A 3D VIRTUAL MODEL OF THE GORIZIA DOWNTOWN (ITALY) BY MATCHING AERIAL AND TERRESTRIAL SURVEYING TECHNIQUES

D. Visintini[a], B. Fico[a], F. Crosilla[a], F. Guerra[b]
[a] Dipartimento di Georisorse e Territorio, Università di Udine, via Cotonificio 114, I-33100 Udine, ITALY - interreg.cart@uniud.it
[b] Laboratorio di fotogrammetria, CIRCE, Università IUAV di Venezia, S.Croce 1624, I-30135 Venice, ITALY - guerra2@iuav.it

KEY WORDS: Laser scanner, True orthophoto, 3D, City, Virtual reality

ABSTRACT

This paper deals with the various aspects of the Gorizia downtown (Italy) 3D virtual model production obtained by a suitable integration of laser and imaging data, both acquired either by means of a helicopter and a terrestrial surveying.
An aerial high-density (15 points/m^2) laser surveying was achieved with an Optech ALTM 3033 system for an area of almost one square kilometre. High-resolution Rollei DB44 digital images were also acquired for the same area. The filtering, classification and 3D building modelling have been successfully carried out by the well-known TerraScan software (Terrasolid); moreover, the high-resolution true orthophoto (0,2 m/pixel) has been accomplished by means of TerraPhoto (Terrasolid).
To fulfil a photo-realistic 3D city model, the aerial orthophoto has been mapped onto the DTM and the building roofs. Nevertheless, to truthfully represent also the building façades of some streets and squares, even a terrestrial survey was carried out. Laser scanning was done by Riegl LMS Z360i system, and a simultaneous acquisition of digital images by "on system" Nikon D100 was carried out. Thanks to reflecting targets set on the facades, topographically measured and automatically detected, the different terrestrial models have been registered and geo-referenced in the same datum (Gauss-Boaga Italian cartographic frame) of the aerial laser surveying.
Finally, the paper shows the aerial and terrestrial orthophotos wrapped on the different surfaces and the extremely faithful 3D visualization of the city so reached. This permits fine virtual navigation also for terrestrial trajectories and not only for aerial ones to enjoy in VRML interactive environment or in AVI movies for tours above and around the streets of Gorizia.

1. INTRODUCTION

Nowadays 3D city models are the most outstanding and noteworthy way to investigate and represent urban areas, e.g. to establish an architectural project in its surroundings, to well deals with town-planning matters, to perform simulations for environmental impact analyses, and so on.
At the same time, the aerial laser scanning surveying seems to be the best technique for such aim, preferable to the photogrammetric one, not for accuracy reason, but for its higher resolution and, above all, automation. If some years ago the final output of a laser survey was the digital surface bypassing the points, nowadays extremely detailed 3D vector models of the surveyed buildings can be obtained. On this emerging topic, also the First International Workshop "Next Generation 3D City Models" has been recently held in Bonn (June 2005).
Nevertheless, for a totally truthful 3D city model, also the representation of building facades is required, so involving also a terrestrial surveying. The main features of aerial and terrestrial surveying steps are discussed in the following, assuming the laser as the system measuring the object and leaving to photogrammetry the only descriptive task to wrap such objects.

2. AERIAL SURVEYING TECHNIQUES

2.1 Laser scanner

Nowadays, the airborne laser scanner represents the most advanced and outstanding technique for the field survey thanks to its excellent levels of automation, efficiency and resolution, consisting in a sample frequency up to 100.000 points/sec, a decimeter accuracy and a point density of 10-20 per square meter. The features, the capabilities and the products of the laser surveys are by now well-known and widely reported in the literature: already in 1999, a first comprehensive collection was published as a *Special Issue on "Airborne Laser Scanning"* of the ISPRS Journal of Photogrammetry and Remote Sensing (Wehr and Lohr, 1999). The novel of these last few years is the large diffusion and truly employ of this technique for urban applications. Thanks to current processing software, allowing an excellent building modelling, an ever-increasing number of 3D city models have been really worldwide accomplished.
In the following, the main surveying steps are briefly reported, together with the corresponding figures relating to our laser surveying later described in detail.

1) Airborne data acquisition
The acquisition stage is performed by means of a scanning system on board of an aircraft or a helicopter and it is characterized by some main geometrical parameters, as acquisition frequency, relative height of the flight, number of echoes, and maximum swath angle. The combination of these values defines the sampling density and strongly influences the survey productivity, the occlusions risk, and the point accuracy.

