SPATIAL SURVEY OF URBAN ENVIRONMENTS

by Luigi Colombo and Barbara Marana

The paper deals some experimental benchmarks regarding urban environment modelling. The employed techniques, which automatically collected point clouds and created the DSM, are terrestrial laser scanning, with a direct GNSSRTK geo-referencing, and UAS imagery.

Fig. 3 - A perspective view of S. Pellegrino Terme inside the point model.

The technological innovation in survey techniques has nowadays led to the development of automated systems, with combined multi-functional sensors including laser scanning, GNSS receivers and imaging. These devices can perform on field metric operations, ranging from spatial modelling, geo-referencing of objects in an assigned coordinate system, fast spatial reconstructions of interiors or exteriors and roofs, with the related thematic information (*colour, materials, decay*).

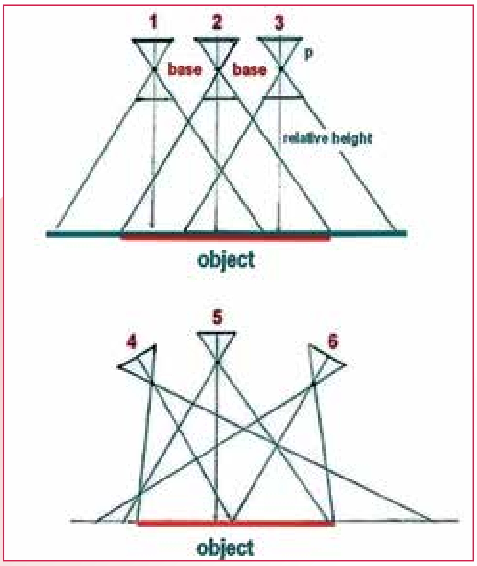

Fig. 1 - Nadir and oblique images.

The automatic sensors allow to mainly collect point clouds, from the ground, from road vehicles or small remotely piloted aircraft (*Unmanned Arial Systems*). This redundant mass of data simplifies the survey process, increasing productivity for 3D modelling and derived sub-products (*vector-raster*), such as perspective views, elevations, orthophotos, horizontal and vertical sections, thematic maps, etc.

Present technologies and techniques

Point clouds are today the first source of spatial information (also texturized with colours or reflected energy). The clouds are generated by automated survey techniques, without contact, and represent the basis for creating the so-called *Digital Surface Models.*
Terrestrial and air-transported laser scanning has been till now the main way to generate *on-line* point clouds; more recently, the research in Computer Vision has deeply transformed imaging survey, allowing the *off-line* extraction of point clouds from image blocks. One speaks in this case of *Dense Image Matching*, referring to the software procedures which guarantee this technologic enhancement.
It is known that the point cloud collection does not occur in a *deterministic* form, as manual surveys (the meaningful points, only), but in a *stochastic* way, with the surveyed points which become the nodes of a sampling grid superimposed over the objects.
The grid step depends on selected spatial resolution, measurement distance, laser beam impact (*normality, obliquity*) and morphologic surface irregularities.
The transition from the grid nodes to the interest points is then performed by applying local interpolation processes.
Much is known and has been written these years about *scanning systems* and associated

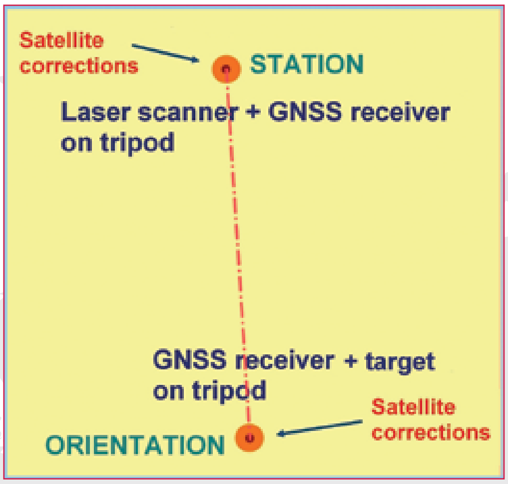

Fig. 2 - Direct geo-referencing for scanning survey.

