AUTOMATIC EXTRACTION OF VERTICAL WALLS FROM MOBILE AND AIRBORNE LASER SCANNING DATA

M. Rutzinger[*], S. Oude Elberink, S. Pu, G. Vosselman

International Institute for Geo-Information Science and Earth Observation, 7500 AA Enschede, The Netherlands
(rutzinger, oudeelberink, spu, vosselman)@itc.nl

Commission III, WG III/3

KEY WORDS: buildings, 3D feature extraction, map updating, position accuracy

ABSTRACT:

Building outlines in cadastral maps are often created from different sources such as terrestrial surveying and photogrammetric analyses. In the latter case the position of the building wall cannot be estimated correctly if a roof overhang is present. This causes an inconsistent representation of the building outlines in cadastral map data. Laser scanning can be used to correct for such estimation inconsistencies and additional occurring changes in the building shape. Nowadays, airborne (ALS) and mobile laser scanning (MLS) data for overlapping areas are available. The object representation in ALS and MLS point clouds is rather different regarding point density, representation of object details (scale), and completeness, which is caused by the different platform position i.e. distance to the object and scan direction. These differences are analysed by developing a workflow for automatic extraction of vertical building walls from 3D laser scanning point clouds. A region growing segmentation using Hough transform derives the initial segments. These are then classified based on planarity, inclination, wall height and width. The planar position accuracy of corresponding walls and completeness of the automatically extracted vertical walls are investigated. If corresponding vertical wall segments are defined by a maximum distance of 0.1 m and maximum angle of 3° then 24 matches with a planimetric accuracy of 0.05 m RMS and 0.04 m standard deviation of the X- and Y-coordinates could be found. Finally the extracted walls are compared to building outlines of a cadastral map for map updating. The completeness of building walls in both ALS and MLS depends strongly on the relative position between sensor and object. A visibility analysis for the building façades is performed to estimate the potential completeness in the MLS data. Vertical walls in ALS data are represented as less detailed façades caused by lower point densities, which is enforced by large incidence angles. This can be compensated by the denser MLS data if the façade is covered by the survey.

1. INTRODUCTION

Airborne laser scanning (ALS) data is available for many urban areas. Recently mobile laser scanning (MLS) campaigns are conducted providing data on urban environments in much higher detail, which can be additionally used for map updating purposes. The derivation of the correct wall position is important for applications such as 3D building modelling (Oude Elberink, 2008). The major drawback of laser scanning for map updating is the incomplete representation of walls. The following study presents a method for automatic wall extraction from laser scanning point clouds and investigates the accuracy and completeness of wall representation in both ALS and MLS data.

The paper is structured as follows. Section 2 gives an overview on studies and applications in surface extraction, mobile laser scanning, building modelling, and map updating. The test site and the used data sets are introduced in Section 3. Section 4 explains the workflow for automatic wall extraction and validation. The results are discussed in Section 5 followed by a conclusion (Sec. 6).

2. RELATED WORK

Still a challenge of surface extraction from laser scanning is the high amount of data to process. Strategies for efficient data processing such as segmentation are needed to extract features from high resolution TLS and MLS data. A comprehensive overview of methods for segmenting laser scanning point clouds can be found in Vosselman et al. (2004b). In the following some recent examples for 2D range image, voxel, and point cloud segmentation are given.

Gorte (2007) proposes segmentation on range gradients in 2D parametric space to extract planar features of a TLS scene. The method works on the original range image data, which doesn't allow segmentation of overlapping scans and therefore is restricted to the application on single scans.

A solution to work in 3D space is the conversion of the laser scanner point cloud to a voxel data structure, which reduces the amount of data to process. The well defined neighbourhood of the voxel data model makes it possible to apply neighbourhood analysis similar to rasterized images. The disadvantage of these approaches is the loss of the original echo position by the aggregation of the irregular distributed point cloud into voxel cubes.

Schmitt and Voegtle (2009) present a voxel-based approach for planar surface extraction from TLS data for building shape reconstruction. Voxels representing the building surface are

---

[*]   Corresponding author.

grouped by similarity of the normal vector, which is calculated for each voxel barycenter.

