LASER SCANNER AND PHOTOGRAMMETRY FOR THE SURVEY OF THE MONUMENTAL CEMETERY IN PIAZZA DEL DUOMO, PISA (ITALY)

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ABSTRACT:

The present paper describes both a high-resolution survey of the facade of the Monumental Cemetery in Piazza del Duomo (Pisa, Italy) was realised. It's performed via the Riegl LMS Z420i laser scanner available at the Department of Civil Engineering (DCE), seat of Topography and Photogrammetry, and a photogrammetric survey of the main entrance portal of the cemetery, in order to provide documentation for restoration purposes.
Technological evolution of terrestrial laser scanning equipment has led to an ever increasing precision and performing speed of surveys. As a consequence, laser applications in architectural high-resolution surveys have become a valuable support and make up an excellent integration of traditional photogrammetric surveys.
The abilities of surveying at very small scanning steps, along with the very high precision, which can be achieved even by a single measurement, and of near-real-time rendering of the photograph of the surveyed object on the three-dimensional model, allow implementation of the obtained model even for restoration purposes, which require detailed surveys at very great scales..

1 INTRODUCTION

The present job is focused on laser scanning surveys, integrated with photographic images, for measuring and documenting purposes.
The research study is aimed at 3-D reconstruction of terrestrial scenes, such as buildings. In these cases, integrating laser scanning data with images allows for a more suitable surface reconstruction and detail identification.
Our primary goal is to seek methods to enable exploitation of metric information collected by the laser scanner in order to support further surveying techniques as well as qualitative recognition.
This paper reports on two different tests carried out on data collected during our survey of the outer wall of the Monumental Cemetery in Pisa.

1.1 Using laser data for photogrammetric control points detection and rectification

In order to join the different scans from a laser survey in a single reference system, reflecting targets are distributed within the survey area. The targets need to be scanned at high resolution in order to compute the position of its centre with accuracy, and are then surveyed via a total station, so that their coordinates are uniquely referred. These operations are rather time-consuming.
Since photogrammetric rendering and photoplan production jobs require many more targets than joining of laser scans, a preliminary test has been carried out, in order to try and reduce survey times in the field, computing target coordinates, needed for the subsequent photogrammetric rectification, by laser data, with reference to the available precision.
The results of photoplan production via classic topographical survey have been checked against those achieved via coordinate computing based on laser point clouds.
For this purpose, a great number of targets has been distributed over the survey object, for subsequent topographical survey.

1.2 Using external images

Low-resolution cameras used in conjunction with laser scanners yield poor geometrical information and final model texture. Using an external camera capable of greater format allows for a better image, and subsequently point cloud, resolution.

2 SURVEY DESIGN

A high-resolution survey of the façade of the Monumental Cemetery in Piazza del Duomo (Pisa, Italy) has been carried out (courtesy of the Opera Primaziale Pisana) via a Riegl LMS Z420i laser scanner integrated with a Nikon D70 digital photogrammetric camera, rigidly fitted to the laser structure.
The use of a partially integrated camera eases point cloud colouring and improves texturing of the triangulated model.
The ability to achieve a metrically correct, 'real-world' looking 3-D model has led to check the usability of the final product as very great scale rendering, for restoration documenting purposes.
In order to perform the survey, a 7-vertices closed traverse has been set up for framing and local control and measured via a reflectorless Sokkia SET1030R total station. Some points have also been measured via GPS in RTK mode, so to frame the survey in the global WGS84 and national Gauss-Boaga reference systems.
Flat targets, distributed over the whole scanned area for both photogrammetric and laser surveys, have been referred to the support traverse. The scans needed to cover up the whole façade have been joined relative to these targets.
Besides, a photogrammetric survey of the main entrance portal of the Cemetery has been designed and performed.

2.1 Laser survey

The façade object of the survey has a width of about 127m and a height of about 10m (12m including the roof cover). On the basis of the laser scanner parameters, the design of the scan scheme has arranged for a distance of up to 20m between scanner and façade and a 60° horizontal span, in order to achieve laser point dimension and linear resolution on the building in the 5mm range.

