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3D MODELLING OF FACADE FEATURES ON LARGE SITES ACQUIRED BY VEHICLE BASED LASER SCANNING

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ABSTRACT: Mobile mapping laser scanning systems have become more and more widespread for the acquisition of millions of 3D points on large and geometrically complex urban sites. Vehicle-based Laser Scanning (VLS) systems travel many kilometers while acquiring raw point clouds which are registered in real time in a common coordinate system. Improvements of the acquisition steps as well as the automatic processing of the collected point clouds are still a conundrum for researchers. This paper shows some results obtained by application, on mobile laser scanner data, of segmentation and reconstruction algorithms intended initially to generate individual vector facade models using stationary Terrestrial Laser Scanner (TLS) data. The operating algorithms are adapted so as to take into account characteristics of VLS data. The intrinsic geometry of a point cloud as well as the relative geometry between registered point clouds are different from that obtained by a static TLS. The amount of data provided by this acquisition technique is another issue. Such particularities should be taken into consideration while processing this type of point clouds. The segmentation of VLS data is carried out based on an adaptation of RANSAC algorithm. Edge points of each element are extracted by applying a second algorithm. Afterwards, the vector models of each facade element are reconstructed. In order to validate the results, large samples with different characteristics have been introduced in the developed processing chain. The limitations as well as the capabilities of each process will be emphasized in terms of geometry and processing time.

1. INTRODUCTION

To meet the great demand of 3D GIS development in urban areas, it is necessary to be able to collect large geo-referenced datasets in a short time. Airborne Laser Scanning (ALS) is often used to provide altimetry data over urban areas. The collected data is used either for production of Digital Terrain Models (DTM) or for extraction and modelling of building roofs. At the pedestrian level, terrestrial mobile mapping laser systems have emerged over the past ten years. Vehicle based Laser Scanning (VLS) systems or MMS (Mobile Mapping System) have the advantage of covering large areas in a short time, with greater accuracy than ALS might provide and with more details on building facades.

The result of a mobile mapping is a point cloud containing millions of 3D points defined by their coordinates and other properties such as intensity and colours. Managing directly this quantity of data in geographic information systems seems to be very complicated. Therefore data modelling becomes the priority of researchers. Indeed 3D models do not only allow reducing the amount of data, but they also make easier their integration in databases.

3D modelling can be performed in manual, interactive or automatic ways. For large areas described by a big volume of data, the automatic techniques are always preferred. The aim of this paper is to present an automatic process for 3D modelling of building facades acquired by a VLS system.

This paper is structured as follows. Section 2 gives an overview of the state of the art related to VLS data processing. The mobile system and data description are introduced in section 3. Section 4 deals with the segmentation and reconstruction approaches respectively. Finally, before concluding, a discussion on the limits of the work is presented in section 5.

2. RELATED WORK

Generating building facade models from terrestrial laser scanner data can be performed with many modelling approaches. Two main categories of approaches can be distinguished: approaches based on meshing methods and approaches based on the reconstruction of geometric primitives. The first category does not require *a priori* knowledge for the modelling (Amenta *et al.*, 2002). The second one is based on the assumption that the object of interest (here facades) can be described by a set of geometric primitives. More particularly, the detection of facade features is mostly based on the assumption that the features are planar (Budroni and Böhm, 2009; Boulaassal *et al.*, 2010). The main advantage of using geometric primitives is the possibility to replace the raw 3D point cloud by a small number of plane parameters. The main drawback is the possible loss of some details.

To extract planes from 3D point clouds, different solutions can be undertaken. For example, Schmitt and Vögtle (2009) convert the raw irregular point cloud, into regular voxels. Then planar features are extracted by merging adjacent voxels having collinear normal vectors. Besides, the procedure based on the analysis of normal vectors can also directly be applied to the raw 3D point cloud in order to detect planar patches via region growing algorithms (Yu *et al.*, 2008). Another solution to extract planes from 3D point clouds is to use robust algorithms. Generally, RANSAC and Hough algorithms are used for this purpose. In our laboratory, both algorithms have been studied and implemented in segmentation algorithms developed for ALS data (Tarsha-kurdi *et al.*, 2007) or for stationary TLS data (Boulaassal *et al.*, 2010).