procedures, much less, perhaps, about the bi-centennial *imaging survey*. This technique was indeed overcome at the end of the previous century by the advent and fast development of laser scanning and only recently it is coming back thanks to Computer Vision support and to remotely piloted aircrafts. However, this cannot be considered a return to the past but rather a "*back to the future*" (as written by someone), because the technological scenario has now significantly changed (processing algorithms and so on).
Laser technology nevertheless provides the relevant advantage (thanks to the measured station-point distance) that just one single ray has to be reflected from an object point for its 3D determination; on the contrary, imagery survey needs at least two homologous reflected rays (from different sensor locations) for each object point and some measured information on the point model, as well.
Additionally, if problems arise in laser scanning applications, regarding reflective, transparent and translucent surfaces (*metals, marble, paints, glass, etc.*), also for imagery approach the surveyed objects must present a meaningful geometry and thematic characters, such as non-uniform or not smooth and monochrome surfaces and few shadows.
These conditions are necessary to allow automatic recognition of homologous points among corresponding frames: the process is performed by means of *digital image correlation* algorithms, with the support of *epipolar geometry* to speed up the search.
The acquisition phase registers a block of photos, longitudinally and transversally overlapped according to the type of selected survey (2D or 3D) (fig. 1): aerial nadir or oblique images are collected through horizontal strips (*ground survey*) together with normal or oblique shootings belonging to vertical strips (*façade survey*).
The aerial carrier brings survey sensors and navigational devices (*GNSS+INS*) for recording real-time position and attitude of the photo-camera: this enables both *autonomous* flights, via pre-defined *way-points*, and a *geo-referencing* process based on GNSS-RTK or PPK techniques (the so-called *Direct Photogrammetry*).
Remotely piloted small aircrafts (*UAS*) are vertical take-off and landing carriers, with hovering functions (the so-called multi-rotorcrafts), or fixed-wing aircrafts. All systems are equipped with a stabilized platform to overcome spatial rotations produced by flight, air turbulence or wind, and can carry a payload, that is the sensors for survey.
The UASs allow lower flight-heights, compared with manned aircrafts; so, a larger image scale is collected, with the same value of camera focal length, and higher levels of detail and height accuracy.
Certainly, the lower flight height increases the forward motion effects on the image, resulting in blurring phenomena; it is possible to limit this problem both by reducing the cruise speed and well combining stops, shutter time and sensitivity (*ISO*) of the digital sensor. So, the motion blur can be kept within the pixel size of the photo and the relative object settlement inside the GSD parameter (*Ground Sampling Distance*).
Some experiences regarding multi-sensor survey for territory documentation were recently performed at the University of Bergamo by the Geomatics group: two applications of them are described below.

Fig. 4 - A 3D view of the point model for the ancient bridge.

Fig. 5 - 3D model: a bank of the Brembo river with hotels and restaurants.

The first experience: the multi-scale survey of S. Pellegrino Terme

This application regards the multi-scale survey with terrestrial laser scanning realized over the urban land of S. Pellegrino Terme, a small ancient town close to Bergamo (*northern Italy*).

Advanced laser-scanning technologies were used, with a remarkable attention to the needed level of detail and with a careful look at buildings, their decorations and history. The reconstructed model was also utilized to create a virtual *walk-through* for land investigation.

The performed survey has pointed out the original development of this settlement, designed for leisure and wellness, which was followed early by a gradual decadence that only new ideas and a renewed love for the site could overcome.

The standards for urban model construction and management (city modelling) were proposed by the Open Geospatial Consortium (*OGC*) with the CityGML: these models are typically multi-scale 3D applications, ranging from landscape simulation to urban planning, from managing calamities to safety monitoring, etc.

A modelling process requires the selection of geometric entities according to the chosen level of detail (*LoD*) and the attribution of textures for augmenting realism. This way, the survey approach for S. Pellegrino Terme documentation was established, together with the set of data to collect.

It is known that laser scanning and imaging provide a dense object-point cloud, which can be geo-referenced in an assigned coordinate system. The geo-referencing is performed either *indirectly*, through control points (pre-marked and measured on the object) and matching procedures based on natural features, or *directly* using satellite positioning and orientation devices.

Fig. 6 - Orthographic elevations of the Spa-buildings, extracted from the point model.

