PHOTOGRAMMETRIC AND LIDAR INTEGRATION FOR THE CULTURAL HERITAGE METRIC SURVEYS

F. Nex [a], F. Rinaudo [a]

[a] Dept. of Land, Environment and Geo-engineering (DITAG), Politecnico di Torino, Corso Duca degli Abruzzi 24, Torino, Italy, (francesco.nex, fulvio.rinaudo)@polito.it

WG V/2

KEY WORDS: Integration, Image, Matching, LiDAR, Automation, Architecture, Cultural Heritage

ABSTRACT:

In the last few years, LiDAR and image-matching techniques have been employed in many application fields because of their quickness in point cloud generation. Nevertheless, these techniques do not assure complete and reliable results, especially in complex applications such as cultural heritage surveys; furthermore, the use of the data provided by these techniques is limited to experienced users. For this reason, several authors have already suggested how to overcome these problems through a combined use of LiDAR data and image information to reach new interesting products. These works considers the integration as the possibility to share point clouds generated by these techniques but they do not propose a complete and automatic integration.
In this paper, a new approach is proposed. This integration is focused on the possibility of overcoming the problems of each technique: LiDAR and multi-image matching techniques combine and share information in order to extract building breaklines in the space, perform the point cloud segmentation and speed up the modelling process in an automatic way. The goal of this work is to reduce the human intervention during these processes (thanks to the automated algorithms) simplifying the work of the users. The algorithm is still in progress; most of the steps have been fully implemented, while others needs of several improvements to show their full potential.

1. INTRODUCTION

The automated extraction of objects from laser scans and photogrammetric images has been a topic of research for decades. Both techniques offer the opportunity to collect reliable and dense 3D point data over objects or surfaces under consideration. In particular, soon after the laser scanner devices had been developed to a commercial level, many people speculated that photogrammetry would be totally replaced by laser scanners. On the other hand, other researches asserted that image matching techniques would be able to produce the same point cloud of LiDAR instruments without using expensive instruments.

However, it has afterwards become more obvious that neither technique would assure complete and consistent results, especially in complex applications (such as architectural and cultural heritage surveys). Laser scanning techniques have non-negligible drawbacks due to the impossibility of directly obtaining radiometric and semantic information and the exact position of the object breaklines (Chen, et al. 2004). Still, LiDAR data has no redundancy, and on the same time, the advantage of images is the similarity to human vision, well-known internal geometry, good interpretability and ability to capture texture and multichannel reflectance information (Rönnholm et al., 2007). On the other hand, image matching techniques cannot assure to generate point clouds without blunders in every operative condition (especially in terrestrial ones): a mayor existing obstacle in the way of automation in photogrammetry is the complicated and sometimes unreliable matching procedure, especially when dealing with convergent imagery with significant depth variations (Habib et al., 2004) or with the presence of bad-textured areas. As a contrast, LiDAR allows a direct and simple acquisition of positional information, along homogeneous surfaces, collecting thousands of points per

second. Both techniques request several automated and manual interventions, once the point cloud has been acquired, in order to produce 3D models or drawings. In fact, it is not possible to achieve a final product in complete automatic way and segmentation and classification techniques need of an experienced user, hours of work using complicated (and expensive) software and PC able to manage millions of points. For these reasons, from a practical point of view, the use of laser scanning instruments and digital photogrammetry techniques has not completely replaced the employment of traditional surveys techniques in many application fields.

Considering the complementary nature of these techniques, several authors have already suggested how to overcome these problems through a combined use of LIDAR data and image information to reach versatile systems and new application potential (Brenner, 2003). In this way, new solutions of integration have been investigated. Some papers consider this integration as a possibility of improving the produced point cloud (Remondino et al., 2008; Alshawabkeh et al. 2004; etc.) in terms of completeness and reliability. Other papers have described this integration considering it as a sharing of radiometric and ranging information in order to simplify the information extraction from laser scanner data. These works, however, only consider single images (Ardissone et al., 2007) and the extraction of information from data is performed manually, using only point cloud data.

