EFFECTS OF DIFFERENT LASER SCANNING MODES ON THE RESULTS OF BUILDING RECOGNITION AND RECONSTRUCTION

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ABSTRACT

Airborne laser scanner systems are of increasing importance for measurement of digital elevation models (DEM) and hence, for acquisition of 3D objects like buildings in urban areas. There are several approaches to the modelling of buildings by means of laser scanning data, but hardly any studies about comparison of the two possible scanning modes, *first pulse* and *last pulse* mode, concerning building reconstruction. In this paper, the effects of first pulse and last pulse measurement on the acquired DEMs are explained, some specific phenomena are described and suitability, i.e. the advantages and disadvantages of each scanning mode, for building reconstruction is discussed. Two examples illustrate the principle differences of the resulting building models, derived from first pulse and last pulse mode respectively. Finally, first experiences on deviations of these models from the correct building shapes (represented by manually measured CAD models) and on the achieved accuracy will be presented.

1 INTRODUCTION

Airborne laser scanning technique is of increasing importance for the acquisition of 3D objects, especially for building recognition and reconstruction in urban environment. There are several approaches for modelling of buildings by means of laser scanner data. Some of these use additional information sources like digital maps, spectral images or other GIS data, e.g. (Brunn & Weidner, 1998), (Haala et al., 1998), (Maas & Vosselmann, 1999) and (Vögtle & Steinle, 2000).

Laser scanning systems can be distinguished with regard to the measurement principle. Most of the available systems use pulsed laser scanning, only a few are based on continuous-wave scanning. When using pulsed laser scanning, it is possible to measure the runtime of the laser signal in two different modes, *first pulse* and *last pulse* mode. For a better understanding of the effects on the captured data these principles are described in more detail in section 2. Generally, it is not possible to acquire laser scanning data in both modes simultaneously due to technical restrictions of the systems. Therefore, one of them has to be chosen before data acquisition, depending on the requirements of the specific application. Even if there are several attempts in using laser elevation data for building reconstruction, there are hardly any studies that discuss which of these two operating modes is more suitable in this context.

Therefore, in this paper the effects of the different laser modes on the elevation data (DEM) and the results of building modelling are explained and special phenomena concerning data processing are described. Finally some examples from our test areas are given and the achieved accuracies as well as the advantages of each operating mode discussed.

2 LASER SCANNING PRINCIPLE

In the context of building modelling in urban environment the investigations were restricted to airborne laser scanner systems. These are active scanners based on laser signals for measurement of slant distances to acquire information about the surface of the Earth and objects on it. As mentioned above, there are several laser scanning systems being operational. Concerning the measurement principle two different methods had been realized: *runtime* measurement using pulsed laser signals and *phase difference* measurement using continuous-wave lasers. Because most systems are based on the first mode, it will be described in more detail in the next section. A good overview on both topics can be found in (Wehr & Lohr, 1999).

2.1 Measurement principle of pulsed laser scanners

This type of laser scanner emits pulsed laser light in exactly determined time intervals. The system measures the runtime of these laser pulses, i.e. the elapsed time between emitting a signal and receiving it after reflection on the surface of the Earth or objects on it. Therefore, slant distances can be derived from these time differences by the well-known formula $v = \Delta s / \Delta t$ or $\Delta s = v / \Delta t$. By means of the exterior orientation of the sensor (recorded by differential GPS (dGPS) and INS systems) 3D co-ordinates of the illuminated surface points can be determined.

2.2 Design of pulsed laser scanning systems

Laser systems need to be designed mainly regarding two components: the *emitting and receiving unit* and the *positioning unit*. Both will be described by means of the operational system TopoSys (Lohr & Eibert, 1995) which was used to acquire the data sets presented in this paper.

