A COMBINED SYSTEM OF DIGITAL PHOTOGRAMMETRY AND 3D LASER SCANNING

N. Perfetti[a], A. Pellegrinelli[a], M. G. D'Urso[b], P. Russo[a]
[a]ENgineering Department In Ferrara, University of Ferrara, via G. Saragat 1, 44100 Ferrara, Italy - email: nperfetti@ing.unife.it
[b] D.i.M.S.A.T, University of Cassino, Via G. Di Biasio 43, 03043 Cassino (FR) - email: durso@unicas.it

KEY WORDS: Digital Photogrammetry, Laser Scanning, Co-registration

ABSTRACT

In this work a project is presented on the future development of a technique based on digital close range photogrammetry combined with 3D laser scanning, to be applied to cultural heritage survey, modelling and documentation. Such technique will require a method to be realized for the block adjustment of the scanner point clouds and the bundles of images spatial rays in the same reference frame. The final goal is an algorithm for computing the 3D coordinates of object points from their plane coordinates measured on only one digital image at a time. An example is described on the co-registration of digital images and point clouds.

1. INTRODUCTION

The technology of 3D laser scanner has remarkably improved from year to year. A lot of equipments is now available, presenting accuracy, field of view and range right for different types of applications.
Although laser data provide accurate DSM (Digital Surface Model), there are still qualitative and quantitative data regarding the surveyed object that the scanner is not yet able to point out and which vice versa appear clearly on digital imagery (Alshawabkeh et al. 2002). For this reason the integration of digital photogrammetry and laser scanning is going to be very popular for cultural heritage documentation. The most interesting products are ortho-rectified digital images, 3D photorealistic virtual models, and recently the so called " solid image" (Dequal et al., 2004).
A basic requirement for the integration of the two techniques is an efficient method of co-registration 3D point clouds and digital images. At present many types of algorithms for automatic registration of point clouds have been developed, as reported by Gruen et al. (A. Gruen et al, 2004).
With regard to the alignment of the laser scanner data with the digital imagery, the following alternative approches are mostly used:
- point clouds are previously registered, then digital images are independently oriented in the laser reference system by space resection (Haala et al., 2004);
- digital images are oriented by bundle adjustment, then the whole photogrammetric block is registered in the laser scanner reference system (Habib at al., 2002);
- digital photogrammetry is used to establish a global coordinate system, measuring the spatial coordinates of optical targets, in which range maps are adjusted by proper rigid motion (Guidi et al., 2003).

A significant problem occurring in co-registration is the detection and measurement of correspondent points in laser scanning clouds and in digital images, so that "tie lines" instead of tie points can be used for increasing the quality of results (Alshawabkeh et al 2002, Habib et al 2002).
As in many technical applications only a simple, but accurate, vectorial model of the object is sufficient, low cost systems of digital close range monoscopic photogrammetry can be usefully employed. Monoscopic photogrammetry however presents some technical problems, among which the identification of conjugate points in different digital images (even if the difficulty is reduced thanks to the use of epipolar line) and the necessity of topographic measurements for bundle adjustment. It is therefore interesting the study of new methods of combining the measurement performances and the algorithms of both photogrammetry and laser scanner, with the purpose of reducing such problems.
In this work a project is presented about a possible application of digital close range photogrammetry combined with 3D laser scanning to cultural heritage survey, modelling and documentation.
A first algorithm for simultaneous orientation and co-registration using tie points or features between scans and images is presented.

2. THE PROJECT

The basic idea is a block adjustment of the points clouds and of the bundles of spatial rays in the same reference frame.
For our project we intend to develop a least square adjustment procedure of both laser scans and digital images orientation parameters, where the 2D and 3D coordinates of tie points or tie object features are the observables.
In this phase it is necessary to study an optimal method for taking images and scans; the first idea is that the point clouds present a minimum overlapping, while two adjacent clouds must be comprised in a single image.
Once digital images and laser scans are aligned in the same reference system, the vectorization of the object can be performed by one image at a time. For this purpose it is necessary the realization of an algorithm for computing the 3D coordinates of an object point by means of the measurement of its image plane coordinates on only one digital image. Such algorithm must provide an object point for any spatial ray starting from any pixel of the digital image and intersecting the point cloud. Then the vectorization of the features of the object is performed on a digital image, without searching for the conjugate points on other images.

3. POINT CLOUDS CO-REGISTRATION METHOD

The first step of the ongoing project is the realization of a method to get 3D point clouds and digital images co-registered. For this purpose a procedure has been developed for a very simple model.
An object is supposed to be scanned by two different positions obtaining two points clouds (S1 and S2) with no common elements. For the same object, two digital images (I1 and I2) have been taken, so that the surface interested by the

two point clouds is visible in both images. The figure 1 shows the geometrical model.

