From Airborne Laser Data to Spatial Information: Object Reconstruction and Accuracy Analysis

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SUMMARY

Recent years have seen airborne laser scanning technology revolutionizing the way in which spatial data is considered. The direct acquisition of 3D information of the terrain and of object on the terrain allows adding the vertical dimension in geographic databases in a relatively direct manner. Nevertheless, as the potential of Light Detection and Ranging (LiDAR) technology is realized, accuracy concerns must receive growing attention. Accuracy can be roughly divided into two parts, internal system accuracy, which concerns the system biases and errors, and "external" accuracy, which concerns with how accurate geographic objects can be reconstructed and delineated. Several studies have been devoted to analyzing internal accuracy, however the external accuracy concerns and the interaction of LiDAR data with geographic databases has hardly been investigated.

Considering laser scanning systems as mean to generate geographic data, we study aspects of external accuracy of LiDAR data. The paper elaborates on two aspects: the ability to reconstruct the shape of objects, and the sources that influence the accuracy of their delineation. We focus in particular on the effect of the data sampling and on the accuracy of the reconstruction. The study uses real data but also simulated laser scanning patterns. The simulator we have constructed allows testing data acquisition with different parameters (e.g., flight pattern, data density) and provides an exact knowledge of the objects shape and their true position.

The paper presents a novel delineation algorithm that was developed to convert the point cloud into a geographic data, and provide a study of the influence of the data characteristics on the accuracy of the correctness of the reconstructed geographic objects. It demonstrate how using knowledge about features of the data acquisition system allow improving the accuracy of the reconstruction in comparison with using off-the-shelf data processing tools.

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1. INTRODUCTION

Building information for city modeling is fundamental for a growing number of applications, among them urban planning, telecommunication, and environmental monitoring. Over large areas such as the one urban environment offers their extraction by manual techniques is time consuming and labor intensive. As a result considerable amount of photogrammetric research has been focused on the development of automatic and semi-automatic techniques to reconstruct the shape of buildings from aerial photography, satellite based imagery and other remotely sensed data.

Building reconstruction from images relies on the extraction of image cues, organization of the extracted features and application of domain knowledge. Most methods rely on 2D feature analysis in which straight lines or corners extracted from aerial photographs are perceptually grouped, but the building model is rather strongly constrained to decrease the uncertainty of building hypothesis generation and its verification (Janes et al., 1994; Kim and Muller, 1995; Noronha and Nevatia, 1997). To achieve an unconstrained building representation an extension into 3D analysis from multiple images has been researched. Higher level features belonging to building structure such as 3D corners (Fischer et al., 1998), 3D lines (Baillard et al., 1999a), and 3D planar polygons (Ameri and Fritsch, 2000) have been extracted and utilized for the reconstruction of a building model. Nevertheless the dependency on the reliability and density of features extracted from aerial photographs that are usually fragmented or missed, or suffer from occlusion and shadow effects is one reason for the little progress made in reaching the ultimate goal automated building reconstruction process.

The shortcomings of image based building reconstruction have motivated the exploration of the potential of other data sources that may compensate the disadvantages that aerial photographs offer for the reconstruction of buildings. Among them, Light Detection and Ranging (LiDAR) technology have proved to be a promising alternative to aerial photography. LiDAR systems provide direct measurements of surface heights with high point density and high level of accuracy; they provide a ready-made dense 3D description of the surveyed surfaces. As an active sensor the system can operate day and night irrespective or the lighting condition and by measuring energy return it penetrate vegetation thus allowing measurement to canopy height and the terrain underneath.

LiDAR data have been used as a single source of information for the reconstruction of buildings with complex shape (Weidner and Förstner, 1995; Vosselman, 1999; Mass and Vosselman, 1999; Wang and Schenk, 2000). Although the advantages that LiDAR data have for building localization and planar patch extraction, a notable drawback is the lack of ability to delineate the building boundaries properly, even with point density as high as 7 points/m^2 (Vosselman, 1999). To localize the detection of buildings ground plans are sometime used as prior information (Vosselman and Dijkman, 2001).

