receiver, the sampling interval must be shorter. As shown in Fig. 2, the advantage of the method is that it can be effective and reduced within a reasonable accuracy range.

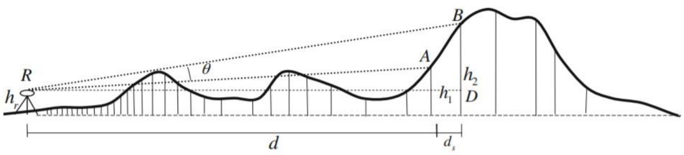

Figure 2. Varied intervals resulting from the adaptive sampling algorithm (Han & Li., 2010) Han & Juan (2016) use image as the source of analysis data for terrain obscuration. It uses the image extraction edge to obtain the masked edge line of each position, as shown in Figure 3. The image extraction method result is much faster than the conventional DSM method in speed, which can also improve the calculation effectively.

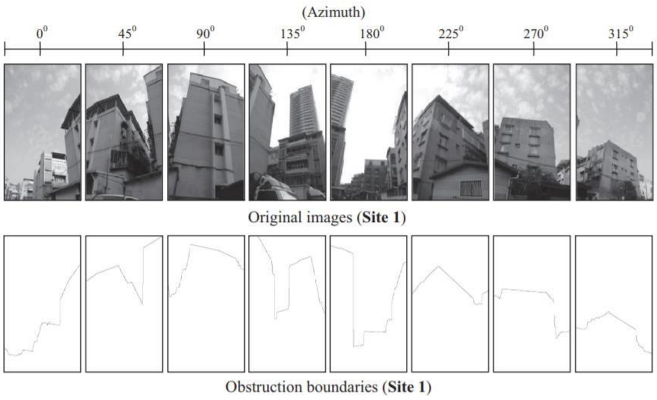

Figure 3. Images and obstruction boundaries (Han& Juan, 2016)

ii. Vector Data

Vector data use points, lines, and polygons to represent the geometric information. The data requires less space because only point coordinates are stored. Nowadays, LiDAR is one of the main remote sensing technology which uses vector data. It can calculate the distance between the sensor and the target by launching the laser wave and measuring the time it takes to reflect the reflected wave. It has high penetration, fast speed and unaffected by day and night. In practical applications, LiDAR has many examples of building terrain 3D models. For example, Rottensteiner & Briese (2002) used high-resolution LiDAR data to test the establishment of a small area DSM in Vienna, as shown in Figure 4.

However, the disadvantage of LiDAR is that it can't actually find the edge contour of the building because it only contains point information. It needs to be supplemented by other methods. For example, Verbree et. al. (2004) uses LiDAR with cadastral map data to manually find the roof of the building. In the region, a three-dimensional construction model of the preliminary Delft city is established, as shown in Figure 5. In addition, the LiDAR point cloud has a large amount of data, so the analysis processing is not easy.

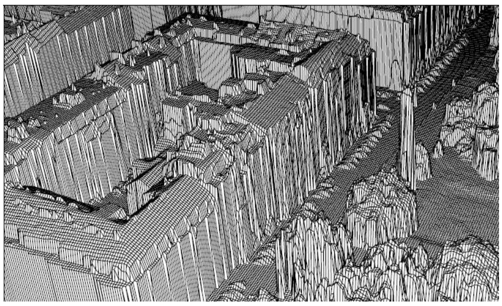

Figure 4. Using LiDAR to construct DSM (Rottensteiner & Briese, 2002)

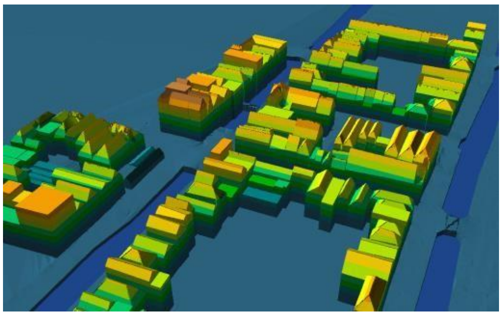

Figure 5. Combing LiDAR and cadastral map to build 3D model (Verbree *et. al.*, 2004)

Traditionally, DSM was originally produced by aerial photography. Aerial photography is a fast and low-cost way to acquire DSM in flat areas with small scales, but Zhou et. al. (2004) proposed that the streetscape in the city is more complicated, especially the high degree of intricacy of the building is very difficult to be completely and clearly identified, so its credibility will be reduced due to image resolution, shadow area, depth discontinuity, material difference, etc., sometimes even need manually select object pairs. It will cause time consuming and budget costs. Rottensteiner & Briese (2002) suggests that LiDAR will be a better option in city area because of the high density point cloud. The building can be detected first in the point cloud, and then reconstruct the edge of the building in order to build 3D model. Therefore, it is more suitable to establish a three-dimensional model for the complicated parts of the city.