To maintain the highest possible accuracy of laser scanning point clouds several studies present segmentation and feature extraction algorithms working directly on the laser scan echoes in 3D space. Homogeneous surface patches can be found by grouping echoes based on similarity of normal vectors (Rabbani et al., 2006) or clustering in feature space (Filin and Pfeifer, 2006). In a further clustering approach planarity is defined by a Hough Transform (Vosselman and Dijkman, 2001),

Recent publications on MLS focus on the presentation of system set-up, their performance and achievable measurement accuracy. A comprehensive study on current devices and manufacturer specification is published in Shan and Toth (2008). Related work on mobile mapping in general can be found in MMT'07 (2007).

Haala et al. (2008) investigate the accuracies of MLS measurements from StreetMapper for architectural heritage collection and 3D city modelling. They compare estimated planes on a selected building façade with walls from a 3D city model. They found constant errors between 12.6 up to 25.7 cm. Post processing could reduce the distances to 7.4 - 9.0 cm. The remaining deviations are explained by the inaccuracies of the façade of the used reference.

Vertical and horizontal geometric accuracy of the SteetMapper MLS platform is analysed by Barber et al. (2008). Corresponding points are selected at target areas clearly identifiable by their intensity values. The planimetric accuracy found ranges from 0.09 - 0.26 m.

Studies to derive building outlines from ALS data face the problem of the different wall representations in cadastral maps. On the one hand there are differences at roof overhangs if the map data represents the wall position and the airborne data the roof outline and on the other hand often map data is acquired from different sources (terrestrial and photogrammetric), which leads partly to differences at building outlines. A comprehensive discussion on problems on building reconstruction from ALS can be found in Oude Elberink (2008). Different possibilities for measuring the detection success for the detection of building footprints from ALS using cadastral map data are presented by Rutzinger et al. (2009). Algorithms for building outline detection for map updating are presented by Vosselman et al. (2004a) and Matikainen et al. (2003). The discrepancies on building outlines are solved if walls can be surveyed directly by laser scanning (e.g TLS or MLS) assuming cadastral data from terrestrial surveying. For example Pu and Vosselman (2006) apply a segmentation on plane fitting to extract planar building parts from TLS data for 3D building modelling.

3. DATA AND TEST SITE

3.1 Test Site

The test site is a 425 m long track in the city of Enschede (The Netherlands). The street width varies between 20 and 50 m. It comprises 45 residential buildings (mainly one story buildings) with gardens and varying vegetation types such as high trees and bushes.

The data contains furthermore temporal objects such as moving and parking cars and pedestrians. The test site is covered by ALS data from overlapping flight strips and a single MLS track.

3.2 Data Set

The ALS data (Fig. 1a) was acquired by the helicopter-based FLI-MAP 400 system with forward, nadir, and backward looking scan directions. The MLS data set (Fig. 1b) was collected by the Optech LYNX Mobile Mapper, which has two rotating laser scanners mounted on the back of the vehicle. The manufacturer specifications of both platforms are summarized in Table 1.
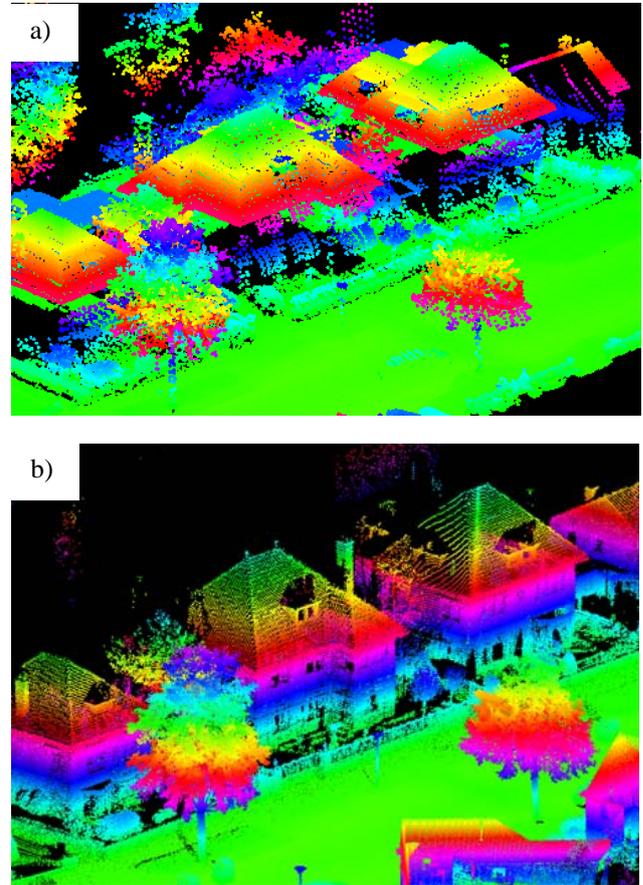
Figure 1: A detail of the test site acquired by airborne laser scanning (a) and mobile laser scanning (b).