Other examples show tightly integration in terrestrial applications (Becker and Haala, 2007; etc.). In these works the window positions on the façade are defined by using both image and point cloud information. Photogrammetry is employed to determine the position of littler details of the façade while the position of these details on the model is defined by LiDAR data. A similar approach, but applied to aerial cases, is described in [Cheng et al., 2008]. The first step of this approach is the

LiDAR data segmentation by means of a region growing algorithm. Then, using this information, the extraction (guided by LiDAR data) of the buildings from images is performed. Building boundaries on images are extracted using the Hough transform. In [McIntosh and Krupnik, 2002] edges detected and matched in aerial images are used to refine the DSM produced by airborne laser scanner data, improving the representation of surface discontinuities, especially building walls. The final result of this approach is the generation of a TIN comprising the breakline information: only straight edges are matched by means of a stereo-pair cross correlation. Anyway, these integrations do not consider a multi-image approach and the photogrammetry helps the LiDAR in the processing but any reciprocal cooperation between these techniques is considered.

Starting from these works, a new integration approach is proposed in this paper. The term "integration" can be defined as the creation of a new entity (Rönnholm et al., 2007). In this approach LIDAR and photogrammetric techniques continuously share information in order to complete the images and point cloud information and, thus, achieve a new product. In particular building breaklines are extracted in the space: this data can easy and speed up the drawing production and the segmentation process during the modelling.

2. THE ALGORITHM

In literature it has been reported that multi-image matching techniques allow an improvement to be made in geometric precision and reliability with respect to image pairs, by extracting points and edges from images and projecting their match in the space (Zhang, 2005). In particular, image matching techniques have shown good results in aerial applications, and allowed considering photogrammetric point clouds that are almost comparable to LIDAR ones, in terms of density. These techniques consider the epipolar geometry between images in order to reduce the search area in adjacent images, and thus decreasing the number of blunders to a great extent. The run on the epipolar line is further reduced by the approximate z-value which is provided by an approximate DSM: the more accurate this model, the more a correct solution (without blunders) is reached. In aerial application this DSM can be provided by feature extraction and photogrammetric matching. Unluckily in the terrestrial case z-values provided by approximate DSM are not sufficient to limit the run of the epipolar line especially in presence of significant depth variations (Nex and Rinaudo, 2009; Habib et al., 2004): blunders are more frequent during the matching procedure and it is still difficult to filter them. Furthermore, the façade texture is often not good enough to allow matching techniques: blank areas in automatically extracted point cloud are very common in correspondence to painted walls. Until now, fully matching techniques have only achieved good results in bas-relief or in limited area surveys.

LiDAR segmentation has instead been performed using point cloud information and several features, such as curvatures (Beinat et al., 2007) or static moments, to group together the points. These algorithms, however, do not guarantee that the right information is obtained especially in architectural applications where several details are ignored and, the boundaries (edges) of singular elements cannot be precisely detected.

In order to overcome these problems an integration of photogrammetric and LIDAR techniques has been attempted. The goal of this work is to reduce to the minimum the human intervention during the process simplifying the work of the final user in the production of drawings and models from data

provided by Geomatics techniques. The main idea of this process is quite simple: the reliable information of laser scanners are used as DSM in the matching algorithms and, then, the obtained information are employed to complete and ease the point cloud segmentation and the modelling. Combining together this information, the individual weakness of the singular technique can be overcome, reaching a reliable result in almost all the operative conditions. The proposed algorithm can be divided into the following steps, as presented in Figure 1.

▪ **Data acquisition.** The data acquisition conditions the goodness of the achievable results: good image quality and a noiseless LiDAR acquisition can improve the results of the automated algorithms. The images are acquired according to an *ad hoc* multi-image configuration (Nex and Rinaudo, 2009) or a sequence of converging images. The scan position is acquired by a central position respect to the image acquisition.

▪ **Image pre-processing.** All images are previously restored and then enhanced. The image restoration is performed by means of an adaptive Gaussian smoothing, while the images enhancement is achieved using a Wallis filter.

▪ **Image orientation (3 or more images).** In this step, the A^2SIFT (Auto-Adaptive Scale Invariant Feature Transform) operator (Lingua et al., 2009) has been adopted in the tie-point extraction. This operator, is able to extract many homologous points in every taking condition (affine transformation, change in scale and illumination, bad textured areas, etc.) to reach the same precision of traditional feature extraction and matching algorithm. A robust (Least Median Square) relative orientation is then performed in order to eliminate any mismatches (Lingua and Rinaudo, 2000). Finally, a bundle block adjustment is performed. Sub-pixel accuracy is requested in order to perform the following matching algorithms. The images are oriented in a Photogrammetric Reference System (PRS) in order to have the z-coordinate normal to the main plain of the façade.