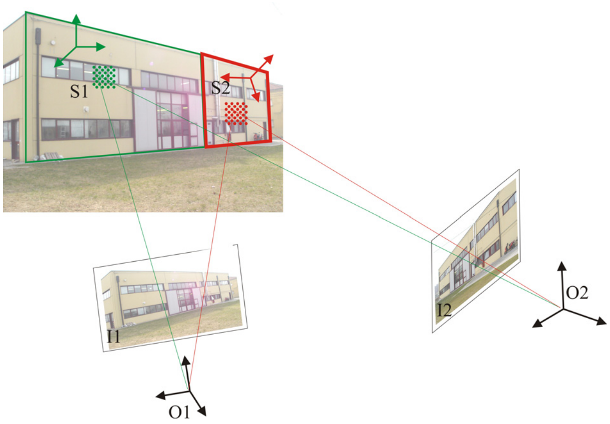

Figure 1. The geometrical model.

The reference systems (RS) considered in the procedure are:

- the image space coordinate system of the image I1
- the image space coordinate system of the image I2
- the RS of the point cloud S1
- the RS of the point cloud S2

The first two systems are three-dimensional, with origin at the perspective centers of the camera, while the RS of the point clouds are tipically the laser scanner RS.

To get the point clouds co-registered in the same RS, the following data are necessary:

i) the camera calibration parameters and the sensor dimensions;
ii) the image coordinates on I1 and I2 of at least three points of the object (natural points or targets) present in the surface intersted by S1;
iii) the coordinates of the same points in the RS of S1;
iv) the image coordinates on I1 and I2 of at least three points of the object (natural points or targets) present in the surface intersected by S2;
v) the coordinates of the same points in the RS of S2;
vi) the coordinates in the image space coordinate system of I1 and I2 of at least two further points (natural points or targets) of the object, present in S2;
vii) the coordinate of the same points in the RS of S2.

3.1 Co-registration procedure

The co-registration procedure for point clouds is organized in the following phases:

1) computation of exterior orientation parameters for both images I1 and I2 in the RS of S1 and in the RS of S2, using data ii), iii), iv) and v);
2) computation of the coordinates of the points vi) in the RS of S1;
3) computation of the parameters of the similarity transformation from the RS of S2 to the RS of S1 using the points 2) and the points vi), plus the coordinates of the camera stations in the RS of S1 and S2 (computed in the step 1);
4) registration of the points cloud S2 in the RS of S1.

3.2 Mathematical Model

The collinearity equations are used for the step 1). For each point two equations can be written (Mikhail et al., 2001):

$$
\begin{aligned}
F_1 &= x - x_p + c\frac{U}{W} = 0 \\
F_2 &= y - y_p + c\frac{V}{W} = 0
\end{aligned}
\tag{1}
$$

where

$$
\begin{pmatrix} U \\ V \\ W \end{pmatrix} = R \begin{pmatrix} X - Xc \\ Y - Yc \\ Z - Zc \end{pmatrix}
\tag{2}
$$

x, y $-c$ are the image space coordinates. .R is the total rotation matrix: ω denotes rotation about the X-axis, φ about the Y-axis and k about the Z-axis. X, Y and Z are the object space coordinates (in the RS of one of the point clouds), X_c, Y_c and Z_c are the coordinates of the camera station (in the RS of the same point cloud).

The collinearity equations must be first used to compute the exterior orientation parameters $(X_c \quad Y_c \quad Z_c \quad \omega \quad \varphi \quad k)$ of the camera for the images I1 and I2, using Least Squares (LS). Then, using the same equations and with the known exterior orientation parameters, the coordinates of the points vi) in the RS of S1 are computed. In the last step the parameters of the similarity transformation from the RS of S2 to the RS of S1 are estimated:

$$
\boldsymbol{X}_{S_1} = T + R_2 \boldsymbol{X}_{S_2}
\tag{3}
$$

$\boldsymbol{X}_{S_1}$ is the vector of the computed coordinates for the points in 2) and $\boldsymbol{X}_{S_2}$ is the vector of the measured coordinates of the points of S2, T is the translations vector and R_2 the total rotation matrix. The estimated parameters (T and R_2) are used for the registration of S2 in the RS of S1.

4. APPLICATION OF THE METHOD: FIRST RESULTS

The above described procedure was applied to a very simple case. The front of a building, figure 2, was divided into two parts, each one of them was supposed to be scanned independently.

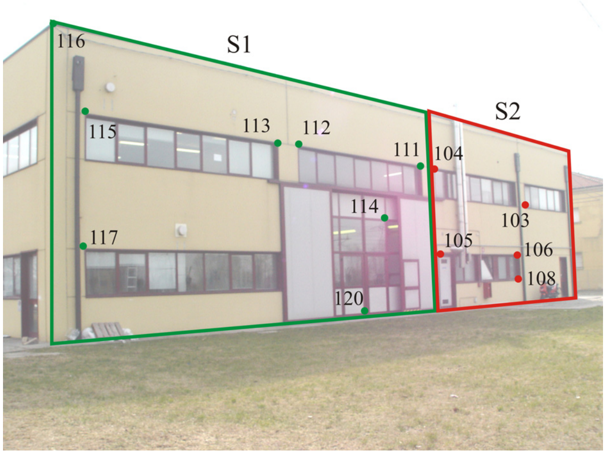

Figure 2. The scanned areas on the front of the building.