The localization quality is enhanced through differential positioning techniques via Internet corrections (code or phase), transmitted from a GNSS reference networks: a few centimetre accuracy (at 95% likelihood) is guaranteed, either interactively via a RTK approach or in Post-Processing (*PPK*). In the described application, the GNSS reference network (NetGeo), by Topcon Positioning, was used.

The *direct* geo-referencing, without control points and an alignment phase, is particularly convenient in applications regarding large areas (requiring several scans) when a level of detail equal or lower than LoD2-3 (likewise the scale 1:200 or smaller) is required.

Obviously, where the satellite signal is not guaranteed, due to urban obstructions, *indirect* or *mixed* geo-referencing have to be applied.

Anyway, it is useful to select some check points (*CP*), among the control points (*GCP*), to assess the final accuracy of the process.

Figure 2 shows the adopted scheme for capturing direct geo-referenced object points: a laser scanner was used (*Faro*) and two satellite receivers (*Topcon*), fitted with a bracket respectively over the scanner and on an orientation point; both the receiv-

Fig. 7 - A view of the monastic complex in Albino

ers, which operated in *static-rapid* mode, were connected via Internet to NetGeo for a fine RTK positioning in the Italian reference system (*ETRF 2000*).
The set of direct geo-referenced scanning stations also provided a pseudo GNSS network, able to act as a geodetic support.
The collected point clouds were altogether 200, with an average spatial resolution of 100 mm in the useful range (10÷350) m; the computer storage has been globally around 26 GB.
S. Pellegrino Terme, a small tourist settlement today, was very fashionable last century in the world of entrepreneurial bourgeoisie. The town is located along the narrow Brembo valley (north of the city of Bergamo): famous for the healing waters, it stands out in the local landscape with the undisputed charm of its architectures and the elegance of the urban environment.
Among the artistic treasures, it must be remembered the municipal Club-House (*1904-1906*), with two towers reminiscent of the famous one in Monte Carlo (*Principality of Monaco*), and the impressive Grand Hotel (*1904*), along the Brembo river, with the large front full of decorations.
The Grand Hotel is connected to the Club-House and the Spa buildings, located on the right bank of the river, through the bridge “Principe Umberto I”.
All these structures were realized at the beginning of the nineteenth century in the years of Belle Époque and Art Nouveau.
The terrestrial scanning survey was performed in a multi-level detail, ranging from OGC-LoD2 and OGC-LoD4, and corresponding to the scales from 1:500 to 1:100.
A Faro laser scanner (*Focus X330*) was utilized, with a built-in photo-camera; this scanner, characterized by a long range (around 350 m), is particularly effective for 3D survey of large territorial spaces because it allows a meaningful reduction of the instrumental stations needed to capture information (see figures 3, 4, 5, 6).
Good results were generally obtained, despite some deficiencies in the building-roof documentation, thanks to the favorable hilly morphology and the large range provided by the scanning device.
The roof knowledge could be better realized through an additional survey from above, using UAS techniques.

The other experience: the UAS survey of the Dehonian complex

The religious complex of Dehonian fathers, is located in Albino, a small town in the valley of Serio, the river flowing down from the mountains surrounding Bergamo.
This Apostolic school was built in 1910; during the years of World War II it became a kind of big ark hosting people evacuated from their homes and moved to Albino, which was considered safer from the bombing risk.
In 1944 a part of the complex was occupied by the Italian military, who remained there until early 1945; during the war, the little town was bombed but the Apostolic school was luckily spared.
In the following years, until 1991, the structure served as Diocesan Seminary; when this activity ceased, the complex of buildings was renovated to create a meeting point for spirituality (fig. 7), still active.
The imaging survey (using a hexa-copter) aimed to provide a spatial model of the built area, including roofs, for documentation and maintenance purposes.
The model, with a level of detail equal to 1:200 scale, was performed by:
- a nadir image coverage with horizontal (parallel) strips (fig. 8a) from heights less than 50 m, taken by a Sony photo-camera with a 14.2 MP CMOS sensor (fixed focal length of 16 mm); the image overlaps were between 80% and 60% and the carrier speed around 5 m/s.
- some up and down vertical strips over the façades, with oblique images taken at a surface distance around 10 m (fig. 8b).

