

NEW INTEGRATION APPROACH OF PHOTOGRAMMETRIC AND LIDAR TECHNIQUES FOR ARCHITECTURAL SURVEYS

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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 architectural surveys: laser scanning techniques do not allow the correct position of object breaklines to be extracted while image matching results require an accurate editing and they are not acceptable for bad-textured images. For this reason several authors have already suggested overcoming of these problems through a combination of LIDAR and photogrammetric techniques. These works considers the integration as the possibility to share point clouds generated by these techniques; however, a complete and automatic integration, in order to achieve more complete information, has never been implemented.

In this paper, a new integration approach is proposed. This integration is focused on the possibility of overcoming the problems of each technique. In this approach 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. This integration is still an ongoing process: the algorithm workflow and first performed tests on real facades are presented in this paper, in order to evaluate the reliability of the proposed method; finally, an overview on the future developments is offered.

1. STATE OF THE ART

In recent years, LIDAR and image matching techniques have achieved good results in many applications, because of their speed and accuracy in point clouds generation. Nevertheless, neither technique assures complete and reliable 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 information and the exact position of the object breaklines; on the other hand, image matching techniques cannot assure that a point cloud is achieved without blunders in all conditions and are not able to guarantee good results in bad-textured areas. Furthermore, once the point cloud has been acquired, several automated and manual interventions have to be applied in order to segment, classify and model the surveyed points. These problems have limited the improvement of these instruments in architectural surveying.

Several authors have already suggested how to overcome these problems through a combined use of LIDAR data and image information to reach highly versatile systems and new application potential (Ackermann, 1999; Brenner, 2003). In this way, new solutions of integration between photogrammetry and LIDAR techniques have been investigated. Some papers consider this integration as a possibility of sharing the point clouds generated by these two kinds of instruments (Remondino, 2008); other papers consider the integration as a possibility of improve (Alshwabkeh, et al. 2004) one technique through the other. Only a few papers have described this integration considering it as a sharing of radiometric and ranging information. These works, however, only consider single images (Bornaz, et al., 2003) and the extraction of information is performed manually; a complete and automatic

integration between laser scanner acquisitions and multi-image matching techniques has never been implemented.

2. A NEW APPROACH

Starting from these works, a new integration approach is proposed in this paper. In this approach LIDAR and photogrammetric techniques continuously share information in order to complete point cloud information and extract building breaklines in the space. In order to do this, image matching techniques and point cloud segmentation have been merged; these techniques work independently and the shared information is used as feedback to perform segmentation and to match algorithms in a more reliable way.

In the 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). Actually, this kind of solution requires an approximate DSM in order to “drive” the solution to the correct match; the more accurate this model, the more a correct solution (without blunders) is reached.

Segmentation in LIDAR applications has instead only been performed using point cloud information such as curvatures (Beinat et al., 2007) or static moments (Roggero, 2002). 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 detected precisely.

The present approach tries to overcome these problems using laser scanner data as approximate DSM (Digital Surface Model) in the matching algorithms and then the breaklines that are extracted from images in the segmentation algorithms. This

integration is an ongoing work which still needs to be completed and tested. The workflow and first achieved results are presented in the following sections. Finally considerations on the performed tests and future developments are described.

3. ALGORITHMS

Image matching techniques have shown good results in aerial applications. Multi-image techniques in particular have improved results in terms of precision and reliability (Zhang, 2005), 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. In aerial cases this value varies smoothly, compared to the relative flight height. Breaklines due to buildings are small, compared to the taking distance: a 40 m high building is only 1/20 of an 800 m flight height. On the other hand, the terrestrial case is more difficult for these techniques: façades are usually rough with balconies or decorations that protrude. In this situation, z-values provided by approximate DSM are not sufficient to limit the run of the epipolar line: 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.