Two digital images of the whole facade were taken with a camera Sony DSCF717 (figure 3).

Figure 3. Digital images I1 and I2.

In order to simulate the point clouds from Laser Scanner, a total station Topcon GPT-2005 was used to determine the coordinates of the object points.
The method described in 3. was applied to compute the co-registration parameters of the two simulated clouds. Table 1 and table 2 show the LS residuals of the exterior orientation for images I1 and I2 for S1 in sensor coordinates. Table 3 and table 4 show the LS residuals of the exterior orientation for images I1 and I2 for S2 in sensor coordinates. Table 5 shows the LS residuals of the similarity transformation for the registration of S2 in the RS of S1.

Table 1. LS residuals of the exterior orientation for image I1 for S1.

point	ex (mm/1000)	ey (mm/1000)
111	-18	-1
112	0	13
113	-24	17
114	15	-3
115	-9	14
116	33	-5
117	-19	-23
120	18	-6

Table 2. LS residuals of the exterior orientation for image I2 for S1.

point	ex (mm/1000)	ey (mm/1000)
111	21	1
112	-11	4
113	-26	-11
114	-3	3
115	-4	-8
116	10	-4
117	14	17
120	-3	-1

Table 3. LS residuals of the exterior orientation for image I1 for S2.

point	ex (mm/1000)	ey (mm/1000)
103	7	-4
104	-2	4
105	2	-4
106	-15	-4
108	8	8

Table 4. LS residuals of the exterior orientation for image I2 for S2.

point	ex (mm/1000)	ey (mm/1000)
103	-6	2
104	7	-1
105	-8	2
106	-1	-3
108	8	1

Table 5. LS residuals of the similarity transformation.

point	ex (mm)	ey (mm)	ez (mm)
103	62	24	1
104	-92	-10	24
105	-82	14	9
106	82	-42	-8
108	3	14	-26
O1	-164	121	34
O2	353	65	-3

The LS residuals of the similarity transformation must be analysed by taking into account that the coordinates of the camera stations were computed in the exterior orientation phase and they are generally more noisier than the tie points. The mean 3D LS residual (considering both tie points and coordinates of the camera stations) is 127 mm. The precision of the registration is represented by the tie point residuals. The mean 3D LS residual (considering only tie points) is 69 mm.

5. CONCLUSIONS

In this paper a project is presented about a research that is going to be started. The system that we have planned to study requires that laser scans and digital images of an object are taken. Once images and point clouds are co-registered in the same reference system, the vectorization of the object would be performed only on the digital images, using one image at a time. For any pixel present in the image, the system would provide the correspondent architectonic element by extracting it from laser data.
A very simple example has been described on the co-registration of digital images and point clouds. The results obtained point out that precision can be improved, by modelling systematic effects (like residual radial distorsion), by increasing the number of corresponding points and by using tie lines in addition to tie points.

REFERENCES

Alshawabkeh, Y., Haala, N., 2002. Integration of digital photogrammetry and laser scanning for heritage documentation. Proceedings of the CIPA WG 6 International Workshop on Scanning for Cultural hHeritage Recording, September,1-2,2002, Corfu, Greece.

Dequal, S., 2003. Un concetto innovativo: l'immagine solida. Bollettino SIFET 1, 2003, pp 67-75.

Gruen A., Akca D., 2004. Least Squares 3D surface matching. Proceedings of the ISPRS working group V/1 Panoramic Photogrammetry Workshop, Dresden, Germany 19-22 February 2004. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXIV, part 5/W16.

Guidi, G., Beraldin, J., A., Ciofi, S., Atzeni, C., 2003. Fusion of range camera and photogrammetry: a systematic procedure for improving 3-d models metric accuracy. IEEE transactions on suystems, man and cybernetics, vol 33, n 4 ,august 2003, pp 667-676.

Haala, N., Reulke, R., Thies, M. & Aschoff, T., 2004. Combination of Terrestrial Laser Scanning with High Resolution Panoramic Images for Investigations in Forest Applications and Tree Species. Panoramic Photogrammetry Workshop, IAPRS Vol. 34, Part 5/W16, 6 pages.

Habib, A., Ghanma, M., Tait, M., Fox, R., 2002. Using ground based laser scanners to establish the orientation of terrestrial imagery. Proceedings of the CIPA WG 6 International Workshop on Scanning for Cultural hHeritage Recording, September,1-2,2002, Corfu, Greece

Mikhail, E. M., S. Bethel, J., McGlone, J. C., 2001. Introdu ction to modern photogrammetry. John Wiley & Sons, Inc.

ACKNOWLEDGEMENTS

This research was part of the National Project “La carta del rischio del patrimonio culturale: rilievo, georeferenziazione, monitoraggio e modellazione multiscala” co-financed by MIUR for 2004.