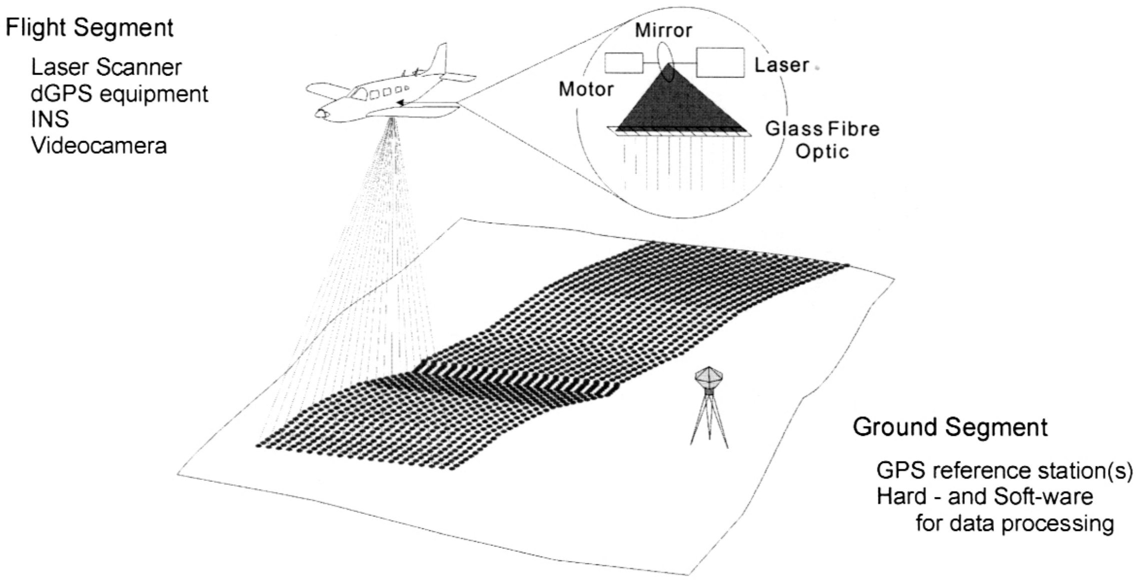

Figure 1: Laser scanner system TopoSys

In this system, the emitting and receiving unit is realized by means of a glass fibre optic. The laser light is emitted on a nutating mirror, i.e. a rotating mirror which deflects it on a glass fiber bunch. The ends of the glass fibres are connected to a row-shaped optic, so the resulting measuring pattern on the surface of the Earth is a single scanning line. In addition to the movement of the airplane this results in a strip-wise data acquisition as shown in Figure 1.

The positioning component of the system consists of several elements. As navigation principle differential Global Positioning System (dGPS) is chosen. Therefore, GPS antennas are mounted on the airplane, as well as on reference stations on the ground. Although this positioning strategy yields to good results concerning the accuracy of the obtained co-ordinates (in the range of some few centimeters), the measurement rate is lower than the one of the laser scanner. Therefore, additionally Inertial Navigation Systems (INS) are used, i.e. navigation units register the rotations of the airplane based on gyros. These are capable to determine a position with a higher temporal resolution (for more details see (Haala et al., 1996)).

In Table 1 the performance parameters of this system are listed. It should be mentioned that the system is capable of acquiring up to 5 points per m^2. This results in data sets of high point density and suitable accuracy in position as well as in elevation.

sensor type	pulse modulated laser Radar	range	< 1000 m
scanning principle	fibre optic line scanner	transmitter	solid state at 1.5 μm
measurement principle	run-time measurement	scan frequency	300 Hz (adjustable)
field of view	+/- 7°	number of pixels per scan	127
swath width (1000m flight height)	250 m	accuracy of a single distance measurement	< 0.3 m
accuracies of point coordinates x,y,z	≈ 0.3, 0.3, 0.1 m	resolution of a distance measurement	< 0.1 m

Table 1: Performance parameters of TopoSys laser system [Lohr & Eibert, 1995]

2.3 Measurement Modes

Emitted laser pulses, reaching the terrain or objects on it, are not of infinite size but increase to illuminated regions (so-called *footprints*) with diameters of about 30 cm for typical measurement constellations. Within such footprints several different objects may be covered and the laser signal is split into different parts.