Point clouds obtained by mobile laser scanning, are still hardly studied and processed in the purpose of 3D building models production. It is interesting to note that the automatic processing of these clouds did not develop as quickly as the acquisition process. Hence the data are generally recorded until an efficient modelling approach is available. That's why the majority of recent publications dealing with VLS focus on the presentation of system set-up, their performance and achievable measurement accuracy rather than data processing. Concerning the general approach to mobile mapping, previous related work can be found in Tao and Li (2007).

Nevertheless, Haala *et al.* (2008) investigate the accuracies of mobile data collected by StreetMapper mobile system for architectural heritage collection and 3D city modelling. They compare estimated planes on a selected building facade with walls from a 3D city model. Alshawa *et al. (*2009) have investigated the automatic extraction of facade planar elements on larges sites from a low cost laser mobile mapping system. They have proven that the computed plane parameters can be improved by considering a plane adjustment in which a weight is assigned to each point according to its accuracy. The more a point is accurate, the more it contributes to the computing of the plane parameters. It was also shown that zero point's detection and the use of the neighbouring points reinforces edge point extraction.

To further explore VLS data processing, a data sample has been collected by Lynx mobile system (Optech). The data processing requires three main steps leading to 3D models: segmentation, edge extraction and reconstruction. Before going into processing details, the mobile system and the used dataset is described in the following section.

3. Mobile system and Data description

The VLS data used in this paper have been acquired by the LYNX Mobile Mapper designed by the Optech Company (Figure 1).

This system uses two oriented laser scanners as well as a navigation system composed of IMU (Inertial Measurement Unit) and GPS (Global Positioning System) antenna. All components are rigidly mounted on the back of a vehicle. A configuration with two laser scanners allows not only to survey the left and right part of the street but also to minimize the gaps in the point cloud which can be produced by obstacles lying between the sensor and the facade. Concerning the position and orientation system, it contains three gyroscopes which measure the acceleration and angular velocity. Therefore all aspects of the vehicle motion *i.e.* position, orientation, velocity, acceleration and orientation can be computed.

Fig. 1. Optech LYNX Mobile Mapper

According to Conforti and Zampa (2011), LYNX Mobile Mapper delivers 3D details surveying at speeds up to 100 km per hour with accuracy that is better than 5 cm, and it is able to measure up to 1 million points per second. Its field of view is 360° and its spatial resolution can reach up to 1cm at 100 km/hr.

The Optech LYNX Mobile Mapper depicted in Figure 1 has been used to acquire a sample data along some streets in the City of Strasbourg. Figure 2 shows a top view of the acquired point cloud.

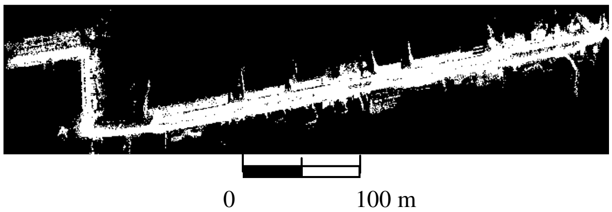

Fig. 2. Top view of point cloud captured by Optech Lynx Mobile Mapper in Strasbourg streets.

This point cloud contains millions of points acquired in a few minutes. Effective density is computed from many samples chosen and extracted from different locations in the scanned streets. This density is about 280 points/m² in average (that is approximately 1 point every 11 cm). Obviously, density is different from a sample to another according to its distance compared to the scanner. The length of path is about 1400 m. The following sections introduce and discuss segmentation and reconstruction algorithms aiming to generate the CAD models of building facades using this data.

4. MOBILE DATA PROCESSING

The segmentation, edge extraction and reconstruction algorithms applied on the mobile laser scanner data under study were initially intended to generate CAD models of facades using stationary terrestrial laser scanner data. Explanation about these algorithms can be found in Boulaassal *et al.* (2010). Obviously, adaptations are necessary in order to take into account characteristics of VLS data.

