ACQUISITION AND AUTOMATIC EXTRACTION OF FACADE ELEMENTS ON LARGE SITES FROM A LOW COST LASER MOBILE MAPPING SYSTEM

M. Alshawa, H. Boulaassal, T. Landes, P. Grussenmeyer

Photogrammetry and Geomatics Group MAP-PAGE UMR 694,
Graduate School of Science and Technology (INSA),
24 Boulevard de la Victoire, 67084 STRASBOURG, France
(majd.alshawa, hakim.boulaassal, tania.landes, pierre.grussenmeyer)@insa-strasbourg.fr

KEY WORDS: TLS, GPS, IMU, Point cloud, Mobile mapping, Algorithm, Building, Façade, Extraction.

ABSTRACT:

Vehicle based mobile mapping technology has been developed quickly in the last decade. The high productivity is the main advantage of mobile mapping systems. Hundreds of kilometers are achieved by mobile laser scanning and the raw point clouds are almost saved without further treatment. It could be noticed that the automatic treatment of these clouds has not developed as quickly as the acquisition itself; hence the data are accumulated until an efficient method of treatment is available. After a brief presentation of the low cost mobile mapping system, this paper shows the first results obtained by application of a contour extraction algorithm on provided data.

A prototype of low cost mobile mapping system has been developed in the MAP-PAGE laboratory for research purposes rather than production ones. The relative accuracy is provided by the system for every point, as auxiliary data. Furthermore, the geometry of mobile mapping point clouds is different from that obtained by a fixe TLS. Such particularities should be taken into consideration while processing this type of point clouds. Thus, the segmentation and edge detection approaches, intended initially to treat stationary TLS data, have been adapted to the particularities of mobile one. The segmentation is based on hypothesis that the most prominent features of façade components are planar. Therefore, a segmentation based on RANSAC algorithm has been applied in a sequential way in order to extract all potential planes from the mobile point cloud. Corrective operations aiming to define the most reliable points of each plane have been implemented. A second algorithm aims to extract the boundary points of the planes resulting from the previous segmentation. This extraction algorithm relies on a Delaunay triangulation based on the lengths of the triangle sides composing the whole triangulated network. This algorithm is able to extract automatically and simultaneously not only the outer (wall borders) but also the inner contours (holes like windows) of façade elements.

Finally, in order to validate the results, large samples with different characteristics have been acquired by the mobile system and have been introduced in the developed workflow. The limitations as well as the capabilities of each process will be emphasized. Results are satisfactory and confirm that the acquisition as well as the processing approaches are reliable for generating a vector model of building façades.

1. INTRODUCTION

Mapping from moving vehicles has been around since advances in satellite positioning and inertial technology has made it possible to design mobile mapping systems with an acceptable cost. The development of mobile mapping is close to the growing demand of 3D urban spatial data, giving a boost to 3D GIS and augmented reality.

Another important development of mobile mapping is the use of laser scanners beside the imaging sensors. The easiness of acquiring and of georeferencing laser data favors embedding of such sensors on mobile mapping platforms. Practically, all recent mobile mapping platforms cannot do without one or a few laser scanners. The present article focuses on the laser scanning data obtained by vehicle-based mobile mapping and on the way to process them.

The key feature of mobile mapping is the direct georeferencing of imaging sensors data using mapping sensors ones. This operation is done easily in real time, especially for laser data rather than for photos. Hence, vehicle-based laser mobile mapping systems can produce data in the same velocity of vehicle. This high productivity requires method of treatment which has to be automatic and robust to satisfy the balance between the acquisition and the treatment without any delay in the series of 3D model production.

Unfortunately, although techniques for the acquisition of 3D building geometries by mobile mapping have constantly been improved, a fully automated procedure for constructing reliable 3D building models is not yet available. This is essentially due to the difficulties of exploring directly and automatically valuable spatial information from the huge amount of 3D points. Thus many post-processing operations must be performed before accessing to the reconstruction of reliable 3D models. One of the most important operations is the segmentation. It is often prerequisite for subdividing a huge number of points into sub-groups of points with similar properties. The second and following operation is the extraction of contours based on these planar clusters. Generally, this operation precedes the construction of the vector model.

