VERY CLOSE NADIRAL IMAGES: A PROPOSAL FOR QUICK DIGGING SURVEY

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ABSTRACT

The main goal of our activity has been the testing of a system for quick and non invasive images acquisition and their suitable processings aimed to obtain 2Do 3D models for archaeological diggings documentation. This purpose has implied the analysis and the selection of a simple and efficient data processing system for the generation of metric products such as digital elevation models and orthophotos, featured by an high level of detail regarding the excavated areas.

The acquiring system has to be quick to meet the excavation requirements and the processing system has to be featured by good quality in terms of accuracy and information richness to ensure suitable final products.

The objective of acquiring very close nadiral images is made up by a mobile framework easily assembled directly on site. The production of orthophotos was carried out starting from the generation and comparison of three different DEMs, originated from different source data and defined by dissimilar accuracy; the evaluation of DEMs is aimed to single out which kind of them, sufficiently meet archaeological excavation requirements, or better, which level of automation fulfil the overall quality reached by more time-spending and traditional methods. The first DEM (a) has been obtained by a traditional method, i.e. a non-gridded DTM, acquired by topographical method directly on site (by a total station), which has been integrated by breaklines and scattered points measured by stereo-plotting. The second DEM (b) has been derived from a DTM automatically obtained by a robotic total station scanning, whereas the last, DEM (c), was produced by image matching solely.

The evaluation of the accuracy of the three different DEMs and related ortho projections let us testing some different kinds of elevation models generation and their suitability for antropic nature objects: the Inverse Distance Weighting algorithm processed with dense break-lines; mesh generation, based on Delauney triangulation, from dense DTM, and the epipolar geometry solution applied to correct nadiral and well textured images. Two commercial software we used are Z-Map (by italian Menci Software) and Photomodeler Scanner (by canadian Eos Systems). The last goal was to test the results in relation with the archaeological diggings context and documentation purposes.

1. INTRODUCTION

Among the various research fields in Geomatics, the study of automated systems aimed to generate dense elevation or surface models (DDEM, DDSM) for the description of objects surveyed from a very close distance, the Cultural Heritage documentation is a very interesting testing ground for the contribution.

In the sphere of CH, the archaeological sites offer several interesting issues for performing and integrating geomatic techniques; this is due to a series of particular features of the archaeological evidences and theirs context.

First of all, the shape of surveyed objects are, in most of cases, significantly different from the original constructions featured by regular geometry, as they were planned. The action of time and nature make the archaeological evidences to look like natural and irregular shapes, but they still maintain the signs of man's project. The goal of studies and activities of cultural heritage operators is to find, to preserve and communicate these signs.

Usually evidences discovered inside an archaeological digging need to be compared with the natural or urban environment where they're placed. The surveying methods and techniques employed have to be low-cost featured and possibly have to be derived from the big scale cartographic updating.

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This last is not our present aim, but we tackle the problem of multi-scale and multi-precision surveys inside the borders of intra-site documentation. The typology, morphology and dimension of archaeological evidences is extremely various and need to be analyzed at the same time by large scale and smaller scale surveys, i.e. both the environment and detailed data have to be correctly collected, represented and easily examinable. (some examples are the building techniques, the material manufacturing techniques and technological details.)

1.1 Research objectives

Considering that by now it's highly recognized that ortho-photos and surface or elevation models are able to provide metric maps and drawings directly usable and managable by the researchers working on the excavated areas; the present target is the evaluation of the accessibility of the technical resources that are necessary for these products generation. (data capture devices, softwares and processing devices, operators' skills).

The available methods for DTM/DEM generation at the appropriate scale are derived from:

- topographical methods: from the traditional ones using total station or GPS technique in real time kinematic surveys, to more automated ones, using automated equipment such as last generation laser stations.
- photogrammetrical techniques: using manual stereoplotting or more automated processings typically provided by digital photogrammetry

- LiDAR techniques

In this paper we don't take in account LiDAR technique. Despite of its huge capability in object description it's still an expensive and onerous methods for ordinary and regularly applied surveys for digging documentation updating purposes.