In order to overcome these problems an integration of photogrammetric and LIDAR techniques has been attempted. The main idea is to use the reliable information of laser scanners as DSM in the matching algorithms and, then, to complete with the obtained information, the point cloud segmentation and the modelling. The proposed algorithm can be divided into the following steps:

- **Image orientation** (3 or more images): in this step a SIFT (Scale Invariant Feature Transform) operator (Lowe, 2004) is 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, 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 (Bellone et al., 1999). Finally, a bundle block adjustment is performed. Sub-pixel accuracy is requested in order to perform the subsequent matching algorithms. The images are oriented in a proper reference system in order to have the z-coordinate normal to the main plain of the façade.
- **Edge extraction from reference image:** all images are previously enhanced using a Wallis filter (Wallis, 1976). This filter is able to sharpen the radiometric boundaries and enhance the edges. 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 Canny operator (Canny, 1986). This filter is able to preserve edge position and to obtain better results in terms of edge completeness than other edge extractors (Zhang et al., 2004). The extracted edges are then approximated, by identifying the pixels where the edge

change in direction as knots and linking these dominant points by straight edges. Any edges shorter than a 20 pixel length are 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.



Figure 1. Original image (top left); image filtered with the Wallis filter (top right), edge extracted by the Canny operator (bottom left) and approximated edges used in the matching process (bottom right)

- **LIDAR data Registration:** the point cloud is registered in the photogrammetric reference system by means of a spatial roto-translation. In this way it is possible to share the information between the images and the point cloud.
- **Edge matching between images:** a multi-image matching algorithm has been set up. The algorithm is similar to the Geometrically Constrained Cross Correlation GC³ (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 DSM, and then, back-projects it onto the other images. Through this algorithm, the dominant points of each edge are matched in all the images in order to reconstruct the breakline positions in 3D. The images are preliminarily undistorted 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 a 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.
- **Improvement of edge location accuracy:** a Multi-photo Least Square Matching (MLSM) (Baltasvias, 1991; Gruen et al., 1988) has been performed for each extracted point. The MLSM has been implemented in order to improve the accuracy up to a sub-pixel dimension. The epipolar constraints have been included in the MLSM 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 test (considering the Principal Component Analysis and the Student's t-test) has been performed to exclude any undeterminable parameters.

- **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 a geometric correspondence (Figure 2). 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 LIDAR data close to the edge point. The breakline is detected considering points (6-10) inside a search area and evaluating the changes in the z-coordinate of these points with respect to the displacements on the x-y axis. If a change in z is detected, a breaklines is individuated.

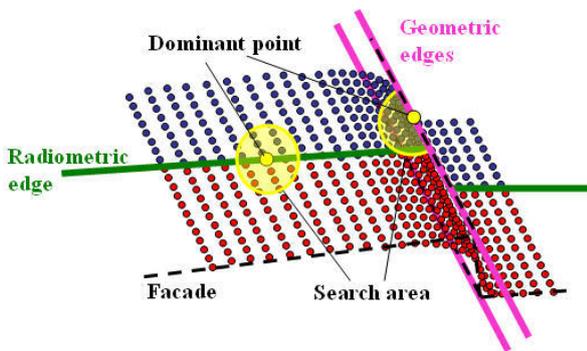


Figure 2. Radiometric and Geometric edges and search area in the geometric filtering

- **Edge filtering:** blunders are deleted from geometric edges using a filter which smoothes the geometry of the edge. In order to do this, the reciprocal point positions on the same edge are considered: in particular the position of a point is predicted considering the neighbouring points and then the difference between the predicted and real position of the point is evaluated. If the difference value is higher than a predefined threshold the point is deleted. This filter is not robust: it will work well if the blunders are isolated from each other.

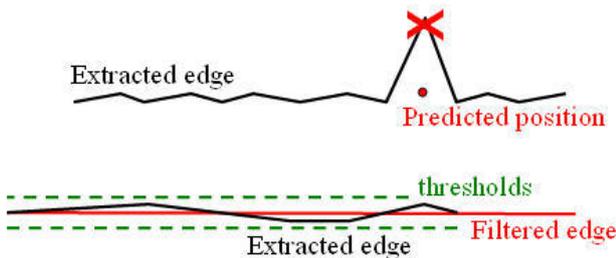


Figure 3. Blunder filtering (top) and edge smoothing (bottom)

Finally, a second filter could be used to smooth the edges to delete the redundant points: if three points are almost aligned (according to a threshold value) in the space, the equation of the line could be estimated by means of a Least Square (LS) procedure, and the intermediate point can be deleted (Figure 3).

