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Article

Feasibility of Facade Footprint Extraction from Mobile Laser Scanning Data

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Summary: Terrestrial laser scanning provides valuable information for building outlining, facade detection and building reconstruction. Especially mobile laser scanning (MLS) is considered as well suited to collect 3D point clouds from building facades along road corridors for large areas. However, the completeness of facade representation in MLS has to be investigated in order to be able to draw conclusions about the usability of this kind of data sets for further applications such as building facade modelling. We investigate the detection rates of a fully automatic point cloud processing method for extracting building facades from MLS. The point cloud is segmented into planar regions, from which vertical structures are extracted. The detection rate is assessed by comparing the detected facade footprints with visible building outlines extracted from a digital cadastre map. The completeness of the extraction is investigated regarding the facade structure, length and the distance of the facades to the vehicle trajectory. It was found that the representation of facades extracted from MLS and the cadastral map might differ if very short facade parts (< 2 m) representing jutties are present on the ground level floor. This leads to an underestimation of completeness. Moreover, it can be shown that there is a direct relationship between further characteristics, e. g. that long facades and facades near to the vehicle are more likely to be detected than others. Facades with a length between 10 m and 20 m reach a completeness of 74%. Most facades are found in a distance of 10–20 m from the vehicle where the completeness ranges from 71% to 50%. The low completeness can be explained by occlusions from moving objects and vegetation, the facade structure, orientation and its complexity. The comparison with digital cadastral data shows that MLS is not that well suited for the detection of building facades as one might expect.

Zusammenfassung: *Möglichkeiten der Extraktion von Fassadengrundlinien aus mobilen Laserscannerdaten*. Terrestrisches Laserscanning liefert wertvolle Informationen für die Abgrenzung und Detektion von Gebäuden und Fassaden. Insbesondere Mobiles Laserscanning (MLS) eignet sich zur großflächigen Erfassung von 3D Punktwolken von Gebäudefassaden entlang von Straßenzügen. Es bedarf jedoch der Untersuchung der Vollständigkeit der Fassadenrepräsentation in MLS-Daten, um Aussagen über die Verwendbarkeit dieser Art von Datensätzen in Anwendungen wie zum Beispiel Gebäudefassadenmodellierung treffen zu können. Wir untersuchen die Detektionsraten einer vollautomatischen Punktwolkenprozessierungsmethode für die Extraktion von Gebäudefassaden aus MLS-Daten. Die Punktwolke wird in ebene Einheiten segmentiert, von denen alle vertikalen Strukturen extrahiert werden. Die Detektionsraten werden analysiert, indem die detektierten Fassaden mit sichtbaren Gebäudeumrissen, die von einer digitalen Katastralmappe extrahiert wurden, verglichen werden. Die Vollständigkeit der Extraktionsmethode wird betreffend der Fassadenstruktur, Länge und Distanz zwischen Fassade und MLS-Fahrzeug untersucht. Fassaden unterscheiden sich in beiden Datensätzen vor allem dann, wenn sehr kurze (< 2 m) Fassadenteile vorhanden sind, die zum Beispiel Erker repräsentieren. Dies führt zu einer Unterschätzung der Vollständigkeit. Darüber hinaus kann gezeigt werden, dass ein direkter Zusammenhang zwischen weiteren Charakteristiken besteht. Insbesondere lange Fassaden und Fassaden nahe dem MLS-Fahrzeug erreichen höhere Vollständigkeiten als kurze und weiter entfernte. Fassaden mit einer Länge zwischen 10 m und 20 m erreichen eine Vollständigkeit von 74%. Die meisten Fassaden werden in einer Distanz von 10–20 m zum MLS-Fahrzeug mit einer Vollständigkeit von 71% bis 50% detektiert. Die geringe Vollständigkeit kann durch Abschattungseffekte von bewegten Objekten, Vegetation und durch die Fassadenstruktur,

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-ausrichtung und ihrer Komplexität erklärt werden. Der Vergleich mit der digitalen Katastralmappe zeigt, dass MLS nicht in jenem Ausmaß für die Detektion von Gebäudefassaden geeignet ist, als man in einem ersten Blick erwarten würde.