On the contrary we took in account the first two methods in order to meet the target of efficiency and low-cost procedures. Among the automated generation DEM we tested, one (we named b) was achieved by capturing data from a robotic total station which is able to perform regular points scanning of large areas. The resulting scans is less dense than the LiDAR's ones but more affordable.

Another kind of DEM (named c) has been derived by stereo image-matching technique.

Both the methods and resulting renderings have been compared with an high quality DEM (a) and relative orthophoto generated by interpolation processes of topographical and photogramme-trical data. These data have been obtained by a traditional total station measuring the level points on ground and the discontinuities of the digging's morphology, integrated with breaklines derived from stereo-plotting of a bundle-block oriented model.

These last photogrammetrical products, onerous for the time-spending collection and elaboration but featured by an high overall quality which is suitable for diggings documentation needs, have been assumed as a comparison term to evaluate the quality of faster automated methods.

The starting point of the entire study was the test of a telescopic pole for the nadiral high scale frame acquisition. The collected frames are featured by a good ground sampling distance (GSD) due to the very close shooting distance and good framing geometry control.

1.2. Choise of case study (a model for diggings' features)

The archaeological digging is often characterized by frequent traits such as:

- the differences in level are small because, unless exceptions, the buildings remains are not so high from their original founding.

- the base level of diggings is always lower than the terrain level of surrounding area close to the digging.

- the digging is often edged by ground sections on which the stratigraphic reading is applied; these well preserved elements of excavated area are often surrounded by uncaved areas which are suitable for materials removal.

These three simple features justify the effectiveness and the repeatability of the telescopic pole employ, and they enable to consider the test area assumed as a typical digging context.

The area is a portion of an ancient roman street (cardo) made up of a stone pavement, showing the typical humpback section for the refluent water drainage. (Figure 1) [1]
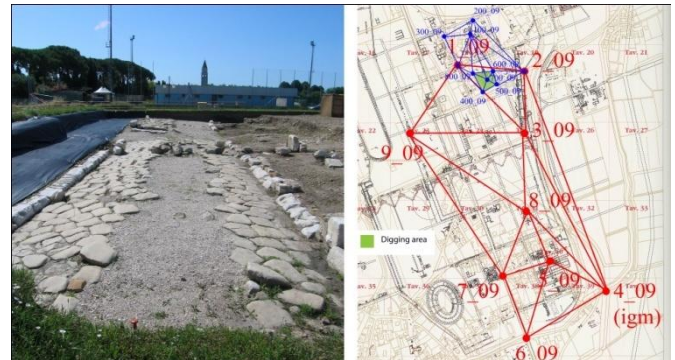

Figure 1. (left) A view of the test area: an excavated portion of a roman *cardo* of Aquileia. (right) The urban GPS network (red) and the excavation area network, located in the northen part of the city.

2. IMAGES ACQUISITION SYSTEM

2.1 The telescopic pole

The system for acquiring the very close nadiral images is made up of a mobile framework easily assembled directly on site.

Low-altitude Aerial Photography has always played a significant role in archaeological investigations; different solutions has been tested for providing Archaeological bird-eye views, even collected with the aim to profit of photogramme-trical potentialities of overlapping images. Among unmanned aerial vehicles, kites, ballons or blimps, even masts, poles and booms have been used. (Verhoeven, 2009)

o Main advantages of poles and similar masts are stability and high scale images collection; the telescopic system enabling the elevation of camera position offers a non bulky solution which is convenient and portable.

o Disadvantages are the presence of terminal portion of pole in the nadiral shot and possible shadows disturbing the views. The slenderness that features pole similar to the device we used limits the raising to 8-10 meters.

The framework we used is a metalwork composed of two parts: the first is a telescopic pole steadily leant on ground with a tripod provided with wheels; the upper part of it is formed by a steady boom which carries the camera lodging at the end of it. The length of the boom has been planned to guarantee that at suitable height the tripod don't disturb excessively the embracement of photograms, and that the camera weight could be balanced by a simple counterweight[2]. The join between the pole and the boom is a pivot which allows us, with the simple aid of two strings, to control the rotation of the boom on the pole.

