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Geomatics tools to record 3D shapes for intervention planning

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Abstract
The paper offers a state of art of Geomatics tools that it is possible to use after a natural and/or human disaster on urban centers or natural landscapes to record the 3D shape. This knowledge is important both for first aid initiatives devoted to safeguard human lives and for support decision on first technical interventions. The same data, if correctly recorded, are the basic step to plan recovering actions and reconstruction strategies.
The high automation level of the metric survey techniques open unsolved questions about the correct use of automatic tools both to acquire primary data and the appropriate management of them to give affordable and accurate metric information to the specialists.
Image based technologies (e.g. 3D photogrammetry, SFM) and range based instruments (e.g. terrestrial and aerial laser scanning systems) are analyzed in terms of best rules to acquire the necessary primary data by highlighting the most common mistakes that automation approach could generate; the same analysis is developed for the software used to manage those primary data where automation processing are in many cases not well understood.
A more skilled use of primary data acquisition instruments and management software will allow a better quality of the resulting 3D models also considering the real needs in the different phases of the emergency after disasters.

Keywords: photogrammetry, laser scanning, drones, 3D, metric survey

1. Introduction
The metric knowledge of a space is, always, the main needed information before every kind of intervention on natural and artificial assets.
The specific topic of the planned interventions strongly influence the level of detail and the accuracy of the knowledge; other important factors, which influence the adopting strategies, are the morphology and the nature of the objet itself. Of the same importance are the media that have to be produced by considering the effective technological possibilities of the users and the deadline for the production of the deliverables.
If in the usual applications of metric survey, the accuracy and the completeness of the final products are the main topics to be reached, the actions planned for emergency situations have to be more oriented, at least in a first step, to give basic information in the most rapid and effective way. The possibility to integrate time by time both the aspects of accuracy and complete 3D modeling could be considered at different times therefore all the steps must be planned and organized to avoid repetitions.
The practical impossibility to plan all the needed actions, due to the restricted times, asks for expert professionals able to work in real time by considering the requirements and the true possibilities to use one or more integrated techniques to give to the users the required instruments and to save the basic data for subsequent elaborations.
All the Geomatics technologies should be considered by giving preferences to the ones who allow rapid and possibly automatic production of the basic deliverables, such as orthophoto maps and point clouds. The selection of the technologies and of the deliverables strongly depend on the dimension of the asset of interest, and on the real needs.
Therefore, natural spaces and urban centers require different solutions then single buildings or infrastructures: the different survey's scales usually required for those different objects allow different

approaches and need different considerations of the “pros & cons” to be analyzed for a correct intervention.
In the following paragraphs an analysis of the today’s state of arts of the Geomatics techniques will be developed by giving some considerations also about the preventive actions to be planned to speed up the metric survey interventions in emergency situations.

2. Image based metric survey techniques

The image based metric survey techniques range from Photogrammetry to Structure From Motion (SFM) approaches and, in the contest analyzed in this paper, are mainly applied to the use of images which record the emitted radiations in the visible band of the spectrum.
In a simplified approach, the management of images by using Photogrammetry or SFM seems to be the same: actually, there are some details that have to be considered during both the image acquisition and the image treatment.
Photogrammetry dates from the XIX century and developed its algorithms by considering the Eulerian geometry of a perspective projection. SFM dates from the second half of the XX century and its algorithms were developed by using the projective geometry.

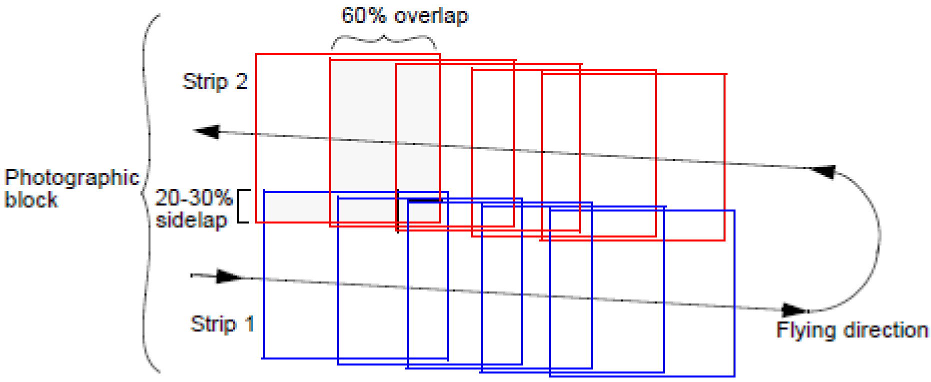

Fig.1: sample of a Photogrammetric block with standard overlaps for natural areas