1 Introduction

Today laser scanning point clouds are acquired among many others for purposes of map updating, 3D building reconstruction, and 3D city modelling. Recently mobile laser scanning (MLS) data is collected especially in urban areas and along road corridors. On the one hand laser scanning is more expensive than 3D reconstruction from images. On the other hand laser acquisitions can be conducted in night time, where less traffic and people disturb the scene. 3D data can be also collected for homogeneous facades with little or no texture where photogrammetric reconstruction approaches would have difficulties. An advantage of terrestrial laser scanning (TLS) in comparison to aerial acquisition methods of photogrammetry and airborne laser scanning (ALS) is that the position of vertical facades is represented directly by echoes reflected on building walls and does not contain roof overhangs. This makes the data set also usable for map updating purposes (in the case of MLS only for those parts, which are visible from the road side). However, due to varying point densities, different viewing positions, scan geometry, and occluding objects, the completeness of the building facades might deviate from user's expectations.

The objective of this paper is the quantitative comparison of extracted building facades from MLS in order to investigate how complete the building facade representation in these data sets is. This might have implications to the potential usability and applications of such data. The ground lines of building facades projected in to the XY plane are extracted automatically from MLS point clouds and are quantitatively compared to the ones from ground plans. The developed workflow is tested within a case study using MLS data from Enschede, The Netherlands.

The article is structured into a section presenting the related work on current segmentation methods for efficient segmentation of planar surfaces, MLS applications, and contributions to facade and building reconstruction from dense laser scanning point clouds (Section 2). In Section 3 the method for segmentation and facade extraction is presented. The data sets and the test site are described in Section 4. Finally, the results are discussed (Section 5) and a conclusion is given in Section 6.

2 Related Work

Automatic feature extraction from high density laser scanning point clouds is still an unsolved research problem. Several methods were presented for efficient range data processing to extract planar features such as building roofs and facades. An overview of segmentation techniques can be found in Vosselman et al. (2004) and Vosselman & Klein (2010). In the following, methods working either in 2D range images, voxel space or 3D point clouds are discussed. A method for extracting planar features in 2D range images from TLS was developed by Gorte (2007). The horizontal and vertical scan angle, the distance between origin and pixel and the derived image gradients are used to assign every pixel to a plane. Finally, the pixels are assigned to planar segments using a region growing segmentation. The algorithm works efficiently in the image domain and is straightforward to implement, but cannot be applied to 3D point clouds of overlapping TLS scenes. Schmitt & Vögtle (2009) present a voxel-based approach to derive planar patches from TLS data. The 3D point cloud is converted into voxel space. For each voxel centre the normal vector is calculated. Analysing the deviation of the normal direction among adjacent voxels, planar surfaces are extracted where the angle difference is below a certain value. The highest accuracy of the laser measurements is maintained, if features are extracted directly from the recorded echoes i. e. from the 3D point cloud. Also in this domain the normal vectors can be used to find planar regions e. g. by estimating the normal using a TIN neighbourhood or a KD-tree (Rabbani et al. 2006, Jochem et al. 2009). Filin & Pfeifer (2006) present a point cloud based approach for planar surface segmentation applying clustering in feature space. Neighbouring points are selected using slope adaptive neighbourhood. Planar segments are then separated e. g. by clustering point attributes such as the X- and Y-component of the normal vector. The segmentation used in this study defines planarity for seed point selection in Hough space (Vosselman & Dijkman 2001, Vosselman & Klein 2010). The advantage of this method is (i) the relatively robustness against noise and (ii) it works also on data sets with inhomogeneous point distributions and data sets containing gaps. The method is explained in detail in the Section 3.

