Surface modelling of complex archaelogical structures by digital close-range photogrammetry

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1 Introduction

Surveying and representation of archaeological sites and objects represents today a very interesting contest where the potentialities of the new digital technologies of Geomatics can be fruitfully expressed. The tackled problems span from the data acquisition and integration processes to the automatic or semi-automatic data handling, or to new methods for data representation and exploration. One of the most interesting questions in this sense is related to the 3D modelling of surfaces and complex archaeological structures, where different problems can of course emerge with respect to modelling of terrain or of simple artificial objects.

In archaeology, the use of 3D models for documentation and visualization purposes is generally applied in few case studies for different reasons: (i) the high “cost” of 3D; (ii) the difficulties of non-experts in achieving easily good 3D models; (iii) the consideration that 3D is mainly an additional “aesthetic” factor; (iv) the difficulty to integrate 3D worlds with other classical 2D data.
Currently we can distinguish three main approaches for the recording, documentation and visualization of cultural heritages sites and objects: (1) image-based methods (Remondino and El-Hakim, 2006) (2) range-based methods (Blais, 2004; Böhler, 2005) (3) a combination of image- and range-based methods (Beraldin et al. 2002). The requirements specified for many applications, including digital archiving or mapping, involve high geometric accuracy, photo-realism of the results and the modeling of the complete details, as well as some automation, low cost, portability and flexibility of the technique. Therefore, selecting the most appropriate 3D modeling technique to satisfy all requirements for a given application is not always an easy task.

The paper describes an experience carried out in the framework of an archaeological activity, where various geomatic techniques were applied and integrated, tying together disciplines like topographical surveying, geophysics, photogrammetry, remote sensing, etc. During the work carried out at the archaeological site of Tilmen Höyük, in Turkey, the approach was to firstly define and maintain a common shared reference system among the different surveying activities and in that realize the data acquisition phase. During the 2005 campaign some experiences were realized in close-range photogrammetry using non-metric cameras, with subsequent data modelling and representation. Aim of the paper is to show some results and discuss problems resulting from the field campaign and data processing.

2 The archaeological site of Tilmen Höyük

The Archaeological Mission of the University of Bologna in Turkey, directed by N. Marchetti, started in 2003 at the ancient town of Tilmen Höyük (Marchetti, 2004). The area of investigation (Fig. 1) is an ancient settlement located 10 km East of Islahiye town within Gaziantep province in the South Eastern Turkey and dating back to 3400 BC. The palace complex with a temple, inner and outer strong defence walls surrounding the city, bring Tilmen Höyük to an important position from an archeological point of view not only in the region, but in the whole country.

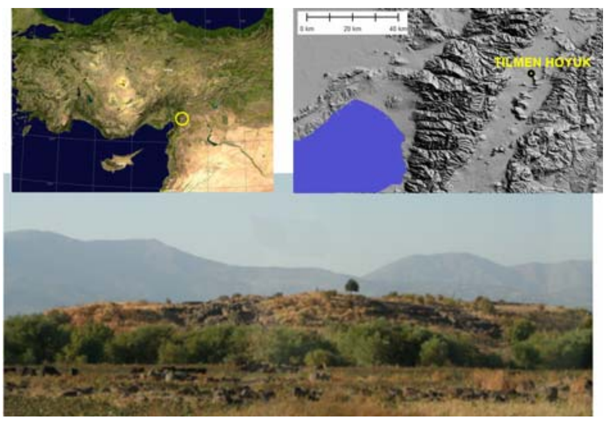

Fig. 1. Geographic location (on colour composite imagery and on SRTM surface model) and a picture of the site.

In order to produce a complete and accurate metric survey of the site, a multi-disciplinary approach was choosen, also with the aim of supporting all the research activities in the area (archaeological, geophysical, agrarian, etc…). The surveying activity involved different methodologies simultaneously applied.