- **Export edges in CAD:** Geometric edges are exported in CAD in order to give preliminary data for the graphic drawing realization of the survey and for a rough evaluation of the achieved results.
- **Guided Segmentation of point cloud:** the LIDAR point cloud is segmented using a 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.

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, but some of them still have to be improved and tested in more detail in the next months (see figure 4).

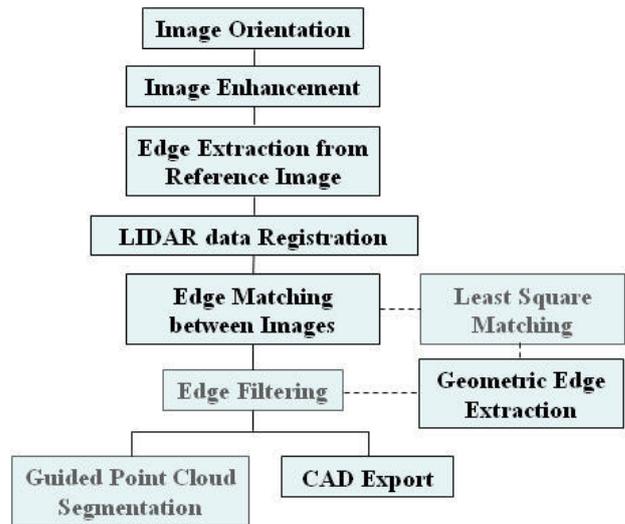


Figure 4. Algorithm scheme (the grey steps are still under development)

4. EXPERIMENTAL TESTS

Several tests have been performed in order to verify the reliability of the algorithm. The first tests were conducted considering a test field in the Photogrammetry Laboratory in the Politecnico di Torino (Turin, Italy). Other tests were performed surveying a real façade in order to consider the reliability of the algorithm in real conditions. In each test, several image configurations were tested and at least three images were processed contemporarily.

The geometrical accuracy in the edge location was evaluated comparing the matched edges with the results achieved by the manual restitution. Finally, the percentage of matched edges on the number of extracted edges was evaluated.

The tests were performed using a *Riegl LMS-420* for the laser scanner acquisitions and a *Canon EOS-5D* for the image acquisition.

4.1 Calibration test Field

This test was performed in order to evaluate the geometric accuracy in the edge extraction and the reliability of the algorithm in the presence of repetitive pattern. A portion of the building was considered in order to evaluate the performance of

the algorithm in a simple but meaningful site, where several typical elements of a façade were visible (Figure 5).

A 0.030 gon scan resolution point cloud and about 15 images have been acquired in this test. Nevertheless, only 5 images were considered in the multi-image matching algorithm: the additional information given by more than 5 images did not improve the final result. The point of view of the reference image (Figure 5) was approximately the same as the scan position in order to have the same occluded areas in the LIDAR and image acquisitions. The other 4 images were acquired on both sides of the reference one and at different heights; the taking distance was on average 8 m and the base from the reference image to the other images is between 1.2 m and 2 m (e.g. the base/distance ratio ranges from 1/7 up to 1/4).

The images were chosen in not normal position in order to guarantee a good configuration in the matching process. An example is shown in Figure 6: epipolar lines run along the object in different directions to help search for the cross correlation maximum. The computational time was higher than that necessary when using 3 images, but the results are better in terms of completeness and reliability.



Figure 5. Reference image of the calibration test, used in the multi-image matching process

Furthermore, the point cloud was filtered at different steps in order to find the right balance between number of points and DSM approximation: it was noticed that a point cloud filtered at a 0.400 gon scan resolution was sufficient to perform the matching algorithm; a denser point cloud did not appreciably change the matching results of small or repetitive details, such as the banister of the balcony. On the contrary, the filtering of the geometric edges had to be performed using the most dense available point cloud.

The extracted edges were complete all over the reference image; each part of the façade was correctly detected and represented (Figure 7). These edges were matched in the other images according to the discussed workflow (Figure 4). Several tests over different parts of the façade were performed: an example is shown in Figure 8.