MLS is a rather young development in the field of laser scanning. Recent publications focus on the geometric quality and problems of registration of the acquired data sets (Haala et al. 2008, Barber et al. 2008). Only little work has been published on feature extraction so far. The focus lies on road geometry determination (Yu et al. 2007, Mcelhinney et al. 2010) and road feature extraction (Brenner 2009, Schwarzbach 2009). Manandahar & Shibasaki (2002) analyse the orientation of echoes along the scan lines separating natural objects from man-made objects, which are described by planarity or linearity. Building facades are extracted by checking the connectivity and comparing the distance to a fitted line to the points of a given scan line. The presented results look visually promising but no further error assessment was computed.

The detection of building outlines from ALS or aerial imagery is hampered by the fact that the building outlines in these data sets are defined by the roof extension and not by the building walls as in the cadastral maps. Furthermore, cadastral maps are often partly surveyed by terrestrial measurements and partly updated by photogrammetry including the roof overhangs. This limits the comparability of cadastral data and data sets from automatic detection approaches (Rottensteiner et al. 2007), in change detection analysis using cadastre maps and laser scanning data (Vosselman et al. 2005, Matikainen et al. 2010), and in automatic building reconstruction procedures (Oude Elberink & Vosselman 2009). A comprehensive discussion on how to describe the quality of detected building footprints is given by Rutzinger et al. (2009a). These shortcomings are not apparent, if data sets are used, which represent building walls at their actual position. Rutzinger et al. (2009b) investigated the completeness of building outlines extracted from ALS and MLS at a sample where overlapping data was available. For instance, dense ALS data contain echoes from building wall points, which might be used to complete cadastral information. However, it has been shown that the representation of echoes on walls in ALS point clouds strongly depends on the flight settings, so that the full building outline might be extractable only for specific cases. Extracted facades from TLS and MLS represent building walls at their "true" position. For example, Pu & Vosselman (2009) extract building facades and model 3D buildings using TLS data.

Concluding the related work, out of the range data segmentation algorithms published, methods are favoured, which have been shown to work efficiently and reliable in the original 3D point cloud maintaining the high precision and accuracy of the laser scanning measurements. The precision of MLS has been investigated and first applications have shown that MLS is well suited for reconstruction purposes. However, the appearance of objects such as building facades in MLS data is influenced by the relative position of the scanner to the object and by occlusion effects caused e. g. by vegetation or temporary objects such as cars, which requires further investigation and quantification.

3 Method

The workflow consists of a segmentation step to detect planar areas and a classification step to select vertical segments. The extracted building facades are then converted to building facade ground lines projected into the XY plane in order to compare them to the cadastre and the potentially visible building outlines modelled for the MLS campaign. In the following these extracted lines are called facade lines.

3.1 *Segmentation*

The point cloud is segmented into planar regions using surface growing segmentation with a 3D Hough transform for seed detection (Vosselman & Klein 2010). From the set of points without a segment label an arbitrary point is selected. All points within a certain neighbourhood from the selected point are transformed into planes in the Hough space. If a bin in the Hough space contains votes from a minimum number of points, these points constitute a seed surface and initial plane parameters are obtained from a least squares fit. Further points are added to the seed surface if they fulfil the following criteria for surface growing. The points added have to be in a certain radius around the surface and must lie within a certain distance to the plane. After adding points the plane parameters are re-estimated. If a point becomes part of the segment it cannot be a seed point any more. Further points are added to the segment until the defined limits are exceeded. Then the point cloud is searched for a new seed surface to start the growing procedure for further segments. Points which do not fulfil the segmentation criteria remain unsegmented.

3.2 *Classification*

In a second step the normal vector is estimated for each segment. The inner product of the normal vector with the vertical axis is then compared to an angle threshold in order to select only vertical segments. Non-vertical segments and unsegmented points are removed. Also small segments, which fall below a certain number of points are deleted. For the vertical segments the facade line representing the ground line of the building facade projected to the XY-plane and its 2D length are used for the error assessment.