4.1 VLS data pre-processing

Several comments can be done when comparing VLS to TLS data. Firstly, they are different in terms of obtainable accuracy, because the VLS data require a synchronization of its positioning and orientation components. Secondly, the density/resolution of VLS data is significantly less than the stationary one. Therefore less of architectural details are detectable. Moreover, the amount of data acquired by mobile laser systems is often higher than that acquired by several successive stationary TLS stations. Figure 3 shows the same part of facade captured by TLS system (a) and VLS system (b).

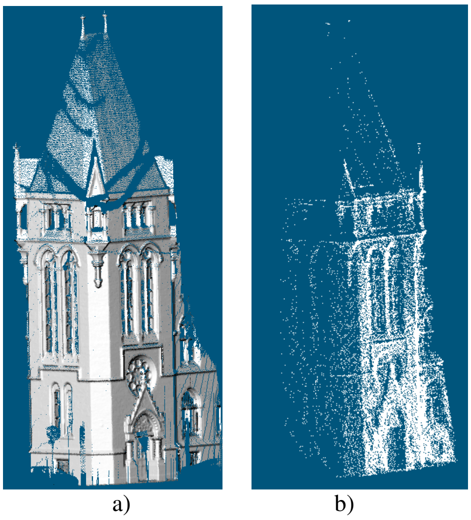

Fig. 3. The same facade scanned by: a) TLS system (density=1200 pts/m²);b) VLS system (density=250 pts/m²)

4.2 VLS data processing

In order to avoid the drawback of managing a huge amount of data as one block, the first step consists into subdividing the entire VLS point cloud into sets of points describing some facades. These sets are then processed separately. At the end of the process they will be merged again into one unique dataset. The mobile data used in this work have been decomposed into sets of point clouds according to the co-linearity of driving path, as suggested by Frueh and Zakhor (2005). Figure 4 shows that the drive-path can be decomposed into three quasi-linear straight segments. The straight segment number 3 corresponds to the biggest part of data. So it has been decomposed one more time into 5 sub-sets.

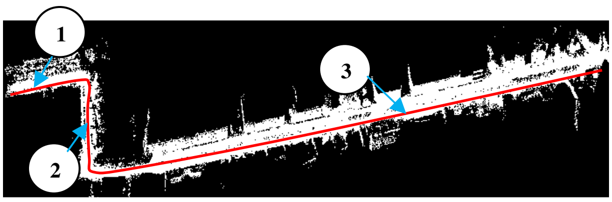

Fig. 4. Driven path (red line) overlaid with the VLS data sample shown in Figure 2.

4.3 Segmentation of VLS data

The segmentation approach developed initially for static TLS data is explained in details in Boulaassal *et al.* (2010). This approach relies on RANSAC algorithm. To detect points representing planar facade components, a tolerance value describing the authorized thickness around a plane is required. The planes are thus described by planar clusters having some specific thickness. The setting of such distance threshold must be chosen carefully. In practice, this distance threshold is usually chosen empirically as it is the case

in this study. However, it may be computed if it is assumed that the measurement error is Gaussian with zero mean and a given standard deviation (Hartley and Zisserman, 2003). Obviously, the value generally chosen for TLS data must be revised for VLS data. With TLS data, the threshold value used is often about 2cm. With VLS data, a minimum of 5 cm distance threshold must be considered. This value is related to the distribution of the points around the calculated plane. For a planar and normally reflecting surface, it characterizes the measurement noise and therefore the point cloud precision. As mentioned in section 2, individual point accuracies are very different in VLS system from those in stationary TLS. In VLS data, every point is acquired in other conditions than its neighbours because the positioning and orientation parameters have changed in the meantime. So, each point has a different accuracy. In this context, instead of simple calculating a mean plane using its composing points, a weighted adjustment has been implemented.
A plane can be specified by one point on the plane and its normal direction components. The weighted plane passes through the weighted centroid given by (x_c, y_c, z_c) of the data:

$$x_c = \frac{\sum x_i w_{xi}}{\sum w_{xi}} \,;\, y_c = \frac{\sum y_i w_{yi}}{\sum w_{yi}} \,;\, z_c = \frac{\sum z_i w_{zi}}{\sum w_{zi}} \tag{1}$$

with the weights: $w_{xi} = \frac{1}{\sigma_{xi}}$; $w_{yi} = \frac{1}{\sigma_{yi}}$; $w_{zi} = \frac{1}{\sigma_{zi}}$