Ten scans have been planned for full covering of the Cemetery façade (Figure 1) and 78 flat, circular (5cm Ø) reflecting targets have been distributed over the survey area, so to achieve an uniform distribution and a higher density in overlapping areas between contiguous scans. Besides, 20 photogrammetric reflecting targets have been placed, along with the circular ones, on the wall below the shrine and on the contiguous blind arches on both sides. Circular targets have been used for joining and georeferencing of laser scans, while photogrammetric targets have served as support points for the photogrammetric survey performed via a Rollei 6008 camera.

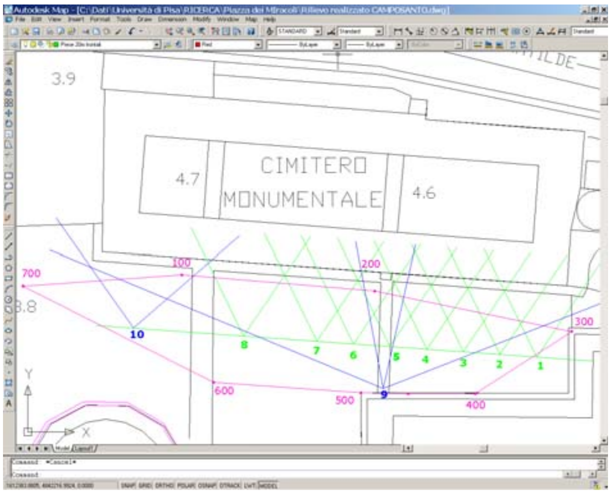

Figure 1 – Traverse, scan positions and targets.

Scan alignment has been checked according to two different modes. In mode 1, scans have been joined, via shared targets, in the scanner's own reference system relative to the first scan (project reference system) and subsequently rototranslated in the topographical system, whereas in mode 2, scans are aligned in the topographical reference system right away.

Both modes yield similar results as to precision (std~5mm). Therefore, if the topographical survey of the targets is performed rigorously, and the coordinates' precision in the laser reference system is good and uniform for each target, higher target densities in overlapping areas would seem unnecessary, since scans can be aligned directly via topographical survey (Figure2).

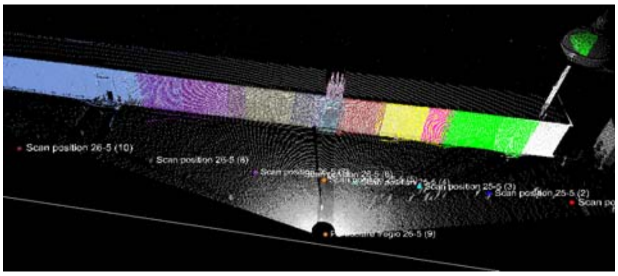

Figure 2 –3-D view of topographically joined and aligned point clouds.

2.2 Photogrammetric survey

Photographic images of the building have been achieved via two different cameras: the Nikon D70s and the Rollei 6008.

2.2.1 Nikon D70s Camera

In order to achieve full covering of the Cemetery wall with the Nikon D70s camera fitted on the laser scanner, the instruments have been placed at a distance of about 20m.

Here are the dimensional characteristics of its sensor:

CCD sensor dimensions:	23.70 x 15.60mm
Maximum resolution:	3008 x 2000pixels
Pixel dimension:	0.0078mm
Total resolution:	6.24Mpixel
Working resolution:	6.1Mpixel

At 20m, a pixel represents at best about 8mm of the object

$$\frac{f}{D}=\frac{1}{L} \rightarrow L = 1\frac{D}{f} = 7.8mm \qquad (1)$$

2.2.2 Rollei 6008 Camera

The semi-metric Rollei 6008 camera, whose sensor dimension is 60x60mm2, has been used to take photogrammetric shots of the main entrance portal.