3.3 *Comparison of Wall Points and Detection Rates*

The possibilities to assess detection rates are manifold. Since only building facades, which are potentially visible from the laser sensor can be extracted from the MLS data, only these are considered as reference in order to investigate the detection success of the proposed method. Visibility is calculated from the MLS GPS trajectory and the cadastral map in order to exclude shadow effects from other buildings. In a second step the selection of visible reference facades is refined by only considering the actual surveyed area as derived from a point density map (1 m resolution). For this comparison the binary representation including areas with number of echoes >1 is generated from a point density map. Then the selection of visible building facades is refined for this area. The detection rate is calculated by computing completeness using two different measures, which are (i) counting and comparing the number of corresponding facades and (ii) measuring and comparing the 2D lengths of facade lines (Fig. 1).

Completeness is defined by the number of true positives (TP) devided by the sum of TP and false negatives (FN). TP are the correct matches i. e. facade lines of the reference corresponding to the facade lines extracted from the laser data. A FN is a facade line contained in the reference but missing in the laser data. In a first step corresponding extracted and reference facade lines have to be found. Correspondence is defined by (i) minimum distance and (ii) angle between extracted building facade and reference facade. The distance threshold accounts for errors caused by differences of object representation in the MLS and the digital cadastral map as well as registration errors. The angle threshold is used to check the similarity in orientation of the lines. In a second step, two different types of TPs for error assessment are defined. Firstly, the corresponding objects, i. e. fulfilling the distance and angle threshold are counted as TP objects. Secondly, in order to be able to give a more detailed description of the correctly detected facade parts, the correctly detected reference facade length [m] has to be considered and

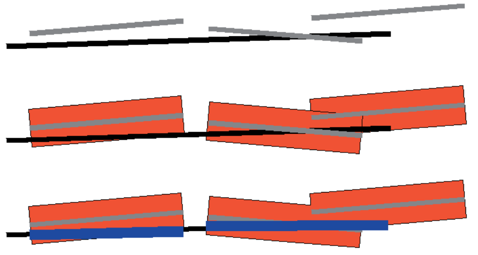

Fig. 1: Definition of correct matches (true positive length) by overlay of extracted facade lines (grey) with the reference facade lines (black), the visualised rectangle representing the minimum distance (red) and the selected reference facade line as true positive (blue).

summed up for the error assessment (Fig. 1). The extracted and reference facade lines might not have the same length or a reference facade is represented by multiple extracted facades. The correctly detected parts of the reference line (i. e. TP line parts) are derived by expanding the extracted facade line orthogonally by the distance threshold defined above, which leads to a polygon (i. e. rectangle) (Fig. 1). If multiple extracted facades correspond to one reference facade line, the generated polygons are first merged, which causes a merging of the geometries if rectangles overlap. The resulting polygons, or single polygon in case of only one extracted line, are then intersected with the reference line and the TP length can be easily obtained by the sum of line parts covered by polygons.

Tests on intervals of length and distance are only applied to the reference (digital cadastral map), while the detected facades are all maintained for potential TP selection. This restricts the further detection rate tests to the comparison of completeness. Moreover, only the potential ability to detect facades is investigated, not a classification of building facades. Therefore, the overestimation of detection is not further investigated as well.

4 Data Sets and Test Site

The MLS data were acquired in leaf-off season using the Optech Inc. Lynx Mobile Mapper. The system has two sensors mounted on the back of the car, which are deflected by two 360 degree rotating mirrors. The sensors scan in two nearly vertical planes perpendicular to each other and both under an angle of 45 degrees with the driving direction. This configuration aims to obtain an optimal visibility of objects and limit effects of occlusion. Each sensor has a scan rate of 150 Hz and a pulse repetition frequency of 100 kHz. The maximum range is specified as 100 m at a 20% reflecting target achieving a range precision of 0.7 cm. The absolute GPS accuracy is defined by 5 cm (Optech Inc. 2008). As reference data the building polygons of the official digital cadastral map of the city of Enschede were used.