3. METHODOLGY

3.1 LiDAR points extraction based on 2D boundaries

The LiDAR data contains large amount of points, which will lead to long-time calculation. To improve the speed of calculation, the LiDAR points will be extract first. Because the research is aim to find a rapid and accurate process to analyze satellite visibility in urban area, the main obstacle in the urban is the buildings. Therefore, using 2D building boundary map to extract the points can drastically reduce the number of points, and also save the calculated time.

3.2 Data Filtering based on height information

However, the extract points may still contain some useless area such as the side building. Yet, the research only needs the part of the roof area to derive the building height. Therefore, modifying the building boundary into smaller size can make sure that the rest of the points are all in the top area. After downsizing the building boundary polygons, the rest of the points will be filtered by a threshold which depends on the building height. If the zcoordinates of point is less than the rough height of buildings, it will be removed. The remain points will calculate the normal distribution, extracting the points only in 68 and 95 confidence interval. By doing these steps, the LiDAR points can be filtered again to reduce the amount of the points, enhancing the calculation speed.

3.3 Roof Plane Extraction

After cleaning the points, the points will be used in plane fitting. The plane fitting uses the basic geometric concepts to identify the roof shape, like Eq.(2):

$$z = ax + by + c \tag{2}$$

The roof shape is divided into three types: plane, slanted and special. Because the buildings have different roof shape, which will also influent to the elevation angle. Therefore, it’s critical to judge the basic roof shape in order to do further analysis.

4. RESULT AND DISCUSSION

The experiment area is located in National Taiwan University. Data resources include LiDAR point clouds from three flight strips, which contains 5,798,616 points (Figure 6) and building boundary map (Figure 7).

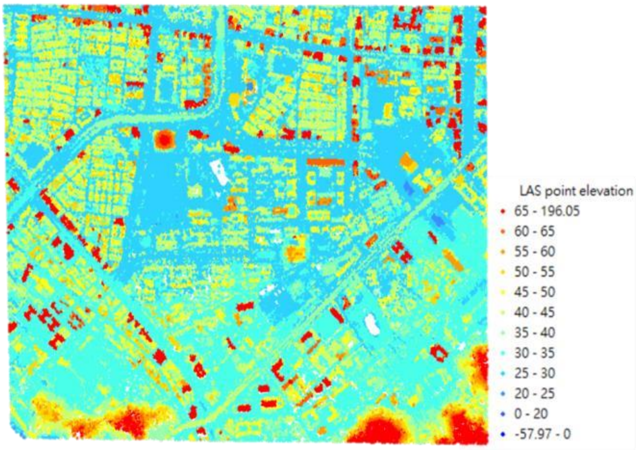

Figure 6. LiDAR point clouds

Figure 7. Building boundary map

The first step is to extract the points from building boundary, and the result is shown in Figure 8. After extracting, the number of points changes from 5,798,616 to 430,896. This can effectively and quickly reduce the amount of data.

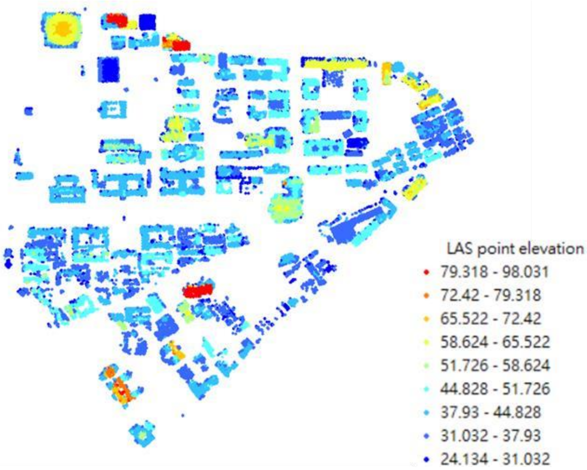

Figure 8. Extracted LiDAR points based on building boundary map

Secondly, the rest of the points will use height threshold and building boundary downsizing to filter again. Because the research only focuses on the top building area, the rest of the building is not so important. Therefore, the points will keep only inside the downsized building polygon by 0.9 times and also above the height threshold. Table 2 shows the result about the number of points' changing of 8 building by building boundary modification and extract points correction. It shows that after running this step, the number of points will remain about 80% or so. It can make the points amount smaller and also delete the unnecessary points roughly.

Table 2. Point clouds before and after applying the proposed filtering approach

Building Number	Original points	Height threshold +Building boundary downsizing	Ratio
Building#1	541	459	84.8%
Building#2	1458	1193	81.8%
Building#3	3827	3001	78.4%
Building#4	656	528	80.5%

Building#5	1639	1256	76.6%
Building#6	1209	994	82.2%
Building#7	24294	19787	81.4%
Building#8	1156	896	77.5%

After points modification, the remain points will run through plan fitting part. Three kinds of roof shape were mention before: plane, slanted and special. According to the roof shape, the research takes Building#2, #4 and #8 to test. Building#2 roof type is plane, Building#4 is slanted and Building#8 is special type. Before using Eq.(2) to fit the points into the plane, the points will do normal distribution to take 68 and 95 confidence interval data into test . The plane fitting result is shown in Figure 9, 11 and 13. The corresponding residual result is shown in Figure 10, 12 and 14.