	FLI-MAP 400 (ALS)	**LYNX (MLS)**
Maximum range	400 m	100 m (at 20% reflectivity target)
Range precision	1.0 cm (1 sigma)	0.7 cm (1 sigma)
Absolute accuracy (GPS)	3.0 cm (for hard level surfaces)	5.0 cm (at 100 km/h)
Scan angle	60 degree	360 degree
Scan rate	150-250 Hz	150 Hz (9000 rpm)
Measurement rate	150,000-250,000 pulses/sec	100,000 pulses/sec per sensor
Echo per pulse	4 echoes	4 echoes

Table 1: Manufacturer specifications of the ALS and MLS system used (Fugro, 2009; Optech, 2008; Shan and Toth, 2008).

For the presented work no pre-selection on echoes is performed and all echoes available from ALS (multi-direction) and MLS (left and right sensor) are used.

4.METHOD

4.1 Vertical wall extraction

First a region growing segmentation is performed to find planar areas in the point cloud. Seed surfaces are found by a 3D Hough transform (Vosselman et al., 2004b). Neighbouring points within a defined radius are added to the seed surface if they are within a distance threshold to the plane. Then the plane is recalculated together with the excepted neighbouring points and new neighbours are searched. The vertical walls are extracted using the same segmentation and classification approach for both ALS and MLS data sets.
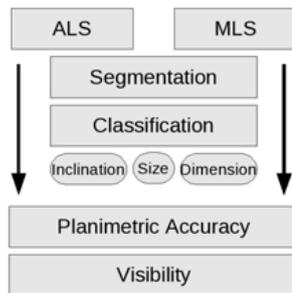
Figure 2: Workflow for wall extraction and validation.

The resulting segments are checked on inclination, size (minimum number of echoes), and dimension (height and width). The check on height and width is necessary to remove remaining segments on fences, garden walls, and planar segments occurring in vegetation. Especially the minimum segment width has to be selected carefully to maintain also very narrow wall parts of the building façade.

4.2 Planimetric accuracy between mobile and airborne laser scanning walls

In order to allow the combined usage of ALS an MLS the relative position accuracy of both data sets has to be checked. A reliable measure for the position accuracy would be the comparison of corresponding building corners derived from intersecting wall segments. Since the edge representation of vertical building façades is rather incomplete in the ALS data this approach could not be applied for comparison and planarity checking (Fig. 4c). The reason for that is that walls, which are perpendicular oriented to the flight line of the helicopter, hardly contain echoes. Although the forward and backward scanning option of the system was used, the deviation of the helicopter from the ideal scanning position (pitch) causes an inhomogeneous distributed point density and even missing reflections on entire walls.
Hence, an alternative distance measure for the planimetric accuracy is used for comparison. This is done by the calculation of the offsets in X- and Y-direction as proposed by Vosselman (2008). He determines planar offsets between extracted roof ridge lines in overlapping flight strips from ALS campaigns.
For each MLS and ALS wall segment a plane is estimated by least square fitting. Corresponding ALS and MLS segments are defined by a maximum distance and a maximum angle criteria between the lines projected into the XY-plane. The angle threshold is introduced to exclude situations, where a corresponding wall within the distance is found but differs in orientation because it belongs to another part of the building.