The test site is a 9 km long track located in the city of Enschede, The Netherlands. The area was defined by buffering the MLS GPS track with a width of 100 m. This corresponds to the specified maximum range of the Optech Inc. Lynx MLS system (Optech Inc. 2008). For this area 927 buildings were extracted from the digital cadastral map. The area comprises one and two storey family houses surrounded by high deciduous trees in the north west of the test site. In the south and east there are also multi-storey buildings and large building blocks. The test site contains a large variety of facade types such as large planar facades from public and industrial buildings and small structured facades with jutties and shutters from family houses. The road width varies between 20 m and more than 50 m at road crossings, which influences the distance from the MLS sensors to the building facades. Ground elevation changes are only marginal and range from 32.8 m to 42.0 m.

5 Results

Segmentation of planar areas was performed using surface growing, which is based on seed point selection in Hough space and a subsequent plane re-adjustment using least square fitting. The parameters were selected after extensive testing on sample facades. For seed point selection and growing a distance to plane criteria of 0.2 m were applied. The bin size in Hough space was set to 3.0° for the slope angle and 0.2 m for the distance. Neighbouring points were selected with a 3D search radius of 0.5 m.

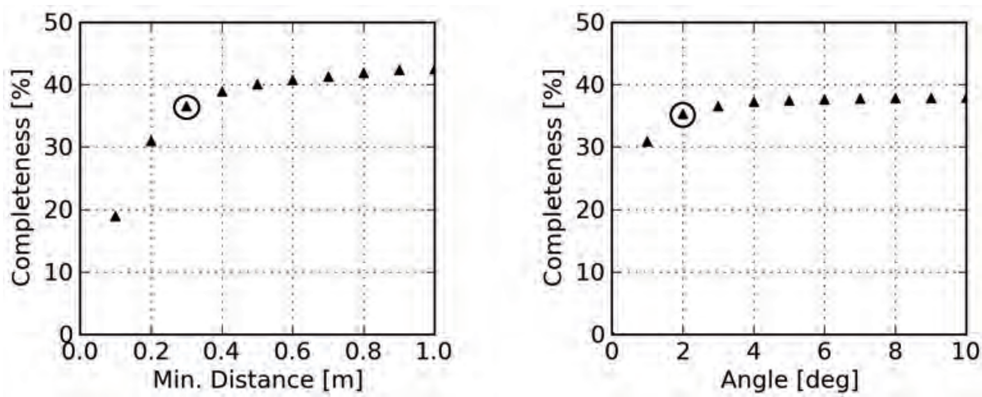

Fig. 2: Estimation of optimal settings for the assessment of the detection rate (marked by a circle). Left: Definition of true positives (TP) by comparing the distance of extracted facade lines to the reference facade lines (< 0.3 m). Right: the angle between the normal vectors (< 2 degrees).

