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HIGH ACCURACY IMAGES AND RANGE BASED ACQUIRING FOR ARTISTIC HANDWORKS 3D-MODELS.

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ABSTRACT:

The research topics and the applications in the Geomatic area are often connected to the land knowledge and management or to human artefacts usually studied and analyzed from expert of other areas. When these subjects are a part of the Cultural Heritage the survey methodology for the documentation and the knowledge need to consider the final users (belong to different disciplines), in order to realize correct descriptive products suitable for all the actors involved in the preservation and the safeguard of the Cultural Heritage.
During the last decade one of the important aim related to the cooperation between the Geomatics group of Politecnico di Torino and the experts working on archaeological sites is to join the new Geomatic methodology and techniques in order to realize documents and products, usable by the specialists, aimed to the archaeological site knowledge and documentation. The past applications were focused on the ancient city, from the urban scale through the archaeological evidences up till the architectural elements. The paper deal with the last experiences of the research group relating to two important archaeological objects. In particular the archaeological artefacts are figurative relief featured by small dimension, carved in the marble and belonging to two architectural elements; the subjects are two theatrical masks, one comical featured and the other tragical.
In order to aid and support other analyses involving restoration strategies one of the goals of the last expedition was the documentation, the survey and modelling of the artefacts. According to the complex shape of the theatrical masks, and in order to obtain all the information requested for a correct survey documentation, a triangulation-based LiDAR system was employed (HandyScan 3D- model HZ). Moreover, since the LiDAR survey was performed on the more complex decorated surface (theatrical masks) in order to achieve a complete 3D model of the marble blocks a photogrammetric survey was realized. In the paper some topics are going to be described, highlighting advantages coming from multi-sensor data fusion techniques, both for obtaining multi-scale models and for general accuracy improvement. Some discussed topics are: the acquisition phases and the obtained results of the 3D HandyScan survey, the photogrammetric processing steps and the realized products, the assembling and integration of the different kinds of data, the 3D representation and the photorealistic modeling phases.

1. INTRODUCTION

The topic of multi-sensor data fusion has received over the years a lot of attention by the scientific community (Barber et al., 2001; Beraldin, 2004; Cabrelles et al. ,2009; El-Hakim et al. 2003; Remondino et al. , 2009).
Multi-sensor data fusion techniques combine data from multiple sensors and related information from associated databases, to achieve improved accuracies and more specific inferences than could be achieved by the use of a single sensor alone. In the field of the integration of laser scanning and close-range photogrammetry, we present an application on two complex archaeological artifacts.
The elected handwork are two theatrical masks (Figure 1), one comical featured and the other tragical. These high-relief masks are engraved on two statue basis which were originally placed in the marble scene of the Flavian Theatre in Hierapolis of Phrygia (Turkey, where the Italian Archaeological Expedition – MAIE has worked since more than fifty years); now they stand on right and left side of one of the modern service entrance of the theatre, which goes to the rooms under the stage, and enables to get to the orchestra.

These marble blocks are 80 cm height, and masks cover more or less half of the block face extension (four of eight among the vertical faces of blocks are decorated, and we carried out a highly accurate survey on them, even though two masks are less readable than the others).

Figure 1 Two theatrical masks of the surveyed marble blocks

According to the complex shape of the theatrical masks in order to obtain all the information requested for a correct survey documentation a triangulation-based LiDAR system was employed (HandyScan 3D- model HZ). This instrument join the handiness and the needed precision for an high accurate survey (it is produced by Creaform, a Canadian Technological centre for reverse engineering and 3D digital solutions).
For each base several scans were achieved and processed with typical LiDAR processing steps. All the scans were referenced in a local coordinates system using some measured target well identifiable in the point clouds.
Since the LiDAR survey was performed mainly for the figurative decoration, a photogrammetric survey has been realized in order to achieve a complete 3D model of the blocks. For this reason, both the products realized using LiDAR and photogrammetric techniques were accurately assembled. In the paper some topics are going to be described, in section 2 the acquisition phases and the obtained results of the 3D HandyScan survey are analyzed. In section 3 the photogrammetric processing steps and the result products are described, section 4 deal with the 3D modelling phase: assembling and integration of the different kinds of data, 3D representation and the texture mapping. Finally in section 5 some conclusion and future works are reported.