It is known that an image-based survey can be performed using algorithms, techniques and software ranging from those of

Fig. 8a – The flight planning for the nadir image coverage.

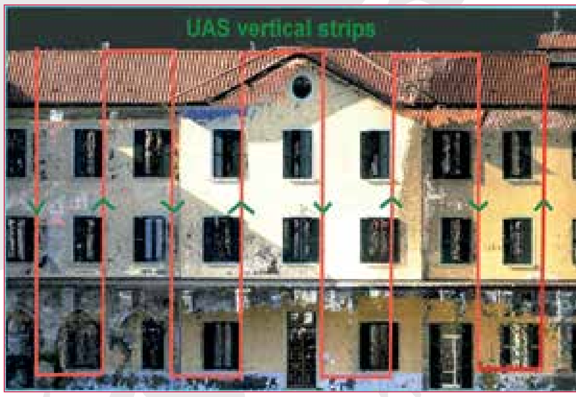

Fig. 8b – Vertical strips with oblique images.

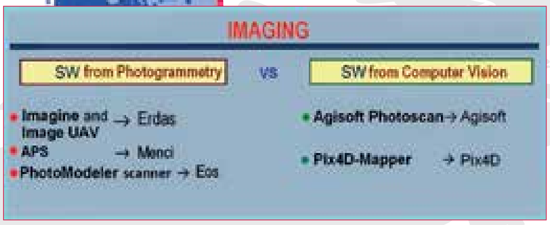

Fig. 9 - Software for imaging.

classical Photogrammetry to the modern ones of Computer Vision; some well-known packages for imaging are shown in figure 9.
The collected nadir and oblique images for the religious complex (fig. 10), around 400 photos, were used to generate a 3D model through a *dense image matching,* performed inside the Swiss-made Pix4D Mapper, a software of Computer Vision. About thirty Ground Control Points, for block adjustment and geo-referencing (*Italian Reference System - ETRF 2000*), were targeted over some selected details (on ground and roofs), measured by direct topographic methods (accuracy equal to a few centimetres) and then observed over the images. Figure 11 points out the geo-referenced orthomosaic performed from the set of photos and regarding the main cloister; figure 12 shows the correspondent 3D reconstruction through a perspective view with photo-textures.
It is interesting to observe that the imaging model has resulted a bit more smoothed in comparison with those performed through a laser scanning approach.

Final remarks

The described experiences have highlighted the great potentiality that laser scanning and UAS imagery can offer for a multi-scale analysis of urban land. This is the result of the meaningful development now achieved in the acquisition phase, the deep ease allowed by automation and the increased reliability. The software has once more had a central role for an effective point cloud management and raster-vector production. The support of GNSS-RTK technology has been useful for cloud connection (*direct* and *automatic*); besides, GNSS and INS units represents a fundamental basis for autonomous aerial navigation and positioning. Surely, the integration between laser scanning and UAS imagery will become more and more interesting, to allow a complete photo-realistic model of urban environments; anyway, some security aspects have to be still improved in relation to aircraft standards and flights.

Fig. 11 - A geo-referenced orthomosaic for the main cloister.

Fig. 10 - The set of collected nadir and horizontal images.

Fig. 12 - A 3D view regarding the reconstructed photorealistic model of the complex.

Acknowledgements

The authors wish to thank the students Lorenzo Filippini, Riccardo Begnis and Daniela Piantoni, who developed their master theses in Building Engineering, and Eng. Giorgio Ubbiali of *DMStrumenti* for the technological support in the measurement campaign.

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KEYWORDS

Land documentation; point-cloud analysis; laser scanning; UAS imagery

ABSTRACT

The paper deals some experimental benchmarks regarding urban environment modelling. The first application has been performed over the small thermal settlement of S. Pellegrino Terme, famous in northern Italy both for the healing waters and for its rich Art Noveau architectural decorations; the second test is the documentation of the religious complex of Dehonians in Albino, a little town close to Bergamo (Italy).

The employed techniques, which automatically collected point clouds and created the DSM, are terrestrial laser scanning, with a direct GNSS-RTK geo-referencing, and UAS imagery.

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