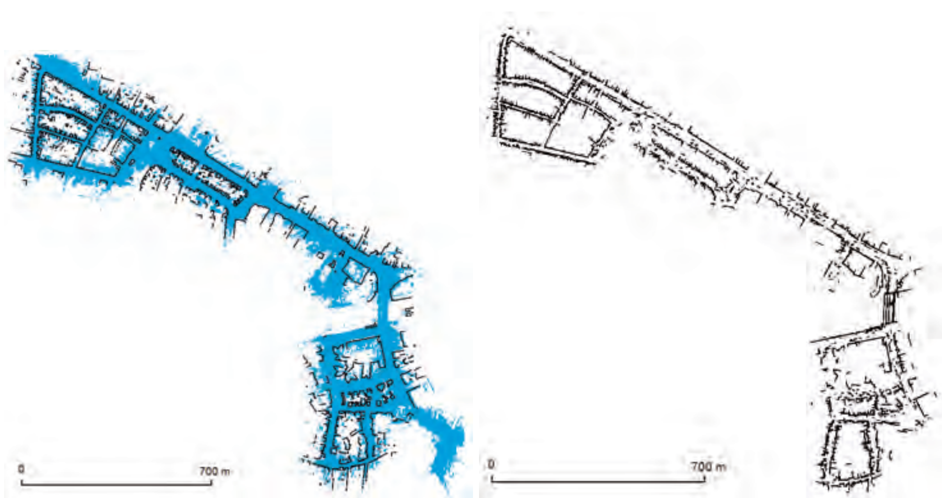

Fig. 3: Building outlines and building facades represented in different data sets. Left: visible digital cadastral map (black lines) with area covered by mobile laser scanning point cloud (blue area). Right: facades extracted from mobile laser scanning data.

A pair of correctly matched facades from MLS and reference (TP) has to meet a certain angle criterion between both ground lines and the extracted MLS facade has to be within a defined distance to the reference facades. These two parameters have to be below a certain value. Fig. 2 shows the tests on the distance and angle criterion. On the one hand the optimal threshold values for distance and angle should be most strict and on the other hand they should not underestimate the detection. The optimal values are found when the curve starts approximating the marginal error value. Hence, the distance is set to 0.3 m and the angle is set to 2 degrees, which results in a completeness of 37% (TP = 7,841 m, FN = 13,620 m). If the number of objects is compared and TP is defined as correct correspondence defined by minimum distance and angle (cf. Section 5.3) the detection rate drops to a completeness of 28% (TP = 1906, FN = 4969). The difference between the two completeness measures is explained by the dominating influence of long walls in the first measure.

The extracted facade lines are compared to facade lines from the digital cadastral map, which are visible from the MLS GPS trajectory. The visibility was calculated between GPS trajectory and digital cadastral map within a range of 100 m, which is the maximum range specified by the data provider. The visible facades were then cropped by the area derived from a point density map, which contain at least one echo (Fig. 3a).

The visual impression of the results is rather positive (Fig. 3). The occurrence of false positives originates from planar vertical segments found at cars and in trees. However, the further analysis focus on true positives and false negatives since the completeness of building facades is of major interest in this study. The low detection rates suggest (Fig. 2) that MLS might not work well for facade extraction. Therefore, it is necessary to investigate the influencing factors on the detection rate in detail. This is done by the selection of two sub areas where the completeness was calculated once only for the road parallel facade parts and once for all facade parts. The reduction in completeness from parallel facades to all facade parts ranges from 5 to 10% (Tab. 1). This shows that the orientation of the facades is not the main factor leading to low completeness. However, the significant difference in completeness is obvious between the two sub-areas. The first sub-area contains planar facades only (Fig. 4, left), while the second sub-area contains buildings with more structured facades i. e. jutties on the ground floor (Fig. 4, right). These small structural parts are also mapped in the digital cadastral map representing the building outline on the ground. While the main walls were extracted correctly from the MLS data, the small structures are often not detected, which leads to a lower completeness in such cases.

In the next step the detection rates for the whole test area are analysed considering the

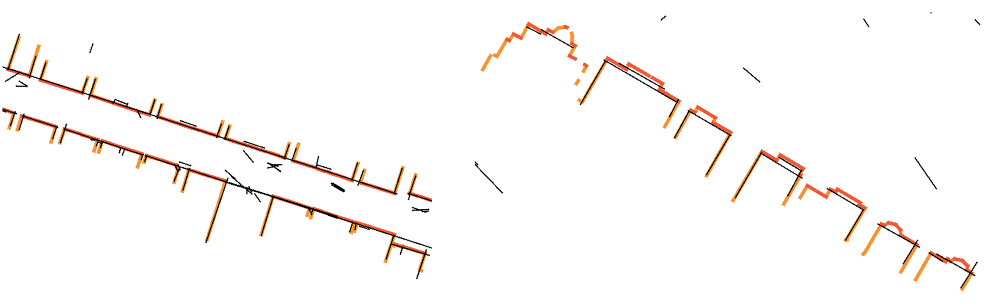

Fig. 4: Extracted building facades from mobile laser scanning (black) compared to the visible facades in the digital cadastral map composed by road parallel facades (red) and perpendicular facades (orange). The first sub-area contains buildings, which have only planar facades (left). The second sub-area contains facades with jutties (right).