The main aims of the Photogrammetry is the metric 3D survey of an object in a specific time by using at least two images taken from two different points of view, while the main goal of SFM was the control of robot movements inside an unknown space. These different goals offer different developments of the two techniques. Photogrammetry was more concentrated on the quality and completeness of the 3D survey without considering too much important the speed to obtain the results; SFM was more concentrated into obtaining solutions in the most rapid way without considering the assessment of quality due to the fact that for robot control approaches the solution is computed and arranged time by time.
The rapid development of the quality of the digital images sensors in terms of radiometric and metric resolutions, and the parallel rapid development of the matching techniques, push the two different approaches towards similar results. This similarity is only apparent because the main goals previously mentioned are always visible in the final results obtainable by using the two different approaches.
The common primary data of Photogrammetry and SFM must be acquired by considering different strategies: a good photogrammetric block just requires two different images for each point to be acquired, while most diffused software based on SFM theory usually require at least three different images to survey a single point to ensure a complete scene description.

Fig.2: Left: Planned (a) and realized flight (b) with a drone. Right: sample of an image mosaicking

Many experimental results show that the tradition of a good photogrammetric block should be used without considering the subsequent used mathematical models because the obtainable precision

strongly depends not only on the taking distance but also on the taking base (the distance between two adjacent images along a strip).
Usually, overlaps are 60% and 20% of sidelap are the best parameters to consider for a good image acquisition strategy. For urban centers or architectural objects, those overlaps must be increased up to 80% and 60% respectively: in this way, it is possible to image a point in four different images and to avoid the perspective occlusions.
For aerial flights, with a direct measurement of external orientation parameters by means of GNSS/INS systems, but also for aerial and terrestrial blocks oriented by using a regular grid of GCPs (Ground Control Points), the addition of two transversal strips will guarantee an overall better quality.
When only one strip is used a more dense network of GCPs must be provided in order to avoid unacceptable results in external orientation parameter estimation.
A special care must be taken for the images acquired by using drones or multirotor platform. In this case, actually, the platform is not as stable as necessary and some of the acquired images con have overlaps greater than the acceptable for a strong estimation of the external orientation parameters. Usually when drones are used to acquire overlapping images for a subsequent photogrammetric application the overlap parameters are fixed at higher values than the ones previously underlined; therefore a selection of the usable images has to be carry out before to start with the photogrammetric survey.