In this paper, the MAP-PAGE team presents its own mobile mapping system and the acquired point clouds, as well as the processing chain applied on these points in order to extract automatically the contours of façades. The precision of the georeferenced point cloud is studied regarding all factors that may degrade it. The segmentation and contour extraction method already developed for static acquisition systems has been adapted to the mobile ones. Additional data as the accuracy and acquisition sequence have been used to improve the results of automatic segmentation.

2. RELATED WORK

Obviously, data provided by mobile mapping systems are affected by non negligible errors. Position, attitude and range sensor are, themselves, affected by a budget of complex errors. Thus, even the industrial and commercial mobile mapping systems suffer from imprecision. For instance, (Talaya et *al*., 2004) estimate the final precision of GEOVAN™ mobile system of 13 cm. (Shi et *al*. 2008) noticed also that the absolute accuracy of the early versions of StreetMapper™ system could reach 30 cm in some cases.

Since the vehicle-based mobile mapping technique is relatively recent, manufacturers focus more on the production of large amount of data rather than on the precision issues. Exchange data files are mostly in simple ASCII format with coordinates values only. Nevertheless, some exceptions could be found; Systems using Optech™ scanners like LYNX Mobile Mapper™ log their data in a LAS format where information about the path acquisition and precision could be found.

Concerning the processing of Lidar data, most of the segmentation techniques are developed for fixe ALS or TLS. They are mainly based on algorithms already used in photogrammetry, computer vision and signal processing fields (Belton and Lichti, 2006). Point clouds obtained by mobile laser scanning, however, are rarely studied and treated in the purpose of producing 3D building models. Nevertheless, (Haala et *al*., 2008) have used the mobile point clouds collected by the StreetMapper system to refine the planar façades of an existing 3D building model. The coarse building model has been generated previously from airborne laser data. In this way, the fine geometric details of building façades like windows, balconies or ornaments can be added by the mobile mapping data. The authors describe the overall geometry of building in using a polyhedral approximation. This method of refinement of façade has firstly been developed for TLS data and not for mobile systems. More details can be found in (Becker & Haala, 2007).

3. MOBILE MAPPING ACQUISITION

3.1 MAP-PAGE mobile mapping prototype

The mobile mapping prototype developed in MAP-PAGE laboratory does not differ, from a theoretical point of view, from whatever operational system except its low cost and low velocity. The designed prototype (Figure 1) is mounted on a trailer intended initially to be drawn by a walking man.

The principle configuration of the system is an integration of the three following components (GPS/INS/AHRS)

- GPS 1200 (Leica®): GPS System working in Real Time Kinematic (RTK) differential mode. Used information is carried on NMEA message (GGA sentence for the position and VTG for the speed over ground). Sampling rate was uniformed at 4 Hz. In the ideal observation condition (GDOP less than 4), GPS precision may reach 2cm in horizontal and 5cm in vertical dimension. Nevertheless, no quality control is performed for real time connexion requirement. Some measures could have up to 2m accuracy.

- AHRS440 (Crossbow®): Attitude and Heading reference System aided by GPS. It uses MEMS (Micro-Electro-Mechanical Systems) tri-axial magnetometer, sensor rates and accelerometer to provide 1.5° accuracy in angle measurement. When the external GPS signal is available, the attitude accuracy improves up to 0.5° thanks to Kalman filter embedded on the AHRS micro processor.

- TLS 3D laser scanner GX DR 200+ from Trimble®: the scan is performed vertically within 60° field of view. The maximum range of the scanner is 200m. It can work in non levelled (non-horizontal) mode. Maximum speed is reached when using a single laser shot for each measure. The last calibration yields a distance accuracy of ±7 mm at 100 m and an angular accuracy of 12”-14” while measuring a single point.

Figure 1. MAP-PAGE mobile system

It could be noticed directly that the orientation sensor (AHRS) is not of the same accuracy grade as the GPS or TLS. Practically, it cannot produce a valid position during a GPS outage because of the high drift of the gyroscopic sensor. Hence, in order to obtain the best estimation of the six degrees of freedom of the path, a combination of Kalman filter and curve fitting is used. More information on path computation can be found in (Alshawa et *al*., 2008).