The normal to the plane is the single vector associated with the smallest singular value of the following matrix:

$$B = A^T W A \tag{2}$$

Where:

$$A = [x_i - x_c\,,\, y_i - y_c\,,\, z_i - z_c\,] \,;\, W = \mathrm{diag}[w_{0i}] \tag{3}$$

$$w_{0i} = \frac{1}{\sigma_{0i}} \quad ; \quad \sigma_{0i} = \sqrt{\sigma_{xi}^2 + \sigma_{yi}^2 + \sigma_{zi}^2} \tag{4}$$

In such way, only the accurate points contribute heavily to the computing of the plane parameters.

Unfortunately, the information required to estimate the point accuracy is not available with LYNX mobile data. For this reason, the same accuracy is given for all points.

The segmentation algorithm is applied on different samples of data. The following figures show samples extracted from part 1, chosen because of their different characteristics and qualities. Figure 5 shows a sample with a high relative density (250 pts/m²) with only a few gaps on the facades. Figure 7, however is of less quality (many gaps on the facade) and of lower density (140 pts/m²). Figures 6 and 8 present the result of the segmentation process applied on these point clouds using a threshold distance of 5 cm. Each colour represents a planar cluster.

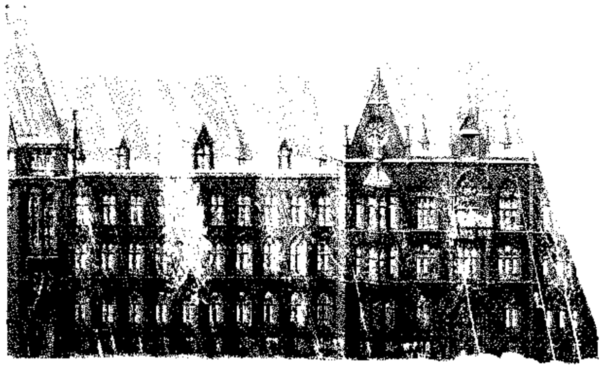

Fig. 5. Large point cloud of facades chosen for its high density and its good quality

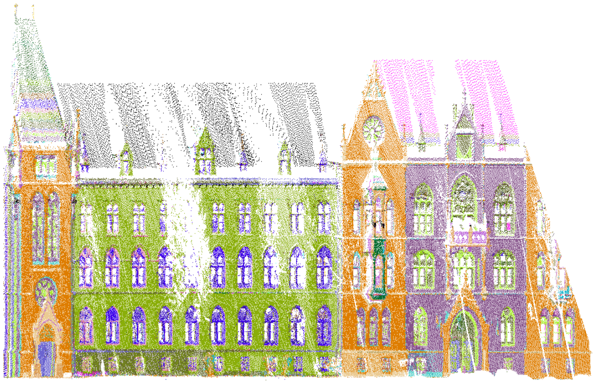

Fig. 6. Segmentation results of previous point cloud.

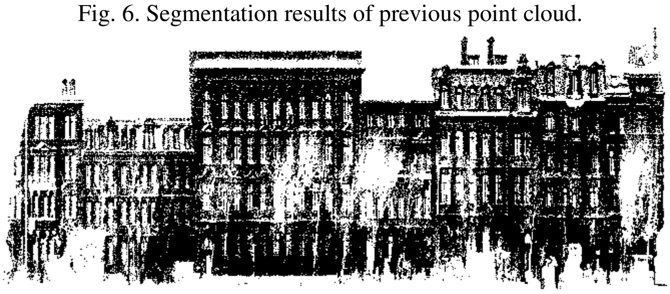

Fig. 7. Large point cloud of facades chosen for its low density and its bad quality

Fig. 8. Segmentation results of previous point cloud.

The segmentation results obtained from the two samples are obviously different. Therefore, density of point and accuracy depend on the quality of point data. That's why the results obtained from Sample 1 are quite better than those obtained from Sample 2.