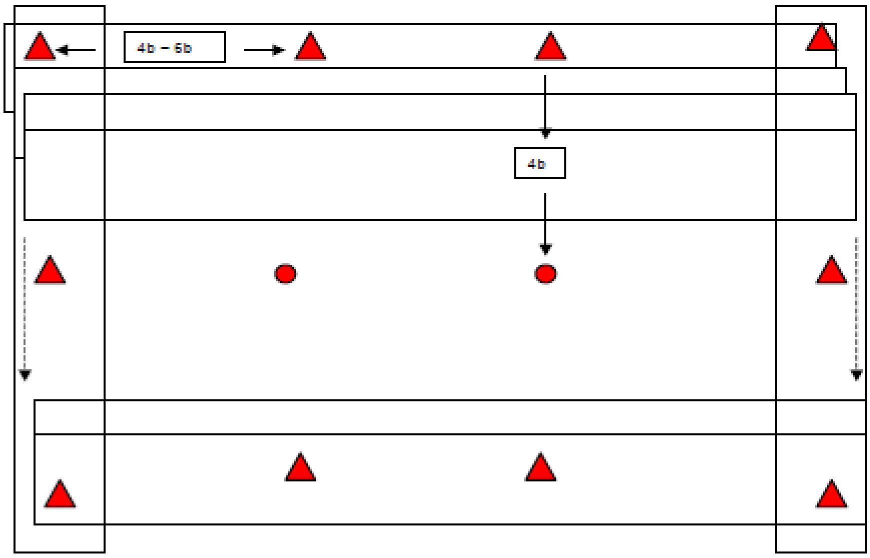

Fig.3: Strips orientation and GCPs location for standard photogrammetric blocks

By using aerial vehicles, oblique images could be acquired: the orientation of these oblique images must be carried out in a different procedure than the one used for conventional aerial images due to the different ground resolution that oblique images offer.
In every condition, it is better to use pre-calibrated cameras with a fixed focal distance and to solve blocks of images taken almost at the same distance. The use of different taken distances in the same block will cause problem especially during the matching due to the different obtained ground resolutions.
Image based techniques could be applied only when sufficient illumination conditions are satisfied.
Once all the orientation parameters are known, the matched homologous points could be estimated and dense point clouds are generated. The main advantage of the point clouds generated by means of photogrammetric algorithm is the possibility to estimate, point by point, the achieved precision. This knowledge could also be used as a filtering parameter to avoid incoherent point cloud generation.

3. Range based metric survey techniques

Range based metric survey techniques are today a common tool for quick generation of point clouds comparable, at least in terms of density, to the ones obtainable by using image based metric survey techniques.
A wide variety of instruments allow performing the acquisition in every condition: aerial, terrestrial and drone devices are now on the market and almost fully automatic software allow solving the primary data acquisition and treatment to obtain coherent point clouds of complex objects. Today almost all the LiDAR instruments are equipped by integrated or externally calibrated digital cameras to allow the coloring of the point clouds to speed up the interpretation of the 3D shapes.

The rapid evolution of cloud-to-cloud registration methodologies, based on ICP (Iterative Closest Point) algorithm, allows recovering many misalignment problems and a correct network of GCPs offers the possibility to connect in an affordable way aerial strips and terrestrial single position point clouds.
Aerial LiDAR systems acquired adjacent strips of point clouds and sidelap of about 20% usually are sufficient to guarantee a continuous and homogeneous covering; terrestrial LiDAR systems have to be used to acquire single position point clouds with a minimum overlap of about 30% in both directions. The GCPs have to be placed inside the overlapping zones to achieved the expected precision during the registration processes.

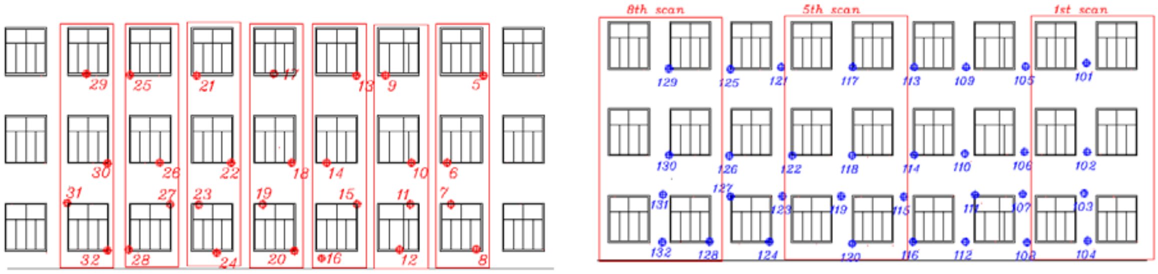

Fig. 4: GCPs (red) and CPs (blue) for a correct multi scan registration and checking

If it is true that LiDAR instruments can acquired without any limit of illumination it must be clear that only photographic images oriented in the same coordinate system where the point cloud are defined, allow a correct and quick interpretation of the shapes and the subsequent coherent 3D modeling. Therefore, also for LiDAR instruments the acquisition has to be performed when sufficient illumination conditions are realized.
LiDAR instruments can be also used as Mobile Mapping Systems and specific integrated acquisition units (LiDAR, imaging and GNSS/INS platforms) are now ready to solve the metric survey in all the possible condition.
While digital cameras are relatively cheap, Lidar based instruments are usually more expensive but just after the acquisition the points cloud are ready to be used for the modeling steps.
Last April, LEICA Geosystems launched on the marked a new terrestrial Lidar instrument, the BLK360 that represent a real innovation in terms of both costs and usability. With its 1.5 kg of weight the instruments can be easily managed also in critical situation and the speed of acquisition (almost 360.000 pt/s) allow to foresee a rapid diffusion of this typology of instruments. The full integration with two digital cameras and one thermic camera will offer a big variety of possible application of this new category of instruments.