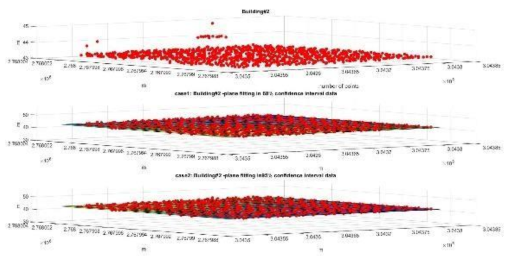

Figure 9. Fitted plane for Building#2

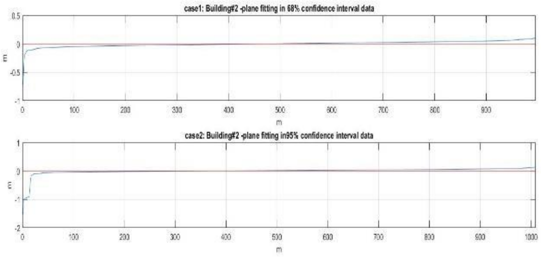

Figure 10. Fitting residual for Building#2

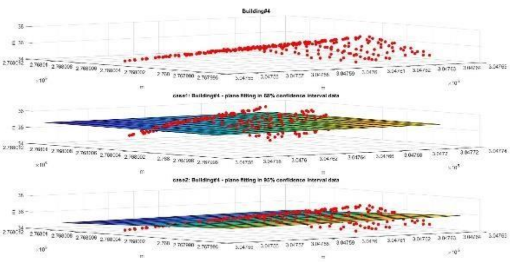

Figure 11. Fitted plane for Building#4

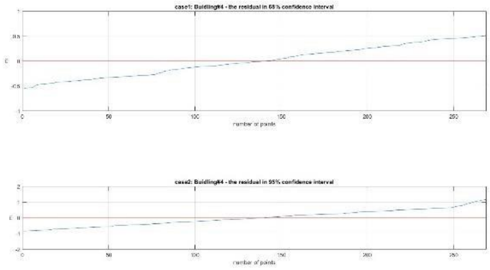

Figure 12. Fitting residual for Building#4

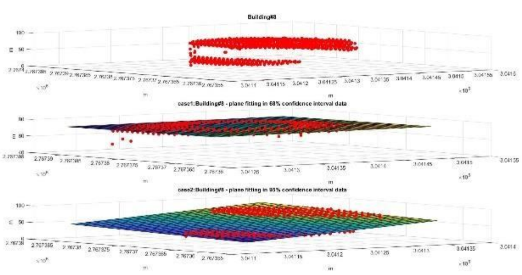

Figure 13. Fitted plane for Building#8

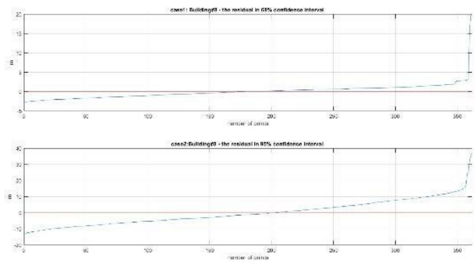

Figure 14. Fitting residual for Building#8

In the comparison of Figure 12, Figure 13 and Figure 14, the different type of roof would have different residual response. Because the more complicated the roof shape is, the more residual it will be. In Figure 12, The plane roof's residual is close to the zero, which means that the plane fitting is almost the same with actual roof plane. In Figure 13, the residual has symmetrical trend because of the slanted roof shape. Last but not least, in Figure 14, the residual tends to have more irregular vibration, and the residual is much bigger than the other two roof types. In conclusion, different roof shape types have different corresponding performance. Therefore, the roof type can be identified by the residual response.

Furthermore, no matter in which types of roof shape, the residual will be smaller in 68% confidence interval than in 95% confidence interval. Because the more points it contains, the data will be more discrete, and will lead to bad plane fitting result.

For now, the research has already completed the preliminary data filtering and roof shape identification. It may help the research for further analysis.

5. CONCLUSIONS AND FUTURE WORK

In conclusion, the research aims to find a quick and accurate way to utilize 3D vector terrain data for satellite visibility analysis in urban area. The research has already finished data extraction and preliminary plane fitting and identification so far. The raw LiDAR data has been through the filtered process which can reduce the amount of data to 70% or so, which has well effective on decreasing data amount. The remain data uses basic mathematical concept to plane fitting, and identifies the basic roof types from the residual response.

In the future, the research will continue calculating the height of buildings in different types of roof shape, and complete the sky visibility analysis. Also, the research will consider the satellite orbit estimation and positioning quality assessment to insure the high quality result.

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