The second step in the process leading to 3D model of building facades is the extraction of edge points.

4.4 Edge points extraction

The extraction of edge points using the previously segmented planar cluster aims to highlight the main structure of the facade. These points are the key of the CAD model reconstruction and allow drastically the reduction of the dataset size. An algorithm aiming to extract the edge points of all planar clusters has been used. This algorithm uses the lengths of the triangle sides connecting the points of a planar cluster, according to the Delaunay triangulation. The edge points are the extremities of the longest sides.
The facade used to illustrate the edge extraction is extracted from the Sample 1 (Figure 6). The algorithm considers every planar cluster separately. Figure 9 shows the main planar cluster of the facade depicted in green colour in Figure 6.
As the planar cluster is defined in 3 dimensions, it is necessary to generate 2D coordinates in order to be able to apply a 2D Delaunay triangulation. To this purpose, a principal components analysis is calculated based on the points of the planar cluster. The coefficients of the two first principal components define vectors that form an orthogonal basis in the mean plane. The third principal component is orthogonal to the first two ones, and its coefficients define the normal vector of the plane. The two coordinates given in the orthogonal basis are considered for triangulation. Then, the lengths of triangles are computed and sorted in ascending order.
To determine the longest sides, a length threshold must be defined. The threshold used with stationary TLS data reaches generally 15 cm. In the case of the VLS data used here, the point sampling is much larger (11 cm) than those reached in TLS data (3 cm). So a threshold of 30 cm has been chosen.

Fig. 9. Example of planar cluster of facade extracted by the segmentation approach presented above.

Fig. 10 shows the triangulated network resulted from point cloud shown in Figure 9 using 2D Delaunay triangulation.

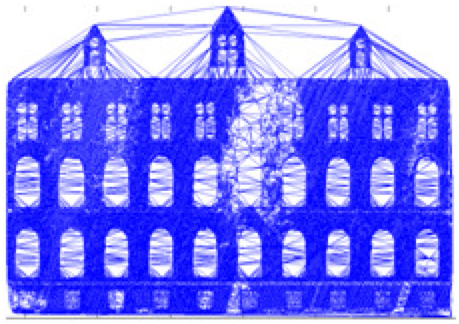

Fig. 10. 2D Delaunay triangulation of the planar cluster depicted in Figure 9.

Finally, the edge points composing the triangle sides whose length is higher than the predefined threshold are shown in Figure 11.

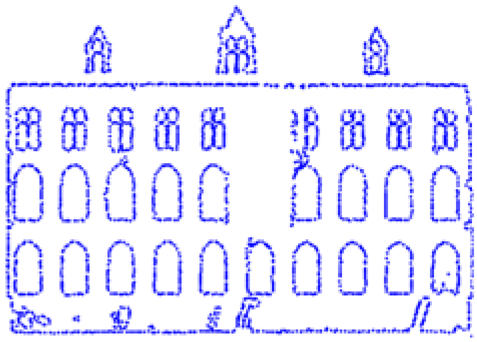

Fig. 11. Edge points describing the inner and outer edges of the facade shown in Figure 9.

The extraction of the edge points is repeated for all planar clusters provided for the facades under study.

Through this operation, only points belonging to the edges are kept. So it allows reducing significantly the volume of data while keeping the important points which describe the main architectural structure of the facade. Furthermore, these edge points simplify the work of the user especially for the production of a CAD model of a facade. Manual or automatic digitizing is even easier in such simplified data than in the whole point cloud. Consequently, it allows an important gain of post processing time.

4.5 Construction of a facade CAD model

The main aim of this part is to reconstruct architectural features based on already-extracted edge points. A new approach has been developed. It starts with the conversion of the edge points of each planar cluster into a binary image. To do this, a regular grid is superimposed on the point cloud. Value one is assigned to cells containing at least one point, and the value zero is assigned to empty cells. Figure 12 is a binary image obtained using the edge points presented in Figure 11. The size of the cell has been defined by a value close to the horizontal spatial resolution.

Fig. 12. Binary image of edge points shown in Figure 11.