4. Image and range based deliverables

By considering the most advanced development of the possibilities to produce affordable instruments of metric documentation based on the use of the above-mentioned technologies, it is possible to split them into two main categories by considering the time needed to produce them.
The separation into those two categories take into consideration the different needs that can follow a natural and/or artificial disaster to act on Cultural Heritage assets.
The deliverables that can be produced in a short time are usually conceived to give the basic metric information for emergency interventions while the results that require more time to be produced offer a complete description of the 3D model of the surveyed asset by using suitable forms of representation more conceived to support the planning of permanent interventions.

4.1 Fast deliverables

The integration between LiDAR and Photogrammetry open the possibility to produce in an almost automatic way basic deliverables.
The first product is the orthophoto. Orthophotos are produced by transforming the central perspective geometry of the photographic images into orthogonal projection on a given plan. The images to be used have to be defined in terms of interior and exterior orientation parameter and a 3D model of the represented objects has to be know.
The orthophoto production from aerial images could be performed just after the flight: usually interior orientation parameters of the used cameras are known in advance and the exterior orientation parameters are directly measured during the flight thanks to the GNSS/IMS platforms. LiDAR survey is executed at the same time of the image acquisition therefore after some automatic data processing (e.g. aerial block adjustment, point cloud filtering) the orthophoto production could be performed and delivered inside the adopted cartographic system. The user can therefore access the final products directly on a cloud system (e.g. WEBGIS) and extract the needed information.

As it is well known orthophoto are not interpreted cartographic products: the semantic content of a traditional map is not provided but the user can directly interpret the interesting phenomena by observing the radiometric contents and digitize them, if needed, into a vector layer or, more simply, extract basic metric information such as distances and areas.

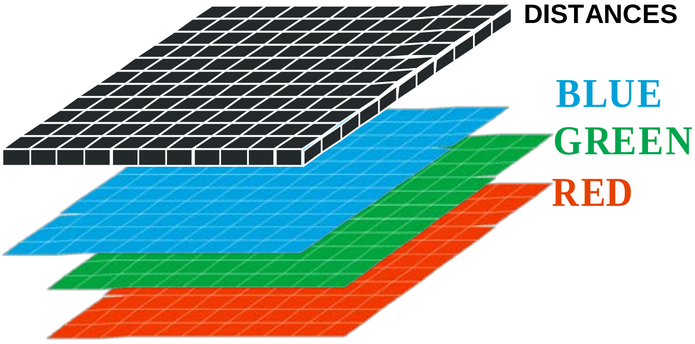

Fig. 5: The Solid Image concept

The unavoidable differences between the geometry of the orthophoto and the one of the maps could be neglected in most cases if the extension of the area of interest is limited to some kilometer squares and the nominal scale of the orthophoto could be considered as the quality of the contained metric information.
The production of orthophoto in urban centers could give unacceptable results if the traditional approach of orthophoto production is used. In those cases, a possible approach is the use of specific resampling algorithms, proposed at the beginning of the XXI century and now implemented in commercial software platforms for precise orthophoto production.
Orthophotos just offer planimetric information: in case also altimetry information are necessary, another quick deliverable is now available: the solid image.