2. LIDAR SURVEY

According to the complexity of the artefacts an high accurate LiDAR equipment was used (3D HandyScan).
In this scanner (Figure 2) the acquisition unit contains two digital cameras mounted onto a rigid body. Four red light leds are placed around each lens and there is a special laser tracker at the bottom of the handle, which is useful during the acquisition process to mark the surveyed points (Achille et al., 2007).

Figure 2. Handyscan 3D: the acquisition unit
(980 g, 160 x 260 x 210 mm)

The more interesting aspect is the dimension and the weight of the acquisition unit which can be handled for long periods without tiring the operator and it allows the possibility of obtaining very many details, even in the case they are very small, i.e few millimetres. (www.creaform3d.com, Bornaz et al. 2004). Surveying objects can be featured by different dimensions: from small objects to larger ones, generally belonging to chattels or being portions of built heritage, indeed.
Before starting the 3D survey several reflective targets (6 mm diameter small circles) have to be glued on the object; these targets (Figure 3) allow to perform the absolute orientation of the scanner cameras, that change continuously and to state a reference system on the object.
This last time-spending phase suggest to use this system when and where the final accuracy is really needed.

Figure 3 Particular of the employed reflective targets

After the geometrical and radiometric calibration of the scanner (Bornaz et al., 2007), the first useful for the relative orientation of the two HandyScan digital cameras, and the second to set the system according to different materials and illumination conditions, our acquisition was performed using a dark towel that has been necessary in order to screen the surveyed surface from the direct light (Figure 4). The survey has took place in August and the disperse light, even reflected by marble blocks and travertine walls present in the areas, caused gross errors in cameras orientation, generating two different points clouds of acquired surface at the distance of a couple of centimeters.

Figure 4 Acquisition phases

For each theatrical mask 5 scans has been acquired (figure 5), each portion overlapped the adjacent ones by a percentage of about 10% in each direction in order to allow the accuracy to be controlled and a correct mosaic of the single mask to be made (the system works with precise box of acquisition, which dimension depends on the request accuracy). The recorded data are: the target positions and the STL format 3D model(Figure 5 left), that could be transformed in an ASCII points coordinate file (Figure 5 right).

Figure 5 STL 3D model and target acquired during a scan (left), point clouds visualizartion (right)

After the acquisition, the generation of a complete model of the acquired parts, request the following performing phases: union of the different portion of scans using the reflective targets, referencing of the entire scan using some control points

measured by topographic survey. In the next sections these phases will be reported.

2.1. Data processing

For each scans using the VxScan software two different ASCII files were generated: in the first one are stored the coordinate of the acquired target, in the second one the coordinate of the points that describes the shape of the acquired artifact.
In order to generate an unique point cloud for each mask the different scans need to be merged; to perform this part of the process, Riscan Pro has been employed. The targets of the central scans were used as reference and the other scans were merged to the central one using the common targets (minimum 7) minimizing the errors. After the process, the residual for all the scans are minor that 1 mm on each target. The results of the registration process is the complete point clouds of the surveyed four masks (Figure 6).