Our research concerns developing algorithms for building extraction and reconstruction without any prior information about their shape. Together with that we consider that accuracy of the reconstruction as a fundamental theme in the reconstruction of buildings from LiDAR data as it defines the quality of the mapping that LiDAR data can provide. Accuracy can be considered as composed of two parts, internal system accuracy, and external accuracy. Internal accuracy concerns the system systematic biases and random errors, whereas the external accuracy concerns the level of accuracy in which geographic information can be reconstructed from the data. A Number of researches have been dedicated to analyzing system accuracy (Filin, 2001; Schenk, 2001 and others); however the reconstruction accuracy concerns has hardly been investigated.

An analysis of the sources of errors in extraction the building parameters shows that there are different sources of influence. Some of them are data related, e.g., point density, flight characteristics, and pattern and scanning condition, while others are object related, e.g., the object height, shape, location and azimuth. A comprehensive study of all the potential effects requires isolating each parameter from and testing its influence, it also requires having a precise knowledge of the actual building location to compare the reconstructed result with the actual boundary. Such experiment is impractical to conduct as it requires a large number of flights with different parameters, different scanning patterns and characteristics. Furthermore, such experiments will have to be conducted over different building shapes with different heights in different orientations, and with the different location within the swath. The optimal test will fix all the relevant parameters but one and will then test its influence, however such test is impractical (if not impossible) to conduct. Conducting such experiment without incurring high cost can be achieved by the generation of a simulator that emulates the data collection pattern of airborne laser scanning systems. Such simulator allows "collecting" data over different types of terrain, different types of building with different characteristics and via different flight patterns. Even more so, with the construction of a simulator the actual coordinates and shape of a building are given, thus comparing the reconstructed results to the actual one is direct.

In this paper we present the results of an analysis of the influence of the various components of the accuracy of the reconstruction of building contours from airborne laser scanning data. The analysis was conducted via simulation of laser scanning surveys with different characteristics over buildings with different characteristics. The organization of the presentation is as follows: Section 2 presents an overview of simulator properties and discusses the proposed method for boundary reconstruction of buildings. The errors analysis of the reconstruction results are discussed in section 3. Following are experimental results. Based on the results we propose an improvement for the building reconstruction algorithm. The concluding remarks conclude the presentation.

2. SYNTHETIC DATA GENERATING AND BUILDING EXTRACTION

For the study of the quality and accuracy of the reconstruction of buildings we develop an airborne laser scanning simulator that generates synthetic LiDAR data. The simulator allows controlling geometric parameters of the scanning system (sensor and flight properties) and the shape and properties of the buildings (height, location, and azimuth).

Simulator properties – to emulate the scanning survey the following parameters are introduced: The field of view (maximum swath angle), flight height and the pulse emission frequency that together define the point density within the scan. The velocity of the flight and the attitude and orientation angles are additional parameters that can be set but they are usually left fixed. In addition to building objects can be placed within the flight path, objects can have different shapes, height, position within the scan, and azimuth. Given these parameter the "simulator" can generate 3D cloud points.

2.1 Building Extraction and Boundary Determination

Our method for building detection is based on testing the slops of the edges that are formed by the triangulation of the point cloud. All edges with a slope exceeding a predefined threshold will be determined as a boundary edge. With the lack of another source of knowledge we assume that the location of the building boundary is at the mid-point of each boundary edge. As the extracted points provide a discrete representation of the boundary, we use Hough Transform to detect the edges that form the linear boundary representation (assuming that it consists of straight lines). The lines derived by the Hough transform provide an approximated solution; to improve it we use a Least Squares adjustment. To detect the building corner from the extracted lines all intersection points between the lines are computed (see Figure 2.1) and analyzed. In general, not all intersection points can are actual building corners; some of them define spurious corners. To remove wrong intersection points the extracted intersections are classified into three types: A – actual corner, B – false corner, and C – non corner (see examples in Figure 2.1). We define the following rules to classify the intersection points:

- The building corner points must be within a close distance from the boundary points.
- The building corner must be a vertex points, it must not fall on a straight line that connect its two neighbouring points.