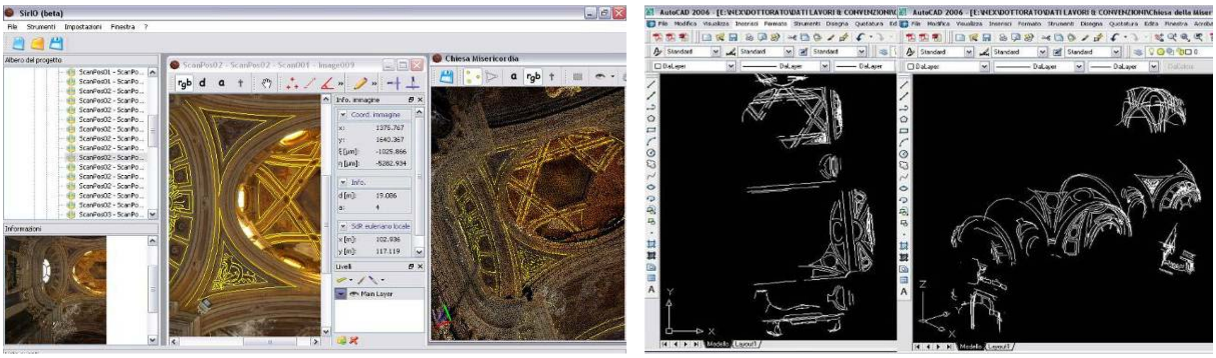

Fig.6: Solid Image used to detect breaklines for 3D modeling of a point cloud

In the solid image the point cloud generated by using LIDAR devices are virtually connected to the oriented images: the user access to the images and define on them the required metric information (e.g. a distance by clicking the two points on the image, an angle by clicking three points, an area by clicking the vertex of the polygon which define the interested area, etc.). The virtual connection between the E,N coordinates of the selected pixels and the point clouds allow to interpolate the height to obtain the numerical values of the requested geometric quantities.
One example of this approach is represented by the project URBEX of the C.G.R. Company (http://www.cgrspa.com/prodotti-e-servizi/servizi-in-cloud-urbex/) where aerial images (both vertical and oblique ones) are offered in a cloud platform allowing the previous mentioned queries. By introducing inside the URBEX platform the images and the point clouds coming out after a flight on areas affected by natural or human disasters it is possible to distribute the updated data to all the potential users through network by allowing the access to a common cartographic documentation. Obviously, the imaged and the point clouds could be updated and stored by using a chronology: in this case, a possible monitoring of the evolution of the observed phenomena is conceivable.
The same approach could be applied also for terrestrial applications and for drone-based approaches (e.g. building metric survey). In those cases some delay in the distribution of the data can occur due to the necessity to estimate the exterior orientation parameters (and in some cases the interior orientation parameters of the used cameras) of the needed images and to the registration of the acquired point clouds.

4.2 Complete deliverables

As described in the previous paragraph, the “fast deliverables” use directly the point clouds generated by LiDAR systems (both mobile and static ones) and a set if oriented images.
The “complete deliverables” consist in the modeling of the point clouds obtained from LiDAR systems or digital Photogrammetry after a segmentation process to produce 3D models and/or 2D traditional representations.
As it is well known those products require a deep knowledge of the object to be surveyed and a lot of time to elaborate in the best possible way the metric information given by the point clouds and the semantic information given by the images.