▪ **Edge extraction from reference image.** A reference image is then chosen: it is usually acquired from a similar point of view as laser scanner acquisition in order to have approximately the same occluded areas in the LiDAR and acquired images. After that, the edge extraction is performed by the well-known Canny operator. The extracted edges are then approximated, by identifying the pixels where the edge changes in direction as knots and linking these dominant points by straight edges. Any edge shorter than a 10 pixel length is not considered in the subsequent matching procedures. The edges are only extracted in the regions of interest: façade glass is always excluded as it could create mismatches and blunders due to reflection.

▪ **LIDAR data Registration:** The point cloud is registered in the PRS by means of a spatial roto-translation. In this way, the information between the images and the point cloud are shared.

▪ **Edge matching between images.** A multi-image matching algorithm has been set up. The algorithm is similar to the Multi-Image Geometrically Constrained Cross Correlation MIGC[3] (Zhang, 2005): it uses a multi-image approach, that is, it considers a reference image and projects the image patch (of each dominant point) of the reference image onto the LiDAR data, and then, back-projects it onto the other images. Through this algorithm, the dominants points of each edge are matched in all the images in order to reconstruct the breakline positions in 3D. The images are preliminarily undistorted (using the camera calibration) in order to ease them into a central perspective. The epipolar constraint limits the search space in the images. The length of this line could be achieved considering the z-value given by the LIDAR point cloud; then, in order to find the homologous point in all the images, this

value is varied into a range (Δz). This work is enforced and improved through the position of already matched points: the z-value of two adjacent dominant points on the same edge must be similar. In this way it is possible to reduce the run of the epipolar line on the façade to few centimetres. Finally, the performed algorithm considers the shaping problems due to the breakline projection and the patch is made resizable in order to optimize the radiometric information in the matching.

In order to improve the rate of the successfully matched points, a relational matching has been developed. This algorithm has allowed several ambiguities to be solved during the matching phases by imposing a smoothness constraint.

Finally, a Multi-Image Least Square Matching (MILSM) (Baltsavias, 1991) has been performed for each extracted point. The MILSM has been implemented in order to improve the accuracy up to a sub-pixel dimension. The epipolar constraints have been included in the MILSM even though the patch shifts are generally less than 1 pixel and the influence of these constraints is reduced. Considering an affine transformation between patches, the estimation of all these parameters is often ill-posed on the image patch of an edge. For this reason, a statistical test has been performed to exclude any undeterminable parameters.

▪ **Edge filtering & blunder detection.** Blunders are firstly deleted from extracted edges using a filter which considers the reciprocal point positions on the same edge: the position of a point is predicted considering the neighbouring dominant points of the edge and then the difference between the predicted and real position of the point is evaluated. If the difference value is higher than a threshold the point will be deleted. This filter will work well if the blunders are isolated from each other.

For this reason, a second filter could be used to correct the edges when several blunders are close together: this algorithm uses the LiDAR data to verify the correctness of each dominant point: when it is farther than a threshold from the point cloud, the point is deleted.

▪ **Geometric edge extraction:** Image matching allows radiometric edges to be extracted. Most of these edges are due to shadows or radiometric changes but they have no geometric correspondence. Only geometric boundaries are of interest in surveying graphic drawings and modelling. For this reason, each dominant point on the extracted edges is considered with respect to the LiDAR point cloud and it is verified whether a geometric discontinuity occurs in the data close to the edge point. An edge breakline is detected considering the shape of the point cloud close to each dominant point and a sudden change in this data is observed.

▪ **Edge smoothing.** The edges extracted by the matching algorithm are random noise affected and they cannot be directly used in the drawing production or in the segmentation process. For this reason, the noisy edges are split in basic elements (linear and curved elements) and each of these elements is smoothed and eased, in an automatic way, into lines and second order curves by means of a polynomial fitting. Finally, the basic elements are recollected in a unique smoothed edge.

▪ **Guided Segmentation of point cloud.** The LIDAR point cloud is segmented using a 2D region growing algorithm and by constraining the segmentation process from crossing the geometric edges. In other words, the edges represent the boundaries of each element of the façade.