3.2 Error model and precision

The precision of the angles measured by the inertial unit is affected by a set of errors like the bias, the resolution and the scale factor of the MEMS gyroscopes and accelerometers. The quality of these measurements drifts with time. It requires another source of data, which accuracy is independent of time to be corrected. The GPS is the traditional solution to bridge the drawbacks of an inertial unit because of their complementary characteristics. The integration between the GPS and the IMU is often made by the Kalman filter method. Thus the final error budget results from the IMU mechanization. It is refined by the calculation of Kalman (see Shin, 2001).

The AHRS used in this experiment is designed for unmanned vehicle control and for land vehicle guidance where no accuracy

estimation is needed. Hence, the quality of attitude measurements is absent in the own AHRS mechanisation and extended Kalman filter output. Since the GPS grade is distinctly higher than the AHRS one and the GPS/AHRS are loosely coupled in Kalman filter architecture, GPS data would correct the INS position and velocity and not the opposite. The quality criterion of path coordinates is directly obtained from the GPS receptor and then propagated while curve fitting procedure.
This work proposes a coarse error model for attitude expressed as follows:

$$\varepsilon = \tfrac{1}{2} b_{\omega}.(t - t_0)^2 \quad \text{and} \quad \varepsilon < \varepsilon_{\max} \qquad (1)$$

Where:

ε = vector of errors on roll, pitch and yaw.
b_ω = vector of biases on x,y and z gyroscopes.
t = time passed since the AHRS is turned-on
t_0 = the instant of last GPS position sent to the AHRS or the instant of last low speed (<0.75 m/sec) detection (stationary yaw lock case).
ε_{max} = the nominal magnetometer accuracy (2°).

The experimentation shows that previous simplification assures acceptable estimation of attitude errors for the used inertial unit, despite of its mono error source (the bias only).

Laser scanning angular errors are negligible in comparison with the roll, pitch and yaw ones. The contribution of distance measurement errors is not so significant compared with the errors coming from the determination of vehicle position. Nevertheless, the effect of the distance itself amplifies the attitude errors.
The final point cloud precision is obtained by applying error propagation law on the direct georeferencing equation using all mentioned errors, as explained in (Alshawa et *al*., 2007).
The precision of each point in the final cloud is calculated using the above assumptions. The theoretical precision is verified by comparing some mobile mapping samples with point clouds obtained in a fixed mode. Figure 3 depicts a colour map of a part of a mobile mapping point cloud according to the precision calculated for each point.

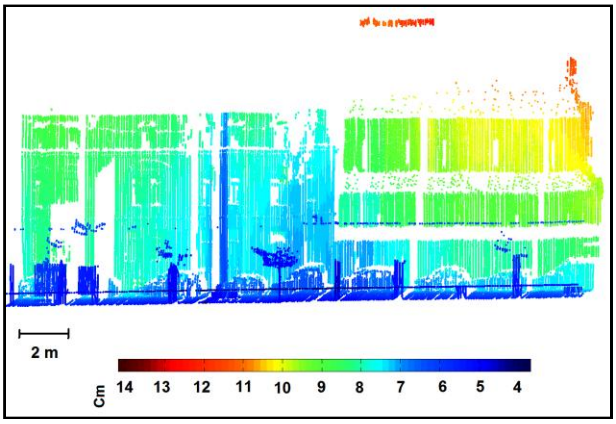

Figure 3. Precision of each point in a cloud acquired in mobile mode. Colors represent the corresponding standard deviation.

Globally, the precision of the point cloud coordinates is better than 15cm. It can be observed that the standard deviation increases with the range, thus the upper parts of the façade are less accurate than the lower parts. The presence of GPS signal is highlighted in Figure 3, the vertical blue profiles correspond to a signal reception with high precision. Nevertheless, the correction effect on the angles is too local. This could be explained by the high drift of the inertial unit

4. MOBILE DATA PROCESSING

The main aim of this section is to describe the post processing chain applied on a 3D point cloud captured by the mobile system described above. The segmentation of laser data and the contours extraction are the main steps to be discussed.

