# DIGITAL PHOTOGRAMMETRY AND LIDAR: NEW IDEAS FOR 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

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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 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 highly versatile systems and new application potential. However, 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. This integration is still an ongoing process: the algorithm workflow and some 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. INTRODUCTION

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 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 information and the exact position of the object breaklines (Chen, et al. 2004); on the other hand, image matching techniques cannot assure that a point cloud is achieved without blunders in all conditions and they are not able to guarantee good results in bad-textured areas (Habib et al., 2004).

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 steps usually needs of an experienced user and many complicated (and expensive) software. For these reasons, the use of laser scanning instruments and photogrammetric techniques has not completely replaced the employment of traditional surveys techniques in many application fields.

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 improving the produced point cloud (Remondino et al., 2008; Alshawabkeh et al. 2004; Papasaika et al., 2006) 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 extraction of information 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. In this way, a complete and automatic integration between laser scanner acquisitions and multi-image matching techniques have never been implemented.

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 technical drawing production and the segmentation process during the modelling. In order to do that, image matching techniques and point cloud segmentation have been merged; these techniques work independently and share information in order to perform segmentation and matching algorithms in a more complete and reliable way, overcoming the limits of these techniques.

This integration is an ongoing work which still needs to be completed and tested. In the following section, a description of the algorithm and the first tests will be presented and discussed. In the performed tests different façade typology and condition of acquisition have been considered in order to evaluate the reliability of the presented method. Finally, considerations on the performed tests and future developments are described.

## 2. THE ALGORITHM

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). 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.

Unfortunately 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 et al., 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.

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.

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 in the matching algorithms and, then, to complete with the obtained information, the point cloud segmentation and the modelling. In particular, laser scanner data are used as approximate DSM (Digital Surface Model) in the matching algorithms and then the breaklines that are extracted from images in the segmentation algorithms.

The proposed algorithm can be summarized into several steps shown in Figure 1. The images are oriented in a proper reference system in order to have the z-coordinate normal to the main plane of the façade. Then, all images are 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) on this reference image. 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.

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. Then a multi-image matching algorithm is set up. The algorithm is similar to the Geometrically Constrained Cross Correlation $GC^3$ (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 DSM (laser scanner point cloud), and then, using the approximate z-value achieved by the DSM, 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. A Multi-photo Least Square Matching (MLSM) (Baltsavias, 1991) has been performed for each extracted point, in order to improve the accuracy up to a sub-pixel dimension.

Nevertheless, the 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. 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: it is verified whether a geometric discontinuity occurs in the LIDAR data close to the edge point. After that, blunders are deleted from geometric edges using a filter which smoothes the geometry of the edge.

Finally, 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.

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.

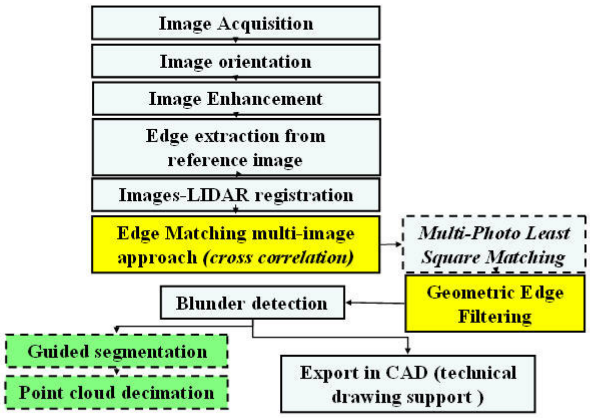


Figure 1. Algorithm scheme (dashed boxes are under development)

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. In Figure 1 the yellow boxes represent the workflow steps where LIDAR information supports the multi-image matching algorithm. On the contrary, the green boxes define the workflow steps where information provided by photogrammetric approach supports the LIDAR segmentation. For a more detailed description of the algorithm refers to [Nex et al., 2009].

## 3. 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). In this test the geometrical accuracy in the edge location was evaluated comparing the matched edges with the results achieved by the manual

restitution. Other tests were performed surveying two different façades (a church and a Royal castle façade) in order to consider the reliability of the algorithm in different conditions. In each test, several image configurations were tested and at least three images were processed contemporarily. Furthermore, 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 calibrated *Canon EOS-5D* for the image acquisitions.