Due to the façade dimensions and the inability to take photographs at different heights, the photogrammetric project has been processed in order to render at scales better than 1:50.

Full covering of the wall from ground level, with a f=80mm objective lens, has required a shooting distance of 16m and a tilt of about 15°, resulting in a mean frame scale of about 1:200.

Colour images have been shot from 3 stations, with a relative spacing of about 3m, so that the central shot was roughly centred with the main entrance portal.

The developed film has been scanned at 1200dpi resolution (pixel size=21mm), so that each pixel would equal a 4mm object (that is about ½ of the Nikon's).

3 EXPERIMENTAL RESULTS - TEST 1

3.1 Target coordinates from laser data

The design of the present survey, as described, shows that linear resolution of the laser scanner at 20m is more than enough to achieve the desired detail level. From the same distance, however, the integrated Nikon D70s camera is not able to achieve an adequate resolution with the f=20mm objective lens. It has therefore proved necessary to achieve additional images from shorter distances with another camera, with appropriate format and lenses, for those parts for which a higher detail level was sought. Using this additional camera has two consequences: the area pictured in a single frame is smaller, and since the camera is not fitted on the laser scanner structure, the external orientation parameters must be computed for each frame, which in turn requires an adequate number of targets for each shot.

Since both laser scans and photogrammetric takes have been performed on the same building, it has been checked whether, distributing on the surveyed area a high number of targets for both methods, and surveying topographically just those needed for laser scan registration, it is possible to compute the topographical coordinates of the remaining targets via automatic detection of reflectors from the scans, given that their resolution is adequate to the size of the sought target, with the precision needed to produce photoplans (1:50 in our case).

Usually, fine scanning a flat, 5cm Ø target from 20m detects it as composed by about 1200 pixels. Target detection from a scan with a resolution of 0.013 deg, such as the present case, yields much less pixels (about 100). Nevertheless, variations between topographical coordinates measured via total station and those automatically computed from a point cloud range few millimetres.

SCANPOSITION (2)											
Name	**X[m]**	**Y[m]**	**Z[m]**	**Pixels**	**Range[m]**	**theta[deg]**	**phi[deg]**		**d_X**	**d_Y**	**d_H**
post_1001	-67.928	-67.204	0.472	53	19.042	95.138	150.005		0.007	0.007	-0.003
post_1002	-67.94	-67.721	2.126	89	19.516	90.188	149.76		0.001	0.000	0.000
post_1003	-67.149	-67.03	3.288	90	19.059	86.69	152.517		0.000	0.002	-0.002
post_1004	-66.326	-66.122	3.477	100	18.405	85.963	155.663		0.000	0.001	0.000
post_1005	-66.805	-66.698	1.628	80	18.75	91.705	153.711		0.004	-0.002	-0.005
...	...	...	...	...	...	...	...		...	...	...

Table 2 – Target coordinates in topographical system computed by laser scans and differences with those measured via total station.

Table 2 shows a sample of the variations between coordinates of some targets derived from topographical survey, and those of targets post_xxxx, obtained straight from laser point cloud.

3.2 Rectification

Coordinates of the photographic support points used to rectify the images taken by the Rollei 6008 camera have been both obtained by the topographical survey and automatically computed by laser scans. Photoplans obtained in either way were comparable in terms of reliability (Figure 3).

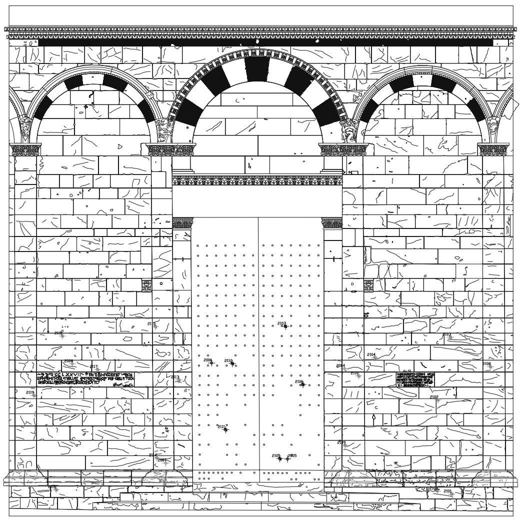

Figure 3 – Photoplan of the main portal.