This acquisition system assures metric accuracy (1:50 scale) and thematic resolution (1:20 scale) that are proper for the archaeological digging documentation. Restrained ballons which are more widespread in this context hardly achieve the requested accuracy, due to the higher flight height and unsteadiness of the system (Chiabrando, Spanò, 2009)

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[1] The excavation area belongs to an important settlement of the North-East of Italy during the Late Roman Empire and the Dark Ages: Aquileia. The archaeological evidences that have been discovered and preserved during many years of excavations are spread in the North part of the modern settlement in a typical urban context. The excavation area selected for the test is diected by Dr. Federica Fontana from the Università di Trieste - Dipartimento di Scienze dell'Antichità.

[2] The telescopic pole system is raised by compressed air, induced by a motor compressor. The system has been planned and improved by Arch F. Goggi and Arch. G. Berruto, respectively heading the Survey Lab. and Model Lab. of Faculty of Architecture (Politecnico di Torino)
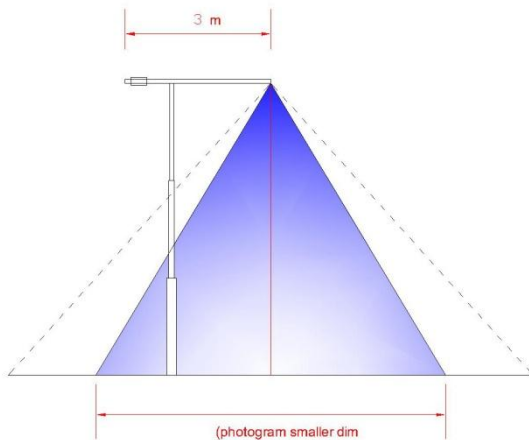
Figure 2 . Assembly and raising pole on site.

Figure 3. Sketch of telescopic pole system and liability of pole presence in correct nadiral images.

Shooting distance (m)	Frame scale	Swath Widt (m)	Pixel dim. (micron)	Ground sampling distance. (m)
6	1/300	7.2x10.8	7,21	0.0021
8	1/400	9.6x14.4	7,21	0.0028
5.7	1/285	6.8x10.2	7,21	0,0020

Table 1 . Acquisition parameters of employed camera: (Canon EOS 1Ds mark II, CMOS sensor 24x36 mm and $3328 X 4992$ pixel, principal distance 20,42mm. In blu background convenient distance, in green mean distance adopted)

3.2 Features of the stripe

The data capture system is very cheap because it doesn't include any ground control systems. In spite of this, the uniform shooting distance, the straightness of stripe axis and the correct photograms overlapping are easily controlled by the pole height, boom orientation and the parallel traslation of the base according to the stripe orientation. (Figure 4)

Figure 4 – The ovest 18 photograms stripe embracing the whole length of the road (about 40m). The regular overlapping proves the steadiness and controllability of system.

The non-,metric camera we used is a Canon Eos ID mark III, with a 24X36mm CMOS sensor and a 20mm lens. The shooting distance was about 6m (similar to the photogrammetrical surveys carried out in other areas of the archaeological digging). The resulting photograms scale was about 1/280 and the base/distance ratio was ¼ (1.5m). Since the differences in height of archaeological evidences aren't so relevant, the stereoscopic covering of 75% was assumend as sufficient for the survey's purposes and the ground sampling distance was about 2mm.

4. DEM AND ORTHOPHOTO GENERATION

4.1. Traditional data source DEM and orthophoto

The photogrammetrical orientation of the images was performed by the determination of camera calibration parameters, in previous works achieved.
The exterior orientation was accomplished with the simultaneous calculation of a whole stripe by the Z-Map software. The ground control points used for the bundle-block adjustment have been previously marked by 5cm paper targets.
The results of the stripe orientation are shown in the table 2.

	RMS X (m)	RMS Y (m)	RMS Z (m)
GCP (6)	0,001	0,002	0,007

Table 2 – Bundle block orientation results.