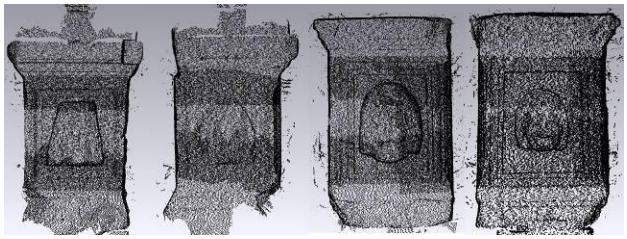

Figure 6 The four scans of the theatrical masks

The next step of the processing phases was the referencing in a common reference system of the four parts of the blocks.
In order to obtain these products a topographic network has been realized close to the marble basis. The network (four vertexes) was surveyed with a traditional topographic survey (by total station) using the rigorous approach of redundant observations.
After the network adjustment, a celerimetric survey of some HandyScan targets properly distributed on the surface of the scanned artifacts were performed (about 15 targets for each face). In addition on lidar target, other targets functional for the photogrammetric process were positioned and measured. The following Figure 7 show the sketch of the topographical network and the silhouette of marble basis.

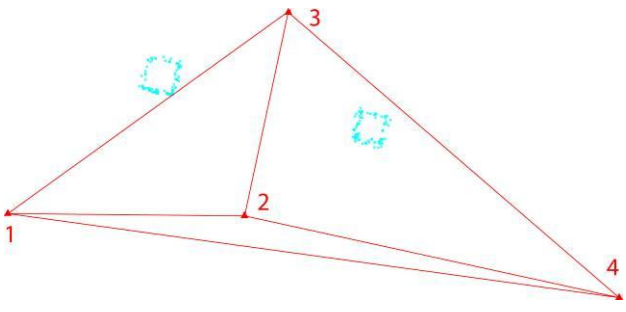

Figure 7 The surveyed network (in red) and the measured targets (cyan)

The referentation process was performed with Riscan Pro following the same strategy used for the union of the different scans. For each part about 10 points were used, the residuals on the points after the referentation, are minor than 2 mm for all the blocks faces.

Afterwards the points clouds were processed in a modeling software: 3DReshaper, by Technodigit, (www.technodigit.com) These program was used in order to clean the clouds, to reduce the noise and to obtain the final mesh (this part will be described in section 5).
As is showed in the following Figure 8 (left) due to the light reflection (on the targets and on the surface of the marble blocks) some surveyed points are not in the correct position (outliers). In order to reduce this "errors" two different approach were followed: first of all an automatic noise reduction using the algorithm implemented in the software (median filter), has been performed (Figure 8 centre), moreover in order to eliminate the outliers a filter that is function of the distance between the scanned points was used (Figure 8 right). With this filter is possible to isolate and delete this points.

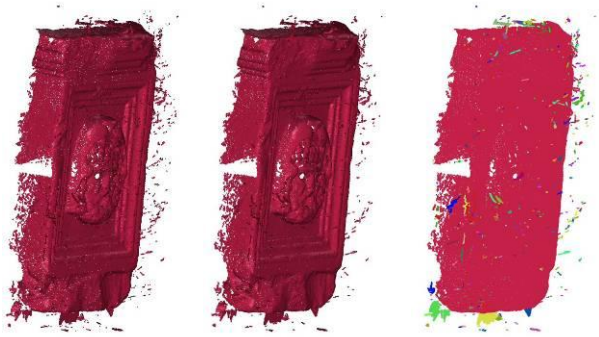

Figure 8 Raw data with outliers (left), the point clouds after the noise reduction (centre), the founded outliers (various color in the image) using the distance filter (right)

Finally a manual cleaning was performed in order to eliminate all still remaining wrong points, not founded during the automatic process .
The final points clouds obtained (Figure 9) has been integrated with photogrammetic data in order to generate the final 3D model of the artifacts.

Figure 9 The final points clouds of the four theatrical masks obtained with the HandyScan 3D

3. PHOTOGRAMMETRIC SURVEY

As just pointed out, a saving time photogrammetric campaign was realized on the simplier faces of the marble basis.

Figure 10
Two non decorated faces of the marble basis

The image acquisition was realized using a film-based semi metric camera: the 6006 Rollei equipped with 40 mm lens. The camera was set up on a topographic tripod at a distance of 1.50 m in order to obtain a frame scale of 1:40 (figure 11). For the baseline the typical proportion employed for the photogrammetric survey has been used: D/Z=1/4. The images were acquired for all the blocks faces.