It has been observed, by superimposition on the rectified images of the points representing the targets as projected on the mean rectifying plan, that in the worst cases, points whose coordinates had been computed via the point cloud had been shifted of about 1cm in comparison with those measured via total station (Figure 4).

Figure 4 – Laser-computed and topographical targets on rectified image.

4 EXPERIMENTAL RESULTS – TEST 2

Resolution of images taken by the Nikon D70s laser-mounted camera has proved to be quite adequate for an overview of the model, but definitely poor for detail analysis and rendering.
Since the RiSCAN PRO software can handle images acquired both when the camera was firmly mounted on the scanner and when the camera was not mounted on the scanner, images acquired by the Rollei 6008 camera (with greater format and frame scale) have been tested for use in laser surveys.
The RiSCAN PRO software provides a procedure for the orientation of external images on the point cloud.

4.1 Orientation of images taken by the Rollei 6008 camera

RiscanPro uses a camera model similar to the one used in the "Open Source Computer Vision Library" maintained by Intel (RiscanPro user’s manual. Riegl Inc., 2004).
The calibration model is described in RiscanPro user’s Manual as follows.
The calibration parameters defining the camera model (intrinsic and internal parameters) are stored within RiSCAN PRO in a tree node called CamCalib_OpenCV01 by default. A complete camera model usually includes also external calibrations parameters defining the orientation and position of the camera in 3D space. This information is held in RiSCAN PRO in the mounting calibration matrix, the COP (Camera Orientation and Position) matrix associated with each image at a scan position and the SOP (Sensor's Orientation and Position) information of the scan position.
The camera model is based on a camera coordinate system.

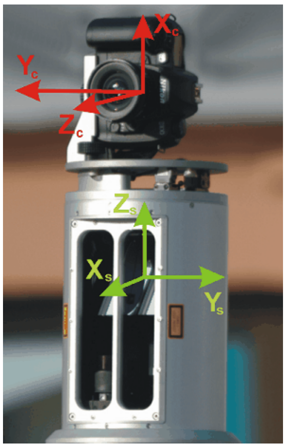

Figure 5 – Laser and camera coordinate system

The image below shows the Nikon camera mounted on top of a LMS-Z420i with the axes of the SOCS (Scanner's Own Coordinate System) and CMCS (Camera Coordinate System). The origin of the CMCS is the centre of an equivalent pinhole camera. CMCS is a right-handed system with the x axis pointing from left to right in the image and the y axis from top to bottom. The z axis is identical to the centre of the field of view of the camera.
The camera model is described by 4 intrinsic parameters and 8 internal calibration parameters.
Intrinsic parameters reflect basic parameters of the camera chip (CCD chip).
N_x and N_y are the number of pixels in the x and y direction, respectively.
The parameters d_x and d_y are the dimensions of a single pixel of the CCD sensor.

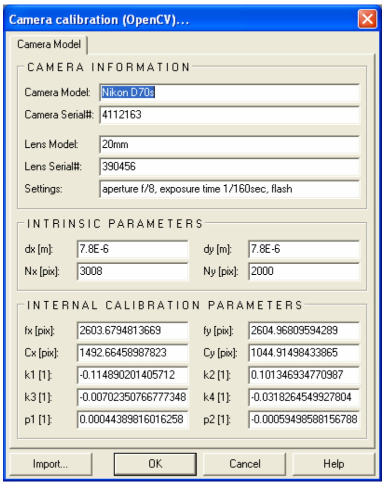

Figure 6 – Nikon D70s RiscanPro camera calibration

Internal calibration parameters can be divided into parameters describing an ideal camera, i.e., a so-called pinhole camera.
This is the focal length f and the centre of projection (the orthogonal projection of the pin-hole onto the chip surface).
Two potentially different focal lengths (f_x and f_y) are used to account for the potentially different pixel size in x and y direction and to account for different focal length's of the lens (cylindrical lens error).
The parameters f_x and f_y are normalized by the pixel size (d_x, d_y):

$$f_x = \frac{f}{d_x} \qquad f_y = \frac{f}{d_y} \tag{2}$$

The centre of the image is (C_x, C_y) in pixels.
Lens distortion is modelled by radial and tangential coefficients (k_i, and p_i, respectively).