▪ **Export edges in CAD.** Geometric edges are exported in CAD in order to give a good preliminary data for the graphic drawing realization of the survey and for an evaluation of the achieved results.

The algorithm has been completely implemented in a *Matlab* code: the computation time has not been assessed during the performed tests. The algorithm is still in progress; most of the steps have been fully implemented and they have shown very good results; other steps have shown promising results, even if some more improvements and tests will be needed in the next months to exploit the fully potentiality of the proposed method.
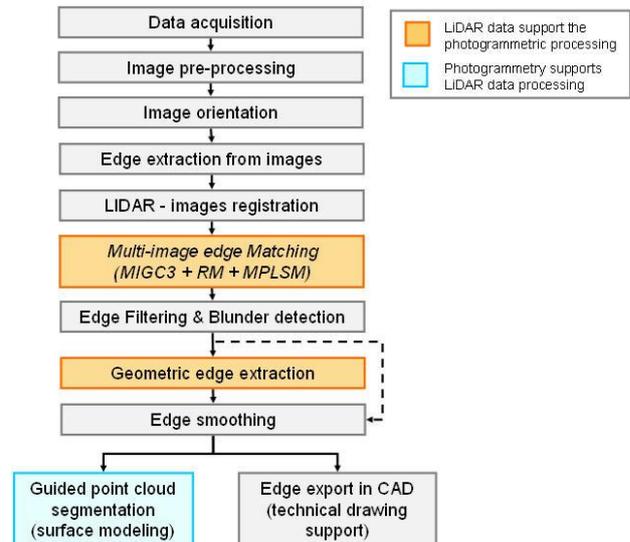

Figure 1. Algorithm workflow

3. EXPERIMENTAL TESTS

In [Nex and Rinaudo, 2009], the geometric accuracy in the edge location was evaluated comparing the matched edges with the results achieved by the manual plotting. In this paper, several examples of real façades will be presented: the main topic of these tests is to show the versatility of the approach. The results achieved on two different façades (a church and a Royal castle façade) are presented. In each test, several image configurations were tested and at least three images were processed contemporarily. The tests were performed using a *Riegl LMS-420* in the LiDAR acquisitions and a *Canon EOS-5D* in the image acquisitions. The extracted edges were checked by means of a topographic survey and centimetric accuracy was estimated.

3.1 Church façade – Roccaverano

This test was performed on a XVI century church façade in Roccaverano (Alessandria, Italy) in order to evaluate the performances of the algorithm in critical conditions. Only three images were available and they were affected by a change in illumination (Figure 2).

Figure 2. Available images of the church facade

For this reason, this test represents a critical situation and the results achievable in these conditions are surely worse than

when an *ad hoc* configuration or a sequence of converging images is used. The edge extraction showed several drawbacks in correspondence to the rounded decorations because of the absence of well-defined breaklines; The 500 year-old decorations were sometimes hard to detect as they are eroded and too far (taking distance is 18 m) to be described in detail.

The matching process was complicated by the taking geometry of the images which were near to the normal case and parallel to the horizontal elements of the facade; in this situation, the epipolar geometry does not improve the homologous point detection of horizontal edges. These results confirmed the reliability of the algorithm, even though the extracted edges were noisy; the mismatch percentage was also higher. Almost 85% of all the extracted edges were matched (Figure 3) but this percentage was lower when only the horizontal edges were considered. As the matching result was very noisy, the 11% of the edges was deleted during the blunder filtering. This problem was due to the long taking distance and the irregular and eroded surface of the church that do not define a regular breakline.
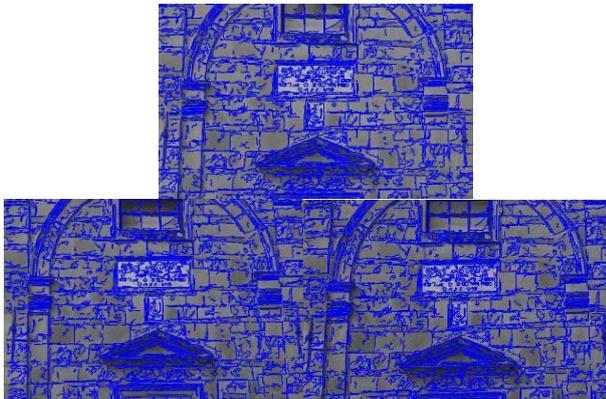

Figure 3. Extracted and matched edges in the reference (upper) and left-right images (lower), before geometric edge filtering

The geometric filtering did not delete all the radiometric edges; the edges (due to shadow) close to the breaklines were not cancelled by the filter (Figure 4). This aspect is particularly critical when insufficiently dense point clouds are available, even if some useless data are preserved using a denser data too. Then, after the filtering some geometric breaklines lost their connection (completeness) in correspondence to the eroded parts of the façade.