The first rule handles type B corners and the second one handles type C points. This leaves us with building corners, type A corners, see Figure 2.1.

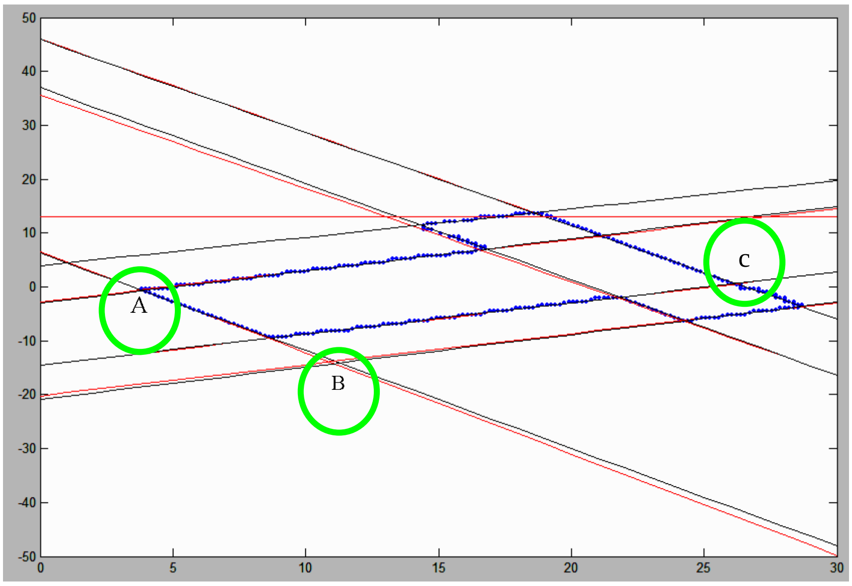

Figure 2.1 Types of intersection points, A-true corner, B-false corner, C- non corner point, red lines estimated by Hough transform, dark lines estimated by least square

3. ERROR AND ACCURACY ANALYSIS

The accuracy of boundary detection is influenced by various factors. Clearly the point density has a deciding influence on the detectability and on the sampling of the roof structure. With lower density the probability of having points closer to the building edges is lower than in case of higher density. It is noteworthy mentioning that the scanning pattern has also an effect on the reconstruction with a regular scanning pattern (see Figure 3.1a) the building edge are routinely missed by the scanning system. With less regular scanning patterns points next to the edges would have probably been detected.

Shadowing - the impact of shadowing/occlusion on the boundary location did not receive the attention it deserve so far. It is most easily understood by looking at the geometric implication of the data acquisition pattern as illustrated in Figure 3.1. The solid box in the Figure 3.1 delineates a box shaped building while the slope lines are the laser beams. Analyzing the type of reflections we can differentiate between three types: i) reflections for the wall, ii) reflections on the roof, iii) reflection past the roof. The laser pulses that hit the front provide a direct definition of the building boundary, pulses on the flat roof are expected to have more or less the same distance between consecutive points, the first pulse that hit back the terrain is however much bigger that the actual point density. As Figure 3.1 shows it is not guaranteed that the mid-point between the last roof point and the following ground point will define the boundary.

The "shadowing" effect has no constant magnitude and is a function of the flying height and of the building parameters. For example it is expected to increase as the building height increases or as a function of the building is position in the swath. Buildings that are positioned further away from the center of the swath will be more affected by it.