The stereoscopic plotting of the photogrammetrical model allowed us to underline the main breaklines and several scattered level points in order to integrate the topographical DTM acquired by a reflectorless total station.
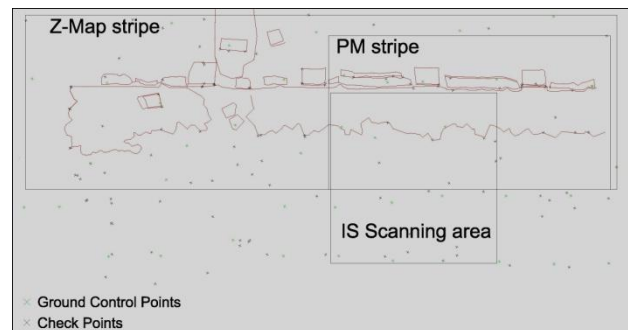

Figure 5 – In CAD environment the breaklines, the measured on site points (ground control points and check points) and plotted points are shown; the picture highlights the different extension of stripes processesd by Z-Map, by Photomodeler and the area subjected to the Geotop Image Station scanning.

In other test cases involving anthropic surfaces, the efficiency of the Inverse Distance Weighting interpolation model with the contribution of breaklines for Dem generation was highlighted. (Chiabrando, Spanò, 2008)
The figure 6 shows the resulting DEM and relative orthophoto, obtained by the mosaic of 8 ortho-projected images; they have been performed by onerous but precise processings, and they have been elected as a reference to compare more automated elaborations.
The orthophoto accuracy was evaluated by the comparison with check points (Table 3); small residuals (on the average 1cm, and some of them near 2cm) let appreciate the suitability for the direct vectorization of sketch drawing upon it, useful for archaeological documentation need.
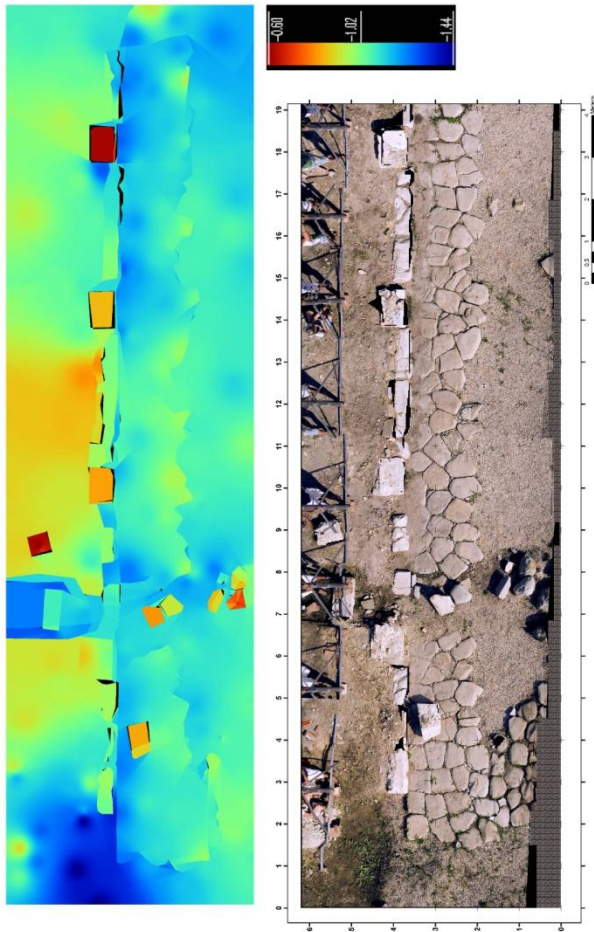
Figure 6 – DEM regarding a portion of the roman road, generated by manual sourced data (stereo-plotting for breaklines and scattered òoints interating a) and IDW interpolation. In the right the performed orthophoto composed by the mosaic of several projected images.
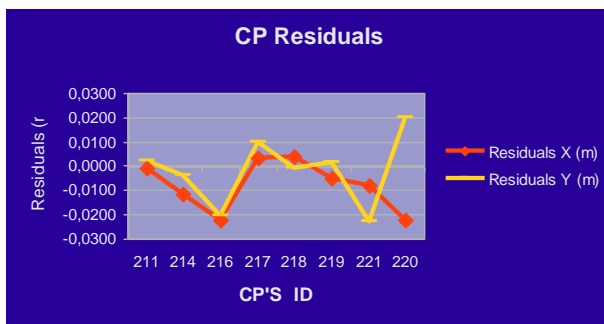

Table 3 –Residuals on check points, measured on the orthophoto of Figure 6 (generated by DEM (a).