The first problem adressed was the absolute georeferencing of the site, performed by GPS. Long period GPS observations were conducted using dual frequency Trimble geodetic receivers on a reference point, named ST01, signalized on the site hill. This allowed the connection of this vertex to the IGS permanent stations of Mersin and Ankara, in order to insert every other local reference point or survey into International Terrestrial Reference Frame ITRF2000 (Fig. 2). In particular, the vertexes coordinates of the polygonal were determined by fast-static GPS method and used by the archaeologists for the survey of the structures with total station and for further geophysical investigation. A kinematic survey was besides conducted to complete the description of the site surface morphology, mainly accomplished by the archaeologists by total station surveying (a local geoidal undulation value was necessary for combining the two kinds of heights). The resulting DTM is of very high detail, describing with good accuracy the natural morphology of the site.

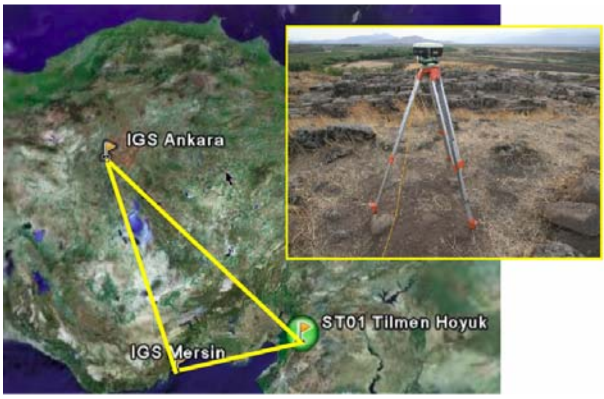

Fig. 2. The reference point and its connection to the near GPS permanent stations.

The results from this activity were also used to perform a orthorectification of high resolution satellite imagery. A panchromatic QuickBird image (DigitalGlobe Inc.) was orthorectified by adopting associated Rational Polinomial Coefficients (RPC), with ground control points and using a local Digital Terrain Model. The last was realized for the archaeological site using the data acquired during the Mission (total station and GPS) and for the outside territory using the SRTM surface model. A DTM accomplished by ASTER imagery, by means of the stereoscopic capabilities of the VNIR bands, was also considered. The projection chosen is UTM (37) - datum WGS84. A little portion of the digital orthophoto of the ancient town is shown in Fig. 3, where is evidenced the location of the terrestrial photogrammetric survey described in the next paragraphs.

Fig. 3. Panchromatic orthophoto from QuickBird imagery with location of the structures subject to the close-range photogrammetric processing.

In order to experiment the potentiality of image-based methods for the metric documentation and the 3D reconstruction of interesting objects, a close-range photogrammetric survey of some structures was also conducted during the 2005 mission. The images were acquired by means of some amateur digital cameras: Canon EOS350D (8 Mpixel) and Nikon Coolpix 5400 (5 Mpixel). The choice of using this type of cameras is often justified in archaeological contexts by the cheapness, easiness and manageability in their use, but leaves open the important problem of camera calibration, that is directly related to the realization of an accurate metric object restitution and the problem of detailed object reconstruction.
The next paragraphs report about the photogrammetric data processing and its problems.

3 Digital close-range photogrammetric modeling

The generation of textured 3D model of objects has nowadays become a very important research field not only for industry or robotic, but also for Cultural Heritage applications, for the completeness of metric and descriptive informations that a product of this type can offer to studiouses.
3D modeling of a scene should be meant as the complete process that starts with the data acquisition and ends with a virtual model in three dimensions visible interactively on a computer. The interest in 3D modeling is motivated by a wide spectrum of applications, such as animation, navigation of autonomous vehicles, object recognition, surveillance, visualization and documentation (Remondino & Zhang, 2006).
A 3D virtual model of an object, textured with a digital

photo, could be considered an evolution of the orthophoto; if the generation of the model is performed by means of photogrammetry, the data process passes through the same steps and encountered the same problems (camera calibration and image orientation) at least until the production of the object DSM.
In the last years different solutions for image-based 3D modeling have been developed. Most of the current reliable and precise approaches are based on semi-automated procedures. In fact, even if the introduction of automated algorithms is a key goal in the photogrammetric and vision communities, fully automated surface reconstruction methods seem not able to achieve a high level of metrical accuracy, a key factor in evaluating this kind of products together with the capability of reconstruct all the object details. The user interaction, in term of point measurements, image triangulation or editing, is therefore so far the most important factor to achieve a precise and reliable 3D model.