Then the centroid is derived for the wall in the MLS data and orthogonally projected to the corresponding wall in the ALS data. The derived distance is the input for the calculations of systematic planar shifts and remaining position errors. The offsets in X- and Y-direction, RMS, and the standard deviation of the offsets are calculated including all the distances between the corresponding walls of both data sets.

In order to define two wall pairs as corresponding a minimum distance has to be defined. Depending on this distance also the calculated offsets change. The distance threshold must be defined in a way so that incorrect correspondences between different building parts will not occur. Figure 3 shows the changing offset values (Fig. 3a) and the number of corresponding walls found (Fig. 3b) depending on the distance threshold.

4.3 Visibility analysis

Since the building wall representation in the MLS data is limited to the façade parts, which can be seen from the street, visibility is modelled by using the GPS track of the MLS platform and building outlines from a cadastre map. Visibility is calculated for a certain radius along the GPS track in regular distances. The selected visible building walls from the map are then used to compare with the detected building walls in MLS and ALS in order to analyse the completeness of the derived walls in MLS and if there is an improvement adding walls from ALS.

5. RESULTS

5.1 Parameter Settings

Segmentation parameters are estimated by visual inspection for ALS and MLS data independently. The minimum segment size is set to 50 points for ALS and 1000 points for MLS respectively. The remaining settings for the wall classification describing the object itself are independent on the data representation and therefore the same in both cases (inclination $< 3°$, height > 2 m, width > 0.5 m).

5.2 Planimetric Accuracy and Correspondences

Estimating the settings for the planimetric accuracy Figure 3b shows that between 0.5 m and 0.1 m the number of corresponding walls and the calculated offsets change only slightly. A higher distance value includes comparison of wall parts which are not corresponding resulting in too high offset values, while a very low distance threshold is unreliable because the number of observations gets too little for the testing.
29 corresponding wall pairs between MLS and ALS are found at a distance threshold of 0.5 m. The offset in X-direction is 0.05 m and in Y-direction 0.01 m. The root mean square and standard deviation are 0.11 m. Using a smaller distance threshold of 0.1 m still 24 corresponding wall pairs with a RMS of 0.05 m, a standard deviation of 0.04 m, and offsets of 0.03 m in X- and 0.04 m in Y-direction are present. Compared to the manufacturer accuracy estimates (Table 1) the offsets show a sufficient registration of both data sets to allow a combined usage.

a)

b)
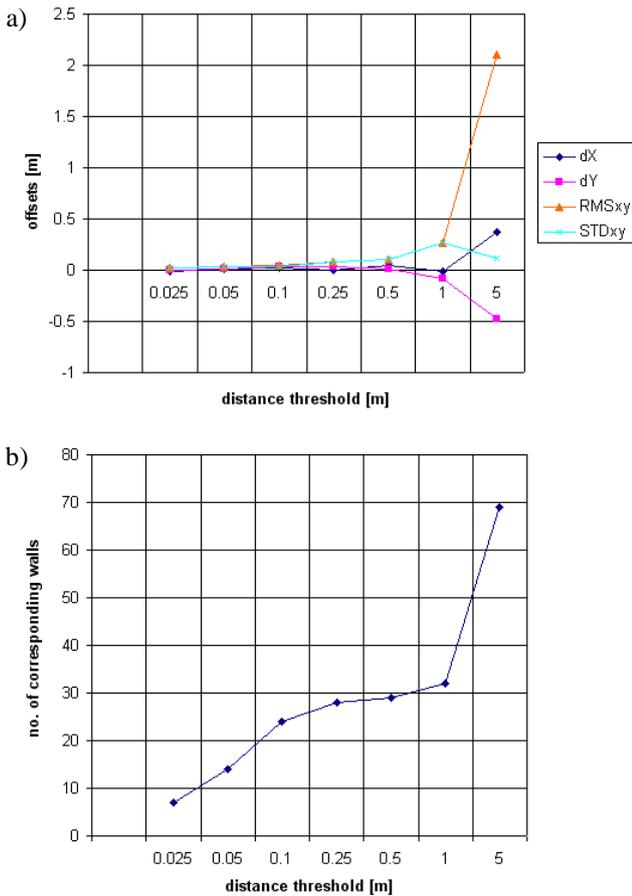
Figure 3: Dependency between distance threshold, offsets and accuracies (a) and number of corresponding walls (b).