4.2 Dem derived from dtm acquired by automated system

Next step of planned activities was the surface extraction from the robotic total station survey, which is a valid and cheaper alternative to the LiDAR techniques. These devises are able to quickly collect large sets of point clouds; their ground resolution depends on the instruments performances and on the acquiring relative position among occupation point and the object. The Topcon Image Station forthcoming from Geotop, is equipped by a coaxial camera which acquires photograms in the same reference system of the station.
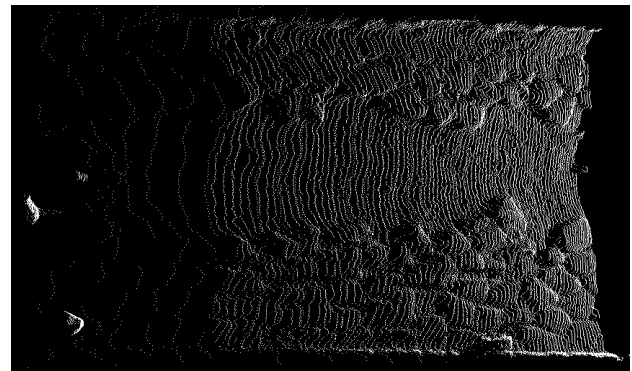

Fig 7 - Visualization of collected points cloud, partially overlapping first DEM.

The topographical DTM acquired with this system was processed with interpolation processing in order to derive the raster elevation model. Firstly we derived the DEM through an interpolation model belonging to the IDW family, then, since dense points clouds are easily and correctly interpolated by Delauney triangulation, a high accuracy DEM has been processed after a mesh transformation. (grid: 0.01x0.01)
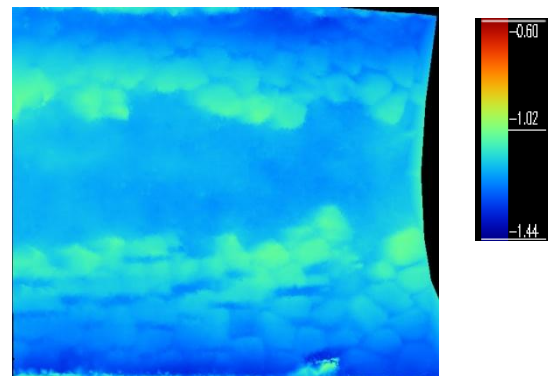

Figure 7 – Highly detailed DEM (b), derived by points clouds acquired by a robotic instrument. (grid: 0.01x0.01)

4.3. DEM derived from image matching technique.

The solution of the image matching allows to determinate the points positioning in the model space starting from the oriented model trough intersection of the epipolar lines. Epipolar geometry enable to determine a point position in the 3D space from the relations between their projection in the 2D space.
In the last years the improvement of well kown image matching algorithm (Gruen 1985, Gruen, Baltsavias 1988) have provided optimization for multi-image approach and the study of geometrical constrains. There are many which establish the correlation on the area and on objects previously recognised. (Remondino, El-Hakim, 2006)
The software we employed for DSM generation is Photomodeler Scanner by the Eos Systems which adopt an area based algorithm and, specifically for stereo-matching, it needs images taken with parallel axes. Better results are obtained with a good variety of the material texture and good lighting conditions. (Walford, 2008, Hullo, Grussenmeyer, Fares, 2009).
The DSM generation process was performed employing stereo pairs correlation, each of them creates a single surface model; a further interpolation of them optimize the result. The image matching is controlled by several parameters (reference surface, correlation area, texture type) which allow to calibrate the process to the features of the surveyed object. Then the series of

models generated are registered and merged together. After the registration, the necessary noise reduction and the decimation we can produce a triangulated mesh and then run the ortho projection. Almost all the procedures are automated. In fact the tie and ground control points collimation which is the only manual operation can be done automatically as well with specified target.