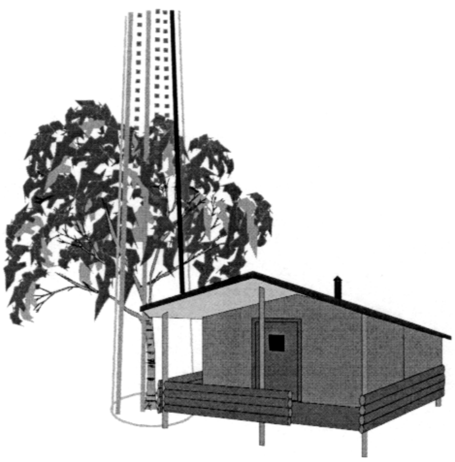

Figure 2: Reflection of laser signal at different elevation levels

In Fig. 2 an example is given to illustrate this phenomenon: A laser ray is covering a tree standing beside a house. The bright solid lines represent those parts of the laser signal that reach the ground, i.e. they penetrate the tree through gaps in the tree structure. Dashed lines indicate reflections at leaves and branches of the tree. These parts of the signal are reflected at a higher elevation level than the other ones and therefore reach the receiving unit earlier. Regarding the measurement principle (section 2.1) the system can register this first signal response at the receiving unit, i.e. operating in *first pulse mode*. In this case the elevation of the highest illuminated point inside the footprint (in this example the canopy of the tree) would be acquired. If the system is operating in *last pulse mode*, the last part of signal response is registered, i.e. the lowest elevation level inside the illuminated region is determined (in this example the ground level).

In the presented example an important effect is obvious too. Buildings which are partly covered by vegetation can be completely acquired in most cases in last pulse mode. As explained above, parts of the signal are capable to penetrate the covering leaves (dark solid line) and are reflected at the roof. This effect can be observed with/at most deciduous trees, but not in all cases of coniferous ones. If solid horizontal surfaces are illuminated by laser signals, there is no difference between first and last pulse mode due to the determined elevation.

Another effect of the different measurement modes occurs when measuring at discontinuities in elevation structure, i.e. break lines at the border of buildings partly covered by a footprint. By using first pulse mode, the footprint represents the higher elevation level at this position; using last pulse mode, the same footprint (at the same position) the ground level is acquired. Therefore, the same building may be acquired with larger or smaller dimensions compared to the correct measures, depending on the scanning mode (Figure 3).

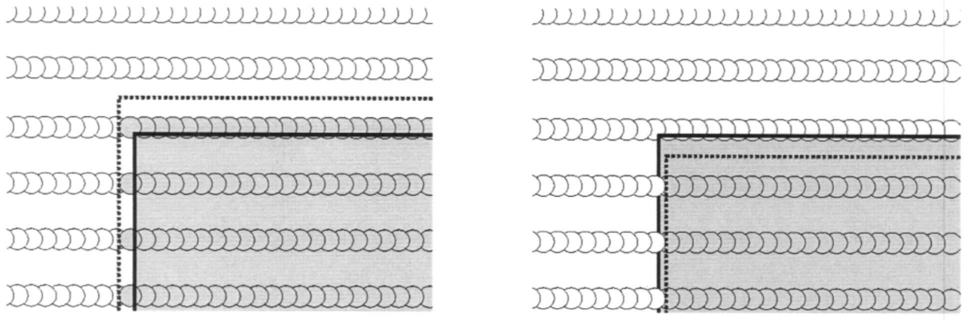

Figure 3: Effects on the size of objects by using laser scanning in different modes, first (left) and last pulse (right); circles illustrate footprints of laser rays, filled circles indicate measured points on higher level; original contour lines (solid) and acquired contour lines (dashed)

2.4 Characteristics of laser scanning data

In first pulse mode, usually the upper canopy of objects is registered (DEM). Therefore, besides solid objects like buildings also most vegetation (trees, bushes etc.) is acquired (Figure 4) which has to be excluded during further data processing for a robust building recognition and reconstruction.