4.1 Segmentation

Firstly, in order to decompose the mobile data into planar clusters, the RANSAC algorithm is applied. As explained in (Boulaassal et *al*., 2007; Boulaassal et *al.*, 2008), this algorithm is applied sequentially. It removes the inliers points from the original dataset once a plane is detected. To determine the points belonging to the given plane, the Euclidian distance between each point and a plane is calculated. To detect points representing planar façade components, a tolerance value describing the authorized thickness around a plane is imposed. The planes are thus described by planar clusters having some specific thickness. The setting of such distance threshold must be carefully chosen. In practice, it is usually chosen empirically. However, it is noticed that this value is the same rank of point cloud precision. Furthermore, the thickness of planes is also related to the architectural complexity of the façade.
This segmentation approach has been applied on many samples of different characteristics (density and object architectural complexity).
The following figures show different samples of mobile data collected by the MAP-PAGE mobile system and their segmentations into potentially existing planes.

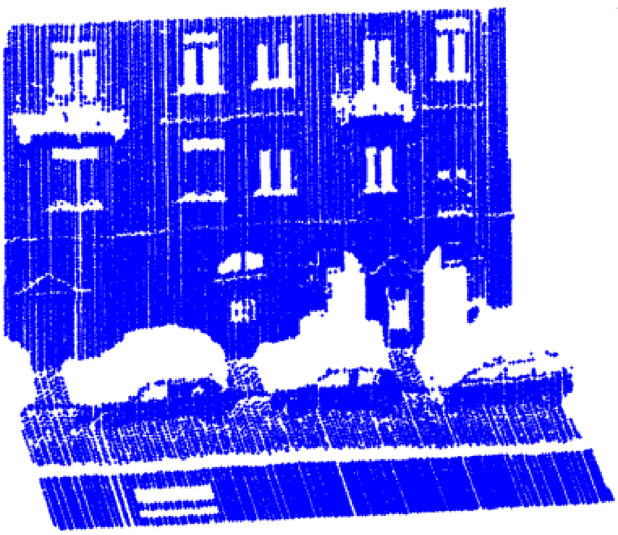

Figure 4. Small scene digitized by MAP-PAGE mobile system, (horizontal resolution =~ 12 cm)

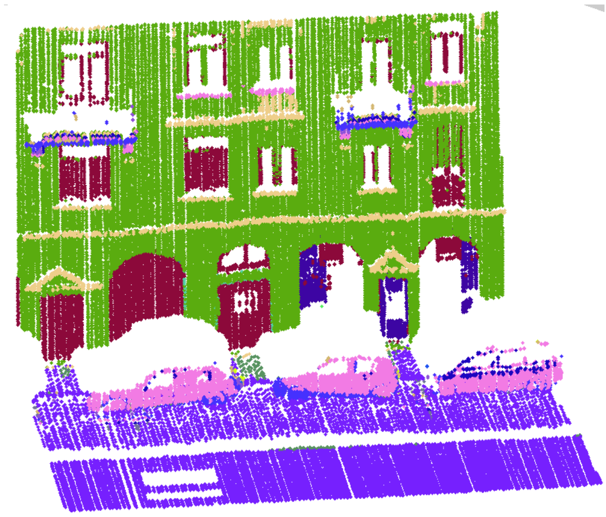

Figure 5. Point cloud depicted in (Figure 4) segmented into planar clusters presented by different colors.

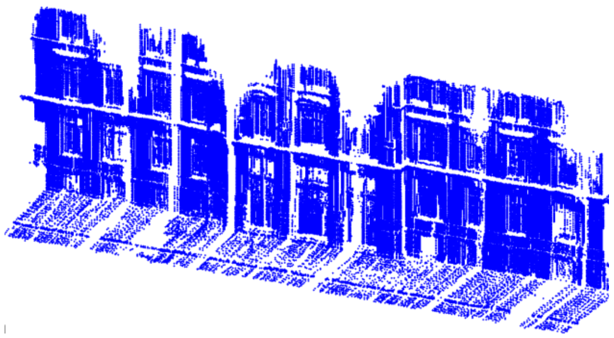

Figure 6. Large scene collected by MAPE-PAGE mobile system (horizontal resolution =~ 15 cm)

Figure 7. Segmentation results of mobile data showed in Fig.6

The existence of mask and occlusion effects could degrade the quality of the segmentation results. Figure 6 shows some gaps on the digitized façade. Therefore, it will be difficult to guess the shape of some lost details. It can also be seen that the quality of results depends on the horizontal resolution as well as the precision of the point cloud.

In order to reduce the effect of low precision points, the weighted least squares plane fitting is suggested in the next paragraph.