2) Data 3D geo-referencing
By exploiting the so-called "direct orientation" of the measurement sensor, this step involves a combination of 3D-rotation and 3D-translation to refer the generic scanned point with respect to a global frame (generally WGS84) via the laser-frame and the INS-frame. The position depends on the combination of six three-dimensional quantities, four of them instantaneously changing (GPS position, INS attitude, laser beam distance, laser mirror rotation): consequently, the final accuracy can be very irregular, also within the same strip, e.g. it is poorer along the sides of the strip.
In any case, at the end of this step, realisable after few hours from the flight, a huge *point cloud*, as that depicted in Figure 1, is available. The 3D-points coordinates are stored in ASCII or binary *raw* files, often of wide dimension (even 100 Mb!). This is the *output* from the black box "acquisition&geo-referencing" and furnished by few companies owners of an aerial laser system. The standard "user-surveyor" begins its job only from now on, no more for the right acquisition of measurements, but

the efficient management of the subsequent processing stages.

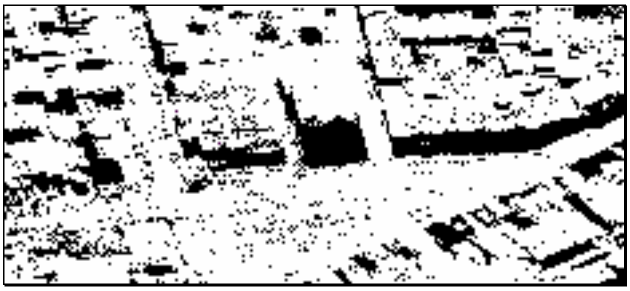

Figure 1. Example of geo-referenced laser points.

3) Laser strips adjustment

Since the geo-referencing of laser points is not over-determined, systematic errors in the data are possible: however, they can be properly minimized by making use of analytical constraints and/or by recalibrating the laser system. In this way, decimetre corrections inside the point cloud occur, especially in the areas scanned by contiguous or crossing laser strips. At the end, the 3D point coordinates assume the maximum likelihood value, e.g. coloured by elevation as in Figure 2.

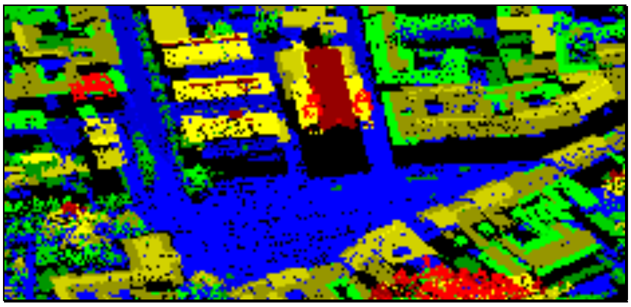

Figure 2. Previous example of laser points after the strip adjustment, coloured by elevation (from blue to red).

4) Points filtering

The main purpose of this step is the automatic detection of the points not belonging to the bare terrain, whose typical result appears as in Figure 3. From the analytical point of view, this topic concerns the estimation of the ground as a trend surface, whereas the points related to buildings, vegetation, cars and so on can be instead considered as measurements outliers or gross errors to be detected and rejected (filtered).

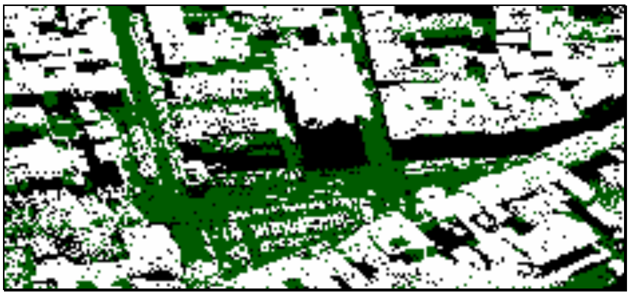

Figure 3. Filtering of the previous laser points: green = ground, white = non-ground.

Afterwards, by a grid or irregular triangulation from the ground points, the *Digital Terrain Model* (DTM) can be obtained.