a)

b)

c)

Figure 4: Cadastral map (in yellow) overlaid by viewing points and modelled visible facades (a), vertical segments extracted from MLS (b) and ALS (c).

5.3 Visibility and Completeness

Figure 4 shows the building parts that theoretically should have been visible (Fig. 4a), the walls extracted from MLS (Fig. 4b) and ALS (Fig. 4c). The cadastral map contains 45 individual buildings which is a total length of 2220 m building façade and 1240 m of those are potentially visible.

From the MLS data 135 wall segments were extracted, which cover a length of 840 m. 470 m of those correspond to the map data. The rest are either additional building walls, which are not included in the map or represent other vertical structures such as garden walls, fences, etc. The comparison of the modelled visibility and the walls extracted from MLS show that some wall parts could not be extracted. This is due to shadow effects caused by objects between sensor and buildings such as trees or parking cars. Another reason are strongly structured building façades, which do not meet the planarity constrains of the applied segmentation or classification criteria.

From the ALS data 262 wall segments were extracted, which cover a length of 1720 m. 570 m of those correspond to the map data. In general this method works rather well but the result strongly depends on the orientation between flight line and building wall. In the case of the used test site the flight line was nearly perpendicular to the main road track. Despite the forward and backward looking option too few echoes are reflected on some walls to detect them completely for every building side.

Nevertheless, the comparison shows the potential for the combined usage of extracted walls from ALS and MLS. While MLS has the potential to provide more detailed façade parts such as step edges between connected buildings and sub building units (Fig. 5) ALS can provide walls which are not visible from the MLS scanner position (Fig. 4b and c).

a)   b)

c)   d)
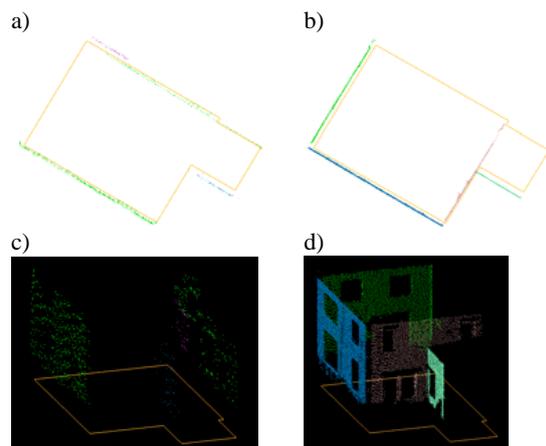
Figure 5: Comparison of vertical walls from ALS (a,c) and MLS (b,d).

6. CONCLUSION

ALS and MLS provide reliable information with high accurate position correspondence on building walls. The façade

description by ALS and MLS differs due to the point density but the planar positions fit very well so that both data sets can be used for correcting and updating map information. This helps especially in 3D building modelling to rely on the wall position measured from laser scanning and only little information has to be taken from map data for the remaining parts. However, the authors recommend the combined usage of well registered ALS and MLS data for map updating (i.e. for 3D building modelling purposes) only if the ALS and MLS data have complementary and complete coverage of the required vertical structures.

The completeness of walls from laser scanning depends on the one hand on the scanner position and on the other hand on occlusion by other objects. The non-visible wall parts in MLS are partly covered by the ALS data. Despite the multi-looking options of the ALS platform used, some building parts remain without reflection.