These parameters must then be achieved for the Rollei 6008 camera with f=80mm objective lens.

4.1.1 Rollei image intrinsic parameters.

Films have been scanned at 1200 dpi, so that the effective X and Y dimension of pixel is:
$d_x = d_y = 2.1167E\text{-}5$(m)
Image dimension:
number of pixels x direction (image width): $N_x = 2578$
number of pixels y direction (image height): $N_y = 2611$

4.1.2 Rollei internal calibration parameters.

According to the calibration certificate, the internal calibration parameters are:

C_K= -80.30mm
X_h =0.05 mm
Y_h = 0.18 mm

These are the same parameters in pixels:
- the focal lengths by the axes x and y :

$$f_x = f_y = \frac{C_K}{d_x} = 3808.077864\text{pixels} \tag{3}$$

- coordinates of the principal point (x_{pp}, y_{pp}) relative to the centre of the frame:

$$x_{pp} = \frac{X_h}{d_x} = 2.362168\text{pixels} \qquad y_{pp} = \frac{Y_h}{d_y} = 8.503803\text{pixels} \tag{4}$$

Pixel coordinates of the frame centre:
frame centre x (x_0)=1290.20pixels
frame centre y (y_0)=1305.97pixels
Hence the coordinates of the principal point in pixels (C_x, C_y):

C_x=1292.562168pixel
C_y=1297.466197pixel

Radial Symmetric distortion

The calibration certificate of the Rollei 6008 camera provides the distortion curve of the objective lens in the balanced (or calibrated) form:

$$\Delta r_b = a_1 r(r^2 - r_0^2) + a_2 r(r^4 - r_0^4) = r(-a_1 r_0^2 - a_2 r_0^4) + a_1 r^3 + a_2 r^5 \quad (5)$$

which expects the distortion be zero at a particular distance r_0 from the principal point, so to minimize absolute values of minimum and maximum distortion, and to which the principal balanced (or calibrated) distance c_b is associated.
According to the calibration certificate, the values of polynomial coefficients and distance r_0 are:
a_1= -0.000009676
a_2= 4.956E-10
r_o (mm)= 20

RiSCAN Pro uses Intel's "OpenCV camera model", which expresses lens distortion according to the Gauss model:

$$\Delta r_g = K_1 r^3 + K_2 r^5 + \ldots \quad (6)$$

to which the principal distance c_g is associated.
This lens distortion is modelled by at least two radial and two tangential coefficients, k_1, k_2, k_3, k_4, p_1, p_2.
In case k3 and k4 are both 0, the camera model is identical to the one described in OpenCV.

These distortion rendering models have been related to each other remembering that:

$$tg\alpha = \frac{(r - \Delta r_o)}{c_b} = \frac{(r - \Delta r_g)}{c_g}$$
$$\frac{\left[r - r(-a_1 r_0^2 - a_2 r_0^4) - a_1 r^3 - a_2 r^5\right]}{c_b} = \frac{\left[r - (K_1 r^3 + K_2 r^5)\right]}{c_g} \quad (7)$$

where c_g is the principal distance obtained for the gaussian model and c_b that obtained with the balanced model.
Developing the above relation, we have:

$$\frac{r - (K_1 r^3 + K_2 r^5)}{c_g} = \frac{r - a_1 r^3}{1 - (-a_1 r_0^2 - a_2 r_0^4)} - \frac{-a_2 r^5}{1 - (-a_1 r_0^2 - a_2 r_0^4)} \frac{1 - (-a_1 r_0^2 - a_2 r_0^4)}{c_b} \quad (8)$$