5) Points classification

The points not classified as "ground" are now assigned in quasi-automatic way, following appropriate homogeneity criteria, to a user defined number of classes, whose usual result is a clustering like that shown in Figure 4. It can be accomplished by exploiting different kinds of criteria/methods taking into account not only the point position but also the value of the reflected laser signal (intensity) characterizing each point and varying for every different scanned material.

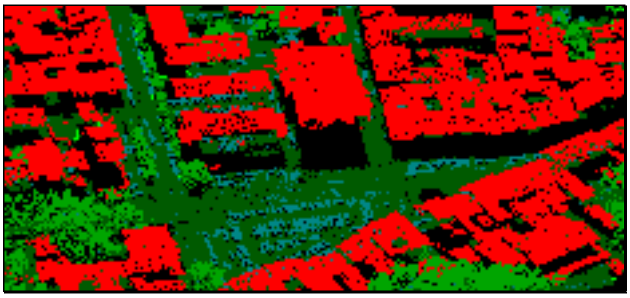

Figure 4. Classification of the previous non-ground points: red = buildings, light green = vegetation, grey-blue = cars.

Considering now points classified either as building or ground and by a grid or an irregular triangulation, the *Digital Elevation Model* (DEM) can be achieved at once.

6) 3D building modelling

Among the object-oriented modelling of the various elements of an urban environment, as e.g. trees or roads, we consider the building 3D-reconstruction only. For such kind of objects, a parametric "knowledge driven" (e.g. Brenner, 1999) or nonparametric "data driven" (e.g. Rottensteiner and Briese, 2003) approach can be followed. For the latter, starting from data classified as buildings, each roof plane is detected in automatic way, so partitioning the points in an automatically computed number of cluster/roof planes. The analytical criterion making it possible is the laser point belongings to the interpolated (unknown) roof planes, within a predefined tolerance range, also taking into account the point density.

After that, the boundary polyline is automatically detected for each roof plane, and last, these irregular lines are suitably rectified into actual roof ridges and eaves straight lines. The correct topology of the entire roof can be recovered by considering the adjacency relationships among roof planes, so estimating coherent position for each vertex; generally this phase is accomplished in an interactive way. The building height is easily computed by considering the distribution of the ground points and, finally, the polyhedral building models as those in Figure 5 can be so obtained.

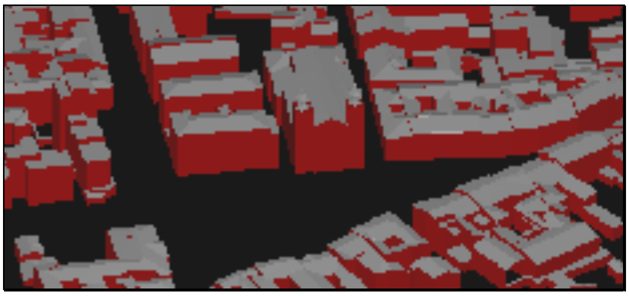

Figure 5. Building polyhedral models of the points previously classified as buildings.

2.2 Integration with photogrammetric images

From itself, an aerial laser scan furnishes extremely detailed 3D models in a quasi-automatic way, without any support coming from other surveying techniques. Nevertheless, the important descriptive and geometrical information held in any photographic image, has not been considered and exploited up to now. Really, as mentioned before, the laser surveying provides "raster" images by plotting the reflected beam

intensity as grey-scale, but unfortunately such radiometric data have quite poor content, being the laser light monochromatic.
In this context, the acquisition of high-resolution colour digital image with a metric camera during the same flight seems to be really mandatory to fully integrate a laser scanning surveying. This can be even fulfilled by installing and connecting also a non-metric camera on the helicopter, so requiring only a small increase of the costs with respect to the complete aerial system (laser scanner + GPS + INS + workstation + control unit).
Having the so acquired aerial images, the production of a digital orthophoto looks like just as the more straightforward and expected cartographic output: thanks to the laser DSM and the external orientation image parameters, directly measured by GPS/INS sensors, the orthoprojection can be carried out at once. In spite of this, to create such a photographic map is a little bit complex for urban areas, where break-lines in the DSM and hidden areas in the images arise. This requires a more sophisticated procedure in order to produce the so-called "true orthophoto" (e.g. Dequal and Lingua, 2002) overcoming the previous problems. The DSM has to be constructed starting from a large amount of points (the so called "dense DSM", DDSM): this means that high-density laser scans are welcome indeed. Instead, the lack of information in the hidden areas is avoided thanks a "multi-image" procedure, namely by exploiting all acquired image available for such areas.
An interesting use of the orthophoto is the assignment of the RGB colour of its pixels to each related laser point, so creating a nice cloud representation as that in Figure 6.