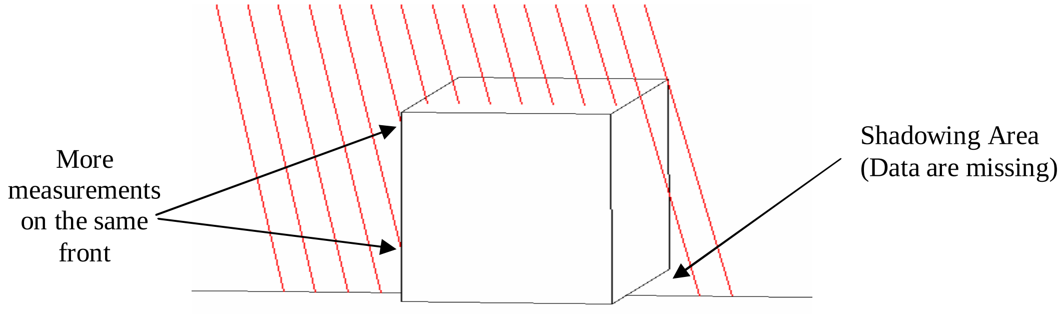

Figure 3.2 Region of shadowing

In terms to accuracy it is noted that some linear features of the building can be detected with high degree of accuracy irrespective of the shadowing effect or to some extent even the point density. For gable roofs the delineation of the ridges will be determined with high degree of accuracy as a result of plane intersection in space.

To examine these effects on the data and on the reconstruction results execute series of experiments using the simulator to generate different data samples. For quality estimation of the results we analyze the effect of the geometric parameters that characterize the building. These parameters, building lengths, azimuth and location are computed and compared with the original known values.

4. RESULTS

To evaluate the accuracy in determining the building boundary, a flat roof building is used. The experiments described below have fixed the flight parameters (trajectory, and the parameters of the scanning system). The parameters that are tested are the height, azimuth and the position of the building within the swath.
The scanning parameters that were used are: 1 km above the ground flying height, Field of view ±4 degrees, 0.05 angular resolution, 50 KHz pulsing emission rate, 400 km/hour velocity. This configuration yields a point density of ~1.8 points/m^2.

4.1 The Influence of the Building Height on the Location and the Dimensions of the Extracted Building

The size of the shadowing gap is expected to be more increase as the height of the building increases. To examine the influences of the object height 8 tests were performed where the height of the building was increased by 5 meters between tests. The initial height is set to 5 meters, the final height reached the 40 meters.

This set of tests was applied three times; for the first test the building was located at the center of the swath, for the second one the building was located 50 meters away from the center, and in the third test the building was placed at the edge of the swath (100 meters away from the center of the swath). In all cases the effect of the height was tested in relation to the determination of the building dimensions and the location of the building centroid. For buildings located at the center of the swath the shadowing is a function of two factors: the building width and the building height, Figure 4.1 show that as the height of the building increases the error in the position determination. Figure 4.2 shows that when the building is located 50 meters away from the center of the swath, the errors in position and the dimensions reach up to 0.5 meter. For buildings located 100 meters away from the center of the swath the displacement in position exceed 1 meter. For such building with a height of 40 meters, the dimensions will increase by 1.4 meters (see Fig 4.3).

Building located at the centre of the swath

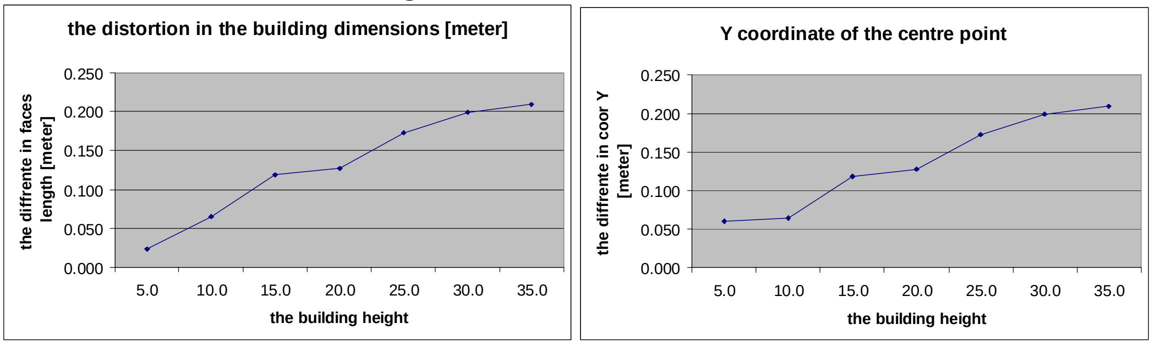

Figure 4.1, (left) the distortions in the length of the building; (right) the displacements in the building position**.**