4.2 Weighted least squares plane fitting

As explained above and illustrated in Fig.3, the relative accuracy provided by the mobile system is different for each point. In order to improve the segmentation, this information can be taken into account during the computation of plane parameters. Thus, a weighted least squares method is implemented. In such method, each point contributes, according to its accuracy, in plane parameter computing.
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:

$$x_c = \frac{\sum x_i w_{xi}}{\sum w_{xi}} \; ; \; y_c = \frac{\sum y_i w_{yi}}{\sum w_{yi}} \; ; \; z_c = \frac{\sum z_i w_{zi}}{\sum w_{zi}} \qquad (2)$$

Where:

$$w_{pi} = \frac{1}{\sigma_{pi}} \text{ , where } p_i = x_i, y_i \text{ or } z_i \qquad (3)$$

The normal to the plane (a,b,c) is the single vector associated with the smallest singular value of the following matrix:

$$B = A^T WA \qquad (4)$$

Where:

$$A=[x_i - x_c \, , y_i - y_c \, , z_i - z_c] \; ; \quad W=diag[w_{0i}] \qquad (5)$$

$$\text{and } \; w_{0i} = \frac{1}{\sigma_{0i}} \quad ; \quad \sigma_{0i} = \sqrt{\sigma_{xi}^2 + \sigma_{yi}^2 + \sigma_{zi}^2} \qquad (6)$$

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

5. EXTRACTION OF CONTOUR POINTS

Once planar clusters are extracted, the extraction of their contours is carried out. To achieve this step, an algorithm based on Delaunay triangulation has been used. It aims to extract the contour points of the planar clusters. This algorithm uses the lengths of the triangle sides composing the whole triangulated network. Indeed, the contour points are the extremities of the longest sides. The chosen side length has to be higher than a certain threshold. The threshold value must be obviously higher than the horizontal resolution of the initial point cloud. Therefore, this algorithm is able to automatically extract the outer (e.g wall borders) and the inner contours (holes like windows) of façades. More details about this algorithm can be found in (Boulaassal et *al*., 2008).

Practically, the algorithm takes the planar clusters as input data (Figure 8); then it performs the 2D Delaunay triangulation (figure 9). Finally, the points composing the longest sides in triangulated network are saved as point-contours (Figure 10).
The full workflow is illustrated by the following figures.

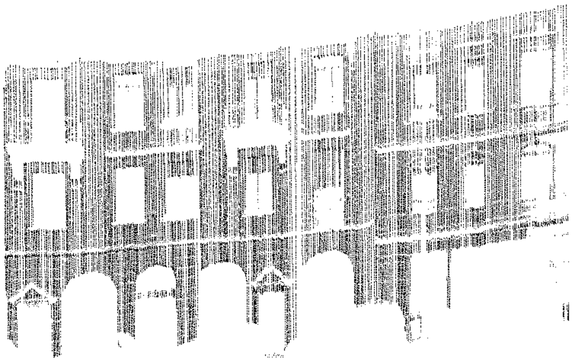

Figure 8. Example of planar cluster extracted by the segmentation approach (tolerance threshold = 12 cm)

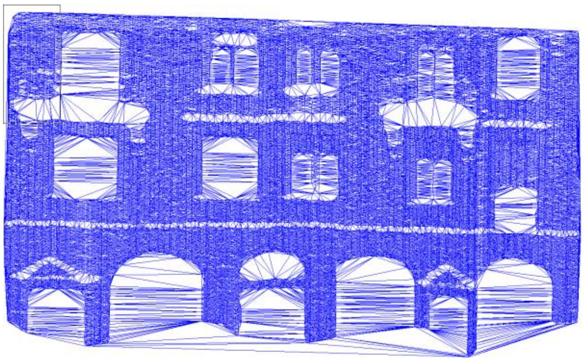

Figure 9. Delaunay triangulation applied on the detected planar cluster

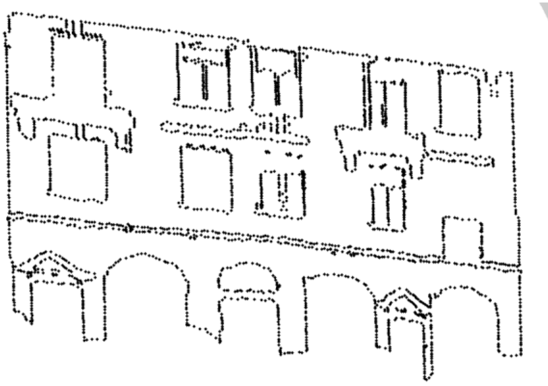

Figure 10. Point-contours corresponding to the longest sides in the triangulated network