Figure 6. Laser points coloured by RGB from aerial orthophoto.

Furthermore, the orthophoto is a significant tool to assist the user during the mentioned processing steps, mainly those not fully automatic for classification and building modelling. In particular, to interactively check and adjust the shape and the topologies of complex roofs with a lot of planes, as typical for historical cities, an orthophoto as "background" is very useful.
Last but not least, the digital orthophoto is widely used for the photo-realistic texturing of the DSM and of DTM plus the building model roofs, as will be better explained in chapter 6.

3. TERRESTRIAL SURVEYING TECHNIQUES

3.1 Laser scanner

As long as laser scanning techniques are concerned, in last years also the terrestrial systems are continuously spreading their application for architectural and cultural heritage analysis: one of the firsts papers on this theme has been presented by Boehler, Heinz and Marbs (2002) at the XVIIIth International Symposium of CIPA in Potsdam.
Two different principles for point positioning are in use for terrestrial laser systems: ranging (distancemeter) lasers using the *time-of-flight* principle (as for aerial ones), and instruments using CCD cameras for which the positioning is based on the (photogrammetric!) principle of the *triangulation*. Furthermore, different commercial systems are available with a broad range of instrumental specifications: measurement range, field-of-view, measurement accuracy, data acquisition speed, robustness, compactness, and transportability. Almost all laser scanners provide, as well as the aerial systems, also information on radiometric intensity data. Some laser sensors deliver with every laser measurement also colour information by converting the ambient light in the direction of the laser beam into an RGB triple. The geometrical data and the additional vertex descriptors are synchronously and sequentially acquired and the spatial resolution of the additional data can thus not be higher.
As general consideration, we can observe as terrestrial systems have a higher diffusion on the market, similarly to what happens for aerial and close-range photogrammetry. In truth, their costs are not yet cheap and, therefore, they can mainly be purchased from universities, public institutions, and specialized centres.
Concerning the main differences of the terrestrial laser scanning with respect to the aerial one, they obviously regard the step 1) data acquisition, but also steps 2) data geo-referencing, 3) data adjustment and, of course, 6) data modelling, now relating to the architectonic elements of building façades. Furthermore, it must be stressed that, since here we bear in mind a 3D model for a whole city, a decimetric level of detail and accuracy (urban scale survey) is more than sufficient for the terrestrial scans.

<u>1) Terrestrial data acquisition</u>

The data acquisition is performed by setting the laser over a tripod in opportune fixed positions (stations), as happens for a topographic EDM total station. In spite of this, most kinds of terrestrial scanner have not neither the possibility to accurately set vertical the principal axis, nor an efficient centring mechanism: hence, the position of the instrumental centre and the principal axis direction remain undefined.
The scanning effect is achieved using one to two mirrors, which allows changes of the deflection angle in small user-defined increments. In addition for the most part of systems, the entire instrument can rotate so achieving a complete panoramic scan, as those reported in Figure 7. High-accuracy in recording the angular values is truly important, since it and laser beam accuracy settle on the precision of point isodetermined position.
In general, for the terrestrial scans thanks to the fixed acquisition, the resulting pattern of points over a façade is much more regular than the aerial flying laser scans over the terrain.

<u>2) Data 3D geo-referencing</u>

Differently from the aerial scans, this step is now really straightforward: the three point coordinates are computed in real-time and in a direct way, thanks to the measured distance laser-point and the "vertical" and "horizontal" instantaneous angles imposed to the mirrors. Such X,Y,Z positions are referred to the instrumental centre, with Z-axis only approximately vertical, that is to a completely arbitrary local origin/datum. Obviously, in the very common case of multiple scan "strips", the direct and real-time positioning referred to different (bad-defined) origins is no more exhaustive and the global geo-referencing problem comes up again, as can be seen in Figure 7, likewise for the aerial scans.

<u>3) Laser "strips" adjustment</u>

This phase is known in computer vision literature as "registration" and differs completely from the aerial case since now the rotation and translations required for each scan can assume a whatever finite value, as can be seen by comparing Figure 8 with Figure 7. This introduces serious computational problems since the iterative estimation of such six values requires approximated values sufficiently close to the (unknown) true ones. In truth, such problems can be definitely skipped if a direct estimation is performed: it needs an optimal solution algorithm as the one based on the so-called "generalized procrustes analysis" (Crosilla and Beinat, 2001).