Figure 4. Extracted edges after the geometric edge filtering

As it can be seen in Figure 3, only few regular lines and curves were detected from the edge extraction; then, these lines have been further complicated by the noisy matching results because of the long taking distance. As a consequence, the smoothing of the edges was not an easy task. Several tests were performed in order to obtain the most reliable solution. In Figure 5, the achieved results are presented. It can be notices that some edges are strongly improved by the smoothing process, while others lead to incomplete results as edges are very short and irregular.
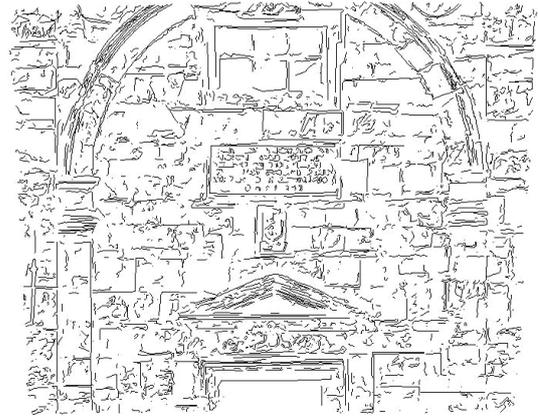

Figure 5. Smoothed edges in the Roccaverano Test

3.2 Royal castle façade - Valentino

The following test was performed on several parts of the Royal castle of Valentino (the Politecnico di Torino Architecture Faculty headquarter) in Torino. The façades are painted and in general the texture is not good enough the traditional image matching approach to be performed. A 0.030 gon scan resolution point cloud of the court palace was acquired and several parts of the palace were considered in order to evaluate the performances of the algorithm in different conditions.

In particular the loggia (Figure 6) of the palace was analysed acquiring 7 images with a converging geometry. The taking distance was between 15 and 18 m. The sequence of images allowed a good matching to be performed. The 83% of the dominant points were successfully matched and only the 5% of these points were filtered during the blunder detection process.

Figure 6. Reference image of the test, used in the multi-image matching process

The results achieved after this step are reported in Figure 7. The quality of the matched edges usually decreases in the parts of

the façade tilted respect to the image planes. In particular surfaces tilted more than 50° cannot be successfully matched and they did not correctly describe the object geometry.
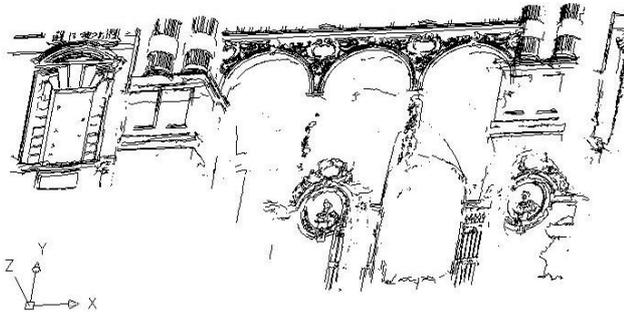

Figure 7. Extracted edges exported in CAD, before the geometric edge filtering in the loggia test

The geometric filtering did not succeed in the complete deletion of the edges due to radiometric variations. Then, some geometric edges were deleted because some missing points on the LiDAR data. The smoothing was performed considering the complete set of edges (radiometric and geometric). The results were very satisfying, especially if the complexity of the façade is considered (Figure 8).
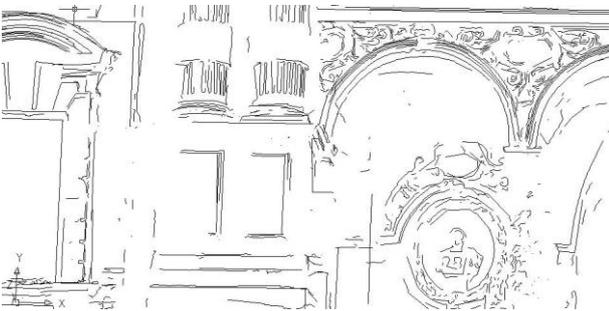