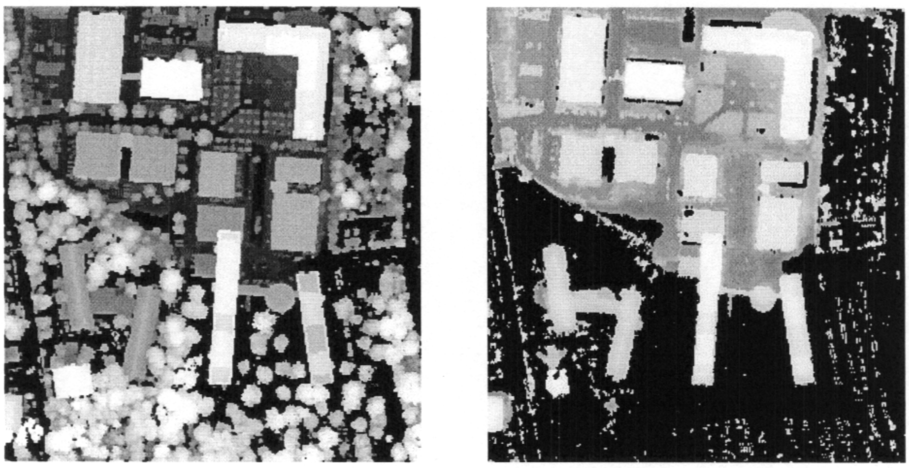

Figure 4: Subset of laser scanning derived DEMs of test area *Karlsruhe*; intensity corresponds to elevation (brighter points are higher); first (left) and last pulse mode (right)

On the other hand, first pulse mode delivers a good coincidence of building contour lines compared to cadastral maps. But some (for this approach) irrelevant details on the roofs, e.g. antennas, dormers, chimneys etc., may disturb the determination of building surfaces, especially of roof planes. This can be observed in Figure 5. At the highest building in the background some antennas are mounted on the roof. In first pulse derived DEM (left hand side), these antennas are acquired, but not in last pulse mode (right hand side).

In DEM of last pulse mode (Figure 4, right side) most vegetation are nearly eliminated, a big advantage for building recognition. A disadvantage of this mode is that buildings appear generally too small, i.e. they have missing borders of about 1 to 2 pixels (compared to cadastral maps) (see section 2.3). Another effect is the smoothing of roof top edges and the loss of details on the roof if desired. For a better illustration of these effects and a visual comparison of the resulting data, some CAD models of buildings (manually measured by means of aerial images) are superimposed with DEM data acquired in first pulse and last pulse mode respectively (Figure 6). The brighter silhouettes represent the CAD models, the dark elements the DEMs. It is obvious that in last pulse DEM buildings are systematically smaller than the corresponding CAD objects, while on the other hand nearly no vegetation is acquired.