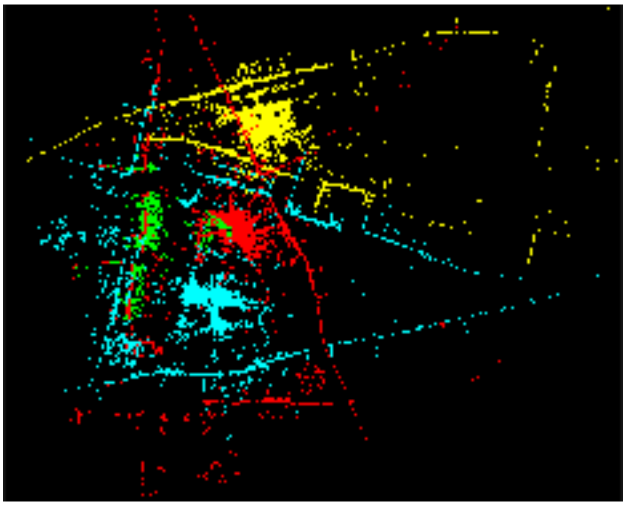

Figure 7. Planimetric view of four different terrestrial laser scans, already translated to the scanning local positions.

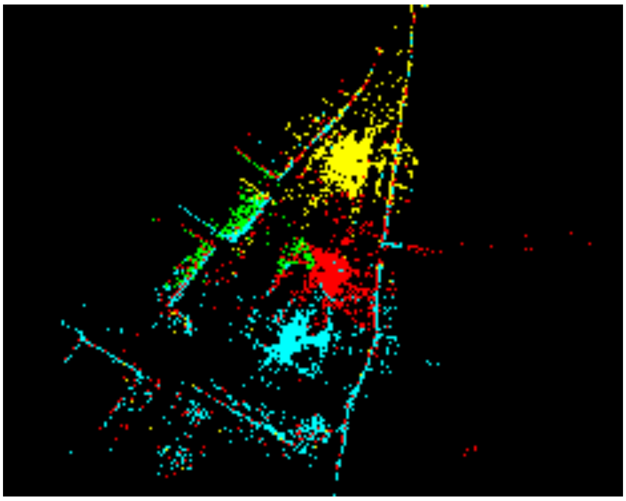

Figure 8. Planimetric view of the previous four different laser scans after a common local registration.

For sake of space, we do not treat in this paper the later steps of filtering, classification, and modelling for terrestrial laser scans, sending to Balletti *et al.* (2004) for more details about them.

3.2 Integration with photogrammetric images

As for aerial case, also for terrestrial scans, high-resolution digital cameras can be used additionally to obtain texturing data with a resolution still better than the laser data.

In principle, texturing 3D models generated from laser scan data with image data is a well-established task and many of the 3D data processing packages provide some tools for texturing the surface of a 3D model. However, using images of a camera without prior knowledge of its position and attitude requires, for example, manual definition of tie points in both the scan data and the image to estimate the image orientation parameters.

Integrating instead a high-resolution calibrated camera into a laser scanning system provides a very efficient, convenient, and powerful system for automatically generating accurately textured high-resolution 3D models. This combination forms an *hybrid sensors* (Balletti *et al.*, 2004) which is composed of a high-performance long range laser scanner with a wide field-of-view and a calibrated high-resolution digital camera firmly mounted to the scanning head of the laser scanner. For each image acquired, the position and attitude of the camera is directly measured with high accuracy in the scanner coordinate system. Scan data and image data can be combined in a straightforward way without the need of user interaction.

4. THE BUILDING MODELS OF GORIZIA

4.1 From aerial laser & imaging

The aerial laser scan over the downtown of Gorizia (North-East Italy) were accomplished in April 2004 by means of an Optech ALTM 3033 system (www.optech.on.ca). Fourteen crossed strips have covered the area with a mean sampling density of 7 points/m^2 for a total of about 20 millions of points. This strip over-covering makes it possible to avoid most part of occlusion and to obtain a high-density sampling that, in average, is equal to 15 points/m^2 in an area of more than one square kilometre. During the same flight, digital images were acquired by a Rollei DB44 calibrated camera (focal length 50 mm, image size 4.080x4.076 pixel, www.rollei.de) coupled with ALTM system.