The inner orientation parameters of the non-metric camera has been obtained by the self-calibration module (Camera Calibrator) (EOS Systems Inc., 2000; Hanke et al., 1997).

The stability of images acquiring system has enabled to estimate a unique set of parameters to describe radial distortion and solve inner orientation.

After stereopairs orientation, the complete bundle block orientation of four photograms has provided different RMS of GCPs accordingly with the number of images where they havd been collimated; in general results are very good and they guarantee a good estimation of epipolar images relative to pairs matching.

Orientation residuals¤	°¤
Overall RMS¤	0,921 (p)¤
maximum RMS¤	2,158 (p)¤
minimum RMS¤	0,053 (p)¤
Overall RMS¤	0,921 (p)¤
Overall RMS Vector Length¤	0,0048 (m)¤
maximum RMS Vector Length¤	0,00805 (m)¤
minimum RMS Vector Length¤	0,00273 (m)¤

Table 4. RMS of GCPs after bundle block orientation.

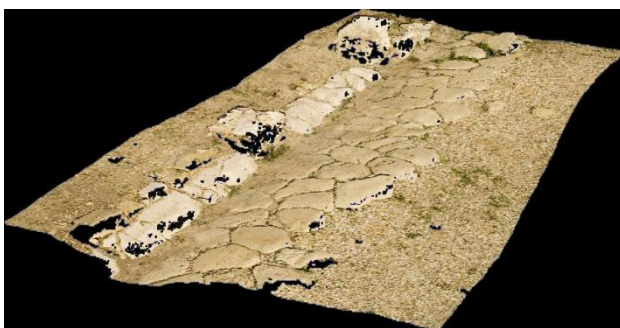Figura 8 – Textured DSM obtained by four images matched.

Figura 9 – 3D view of textured model.

The DSM has a the resolution of one point/1cm Once obtained, photomodeler DSM has been subject to some sampling check that is possible to read in table 5.
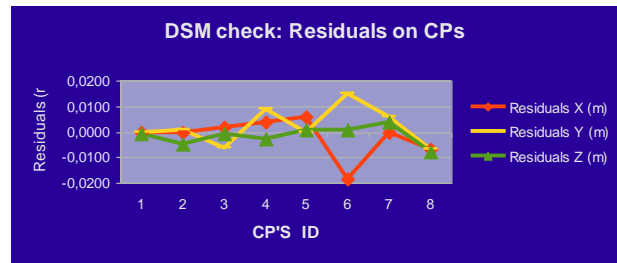

Table 5 – Evaluation of stereo matching DSM: residuals measured on check point are good for survey purpose.
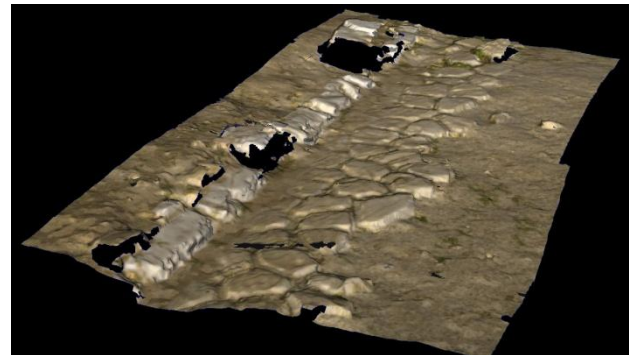