To simplify and accelerate the automatic reconstruction of facade elements, it is appropriate to decompose the elements into disjointed labelled components. A component corresponds to a set of connected pixels forming an individual entity with its own label. Then the points corresponding to each labelled entity can be retrieved. Figure 13 shows the labelled image in which each colour depicts a connected entity; Figure 14 depicts the edge points covered by the pixels.

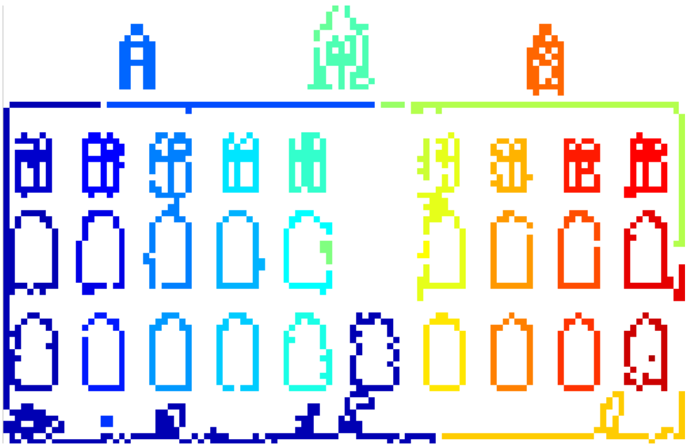

Fig. 13. Labeled image of different connected pixel sets. Each color corresponds to a connected entity.

Fig. 14. Edge points corresponding to the different connected components.

Currently, reconstruction is accomplished for each component separately. Afterwards, points are sorted and aggregated according to the region growing principle. A first “seed point” of the component is randomly chosen. Distances to other points are computed and the nearest point is found and considered as the new “seed point” and so on until all points are sorted subsequently. Then the points are connected by lines in order to produce a CAD model.

This chain of algorithms leads to generate a CAD model of facades. Figure 15 shows segmentation results of two data samples introduced above. Figure 16 depicts the CAD models generated based on planar clusters shown in Figure 15. The results are very satisfying regarding the irregular density of VLS point clouds.

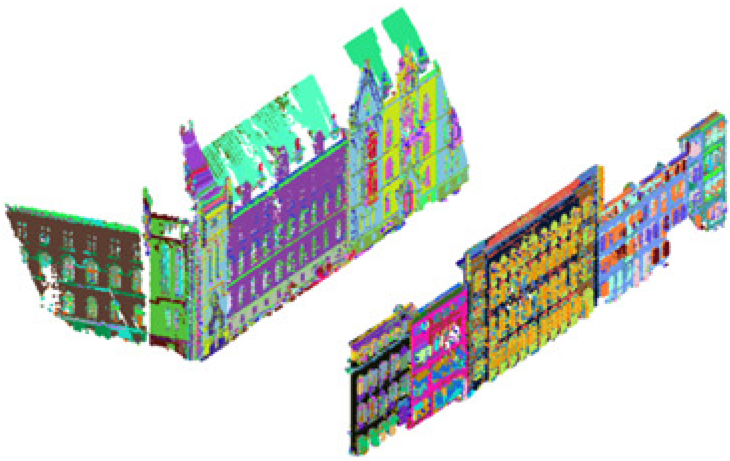

Fig. 15. Segmentation results of facades of two sides of the street

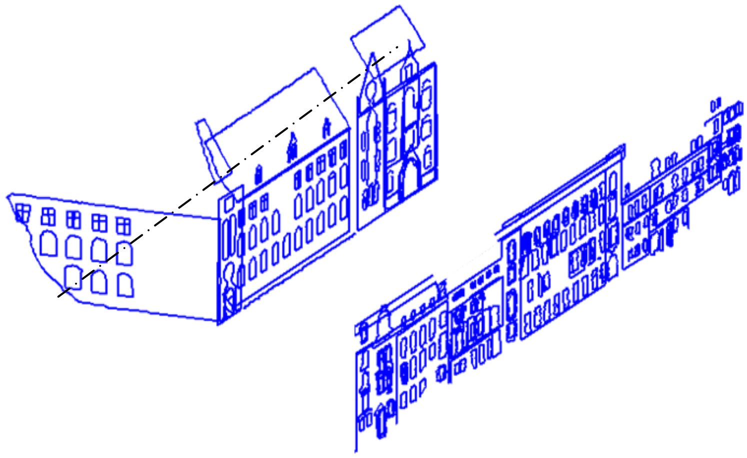

Fig. 16. Final CAD models of facades

5. DISCUSSION

In this part, the limitations as well as the capabilities of each algorithm contributing to the entire process chain will be discussed in terms of geometrical accuracy and processing time.