The complete data processing (filtering, classification and building modelling) has been carried out by means of the TerraScan software (Soininen, 2003) from Terrasolid running in MicroStation (Bentley) environment. The modelling phase, allowing reconstructing 355 edifices, is here only described. By means two others software from Terrasolid as TerraModeler and TerraPhoto, the various TIN surfaces (DSM, DTM, DEM) and a high-resolution true orthophoto with pixel equivalent to only 0,2 m have been produced respectively.

<u>3D building modelling</u>

TerraScan applies a nonparametric approach for the building modelling: by means of the command "Construct building" and, starting from a previously classified dataset (Figure 9, left), homogeneous groups of points belonging within a threshold to the same roof plane are automatically obtained (Figure 9, right).

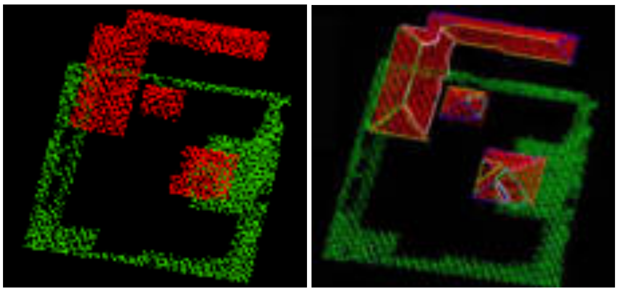

Figure 9. Modelling by TerraScan 1. Left: classified points (red = buildings, green = ground). Right: roof planes segmentation.

Afterwards, TerraScan software makes possible an interactive assisted editing to achieve a topologically correct roof model. As mentioned before, the obtained orthophoto has been very useful to correct the shape of the extracted roof planes. The commands "Delete boundary vertex" has allowed to eliminate the vertex points defining too irregular roof boundaries, while by "Modify boundary shape" the position of vertex or segments have been corrected. Successively, the command "Auto align boundaries" has automatically found the intersections between adjacent planes, which are univocally determined by the roof slope. Also the eaves lines displacement has been improved by keeping the orthophoto as background. At last, the command

"Align boundary segment" has merged in a single line the segments aligned in the reality but not (yet) in the modelling.
At the end of all these operations, the correct topological relationships have been fulfilled for the building roof and, at the same time, it more likely shape has been found (Figure 10, left).

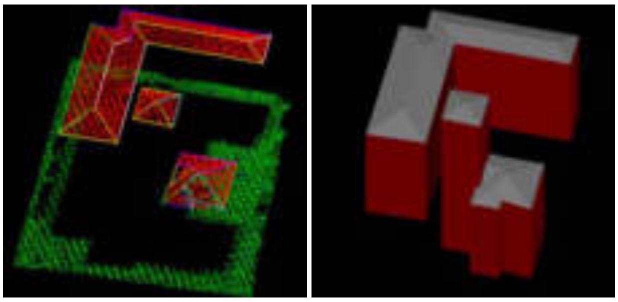

Figure 10. Modelling by TerraScan 2. Left: topologically correct roofs segmentation. Right: extruded building models.

Finally, its vertical walls are modelled: these are simply built as an "extrusion" of the roof perimeter, once the distance between the eaves lines and the walls, and the minimal height of the terrain around the building are fixed (Figure 10, right).
It must be underlined as the building modelling, although a quasi-automatic process, requires a considerable knowledge and experience to the user. In the interactive step of the assisted editing to fulfil the correct roof topology, a wrong decision can bring to a coarse or incorrect model. To this regard, a recent paper (Crosilla *et al.,* 2005) report an in-deep analysis about the likelihood and the accuracy of the Gorizia models from laser data: it states that the volumes of building models quasi-automatically derived from laser scans with 15 points/m^2 are significantly equivalent to the reality.