Photogrammetry is nowadays much more frequently used to generate computer 3D models, for its generally easy and cheap image data acquisition procedure as well as for the availability of a wide array of new technologies to support the generation and analysis of such models.
On the other hand, data processing is still a difficult task, in particular if the images are uncalibrated or are acquired under a non-conventional geometrical configuration, or the object is very complex, as often in case of archaeological ruins or buildings. One of the critical phases is certainly the camera calibration process (Remondino & Fraser, 2006) and the detailed surface measurement, explained in the next paragraphs.

3.1 Consumer digital cameras calibration

In order to obtain inner orientation parameters of the employed consumer digital cameras, a self-calibration approach was adopted by the bundle adjustment implemented in PhotoModeler Pro v5.0 (EOS Systems Inc.). Working with unstable non-metric cameras, it should be necessary to perform the self-calibration on the field as a part of the photogrammetric project, contemporary to data acquisition. Unfortunately this is not always possible, especially when the photogrammetric survey has to be performed in a short time, like archaeological work conditions often impose and as the typical network for camera calibration is very different from the conventional image network for scene reconstruction. Furthermore, for precise calibration procedures, targets or well signalized points are necessary as natural points are not well measurable in the images.

The used software can apply a bundle adjustment analytical model for calibration by using several images of a plane test-field, supplied with the software. In this case the process is fully automatic, requiring nothing more than images recorded in a suitable multi-station geometry, an initial guess of the focal length and image-identifiable coded targets which form the object point array. The real important point is a favourable network geometry: (1) photos must be taken with the same focusing condition of the application case; (2) in order to eliminate the high correlation present among some of the inner orientation parameters and increase the precision of the adjustment, a convergent scheme of acquisition including orthogonal rolled images is recommended (Fig. 4); (3), to compensate the planarity of the test-field, the images should be acquired at different distances from the object.

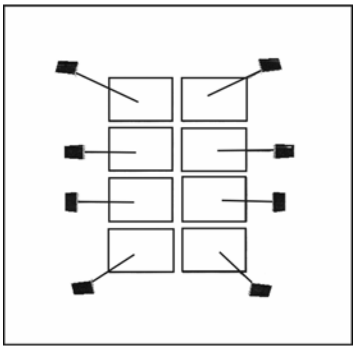

Fig. 4. Example of acquisition scheme of test-field for camera calibration process.

Once the camera(s) is calibrated, the interior orientation parameters can be used to retrieve the exterior orientation parameters of the data set and derive accurate surface models by applying dense image matching algorithms.

3.2 Data processing and final products

The methodology in terrestrial photogrammetry changed significantly in the last years thanks to the improvement of matching algorithms and the introduction of simplified digital tools that permit, also without stereoscopic skills, a 3D object model reconstruction.
Different solutions can be experimented using digital photogrammetric systems, in terms of data acquisition (semi-metric and digital cameras), data processing (monoscopic and stereoscopic plotting, with and without the use of Control Points, in the last case requiring at least the measure of one distance on the object), automated surface model reconstruction, generation of different representation products (e.g. orthophotos, VRML models, …).
But, even if new technologies and software offer different solutions and final products nowadays a commercial package specific for terrestrial image able to derive automatically precise and reliable 3D models doesn’t exist. Some of the most known softwares for

monoscopic close-range photogrammetry, e.g. iWitness (Photometrix) or PhotoModeler (EOS Systems), perform the restitution of objects based on manually measured sparse points, permitting to mix in the same project images acquired from different cameras and creating a metric environment where is possible make measurements, sections, vector drawing and 3D modeling of regular geometric shapes. But these systems still require an important manual intervention by the operator and cannot perform dense matching on irregular shapes. Other photogrammetric stations, as for example Socet Set (Bae Systems) and Leica Photogrammetric Suite (Leica), perform the automatic extraction of very dense Digital Surface Models but a post-editing phase is in general necessary and they find difficult to work with highly convergent terrestrial images.