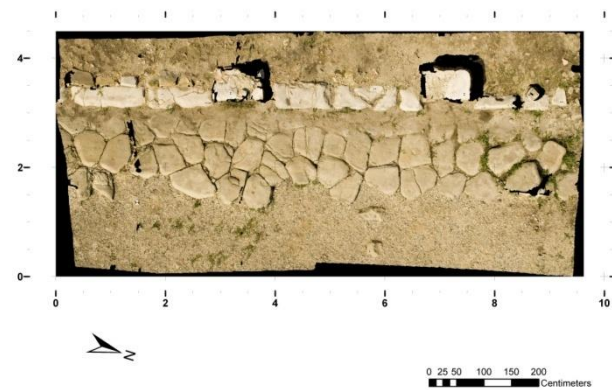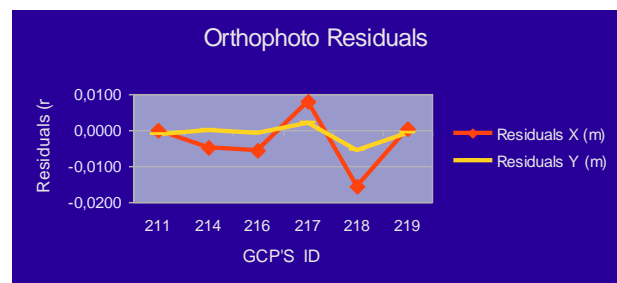Figure 10 – A view of textured mesh (203464 triangles)

Figure 10 –Orthomap of the 60mq part of the roman cardo.

Also the final orthophoto mosaic has been checked by measuring residuals on some Cps. Table 6 reports result, and it's possible to say that they are surprisedly better than residuals on the first ortho projection (Table 3).
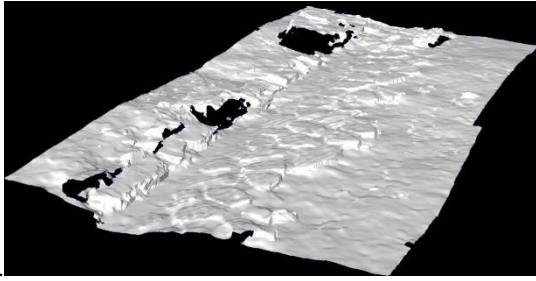
Figure 11 – Automatically triangulated mesh enlighting holes.

6. CONCLUSIONS

This experience has proved that the pole framing system is a good solution for the archaeological context due to its efficiency and low cost features.

It's necessary to consider that the use of nadiral images, planned from the beginning of the test, has been mainly focused to perform a quick description of horizontal projection and cross section regarding the digging. (updating plans and cross section). Complete models can be reached by further and inclined images in order to restrict the extension of holes (Fig. 11)

This simply target con be performed by the use of low cost instruments and devices: the pole, a digital professional camera, the topographical survey of several targeted points, and the software enabling the generation of DSM by image matching.

The results, obtained quickly, are comparable and even more accurate than the ones derived by more sophisticated and complex devices and processings: the robotic total station and time consuming processings reported in par. 4.1 (The studies and the applications proving the effectiveness of multi image approach are very many, even comparing image matching with LiDAR processings, and testing procedures and results on different object types or different commercial solution. Same sampling experiences reached at the Politecnico of Torino can be read in Nex; Rinaudo, 2009 [1] [2]

The further automated elaborations, such as sections applied to significant projection planes for archaeological evidences documentations, expedite and make easier the extraction of vectorized drawings for digging description. (Fig 12)
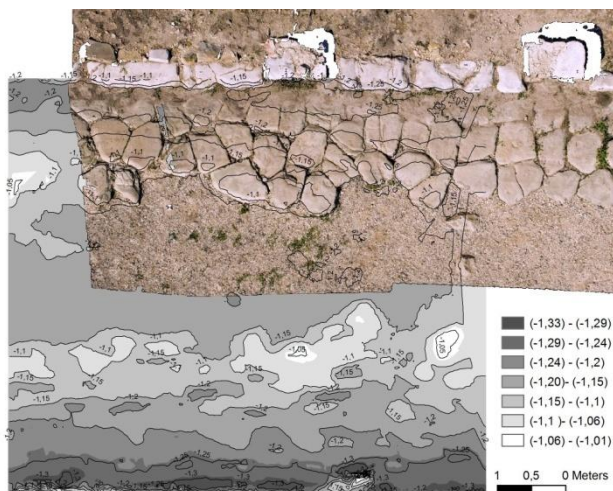

Figura 12 –Contours extraction from DEM and DSM is compared in the view with the orthophoto. Vector sketches of the shape of evidences can be expedited by automatic features generation.

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