Tab. 1: Completeness for the extracted facade lines in Enschede and two selected sub-areas investigating all facade parts and only facade parts, which are parallel to the MLS vehicle.

Test site	TP_{obj}	FN_{obj}	$Comp_{obj}$ [%]	TP_{len} [m]	FN_{len} [m]	$Comp_{len}$ [%]
Enschede test site	1,906	4,969	28	7,841	13,620	37
Sub-area 1 (parallel)	55	4	93	244	22	92
Sub-area 1 (all)	101	17	86	433	79	85
Sub-area 2 (parallel)	14	25	36	21	50	30
Sub-area 2 (all)	25	78	24	75	135	36

facade length and the distance of facades to the laser scanner. Further influences on the detection rate are the occlusion of facades by other objects, which is more likely to happen if the distance to the MLS vehicle is larger. On the other hand larger facades might be easier detectable whereas small areas might be more likely occluded.

The effects of the reference facade line length (Fig. 5) and the distance of the facade to the GPS trajectory (Fig. 6) on the detection rate results are analysed for different intervals. Fig. 5 gives a more detailed insight into the facade lines with a length from 0–100 m whereas facade lines from 1–10 m are analyzed in 1 m length intervals. The comparison of facade lengths in the range of 0–10 m shows that completeness increases with increasing facade length. This can be explained by differences in the representation of facades in the digital cadastral map and the laser data. For example, there are small jutties, which are included in the digital cadastral map but not apparent in the MLS point cloud. In the interval investigated the completeness is better than 60% for facades longer than 5 m. These are the facades which give the substantial shape to the building. The number of small segments (< 3 m) is rather high. These are often points of sub structures, connections between edges or parts of irregular facades. Small reference facades also occur on building walls which are

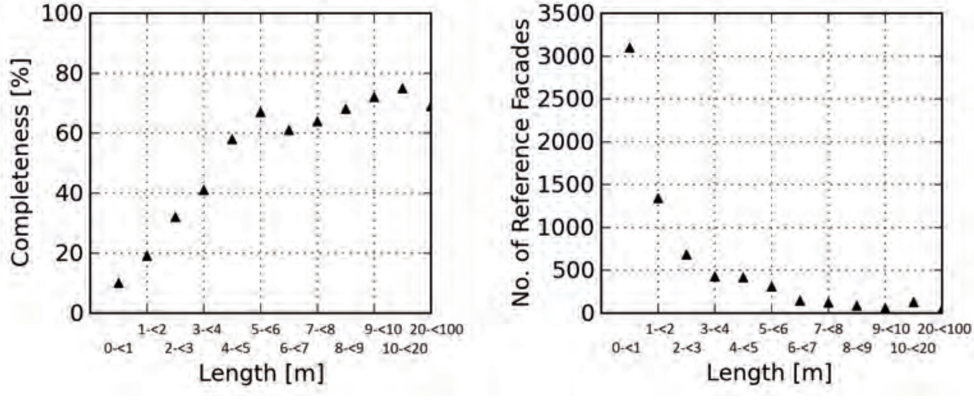

Fig. 5: Completeness (left) and number of reference facades (right) for facade length intervals from 0–< 10 m in 1 m steps, 10–< 20 m, and 20–< 100 m.