Figure 8. Smoothed edges in the loggia test

A second portion of the façade was a building corner. In this test, 6 images according to an *ad hoc* geometric configuration were acquired: in particular all the images were taken at different heights and on both sides of the reference image. As in the previous tests, glasses were deleted in order to avoid blunder generation during the matching process (Figure 9).

Figure 9. Extracted edges on the reference image in the corner test

The quality of the extracted edges were high, in terms of completeness, all over the image (see Figure 9): 132412 dominant points were extracted in the analysed area. The 84% of these points were successfully matched, achieving a very good result. Then, only the 7% of the matched points was deleted by the blunder detection process (Figure 10).
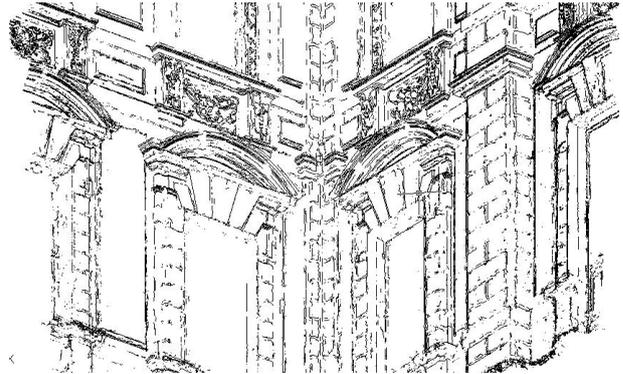

Figure 10. Extracted edges before the geometric filtering

The edges were filtered according to the geometric edge filtering. The results are very similar to the data before this step: only few shadows were removed, while some decorations were preserved because curvatures in correspondence of these details are very high.

Finally, the results in Figure 11 show the effectiveness of the edge smoothing in all the parts of the façade. It can be noticed that the algorithm is able to recognize the arcs from the lines and ease them in regular second order curves.

Figure 11. Smoothed edges in the corner test

4. CONCLUSIONS AND FUTURE DEVELOPMENTS

A new integration approach between the LiDAR data processing and the multi-image techniques has been presented. This approach has shown to achieve good results in a quite large variety of applications.

This work is very far from being a complete and efficient software. Nevertheless, it has demonstrated that the integration between these techniques can improve the results provided by each of them separately: new products have been achieved, increasing the automation of the process and reducing the manual intervention to few simple operations.

The photogrammetric algorithms have been fully developed: the matching algorithms needs only of little modifications, but the improvements in the final results are reduced, as the matched

edges are almost complete in every operative condition. On the contrary, several improvements are still requested to exploit the full potentiality of the method in the geometric filtering of the edges and in the segmentation process. This last step needs big modifications to be performed before showing satisfying results. The rate of points correctly matched is usually about the 80%. Then, the number of mismatches is reduced and they can be easily deleted by using the LiDAR information. In general, the results depend on the image taking configuration: almost normal case images are weak in the matching of edges parallel to epipolar lines. This problem could be overcome by just using more than three images and an *ad hoc* taking geometry or converging images. These configurations allow epipolar lines with different direction to be obtained (Nex, 2010); instead, converging images (more than 25°) could suffer from problems due to affine deformations of the image patches during the matching.

The taking distance should be chosen according to the degree of detail requested in the survey: 15 m distance can be considered the maximum for architectural objects to be drawn at 1:50 scale. The algorithm has shown that it can achieve good results for repetitive patterns, particularly if more than three images are used. The number of mismatches is usually low and decreases as the number of images increases. Glass, however, must always be deleted from all the images, in order to avoid mismatches.

Dense point clouds in the laser scanner acquisition are not strictly necessary during the matching process while they are instead requested in the filtering of geometric edges. The more the laser scanner data is dense the more the filtering is accurate; nevertheless, useless data are not successfully filtered and the algorithm still needs of some improvements.