Making the coefficients equal, gaussian model values can be derived from those of the balanced model and vice versa:

$$K_1 = \frac{a_1}{1 - (-a_1 r_0^2 - a_2 r_0^4)}$$
$$K_2 = \frac{a_2}{1 - (-a_1 r_0^2 - a_2 r_0^4)} \quad (9)$$
$$c_g = \frac{c_b}{1 - (-a_1 r_0^2 - a_2 r_0^4)}$$

In this case:

K_1= -9.71282E-06
K_2= 4.97486E-10

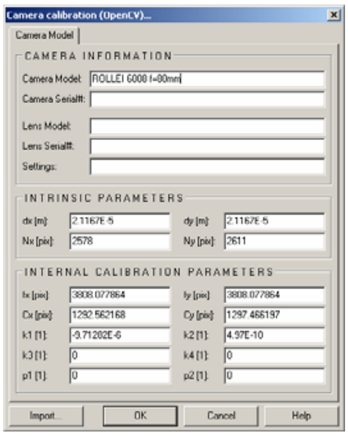

Figure 7 – Rollei RiscanPro camera calibration

Once the camera calibration have been defined, it is possible to perform the external image orientation, using points both detectable on the image and with known coordinates in the model reference system.
Image orientation on laser scans using target coordinates measured via topographic survey has yielded good results (std=0.83pix) (Figure 8).

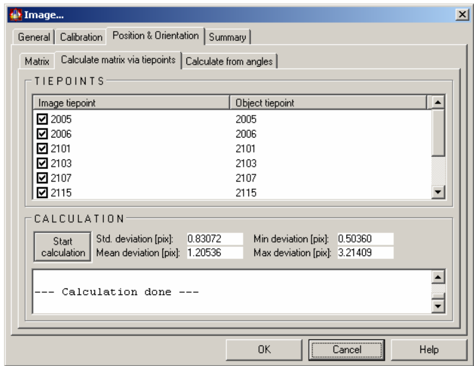

Figure 8 – Rollei Orientation results

External orientation has been repeated using target coordinates computed from the laser point cloud (std=1.40pix; Figure 9).

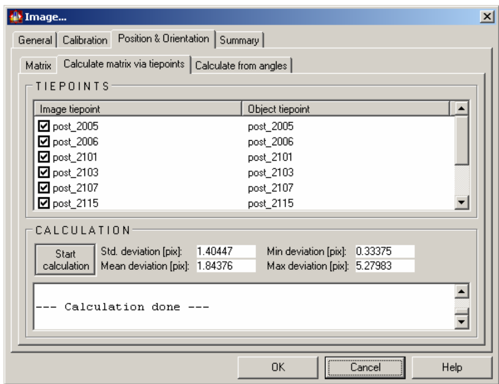

Figure 9 – Rollei Orientation results

The comparison between the point cloud texture obtained with the Nikon and the Rollei cameras shows that the latter's definition is better matched with the laser scan resolution. Figures 10 and 11 show two examples of point cloud texturing on a finely sculpted label and a capital, respectively.

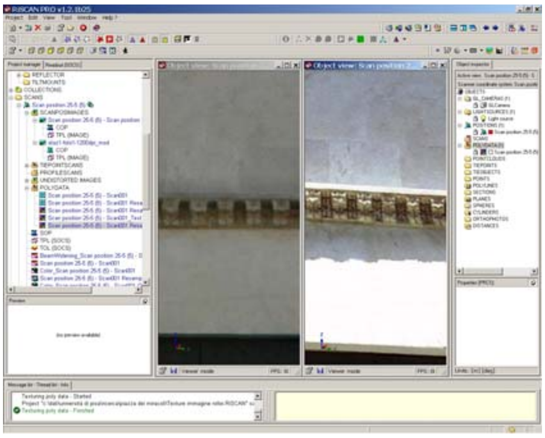

Figure 10 – Texture with Nikon (left) and Rollei image (right)