Building located 50 meters from the centre of the swath

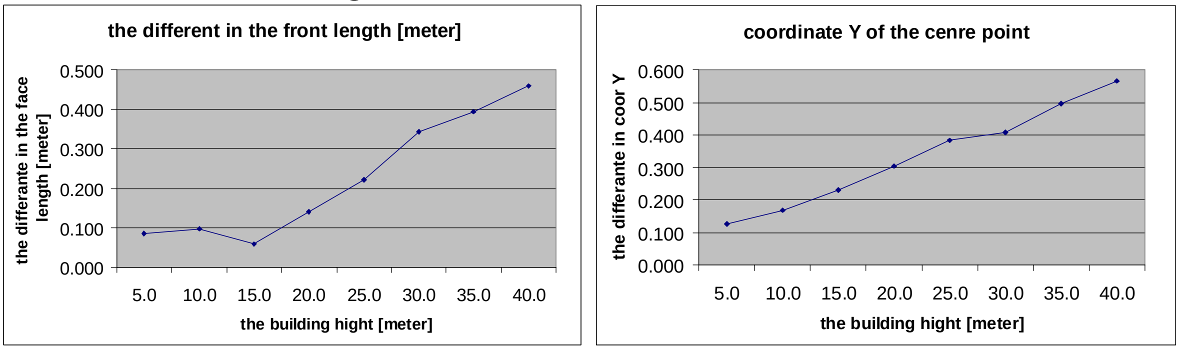

Figure 4.2, (left) the distortion in the length of the building, (right) the displacement in the building position**.**

Building located 100 meters away from the centre of the swath (end of the strip)

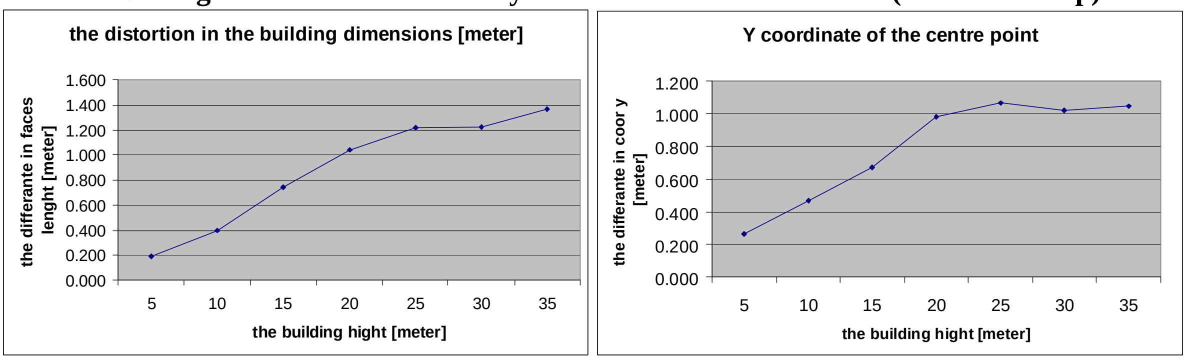

Figure 4.3 (left) the distortion in the length of the building, (right) the displacement in the building position**.**

4.2 The Influence of the Building Azimuth on the Location and the Dimensions of the Extracted Building

Here the orientation of the building with respect to the flight trajectory was tested. Again three tests were conducted, where the building was located at three different distances from the center of the swath (0, 50,100) meters. Orientation of the building in four different azimuths was tested, 0, 15, 30, and 45 degrees.