Figure 11 A stereoscopic acquisition of a theatrical mask using the Rollei 6006

As reported in section 2.1., for the photogrammetric process several target has been measured using a reflector less Total Station, these targets were used as Ground Control Points (GCP) in the process. All the photogrammetric phases were achieved using a digital photogrammetric software: Zmap (Menci Software).
First of all the films were scanned, moreover the internal orientation was calculated, after that the bundle block adjustment process was performed and finally the digital plotting has been realize.
Plotted breaklines and measured points have been exploited in order to obtain suitable DEM of faces basis, generated by IDW interpolation (www.menci.com, Chiabrando F., Spanò A., 2009). In the following sections the photogrammetric processing results of two non decorated faces will be analyzed.

3.1 Bundle block adjustment

In order to help the discussion the analyzed block could be simplified in the following schema (Figure 12).

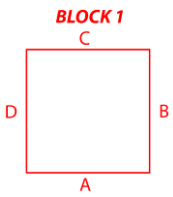

Figure 12
Analyzed block: face A and B surveyed by LiDAR, face C and D photogrammetric survey

Bundle block adjustment involves the simultaneous least squares adjustment of all the bundles of rays, from all the exposure stations, to all the measured image points.

In our case for each part two photograms were acquired and processed.
In order to perform the bundle block adjustment for each face 14 points has been employed as GCP and 10 points as Control Points in order to analyze the final result of the Bundle block adjustment.
The residual on the GCP and the CP after the bundle block adjustment are showed in table 1.

Face		*RMS x [m]*	*RMS y[m]*	*RMS z[m]*
C	GCP	0.002	0.003	0.003
C	CP	0.006	0.005	0.005
D	GCP	0.001	0.002	0.002
D	CP	0.004	0.005	0.003

Table 1 Mean RMS on the GCP and CP after the bundle block adjustment (face C and face D)

3.2 Digital plotting and DEM extraction

In order to generate a product which can be easily integrated with the point clouds derived from the LiDAR survey a complete DEM of the faces C and D has been realized.
The strategy employed is the following: first of all the edges of the two face moldings were photogrammetrically plotted, after that several points on the faces of the block were extracted (again using the photogrammetric plotting) and finally using the Inverse Distance Weighting (IDW) algorithm implemented in ZMap the DEM's were generated. In particular IDW algorithm works better if the edge are used as break-line; the plotted point, the GCP and the CP concur to the interpolation process as vertexes belonging to the generating surface. In order to obtain the final result showed in Figure 12 the following parameters for the IDW algorithm has been employed: inverse distance=0.4 m, research radius=0.15 m.

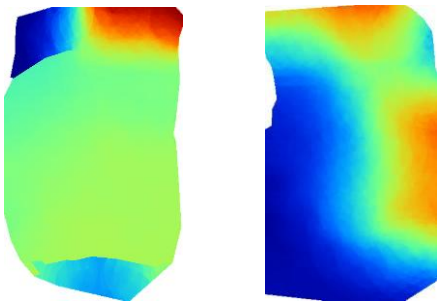

Figure 12 Face C DEM (left), Face D DEM (right)

The realized DEM's were subsequently exported as ASCII file in order to use the resulting altimetric informations for the modelling phase.

4. 3D MODELLING

Once a point cloud is available, a polygonal model is usually generated to produce the best digital representation of the surveyed object or scene. Some fixings for closing holes, editings of incorrect faces of mesh related to non-manifold parts, are always necessary and time consuming. Those errors are visually unpleasant, but they might cause lighting blemishes due to the incorrect normals and the computer model will also be unsuitable for reverse engineering or physical replicas.