4.2 From terrestrial laser & imaging

The laser and photogrammetric terrestrial survey was recently done by means of the Riegl LMS Z360i scanning system (www.riegl.com) integrated with a Nikon D100 calibrated camera (focal length 28 mm, image size 3.089x2.026 pixel, www.nikonimaging.com). They form a *hybrid sensor* taking use of the respective advantages of both surveying techniques. It is a portable rugged terrestrial sensor, intended for the fast acquisition of high-quality 3D images even under difficult environmental conditions. The crucial idea behind this combination is not to regard those as competitive but complementary technologies: the most impressive result of laser scanner is the definition of surfaces, whereas the strength of imaging lies in its capability of recognizing edges. The accuracy of the details is provided from the camera high-definition (6,1 Mpixel), while the accuracy of the whole scene comes from the laser scanner (minimum angular resolution equal to 0,005°).
Such instrument was used to perform the façade scans of the main square of Gorizia (Piazza della Vittoria) reported in the previous Figure 7 & 8, where the three 360° scans are coloured in yellow, red and cyan, while in green is the 80° more detailed scan of the church of St. Ignatius. Many other scans have been performed along some important streets and in the internal courtyard of the medieval castle. Here we describe only the elaborations on scans (a total of 10 millions of points) and images (55 digital images) of the square, acquired in less than one hour at all! The laser sampling and the image resolution decrease with the distance from the façades: anyway, from each of the four stations, up to 200 points/m^2 have been acquired.

5. MATCHING TERRESTRIAL AND AERIAL SCANS

The matching among different scans is a geometrical problem strictly related to the step 3) laser strips adjustment. If we consider, as it happens in our case, aerial scans already correctly geo-referenced and adjusted in a global cartographic reference frame, the matching of terrestrial scans (separately each one or already registered) and aerial ones means a global geo-referencing of the firsts. To analytically and practically solve this problem, some points have to be known and/or observable either in aerial scans and in terrestrial ones, as for instance the vertexes of the eaves lines. In spite of this, if some points are observable on the terrestrial scans only, but their 3D coordinates are referred to the global frame (that of the aerial scans), the problem can be solved yet again. This is the way we have pursued, very simple from the operative point of view and exploiting the availability of our topographic net, whose datum is the Gauss-Boaga Italian cartographic frame (see Figure 11), established for testing likelihood and accuracy of laser surveys (Crosilla *et at.*, 2005). The DGPS fast-static measurements in 6+1 vertexes easily allowed the global reference, while mutual topographic measures with EDM total stations from/to this and other points made possible to thicken the net up to 14 vertices.

Figure 11. Topographic net: in blue vertexes measured by EDM only, in red measured also by fast-static DGPS.

From the vertices of such a net, again by EDM measurements the East,North,Height coordinates of some reflecting targets set on the building façades have been easily estimated. These global coordinates and those scanner referred, automatically detected thanks to their high-intensity reflectance, allow to geo-reference each terrestrial scan. This estimation has been fulfilled by means of the software RiSCAN PRO (www.riegl.com).
The centimetric accuracy of the so obtained terrestrial scans geo-referencing is qualitatively proof from the well agreement among aerial and terrestrial data shown in Figure 12: let note in the left particular the fine matching for the onion-shaped dome.

6. 3D VIRTUAL MODELS

By using altogether the laser and imaging aerial and terrestrial data in an integrated exchange among different software as MicroStation (Bentley), AutoCAD (Autodesk), ArcScene (ESRI), VrmlPad, Internet Space Builder and Internet Space Assembler (ParallelGraphics), an extremely realistic 3D virtual model of the Gorizia downtown has been finally reached. Below figures are rendering frames constituting an AVI movie of a virtual mid-air navigation meanwhile the 3D representation improves its contents, adding new information for each frame.

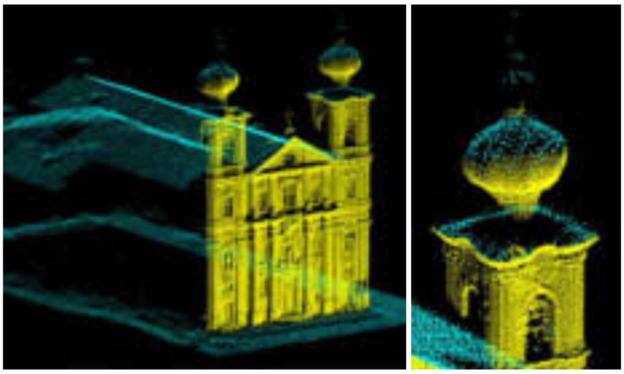

Figure 12. Matching of terrestrial (yellow) and aerial (cyan) scans: on left, particular of one onion-shaped dome.