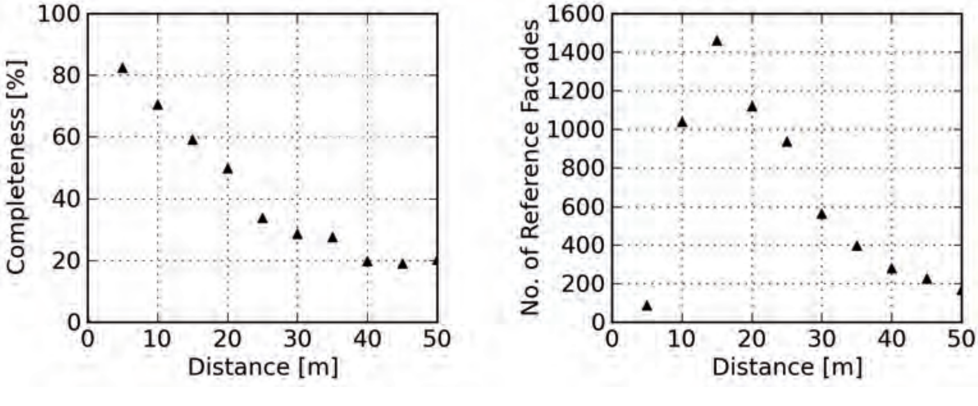

Fig. 6: Completeness and number of references for distance intervals of facade to trajectory from 0 m to 50 m in 5 m steps.

located farther away from the trajectory (i. e. located at the backside of buildings). Moreover, the facades in Fig. 5 include also those, which are relatively far away from the sensor containing only a low number of reflected echoes, which generally lowers the detection rate. Facades with a line length between 10 m and 20 m reach a completeness of 74% (128 reference facades). Facade lines, which are longer than 20 m and shorter than 100 m, reach 69% (38 reference facades). The number of facades decreases by increasing length. In spite of this, a clear relationship namely increasing completeness by increasing facade line length is evident.

The investigation of the distance to the GPS trajectory (Fig. 6) shows decreasing completeness for increasing distance. On the one hand this is related to the difficulty of detecting vertical segments which are occluded by other objects such as trees or cars. On the other hand the decreasing point density makes it more difficult to detect facades in larger distance. The MLS data contains vertical walls until a distance of 80 m. About 53% of the reference facades occur in a distance interval of 10–20 m – where the completeness ranges from 71% to 50%. Generally speaking a decreasing completeness with increasing distance to the sensor can be seen.

6 Conclusion

MLS is a novel laser scanning technique, which is of interest for automatic building facade detection (Fig. 7) and provides valuable information for 3D building facade modelling. The method presented is fully automated and allows the extraction of building facades for large areas. A detailed error assessment helps to investigate the properties of the extraction results and their usefulness for further applications. However, the comparison between facade lines extracted from MLS and a digital cadastral map is difficult to make since MLS extracts tentatively the large and dominate facade parts while the cadastral map only contains the outline of building walls, which often includes jutties from the ground floor.

Fig. 7: Extracted laser echoes of facade segments from mobile laser scanning coloured by segment.

In general the completeness of building facades is lower than one might expect, which limits its applicability for building reconstruction. It can be shown that there is a relationship between completeness and the distance to the vehicle trajectory since facades with a large distance more likely suffer from occlusion. The same holds for facade length. Small facade parts are more difficult to detect or are not part of the detection because of different facade representation in the digital cadastral map and the MLS point cloud.

Care has to be taken in acquisition planning that a data collection in leaf-on season might further decrease the reflections on building facades behind deciduous plants and therefore lower the detection rate. A further restriction of MLS is that it is only possible to survey building facades, which are facing accessible roads. However, automatic facade extraction can be used to provide data for applications, which only need this kind of building representation such as 3D street view modelling and traffic related analysis.

The presented study simplifies the 3D extent and shape of facades to a 2D line, which can be compared to commonly available 2D cadastral data. Future work should investigate facade representation in 3D by comparing MLS facade point clouds to independently generated 3D building reference models. Further work is necessary to evaluate systematically different MLS systems in terms of accuracy and completeness in order to be able to recommend strategies for operational extraction of building facades. In near future MLS point clouds will be acquired area-wide for urban environments and will serve as input in operational 3D city modelling of street views. Comprehensive knowledge on quality is required in order to be able to assess the potential of MLS point clouds for such applications.

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