The comparison with the visibility study shows that not all the potential visible wall parts could be extracted from the MLS data. Some façade parts, which are occluded by vegetation or very narrow wall parts are lost within the wall extraction procedure. Further façade parts, which do not meet the planarity and vertical constrains are lost as well.

Future studies should investigate different influencing factors between street orientation and flight line directions to identify where and when walls from ALS can be surveyed best. This combined with information on street accessibility and visibility can be used to give a recommendation on both ALS and MLS campaign planning in order to provide data sets which are optimized for 3D city modelling and map updating.

ACKNOWLEDGMENTS

REFERENCES

Barber, D. Mills, J., Smith-Voysey, S., 2008. Geometric validation of a ground-based mobile laser scanning system, ISPRS Journal of Photogrammetry and Remote Sensing, 63, (1), 128-141.

Filin, S. and Pfeifer, N., 2006. Segmentation of airborne laser scanning data using a slope adaptive neighborhood. ISPRS Journal of Photogrammetry and Remote Sensing 71 (6), 743-755.

Fugro, 2009. FLI-MAP. http://www.flimap.nl (accessed April 5, 2009)

Gorte B., 2007. Planar feature extraction in terrestrial laser scans using gradient based range image segmentation, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 36, part 3/W52, pp. 173-177.

Haala, N., Peter, M., Cefalu, A., Kremer, J., 2008. Mobile Lidar Mapping For Urban Data Capture. VSMM 2008, Digital Heritage – Proceedings of the 14th International Conference on Virtual Systems and Multimedia, pp. 95 - 100.

Matikainen, L., Hyyppä, J., Hyyppä, H., 2003. Automatic Detection of Buildings from Laser Scanner Data for Map Updating. International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences, vol. 35, pp. 218-224.

MMT'07, 2007. 5th Symposium on Mobile Mapping Technology. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol 36-5/C55. http://www.cirgeo.unipd.it/cirgeo/convegni/mmt2007/proceedings/ (accessed June 26, 2009)

Optech (2008): LYNX Mobile Mapper Data Sheet. http://www.optech.ca/pdf/LynxDataSheet.pdf (accessed April 5, 2009)

Oude Elberink, S., 2008. Problems in Automated Building Reconstruction based on Dense Airborne Laser Scanning Data. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 37, part 3A, 93-98.

Pu, S., Vosselman, G., 2006. Automatic extraction of building features from terrestrial laser scanning. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 36, part 5, Dresden, Germany, 5 p. (on CD-ROM).

Rabbani, T., Heuvel, F., Vosselman, G., 2006. Segmentation of point clouds using smoothness constraints. International Archives of Photogrammetry and Remote Sensing and Spatial Information Sciences, vol. 36, Dresden, Germany, pp. 248-253.

Rutzinger, M., Rottensteiner, F., Pfeifer, N., 2009. A Comparison of Evaluation Techniques for Building Extraction From Airborne Laser Scanning. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 2 (1), 11-20.

Schmitt, A. and Vögtle, T., 2009. An advanced approach for automatic extraction of planar surfaces and their topology from point clouds. Photogrammetrie, Fernerkundung und Geoinformation, 1, 43-52

Shan, J. and Toth, C.K., 2008. Topographic laser ranging and scanning – Principles and Processing. Taylor and Francis Group. 590 pp.

Vosselman, G., 2008. Analysis of planimetric accuracy of airborne laser scanning surveys. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 37, part 3A, Beijing, China, pp. 99-104.

Vosselman, G. and Dijkman, S., 2001. 3D Building Model Reconstruction from Point Clouds and Ground Plans. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 34, part 3/W4, pp. 37-43.

Vosselman, G., Gorte, B.G.H., Sithole, G., 2004a. Change detection for updating medium scale maps using laser altimetry. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 34, part B3, Istanbul, Turkey, pp. 207-212.

Vosselman, G. Gorte, B.G.H., Sithole, G., Rabbani, T., 2004b. Recognising structure in laser scanning point clouds. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 46, part 8/W2, Freiburg, Germany, pp. 33-38.