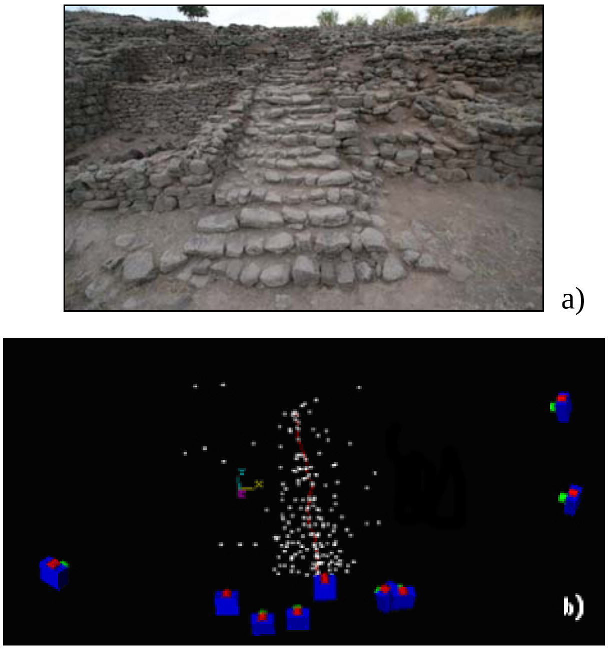

Fig. 5. The big stair of Tilmen Höyük (a) was acquired by different cameras and positions and distances. The recovered camera poses together with the object coordinates of some measured tie points (b)

One of the products that the new digital photogrammetric systems could permit to obtain in a simple and fast way, is the orthophoto. The use of orthophotos in Archaeology and in general for Cultural Heritage applications is so becoming quite common, due to their property of combining metrical characteristics together with an high level of photographic detail, useful to evaluate colours, material, decay, textures, etc.
Fig. 6 shows the orthophoto of a wall in the Tilmen Höyük site. It was produced using, Socet Set v.5.3 orthophoto production tool, with a bilinear transformation as resampling method and a dense DSM (5 mm medium post-spacing) as base. The DSM was automatically extracted by the software, but as already said, a manual editing was necessary, especially at the wall bottom and top, when the surface morphology changes suddenly. The Ground Sample Distance of the orthophoto is 10 cm.

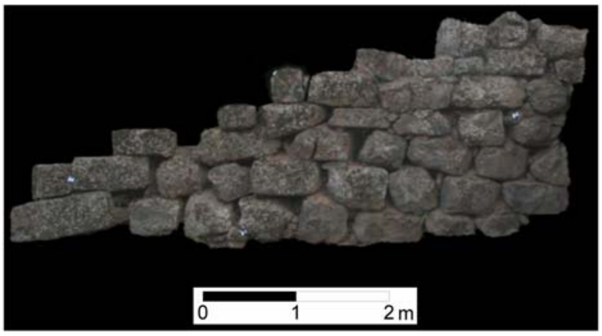

Fig. 6. Orthophoto of a site wall.

3.3 A typical case study

In this section we report the 3D modeling results of a little wall in Tilmen Höyük site (ca 6.4 square meters), chosen as example of object of archaeological interest (Fig. 7).

Fig.7. The chosen object for 3D modeling application.