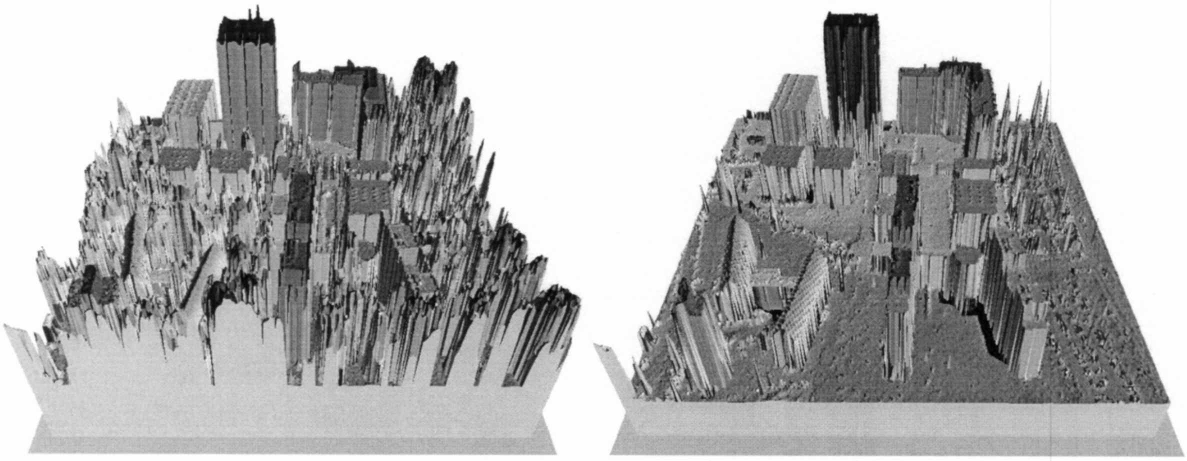

Figure 5: Oblique view on laser DEMs; left: first pulse mode, right: last pulse mode (same subset as Figure 4)

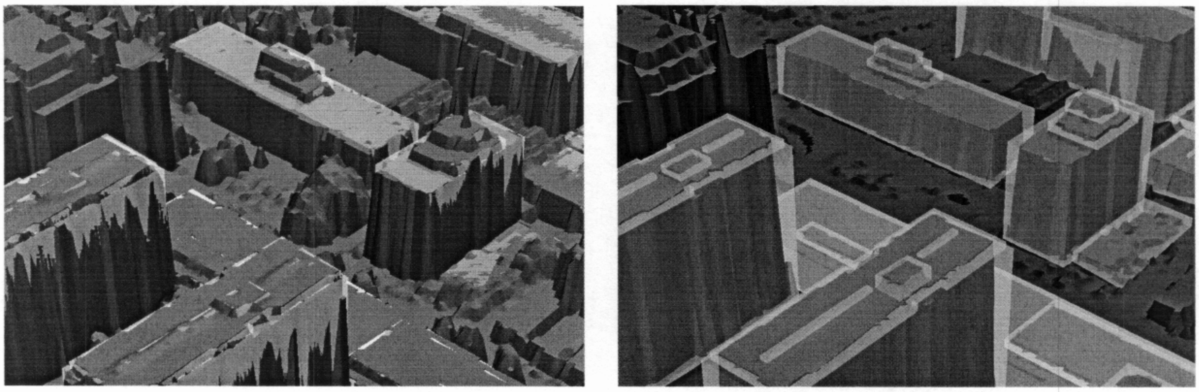

Figure 6: Superimposition of CAD models and first pulse and last pulse DEM respectively; the brighter silhouettes represent the CAD-models, the dark elements the DEMs

3 EFFECTS ON BUILDING RECONSTRUCTION

3.1 Recognition and reconstruction process of buildings

For understanding the effects on building reconstruction a short description of the approach developed at IPF has to be given. This method is based on laser scanning elevation data (DEM) and spectral information (CIR aerial images). During preprocessing a stepwise elimination of objects which are not buildings is carried out. After geometrical rectification, vegetation areas are extracted in the CIR images by means of vegetation index (NDVI). A superimposition of these with the laser DEM enables the elimination of 3D vegetation objects like trees or bushes (Figure 7, right side). All remaining 3D objects are separated and for further processing regarded as building hypotheses. For each object, plane parts (e.g. roof planes) are extracted by a specific region growing algorithm. An intersection of these planes leads to contour lines and corner points of the object (e.g. as wireframe model). A detailed description of this method is given in (Vögtle & Steinle, 2000).