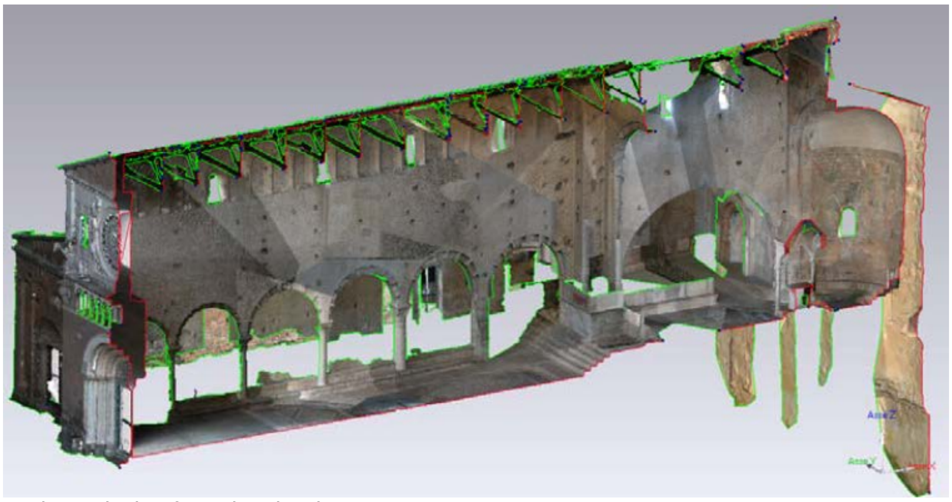

Fig. 7: Geometric analysis of a point cloud

In this case particular attention is given to the real aims of the survey also by considering the approach that will be adopted for the restoration intervention.
Sometimes those deliverables need the use also of historical survey to reconstruct lost shapes and details. Those existing surveys are integrated inside the new measurements by putting in evidence the possibility to recover old regularities.
Complete deliverables need also a check of the obtained results in order to guarantee the quality of the survey: the check is not only about the achieved accuracies but also in the completeness of the survey and in the coherence of the realized 3D model. Different strategies can be adopted to do those checks and they have to be evaluated case by case by considering the real use of the metric survey.

5. Metric survey common tasks

In any kind of metric survey, some common tasks have to be realized to guarantee the quality of the primary data acquisition and the subsequent treatments.
During the planning of the metric survey activities a control network has to be defined and, in case, realized in order to define the unique 3D coordinate system and to limit the error propagation.
For aerial and all the techniques based on the use of GNSS/IMU platforms this task do not require particular attention: all the measurements will be defined inside the reference and coordinate systems of the specific used GNSS constellation (e.g. GPS, GLONASS, GALILEO, etc.). Inside Europe, as a common agreement defined in the INSPIRE directive, the cartographic system is the UTM/WGS84 that, from 2011 is also adopted as the official cartographic system in Italy.
For terrestrial local surveys sometimes is not necessary (and sometime could be a mistake) to adopt the official cartographic system. In those cases a local 3D Cartesian coordinate system could be defined by materializing a control network with a set of point surrounding the space were the survey will be performed. This network needs to be realized in such a way that it would be possible to use it also after the survey.
When image and range based techniques are used a second order control network is needed to allow the orientation of the image blocks and the registration of the single point clouds. The vertexes of this network are the GCPs mentioned in the previous paragraphs. The number and the relative location of the points of the second order control network need an effective planning in order to be able to satisfy all the requirements in terms of precision and accuracy.
Usually those points (the so-called Ground Control Points) are surveyed by means of a total station by ensuring a precision greater than the one required for the final deliverables.
During the GCPs survey it is possible also to provide a second class of point useful for the subsequent checks of the survey. Those point are named Check Points (CPs) and must be distribute especially in

the zones where the surveyor know some problems could arise in terms of precision and coherence of the final 3D model.

6. Conclusions

The technologic development opens every day new possibilities to perform affordable metric surveys, which can satisfy the requirement in any kind of situations.
Aerial and mobile systems can provide in a short time all the necessary information for rapid interventions such as people recovering, building reinforcements and possible transportation network detection. The introduction of oblique images allows also building façade inspection in a coherent metric system useful to plan reinforcement interventions as preventive actions to allow a correct plan of future restoration actions. The only limits on the use of those solutions are the weather conditions and poor illumination situations. When those obstacles are not present, aerial and mobile systems could provide data ad any interesting level of accuracy.
Not yet implemented on commercial platform is the possibility to automatically extract the breaklines from a point cloud and a set of digital images: the first results presented some years ago put in evidence the possibility to speed up by using automatic tools and strong integration strategies between Photogrammetry and LiDAR.

Fig. 8: Automatic extraction of breaklines from point clouds and digital image integration

Terrestrial methods are more suitable for the production of detailed 3D models as basic information for restoration design and structural interventions.
To act in emergencies, to produce affordable metric survey could be helped if some preventive actions are provided.
The most important thing that can be realized in advance is the establishment and materialization of control networks useful for all kind of terrestrial surveys. Of the same importance is the acquisition of metric data (e.g. image blocks for photogrammetric applications and/or point clouds) that do not need to be elaborated in advance but can be used to provide ancillary information for reconstruction or reassessments.
One of the possible actions always recommended by international organizations such as CIPA-HD is the basic image acquisition by using the so-called 3x3 rules. Those rules were proposed many years ago as a simple but effective action to document Cultural Heritage and they are updated regularly by considering the technological advancements. The aims of these rules are to push the people to provide basic information to acquire images and basic metric information to allow a possible metric survey by means of photogrammetry of specific assets.

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