Concerning to the segmentation approach, the error is due mainly to the threshold value defining the thickness of the planar clusters. The estimation of this value is necessary to extract planar surfaces because facade planes are not simply adjustable by mathematical plane models. Moreover, the raw point cloud has a thickness which is usually generated by noise coming from the surface roughness, from the object colours and from the VLS resolution capacities. This error is increased with VLS data (compared to TLS data) because the threshold value is higher.

The effect of the segmentation errors appears in the edge points since the last ones are exclusively extracted from points which compose planar clusters. Consequently, the same error can be found in the CAD models. At this stage, the limitation of the reconstruction algorithms is the linking of points by lines without any adjustment. Actually, the adjustment can be useful if we want to obtain the CAD model as it was built. If the aim is to reconstruct the current state of facades with possible modifications or degradation, the linking technique may produce better results. Furthermore, this technique is more suitable to reconstruct automatically edges extracted from VLS data, even if it is much easier with stationary TLS data (see Boulaassal *et al.*, 2010).

The quality of the obtained geometric models could be assessed quantitatively. For this purpose, results of each processing step leading to the generation of the final vector model must be assessed. As to the segmentation results, it is necessary to have an idea about the quality the quality of planar clusters, because they play a role for further process. they can be assessed from the comparison of planar clusters obtained automatically with planar clusters considered as reference (*e.g.* results of a manual segmentation). An assessment table has been devised based on Boolean operations which enable to determine the rate of agreement between the calculated and the reference planar clusters. In the same way, the results of the geometric reconstruction step must be evaluated, in a qualitative and if possible in a quantitative way. Once again, it is necessary to get a reference model. To do this, it is possible to relay on quality indices enabling to give an assessment about the quality of produced polygons (McGlone and Shufelt, 1994; Henricsson and Baltsavias, 1997; Schuster and Weidner, 2003). More details about the quality assessment of geometric façade models reconstructed from TLS data can be found in Landes et al. (2012). It must be adapted in the future for VLS data.

Concerning the processing time, 2/3 of the total time is required by the segmentation algorithm. The segmentation time depends on the number of points contained in the raw data, the architectural complexity of facades and the computer performance. Architectural complexity consists in the number and size of planar clusters composing the facades to be extracted. The processing time is essentially due to the number of iterations necessary in the RANSAC paradigm.

6. CONCLUSION AND FUTURE WORK

This paper has presented a processing chain leading to the generation of CAD facades models from mobile data. The proposed solution enables firstly the automatic extraction of planar surfaces from building facades. Secondly, it achieves the extraction of edge points composing the boundary of each facade element. Finally the boundaries are used for producing the CAD models.

The segmentation algorithm is derived from RANSAC algorithm and has been adapted in order to extract all potential planes. As expected, an adaptation of the threshold parameters was necessary, since this algorithm was initially intended to segment TLS point clouds.
The second algorithm presented in this study aims with the extraction of the edges of planes resulting from the previous segmentation. This extraction algorithm relies on Delaunay triangulation. An adaptation of the threshold parameters of extraction has also been performed according to the spatial resolution provided by mobile data characteristics.
Since the whole scene is relatively large, it is difficult to reconstruct automatically different architectural elements with irregular shapes. Currently, the reconstruction is ensured by the separation in the algorithm of the different connected components. Then each component is reconstructed separately. The final result is a CAD model in which the geometry of the detected facade elements is provided. In the future, the process developed for assessing the quality of CAD models obtained from TLS data will be adapted for VLS data.

Further developments on the achieved CAD models will be focused on texturing and specific data matching.

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