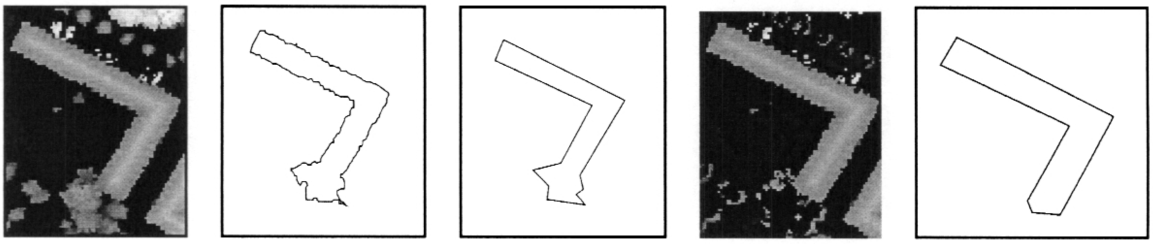

Figure 7: Recognition of 3D objects as building hypotheses; left side: original first pulse DEM, original contour line of separated building including disturbing object, same Douglas-Peucker filtered; right side: first pulse DEM after vegetation reduction, resulting contour line (Douglas-Peucker filtered)

3.2 Examples

Several different data sets had been investigated concerning building reconstruction by means of the above mentioned approach. In a first attempt, the data acquired by first pulse mode were preprocessed as described in the previous section, while last pulse data remain in original status. Additionally, for experimental purposes the first pulse DEM was introduced without any preprocessing, i.e. without elimination of disturbing objects like vegetation. As examples two buildings in different environments are chosen, both located in our test area *Karlsruhe*. The presented DEMs were acquired by the TopoSys laser scanning system. The flight for data acquisition in first pulse mode was carried out in summer of 1997, the one for last pulse mode in the beginning of 1998. Both data sets were georeferenced and resampled to a grid of 1m x 1m. In the DEM roof planes were segmented and contour lines and edge points were computed by intersection process which leads to wireframe models. In Figure 8 the results for the first test building, using first and last pulse mode, are shown.