6. ZERO POINTS DETECTION

Since the Trimble® GX scanner does not provide a time-stamp for each laser measurement, a network analyser was used to survey the connexion between scanner and PC to get an accurate instant for every laser shot. As a secondary result, some interesting notices are made. The scanner fixes its direction of view according to predefined angular increment and then a laser pulse is sent. If an object is met, the scanner registers the distance to the object coupled with the value of the angle. Otherwise a zero value is registered, what will be called "zero points" in this article. Almost all scanners, including Trimble® GX, get rid of these measurements because they don't represent a real measurement but only a lost laser ray.

Zero points, themselves, present no interest, but their adjacent points do. A simple analysis leads to the two following notes:

- If the last scanned points belong to a façade surface, they probably represent edge points (except vertical edges and self occlusion gap contour)
- If a high alternation between zero points and real scanned points occurs, the scanned object may be vegetation. This is due to the spaces existing between leafs where the laser ray may pass through, without interception.

The only method allowing to distinguish first and second cases is to observe the density of points. Figure 11 shows the distribution of points adjacent to zero points in a typical mobile mapping mission. Finding these points is not difficult while the points are in chronological order. If the index idx_0 characterize the location of zero points in a point cloud matrix, the adjacent point will be found at the index idx_0+1, idx_0-1.

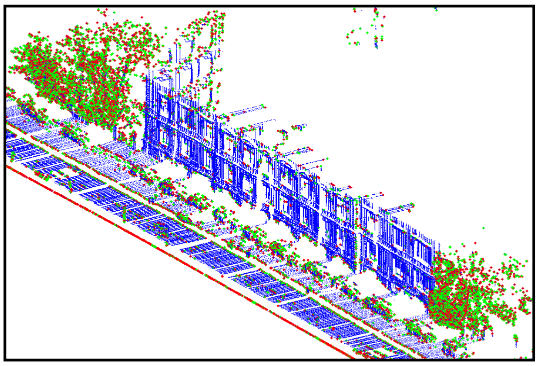

Figure 11. Point cloud (blue) showing the distribution of zero points and their neighbours (green: idx_0+1, red, idx_0-1)

A region growing-like method is used to group these points into subsets. Indeed, an arbitrary kernel is taken and the distance to the n nearest neighbours is studied (n= 2-4 in edge case, n = 10-20 in vegetation case). If the distance is less than a specified threshold, the kernel is enlarged by adding the accepted distances. Threshold could be considered equal to the average distance between two successive scan profiles multiplied by a factor of 1.5. This value is set as a experimental ratio of horizontal resolution which is usually higher than the vertical one in mobile case. While points lying in this threshold are found, the last steps are iterated. Final subsets will be the last form of kernels when no more "near" neighbours are found.

Vegetation can easily be distinguished from edge points using following states:

- Spatial distribution of vegetation points is random and of high standard deviation, whereas it is clustered for edge points. This has been confirmed by applying statistical tests on distances between neighbouring points.
- The density and number of vegetation points are obviously higher than the edge ones.

Hence, vegetation points can be separated and deleted from the original point cloud. Same operation can be applied on data provided by fix scanners; nevertheless mobile data give better results. Indeed, because of the change of scanner position, the laser ray travels between leafs and increases the amount of zero points.

7. CONCLUSION

Both registration of large urban scene using low cost mobile mapping system and automatic treatment of mobile data, have been discussed in this paper.

The prototype of low cost mobile mapping system uses MEMS inertial measurement unit with a low angular accuracy despite of the integration of GPS measurements. The quality of the point cloud collected by such system could be affected by errors coming from GPS, IMU, TLS and synchronisation. The used scanner allows performing 3-4 profiles by second only. Hence, the accuracy as well as the density of point cloud is often inhomogeneous depending on scanning conditions.