A detailed 3D model is required to derive different kinds of representation and documentation products, to perform stability and structural analysis or simply for visualization of the archaeological site.
An in-house surface measurement program developed to match (convergent) close-range images and based on multi-photo geometrically constrained least squares matching was used (Remondino & Zhang, 2006). The multi-image matching approach was originally developed for the processing of the very high-resolution images and afterwards modified to process other image data, such as the traditional aerial photos or close-range images.
The program, starting from the known interior and exterior orientation parameters, performs firstly the an

image pre-processing and generates image pyramids. The images are enhanced combining an adaptive smoothing filter and the Wallis filter, in order to reduce the effects of the radiometric problems, such as strong bright and dark regions and optimizing the images for subsequent feature extraction and image matching. Then the DSM is created by means of a Multiple Primitive Multi-Image (MPM) matching.. All available images are matched simultaneously, without having to match all individual stereo-pairs and then merge the results. Primitives like feature points, grid points and edges are extracted and matched using together area-based, feature-based and relational based matching procedures. Moreover, at each pyramid level, a TIN is reconstructed from the matched features and used to constraint the search in the next pyramid level. This type of approach permits to generate a very accurate surface model that can be also textured with a digital photo of the object and is characterized by a high level of detail representation.

Figure 8 shows the obtained 3D model of the wall, which contains approximately 200.000 points. Some simple examples of the geometric study of the object are also presented.

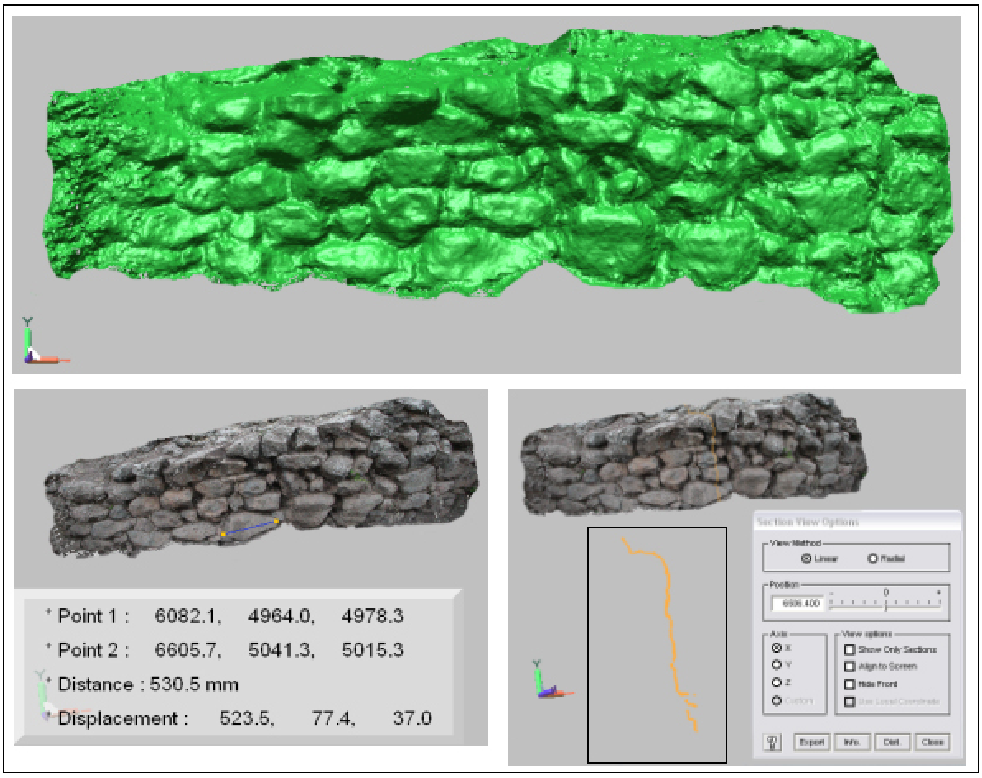

Fig. 8. The 3D model of the wall and simple applications: distance measurements and sections.