In general, the achieved results have shown that the percentage of mismatches is low, though no strict thresholds were used in the rejection of the matched points; furthermore the mismatches were concentrated in correspondence to the basements. The mismatches on glass, due to glass reflection, were avoided, by ignoring the windows in all images. Some elements of the façade, such as the banister, were not completely represented, because of their small dimensions and their repetitive pattern.

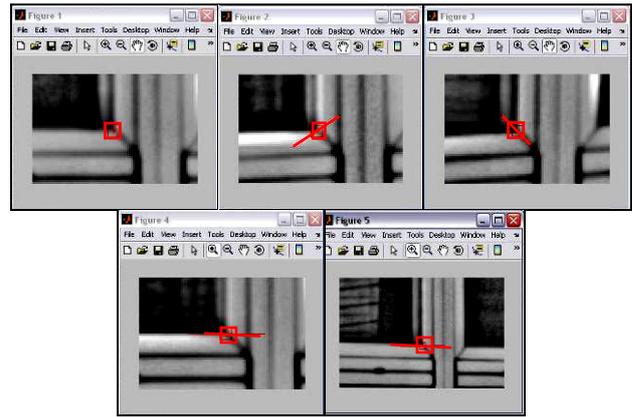


Figure 6. Epipolar configuration in Calibration Test Field



Figure 7. Example of extracted edges in the calibration test

The edges in correspondence to the repetitive patterns on the walls were almost completely matched while the percentage decreased slightly for the window frames, because of the proximity of the window areas. Nevertheless, the completeness of the extracted edges is high: the percentage of matched edges, on the façade, was approximately 92%.

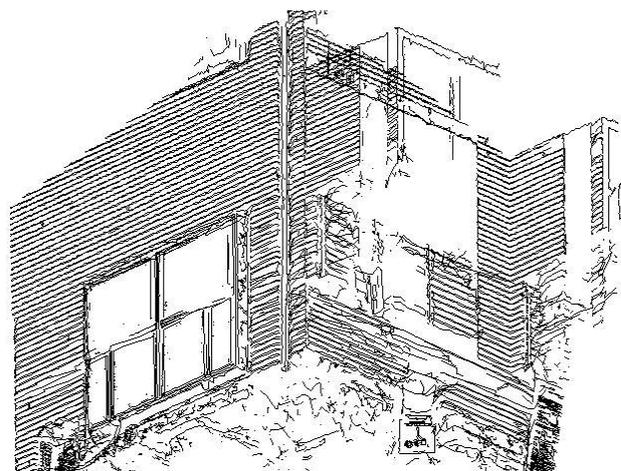


Figure 8. Extracted edges exported in CAD, before the geometric edge filtering

Finally a comparison between the manual photogrammetric plotting (using 2 images acquired by a *Rollei 6008* in normal conditions) and the matched edges was made in order to

compare the achieved accuracy. About 100 edges displaced all over the image were considered in this test. The test results are shown in Table 2.

Mean taken Distance [m]	Δ mean [mm]	RMS [mm]	Theoretical RMS [mm]
8	3	12.3	1.20

Table 2. Accuracy evaluation of the extracted edges in the calibration test

The theoretical Root Mean Square has been computed, considering the equations proposed by [Forstner, 1998] for the multi-image case. An average base between images of 1.65 m and a focal length of 25 mm have been considered. The achieved accuracy is lower than the theoretical one. Nevertheless, the extracted edges have been matched using an algorithm that reaches a pixel accuracy. Performing the MLSM algorithm, sub-pixel accuracy (0.1-0.2 pixel size) will be reached and it is expected to improve this result of about 5 times.

4.2 Church façade

A second test was performed on a XVI century church façade in Roccaverano (Alessandria, Italy) in order to evaluate the performances of the algorithm in a real case. Only three images were available and the images were affected by a change in illumination (Figure 6). For this reason, this test represents a critical situation and the results achievable in these conditions are surely worse than when an *ad hoc* image configuration 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 about 15 m) to be detected 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 façade; in this situation, the epipolar geometry does not help in the homologous point detection.