Two adaptations have been proposed: the first one consists on the weighted plane fitting where each point contributes to plane fitting according its own precision. The more a point is accurate the more it contributes to the parameters plane computing. Such way can help to reduce the error effects on the façade building geometry. The second one consists on zero point detection and using their neighbour points to reinforce contours extraction.

Indeed, the point contours extraction is carried out based on Delaunay triangulation and the side lengths computing. The contours quality depends on the point cloud density which restricts the tolerance threshold of side lengths. The inhomogeneous density over the whole data could provoke a loss of some points. To recover those points, another auxiliary method is proposed. It is based on zero point detection and their neighbour points according to the chronological order acquisition. It consists in the second adaptation implemented in this paper. The contours obtained can thus be reconstructed to produce a CAD model of a building façades.

8. FUTURE WORK

MAP-PAGE mobile system is being developed in order to reach its final configuration. Improving the velocity of the scan by stopping the scanner horizontal rotation can increase the density of the acquired point cloud. Therefore, more building details could be detected. A high resolution camera will be installed on the mobile platform to work side by side with the current sensors. The angular values detected by the AHRS could be refined by a bundle adjustment possess. Furthermore, colour information would be available to be used in modeling process.

The segmentation and the contours extraction algorithms applied subsequently present some advantages. Among the huge number of points, only the more important ones are kept. These point-contours enable to highlight the main edges on building façade and constitute the characteristic lines which could be digitized easily in order to generate a vector model of the façade.

REFERENCES

References from other literature

Alshawa, M., Smigiel, E., Grussenmeyer, P., Landes, T. 2007. Integration of a Terrestrial Lidar on a Mobile Mapping Platform: first experiences. 5th International *Symposium on Mobile Mapping Technology MMT'07*, 29-31 may, 2007, Padua, Italy. 6p.

Alshawa, M., Smigiel, E. ,Grussenmeyer, P., 2008. Integration of a TLS in a Low Cost Mobile System. In: Proceedings of the 14th *International Conference on Virtual Systems and Multimedia: VSMM 2008*, Conference on Virtual Systems and MultiMedia Dedicated to Digital Heritage, Limassol, Cyprus, October 20th-25th, pp. 1-7.

Becker, S. and Haala, N., 2007. Combined feature extraction for façade reconstruction. Proceedings of *ISPRS Workshop on Laser Scanning 2007* and *SilviLaser 2007*, Espoo, September 12-14, 2007, Finland.

Belton, D. and Lichti, D. D., 2006. Classification and segmentation of terrestrial laser scanner point clouds using local variance information. *IAPRS.* Vol XXXVI, Part 5, Dresden 25-27 September 2006. 6p.

Boulaassal, H., Landes, T., Grussenmeyer, P. 2008. Automatic extraction of planar clusters and their contours on building façades recorded by terrestrial laser scanner, In: Proceedings of the *14th International Conference on Virtual Systems and Multimedia: VSMM 2008, Conference on Virtual Systems and MultiMedia Dedicated to Digital Heritage*, Limassol, Cyprus, October 20th-25th, pp.8-15.

Boulaassal, H., Landes, T,. Grussenmeyer, P,. Tarsha-kurdi, F., 2007. Automatic segmentation of building façades using terrestrial laser data. *ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007 Espoo*, September 12-14, 2007, Finland IAPRS Vol XXXVI, Part 3 / W52, 2007. 6p.

Shin, E. H., 2001. Accuracy improvement of low cost INS/GPS for land applications. University of Calgary. UCGE Reports Number 20156. 119p.

Haala, N., Peter, M., Cefalu, A., Kremer, J., 2008. Mobile lidar mapping for urban data capture. *VSMM 2008 - Conference on Virtual Systems and MultiMedia Dedicated to Digital Heritage*. Limassol, Cyprus, October 20th - 25th, 2008. Project paper. pp. 101-106

Shi, Y., Shibasaki, R. and Shi., Z.C., 2008. Towards automatic road mapping by fusing vehicle-borne multi-sensor data. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Vol. XXXVII. Part B5. Beijing 2008.6p

Talaya, J., Alamus, R., Bosch, E., Serra, A., Kornus, W. and Baron, A., 2004. Integration of a terrestrial laser scanner with GPS/IMU orientation sensors. *XXth ISPRS Congress,* Commission 5,12-23 July 2004 Istanbul, Turkey. 6p