The results of the experiments are given in Table 4.1 where Lx & Ly refer to the dimensions of the building, Cx refers to the coordinates of the centroid of building. As the effect on the values of Cy behave similarly to those of Cx they are not displayed. Although table 4.1 does not reflect changes in the height of the building the combined effect of the height and the orientation were tested as well. Results did not show an effect that was different that the combine effect of the two individual parameters.

Distance of the building from the centre of the swath										
		0.00 m			**50.00 m**			**100.0 m**		
Azimuth		**Lx**	**Ly**	**Cx**	**Lx**	**Ly**	**Cx**	**Lx**	**Ly**	**Cx**
15	average	**0.01**	**0.28**	**0.00**	**0.14**	**0.71**	**0.00**	**0.35**	**1.25**	**0.00**
	STD	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.00**	**0.07**	**0.25**	**0.04**
30	average	**0.02**	**0.22**	**0.00**	**0.29**	**0.60**	**-0.01**	**0.64**	**1.18**	**-0.01**
	STD	**0.03**	**0.02**	**0.01**	**0.01**	**0.02**	**0.01**	**0.02**	**0.04**	**0.01**
45	average	**0.07**	**0.16**	**0.00**	**0.43**	**0.48**	**-0.01**	**0.92**	**0.97**	**-0.01**
	STD	**0.02**	**0.03**	**0.01**	**0.02**	**0.02**	**0.01**	**0.04**	**0.06**	**0.05**

Table-4.1 the magnitude of the distortions in horizontal dimensions Lx & Ly, and Cx the centre coordinates of the building

Figure 4.4 provides a graphical illustration of the azimuth effect on the distortions in the building dimensions as a function of azimuth and the location.

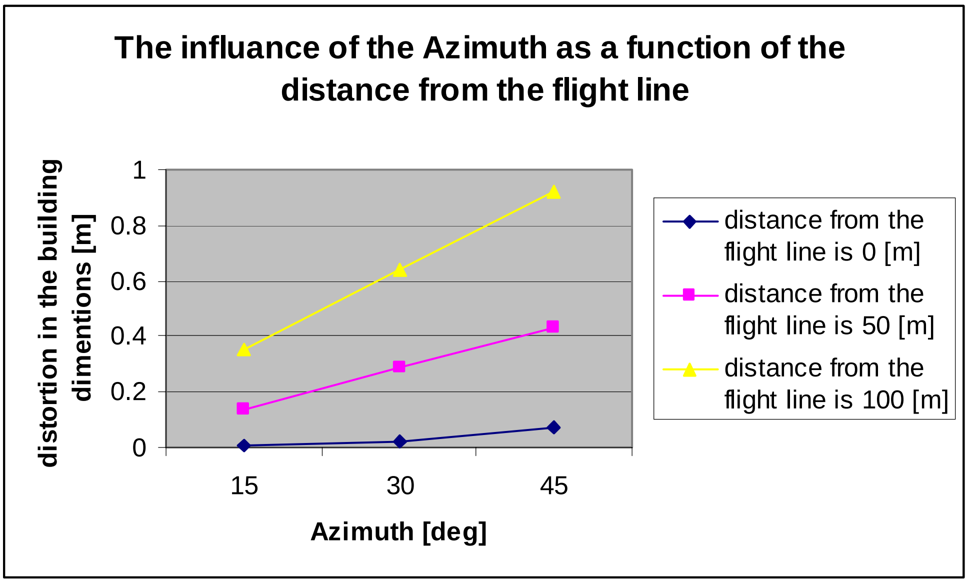

Figure 4.4 Distortion of the building dimensions as a function of azimuth and the location.

The results show that the building orientation affects the building dimension. When the building main axis is parallel to the flight direction only the front face of the building (the one perpendicular to the flight direction) will be affected by the shadowing. When the azimuth gets closer to 45 degrees the shadowing effect affects more fronts. Notice that the distortion has at the 45 degree azimuth has doubled itself from the one with 0 degrees azimuth.