### 3.1 Calibration test Field – Photogrammetry Lab.

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.
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: it has been tested that the additional information given by more than 5 images did not improve the final result. The point of view of the reference image 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 2: 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 (approximately the double), but the results are better in terms of completeness and reliability.

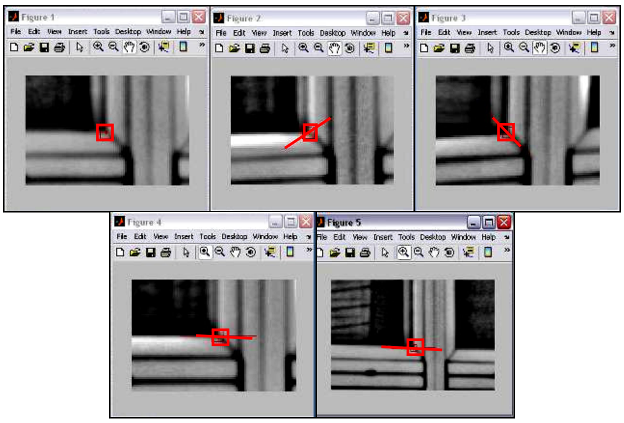

Figure 2. Epipolar configuration in Calibration Test Field

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 3). These edges were matched in the other images according to the discussed workflow (Figure 1). Several tests over different parts of the façade were performed: an example is shown in Figure 4.

Figure 3. Example of extracted edges in the calibration test

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. 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 was high: the percentage of matched edges, on the façade, was approximately 92%.
On the other hand, the geometric edge filtering has detected all the façade breaklines even if some useless points have not been removed, as shown in Figure 4. In this filtering a 0.100 gon scan resolution point cloud has been used.
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 1.

| **Mean taken Distance [m]** | **Δ mean [mm]** | **RMS [mm]** | **Theoretical RMS [mm]** |
|---|---|---|---|
| **8** | 3 | 12.3 | 1.2 |

Table 1. 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 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.


Figure 4. Extracted edges exported in CAD, before (top) and after the geometric edge filtering (bottom)

### 3.2 Church façade – Roccaverano

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 critical conditions. Only three images were available and they were affected by a change in illumination (Figure 5). 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.

Figure 5. Available images of the church facade

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 help in the homologous point detection. Several tests were performed on the different parts of the façade. 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 6) but, as expected, this percentage was lower when only the horizontal edges were considered.

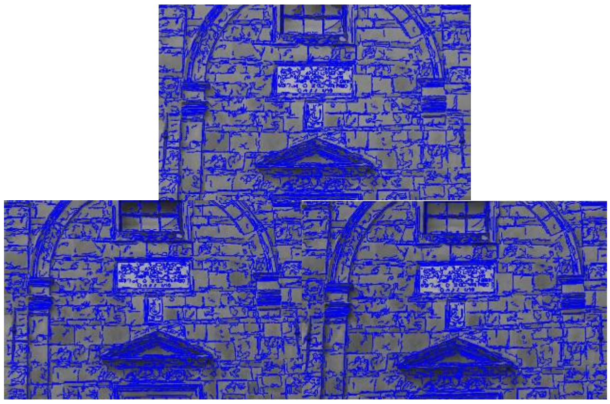

Figure 6. Extracted and matched edges in the reference (upper) and left-right images (lower), before geometric edge filtering

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

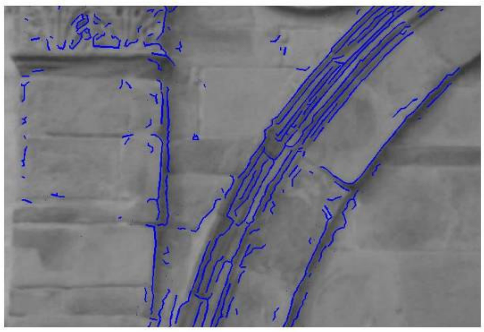

Figure 7. Extracted and matched edges after the geometric edge filtering: the shadows close to breaklines are not deleted

### 3.3 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 8) of the palace was analysed acquiring 7 images with a convergent geometry. The taking distance was between 15 and 20 m. Unfortunately, it was not possible to acquire images at different heights: the epipolar lines were approximately parallel to the horizontal elements of the façade. As a consequence, the percentage of correctly matched points was not the same all over the image. In general the percentage of horizontal lines matched was lower than vertical ones, while decorations on the façade were completely matched (Figure 9).