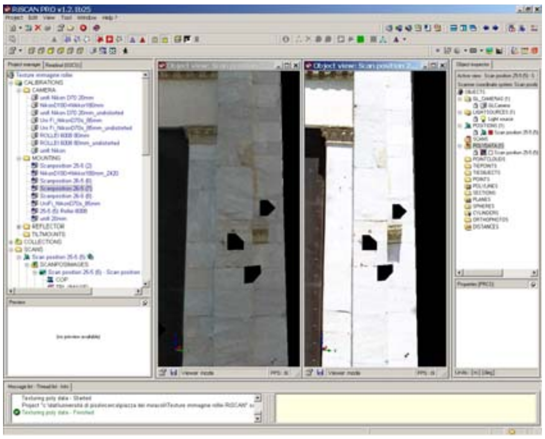

Figure 11 – Texture with Nikon (left) and Rollei image (right)

This is also pointed out by mesh textures, as can be seen in Figure 12, which shows an example of mesh texturing on a finely worked label. The definition is definitely greater and allows for detail detection even beyond the laser scan capabilities.

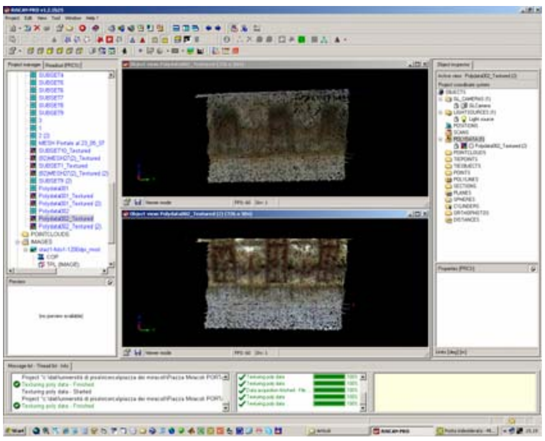

Figure 12 – Texture with Nikon (up) and Rollei image (down)

5 CONCLUSIONS

The present job is aimed to the research of methods which allow for the exploitation of metric information acquired by laser scanners to support yet other surveying techniques as well as qualitative detection and restoration documenting.
The performed tests point out the following:
If laser scans are performed at high density, the good results obtained in our tests could enable the use of target coordinates as computed by laser scans for the production of photoplans.
While studying the 3-D model, use of images with greater format, resolution and scale, once they've been orientated on the point cloud, allows for the detection of details of great interest in restoration, otherwise hardly, if ever, detectable. Anyway, it must be remembered that the detail level which can be rendered must be compared with the laser scanner's intrinsic precision.

6 REFERENCES

RiscanPro user's manual. Riegl Inc., 2004. http://www.riegl.com

Wiggenhagen M., (2002) Calibration of digital consumer cameras for photogrammetric applications, IntArchPhRS, Com. III, Graz, Vol. XXXIV Part 3b, pp 301-304

Brown, D.C., (1971): Close-Range Camera Calibration, Photogrammetric Engineering, Vol. 37, No. 8, pp. 855-866.

Guarnieri, A., Remondino, F., Vettore, A., 2004: Photogrammetry and Ground-based Laser Scanning: Assessment of Metric Accuracy of the 3D Model of Pozzoveggiani Church FIG Working Week 2004. TS on "Positioning and Measurement Technologies and Practices II - Laser Scanning and Photogrammetry"

Bitelli G, Girelli VA, Tini MA, Vittuari L, Zanutta A, Laser a scansione terrestre e fotogrammetria digitale nel rilevamento dei Beni Culturali: esempi dalla Piazza di S. Stefano in Bologna. ASITA, 2003.

G. Caroti, S. Orlandini, A. Piemonte, Rilievi laser scanner e fotogrammetrici del Camposanto Monumentale di Piazza del Duomo, Pisa, 10a Conferenza Nazionale ASITA, vol. 1, pp. 557-562, Bolzano 2006

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