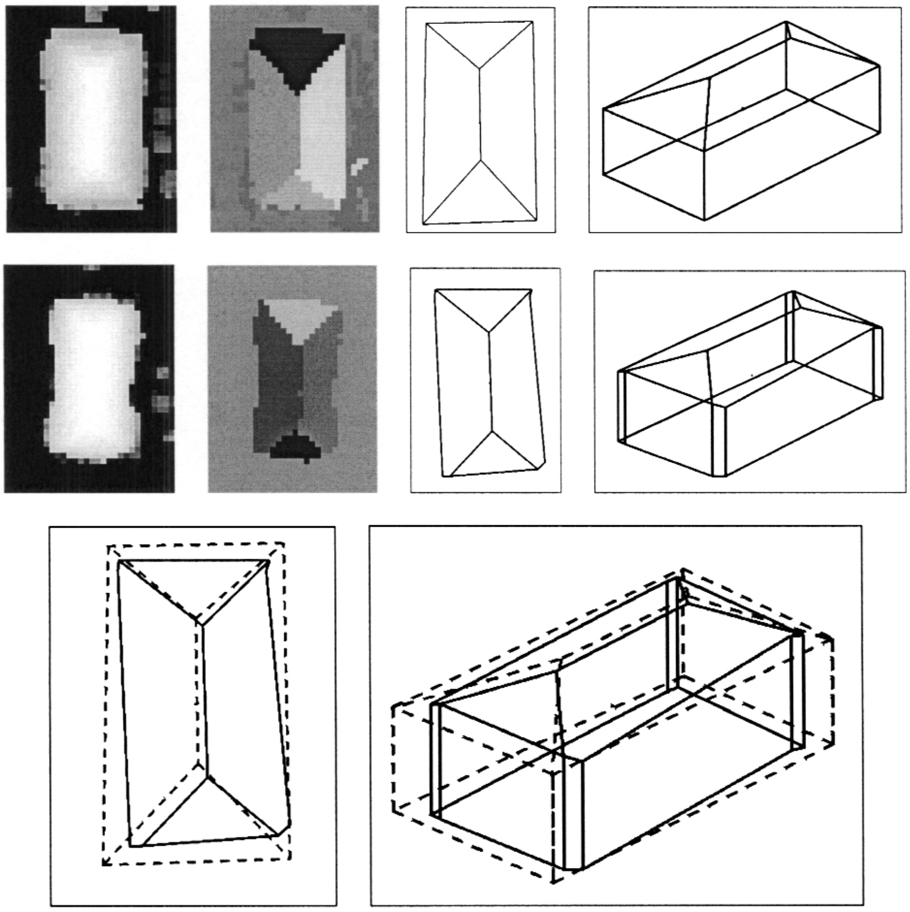

Figure 8: Reconstruction process for test building 1; from left to right: laser DEM, segmented roof planes, wireframe model in vertical view, same in oblique view; first row contains results derived from first pulse data, second row results from last pulse data; in the last row overlay of both results

The differences between these results are quite obvious. Using first pulse mode, the building contour lines approximate quite well the shape of the roof planes. For last pulse mode, poorer results are obtained. The building is modelled much smaller and the contour lines do not fit very well to the shape of the house. This is caused by the kind of measurement, as shown in section 2.3.

By means of the second test building another phenomenon can be outlined. In Figure 9 (left side) the results are presented for first pulse measurement without elimination of vegetation (due to experimental purposes). The example shows that this can cause serious problems: a tree is standing very close to the building; because the tree and the roof have similar elevations, parts of the tree were considered during segmentation as belonging to one of the roof planes. Therefore, the lower left building corner was set at the end of the tree, and not at the end of the building.

However, as mentioned above, the modelling in this approach is based on a vegetation reduced DEM. This leads to another result in the reconstruction process (Figure 9, right side). In automatic processing it is important to extract 3D objects as building hypotheses, i.e. regions for further processing. For the second example, significant differences between both versions occur. Because the tree was nearly eliminated, no building hypotheses has been established at this position (see Figure 7). Therefore, the plane extraction process did not include the tree canopy and the roof plane was not extended outside the house borders, i.e. the reconstructed house model coincides much better with corresponding CAD model (Figure 9, right side).

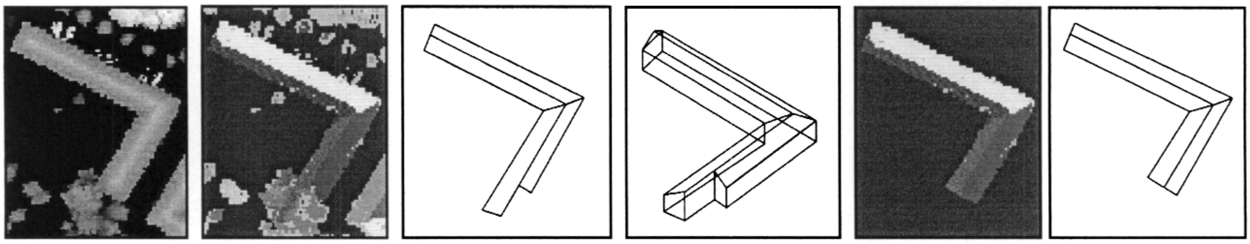

Figure 9: Reconstruction process for test building 2; left to right: first pulse DEM (not vegetation reduced), segmented planes (including disturbing objects), wireframe model (vertical view), same (olique view), segmented planes from vegetation reduced DEM, resulting wireframe model (vertical view)

Figure 10 shows a vertical view of the superimposition of the wireframe models derived from vegetation reduced first pulse and last pulse DEM. The latter is again much smaller than the other one, but contains an additional small plane in the upper left part. The correct shape is of type *hip roof*, therefore none of the data sets lead to a correct description, but with last pulse DEM a better coincidence concerning the shape can be achieved, not concerning the dimensions of the building.