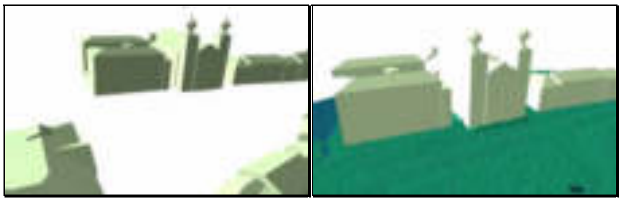

Figure 13. Left: building models. Right: plus, shaded DTM.

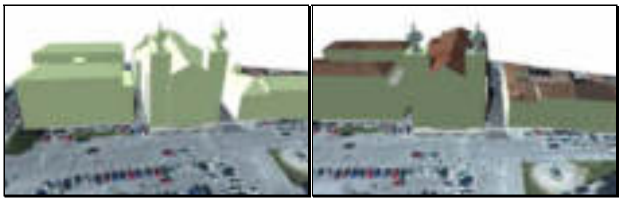

Figure 14. Left: plus, aerial orthophoto wrapped on the DTM. Right: plus, aerial orthophoto wrapped on the model roofs.

In Figure 13, a shaded DTM is added to the 3D building models, while Figure 14 shows the aerial orthophoto wrapped first on the DTM and later on the model roofs. Figures 15 and 16 show the façades enhanced thanks to the terrestrial survey: first adding the laser scans, later wrapping the orthophotos.

Figure 15: plus, terrestrial laser scans of the building façades.

7. CONCLUSIONS

Nowadays advanced integrated laser and imaging surveying techniques allow fulfilling extremely detailed and realistic 3D city models: laser furnishes the correct geometry while images supply the photographic description in form of true orthophoto. Moreover, high-density aerial laser surveying assures excellent data to create 3D building models really close to the reality. Suitably matching of terrestrial and aerial surveys permits better interactive visualization to the user, so to ulteriorly exploit the enormous level of information achieved and made available.

Figure 16: plus, terrestrial orthophotos wrapped on the façades.

REFERENCES

Balletti, C., Guerra, F., Vernier, P., Studnicka, N., Riegl, J., Orlandini, S., 2004. Practical comparative evaluation of an integrated hybrid sensor based on Photogrammetry and Laser Scanning for Architectural Representation. In: *The Int. Arch. of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Istanbul, Turkey, Vol. XXXV, Part B5, pp. 536-541.

Boehler, W., Heinz, G., Marbs, A., 2002. The potential of non-contact close range laser scanners for cultural heritage recording. In: *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Proceedings of the XVIIIth International Symposium of CIPA, Potsdam, Germany, Vol. XXXIV, Part 5/C7, pp. 430-436.

Brenner, C., 1999. Interactive modelling tools for 3D building reconstruction. *Photogrammetric Week 99*, Herbert Wichmann Verlag, Heidelberg, pp. 23-34.

Crosilla, F., Beinat, A. 2001. Generalised Procrustes Analysis for size and shape 3-D object reconstructions. *Optical 3-D Measurement Techniques V*, Copy and Druck, Wien, pp. 345-353.

Crosilla, F., Beinat, A., Visintini, D., Fico, B., Sossai, E., 2005. Likelihood and accuracy analyses of 3D building models from airborne laser data. In: *Proceedings of Italy-Canada 2005 Workshop on "3D Digital Imaging & Modeling: Application of heritage, industry, medicine & land"*, Padua, 7 pages (on CD).

Dequal, S., Lingua, A., 2002: True orthophoto for architectural surveys. In: *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Proceedings of the XVIIIth International Symposium of CIPA, Potsdam, Germany, Vol. XXXIV, Part 5/C7, pp. 269-276.

Rottensteiner, F., Briese, C., 2003. Automatic generation of building models from LIDAR data and the integration of aerial images. In: *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Dresden, Germany, Vol. XXXIV, Part 3/W13, pp. 174-180.

Soininen, A., 2003. *TerraScan*. User Guide. Terrasolid.

Wehr, A., Lohr, U., 1999. Special Issue on "Airborne Laser Scanning". *ISPRS Journal of Photogrammetry and Remote Sensing*, 54 (2-3).

ACKNOWLEDGEMENTS

This work was carried out within the research activities financially supported by the INTERREG IIIA Italy-Slovenia 2003-2006 project "Cadastral map updating and regional technical map integration for the GIS of the regional agencies by testing advanced and innovative survey techniques".