In order to evaluate the potentialities of commercial software in recovering detailed DSM from convergent terrestrial images, a test was also conducted using one of the most advanced photogrammetric workstations.

The result is shown in Figure 9. Compared to Fig.8, it's evident that the process was not completely successful. The reasons could be multiple.

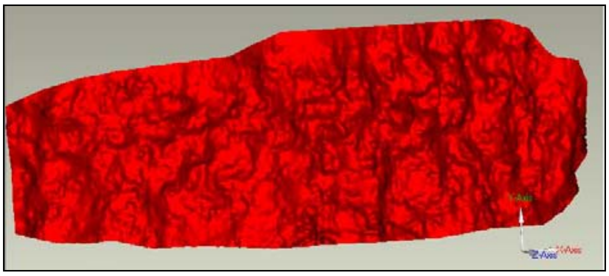

Fig. 9. 3D model of the same wall by commercial software.

As said before, commercial software especially destined

for 3D modeling by terrestrial images are virtually not existing today, so in many cases they fail when working with a geometrical conformation far from the classical photogrammetric block acquired by aerial or satellite platform. For instance, in close-range photogrammetry convergent images with different scale are very common.
Furthermore commercial software often use only stereo-pair surface measurement, while, exploiting the multi-image concept, highly redundant matching results are obtained and this allows automatic blunder detection.
Finally, it is important to underline two concepts about the area-based matching algorithms that some commercial software usually adopt:

- the image patches are assumed to correspond to planar object surface patches and this assumption is not valid along edge or conrners, therefore the features are smoothed out;
- smaller image patches could theoretically avoid or reduce the smoothing effect, but they may be not suitable for the correct matching, containing not enough image signal content.

Figure 10 shows the comparison, related to a single stone of the wall, between the two recovered DSMs. The green colour is when the points have the same Z value (depth coordinate), obviously considered the error associates at this survey, estimated in about 3mm; yellow colour is when the Z value of DSM by commercial software is lower, in an order of about 1 cm; it's evident that the central part of the stone was completely smoothed. These discrepancies emerge by a study at a local level, while considering the overall dataset the mean of these difference values is in the order of 2 mm.

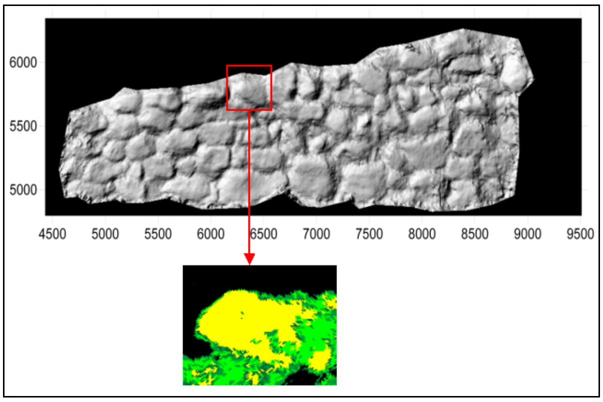

Fig.10. Particular of the comparison between the two DSMs.

Conclusions

In this contribution we briefly reported about different geomatic techniques employed in the Tilmen Höyük site, with particular emphasis on the problems encountered using terrestrial photogrammetry. Between the available surveying methods, images provide all the information useful to obtain 3D geometry and textured results. Image-based modeling techniques can really increase quality and quantity of 3D information in archaeology, with low cost results and an integrated approach. The choice on a specific software or method depends on the final aim, on the complexity of the object or monument to document and the type of representation/communication we want to obtain.
Questions related to 3D photogrammetric modelling by non-metric cameras and the use of commercial and scientific software for surface matching were addressed in the paper.. Results show that one of the crucial points is the generation of accurate 3D models and that there is the need of a larger development of packages specifically devised for this purpose. Results are not to be considered only as representation products, but they can be of valuable interest also for specific analysis of the structures and for engineering applications.

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