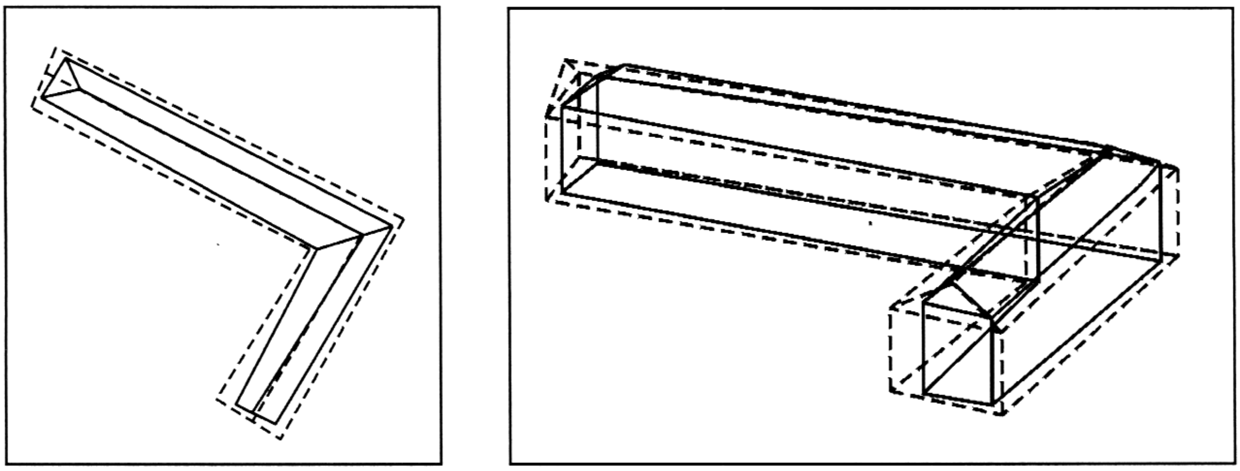

Figure 10: Superimposition of the reconstructed buildings as wireframe models, derived from first pulse (dashed lines) and last pulse mode (solid lines)

A numerical comparison between the results of first and last pulse derived wireframe models has shown mean differences of about 0.8m to 1.5m in position and about 0.2m to 0.6m in elevation. Regarding the fact that these models are systematically too large (first pulse mode), respectively too small (last pulse mode), these results seems to be adequate for most applications concerning 3D city models. Compared to manually measured CAD models (accuracy +/- 0.20m), the deviations are in the order of about +/- 0.2m to 0.9m in position and about +/- 0.2m in elevation.

4 CONCLUSIONS

In this paper the different characteristics of first and last pulse modes of laser scanners were explained, as well as the effect on the building recognition and reconstruction process. It was found that data acquired by first pulse mode does coincide better with the contour lines of cadastral maps or manually measured CAD models. On the other hand, last pulse mode was found to be advantageous concerning the roof shapes, because it is not affected as much as the first pulse measurement by disturbing objects on the roofs (e.g. antennas, chimneys). Another advantage of last pulse measurement is that most vegetation is not acquired. In first pulse mode this has to be taken into account by specific preprocessing procedures. But the necessary spectral information is already acquired by operational systems by means of video cameras or spectral scanners.

More generally, the results of building modelling depend on the quality of the building hypotheses. Mainly vegetation but also objects on the roofs may disturb a correct separation of 3D objects and therefore, a correct reconstruction of the buildings. Problems could also occur, if complex building structures are acquired where the surfaces consists of a lot of small planes partly occluded.

Nevertheless, first experiences show the principle suitability of laser scanning data for building reconstruction. The differences founded between building reconstruction based on first and last pulse derived DEMs compared to CAD models indicates that they are of sufficient accuracy for most applications. In most cases the buildings could be successfully reconstructed regarding their shape and dimensions. In future, further investigations have to be done to verify the first experiences concerning the differences of first and last pulse based building reconstruction.

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