Figure 8. Reference image of the test, used in the multi-image matching process

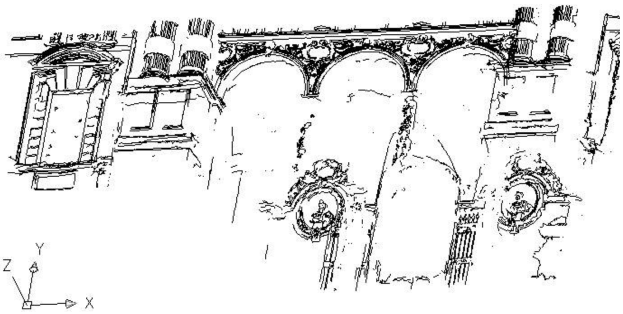


Figure 9. Extracted edges exported in CAD, before the geometric edge filtering in the loggia test

The accuracy in the edge matching was comparable to the previous tests; nevertheless it was noticed that the quality of the matched edges decreased in the parts of the façade tilted respect to the image planes. It was shown as surfaces, tilted more than 50°, can't be successfully matched and the extracted edges did not correctly describe the geometry of the object.

Figure 10. Extracted edges on the reference image in the corner test

A second part 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 10).
The quality of the extracted edges is high, in terms of precision and completeness, all over the image. The extracted edges have centimetre accuracy and the random noise of the edges is reduced (Figure 11).

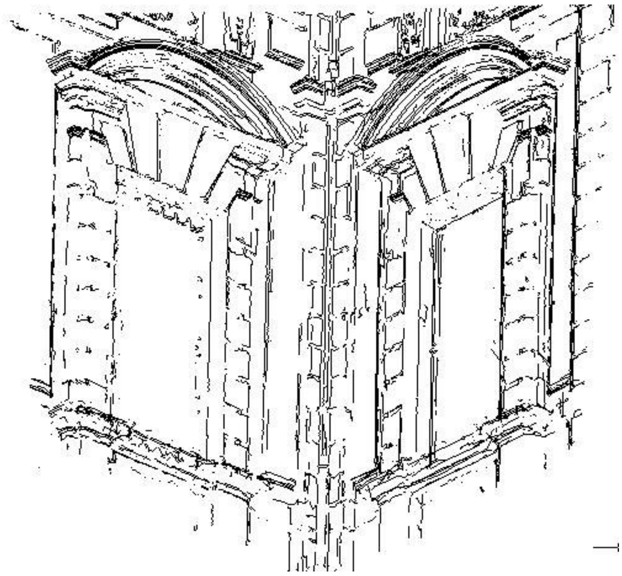

Figure 11. Extracted edges before the geometric filtering

## 4. 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 in the algorithm have to be defined. In the performed tests, the achieved 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 12); instead, convergent images (more than 20°) could be subject to problems due to affine deformations of the image patches during the matching algorithm.
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. 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 necessary instead in the filtering of the geometric edges. The

more the laser scanner data is dense the more the filtering is accurate; nevertheless, useless data are not always successfully filtered and the algorithm needs of some improvements. Problems due to the presence of shadows close to the geometric breaklines will be reduced in the geometric edge filtering if the sun does not light directly the façade up.
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°, respect to the image planes, tilted surfaces or partially occluded surfaces are not correctly matched.

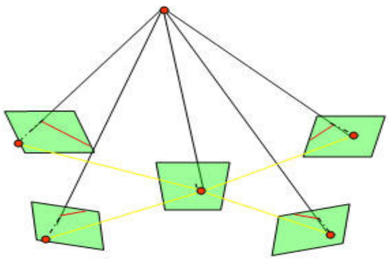

Figure 12. Optimal image configuration: epipolar lines are in red

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 dominants points; then it is planned to carry out an LS B-Snake matching (Zhang, 2005) which could slightly improve the quality of extracted edges. Nevertheless, edges must be smoothed and interpolated before their direct use in technical drawings or in the modelling process as they are affected by random noise.
The traditional point cloud segmentation will be improved 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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