5. RECONSTRUCTION BY THE INSERTING OF VIRTUAL POINT

5.1 Virtual Point

The dimensions of the shadowing gaps can be estimated using the sensor geometric parameters; the location and the height of the building (see red lines in Figure 5.1). It can easily be noticed that the distance between every two points in the scan line is the same, assuming no big difference in height between these points. We can utilize this distance to create a "virtual point" (Figure 5.1) that will have the height of the terrain with a distance from the previous point as it was with the building height. This will decrease the uncertainty in determining the building borders.

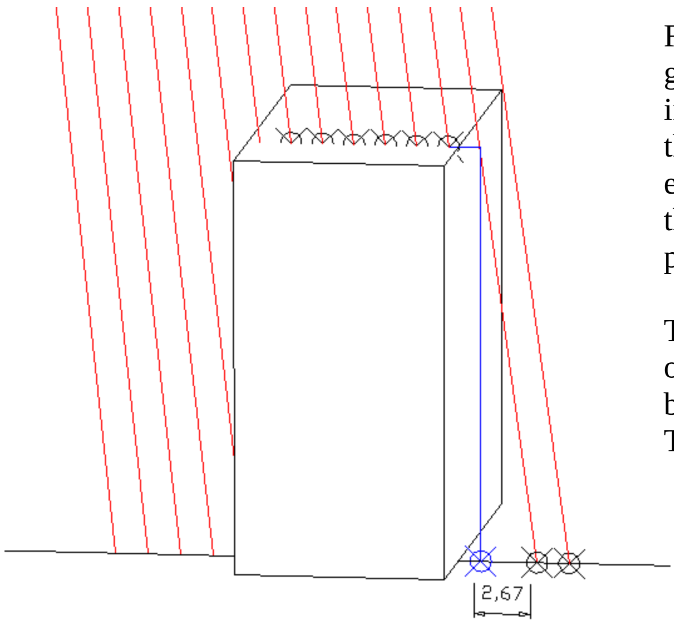

Figure 5.1 shows that the shadowing gap is about 3 meters in size. With the insertion of the virtual points (in blue) the border of the building will be estimated as the mid distance between the virtual point and the closest roof point.

The result of that is an improvement of the accuracy in determining the building parameters it could be seen in Table 5.1 and Table 5.2

Figure 5.1 Inserting the virtual point in the Shadowing gaps

Distance from the flight line 100 [m]	Lx [m]	Ly [m]	Cx [m]	Daz [deg]
Average	0.64	**1.13**	0.00	0.87
STD	0.24	0.19	0.04	1.14

Table 5.1 The extracted values without the virtual point

Distance from the flight line 100 [m]	Lx [m]	Ly [m]	Cx [m]	Daz [deg]
Average	0.14	**0.20**	-0.04	-0.20
STD	0.04	0.14	0.01	0.25

Table 5.2 The extracted values after adding the virtual point

As both tables show the insertion of the virtual point has successfully decreased the distortion in Ly from 1.13 meter to 0.2 meter.

6. CONCLUSIONS

Although Laser data seems to be accurate, the accuracy of the information that can be derived from it is actually a function of many other factors. Some of these factors can be controlled by the LiDAR system but others are related to the scanned objects. The accuracy of the extracted information is varies from one object to another, it depends on many geometric properties of the object it self like: its location relative to the flight direction and its height.

Data transformation from irregular from to regular one (raster) must done using the virtual points in order to decrease the shadowing problem for obtaining more accurate description of the real word. The results show that using the virtual point can improve significantly the accuracy of the results and minimize the distortion in the object dimension, in extreme condition, from 1.13 meters to 0.2 meter.

Our research includes many experiments to examine the influence some geometric properties of the buildings, the results show that the geometric parameters must be taken in account in both flight planning and data processing levels. For good results we suggest, as in optical Photogrammetry, to scan the same area with two or more overlap strips. Doing that, not only we can eliminate shadowing effects but also improve the density and promising more accurate results.

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BIOGRAPHICAL NOTES

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