Figure 6. Available images of the church facade

Several tests were performed on the different parts of the façade, and the achieved results have been compared with the manual restitution data. These results confirmed the reliability of the algorithm, even though the geometrical precision of the edge is lower than in the previous test and the extracted edges are noisier; the mismatch percentage was also higher. Almost 85% of all the extracted edges were matched (Figure 7) but, as expected, this percentage was lower when only the horizontal edges were considered. Some authors (Zhang, 2005) have already proposed a “free-form” matching, considering dominant points on an edge as a whole, in order to overcome difficult situations due to normal images. This solution has led to good results in the aerial case; in terrestrial applications, edges have

generic shapes and this approach has proved to be more difficult to implement.

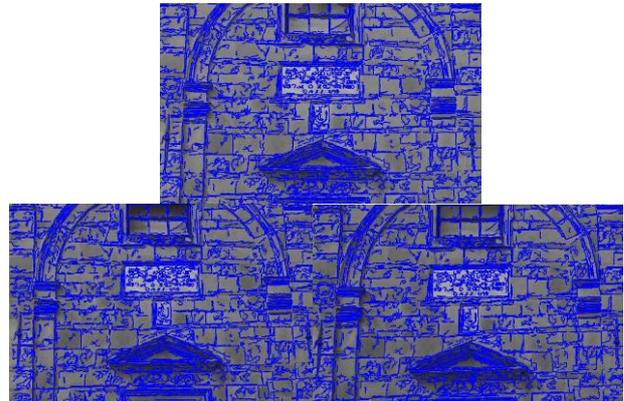


Figure 7. Extracted and matched edges in the reference (upper) and left-right images (lower), before geometric edge filtering

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 8). This aspect is particularly critical when insufficiently dense point clouds are available.

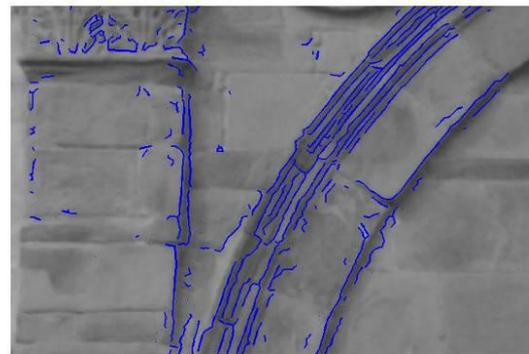


Figure 8. Extracted and matched edges after the geometric edge filtering; the shadows close to breaklines are not deleted.

5. CONCLUSIONS AND FUTURE DEVELOPMENTS

The performed tests have allowed a first evaluation to be made of the potentiality of the proposed method, even though this analysis is not complete yet and further tests and changes have to be defined. Nevertheless, the results have already shown the reliability of the algorithm. 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. Images acquired at different heights allow epipolar lines with different direction to be obtained (Figure 9); instead, convergent images (more than 20°) could be subject to problems due to affine deformations.

The taking distance should be chosen according to the degree of detail requested in the survey: in general, a 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.

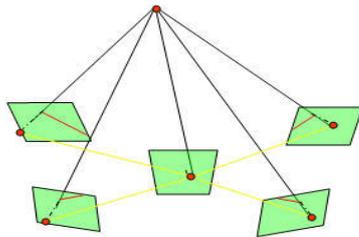


Figure 9. Optimal image configuration: epipolar lines are in red

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 LIDAR acquisition are not strictly necessary during the matching process while they are necessary instead in the filtering of the geometric edges. In fact the algorithm has shown some problems because of the presence of shadows close to the geometric breaklines; a more dense point cloud could overcome this problem. Furthermore, 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.

It is expected that the geometric precision in the edge matching will be increased by implementing a Least Square Matching (LSM). A first step will be to perform a Multi-Photo LSM of dominant points; then it is planned to carry out an LS B-Snake matching (Zhang, 2005) which could slightly improve the quality of extracted edges.

A great advantage in the traditional point cloud segmentation will be obtained from the extracted edges. The segmentation will be guided by edges that define the boundaries of each façade portion and fix a constraint in the region growing algorithm. In this way it is expected to make the modelling procedures easier.

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