Rounded edges are difficult to model as it is difficult to identify the position of the breakline in the image: in this situation, the algorithm does not allow good results to be obtained. Furthermore, more than 50° tilted surfaces, respect to the image planes, are not correctly matched.

The segmentation process will be tested more in detail in order to overcome the problems that actually limit its performances. In particular, the region growing algorithm will be improved in the growing process: actually, it does not achieve correct results when the boundaries of each element furnished by the photogrammetric process are not complete. Some additional parameters will be computed and considered in the growing process to limit the grown of the regions.

Considering the promising results achieved by the presented approach, several further investigations will be performed considering new instrument integrations. In particular, the integration between terrestrial images and Time of Flight (ToF) cameras and the integration between aerial images and data provided by Airborne Laser Scanners (ALS) will be considered.

REFERENCES

Alshawabkeh, Y., Haala, N., 2004. Integration of digital photogrammetry and laser scanning for heritage documentation. Proceedings of: *XXI ISPRS Congress*; Istanbul, Turkey.

Ardissone P., Bornaz L.; Rinaudo F., 2007. 3D Height Accuracy Survey and modeling for Cultural Heritage documentation and restoration. In: *VAST 2007 - Future technologies to empower heritage professionals*, Brighton 26-30 November 2007

Baltsavias E., 1991. Multiphoto Geometrically Constrained Matching. Phd. dissertation, ETH Zurich, Switzerland, ISBN 3-906513-01-7

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

Beinat, A., Crosilla, F., Visintini, D., Sepic, F., 2007. Automatic non parametric procedures for terrestrial laser point clouds processing. Proceedings of: *PIA07 Photogrammetric Image Analysis*, Munich, Germany September 19-21, 2007

Brenner, C., Building reconstruction from images and laser scanning, Proc. *ITC Workshop on Data Quality in Earth Observation Techniques*, Enschede, The Netherlands, 2003

Chen, L. C., Teo T. A., Shao Y. C., Lai Y.C., Rau J. Y., Fusion of LIDAR data and optical imagery for building modeling, 2004. Proceedings of: *XXI ISPRS Congress*; Istanbul, Turkey.

Cheng, L., Gong, J., Chen, X., Han, P., 2008. Building boundaries extraction from high resolution imagery and LiDAR data. In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Science*, Vol. XXXVII, Part B3b, Beijing, 2008.

Habib, A. F., Ghanma, M. S., Tait, M., 2004. Integration of LIDAR and photogrammetry for close range applications . Proceedings of: *XXI ISPRS Congress*; Istanbul, Turkey.

Lingua A.; Marenchino, D.; Nex, F. Performance analysis of the SIFT operator for automatic feature extraction and matching in photogrammetric applications, In: *SENSORS*, pp. 3745-3766, 2009, Vol. 9(5), ISSN: 1424-8220, DOI: 10.3390/s90503745

Lingua A., Rinaudo F., 2000. Aerial triangulation data acquisition using a low cost digital photogrammetric system. In: *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXIII/B2; p. 449-454, ISSN: 0256-184

McInotsh, K., Krupnik, A., 2002. Integration of laser-derived DSMs and matched image edges for generating an accurate surface model. In: *ISPRS Journal of Photogrammetry and Remote Sensing*, Vol. 56, Issue 3, April 2002, pp. 167-176

Nex, F., 2010. Multi-Image Matching and LiDAR data new integration approach. PhD Thesis, Politicnico di Torino, Torino, April 2010.

Nex, F., Rinaudo, F., 2009. New integration approach of Photogrammetric and LIDAR techniques for architectural surveys. In: *Laserscanning 2009*, Paris, 1-2 september 2009

Remondino, F., El-Hakim, S., Voltolini, F., 2008. Integrating Techniques for Detail and Photo-Realistic 3D Modelling of Castles. In: *GIM International*, Vol.22(3), pp. 21-25

Rönnholm, P., Honkavaara, E., Litkey, P., Hyyppä, H., Hyyppä, J., 2007. Integration of laser scanning and photogrammetry. Proceedings of: *IAPRS 2007* Vol. XXXVI, Part 3/W52, Espoo, Finland, September 12-14.

Zhang, L., 2005. Automatic Digital Surface Model (DSM) generation from linear array images.Thesis Diss. ETH No. 16078, Technische Wissenschaften ETH Zurich, 2005, IGP Mitteilung N. 90