Finally photo-realism, defined as having no difference between a view rendered from the model and a photograph taken from the same viewpoint, is generally required and obtainable with the texture mapping phase.
In the present work in order to join and integrate the data; all the information were inserted in the elected modeling Software (3D Reshaper).

4.1 Data processing and assembling

Before data assembling (that has been very quickly as all the faces models were calculated in the same reference system), a mesh for every part of the marble block model has been generated from the point clouds, afterwards the mesh was cleaned and corrected (the little holes were filled) and finally the mesh has been smoothed. The results of the two decorated face are shown in Figure 13.

Figure 13 The 3D models of the decorated parts.

Only few corrections have been achieved on the mesh before the smoothing; we can assert that the previous cleaning and the noise reduction on the point clouds were correctly performed.
Really, for the simpler portion of faces, the modeling process were realized without corrections.
After the meshing phase all the parts were merged in a common file in order to analyze the gaps between the faces of the artifacts.
In figure 14 two different views of the data merged in a common file are showed.

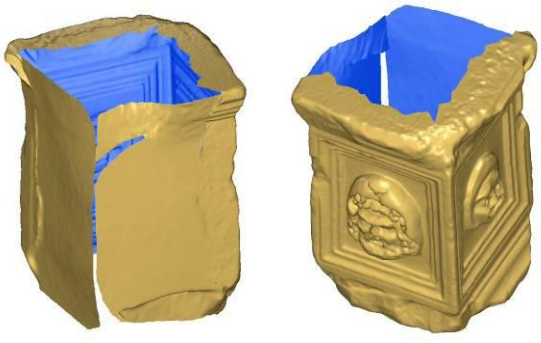

Figure. 14 Complete raw 3D model

4.2 Editing and integrations

In most cases, after the 3D processing management, some integrations and editing intervention need to be performed in order to achieve a correct model.

In the present project, considering the high scale of the marble blocks models, a normal time spending revision of models have been accurately performed.
The preliminary plan of multi-sensor data fusion made urgent the comparison between the differently sourced data. An analysis of the discrepancies between the results of LiDAR and photogrammetric survey have been carried out, examining twice acquired data.
These discrepancies, measured on several control points, were minor than 5 mm for each control point; so it was confirmed that the very high precision photogrammetric survey equalize the results obtained by triangulated scanner system.
Finally in order to generate a complete model some parts of the blocks needed to be integrated, because of information gap in the zones of connection among differently generated models, i.e in the spoilt edges of basis. We used two methods: a more precise one and a less precise. The first method has been possible when some metric information derived from the photogrammetric plotting and not employed for the generation of the DEM were available. Thank to these data a correct integration was realized.
For areas of blocks where no metric data were available the second strategy adopted consists in a integration that agree with the more presumable shape of the missing portions (only a visible checking by the photographic documentation has been possible).
The integrated areas using this last method are the top and the bottom of the blocks (assumed flat) and some areas of the corner connecting the two faces surveyed with a photogrammetric approach.
The following Figure 15 show the complete model realized after the editing and the integration phases.

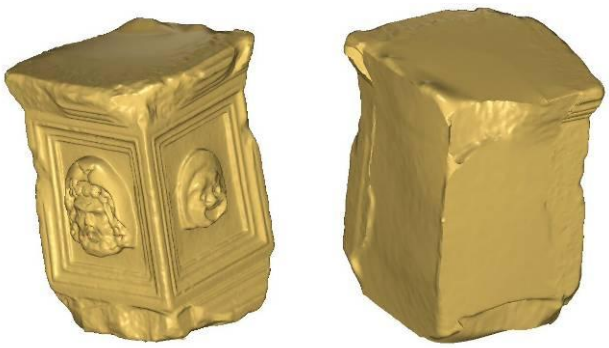

Figure 15 Complete edited and integrated 3D model

4.3 Texture mapping

In order to achieve a photorealistic view of the surveyed artifact, the texture module of 3DReshaper has been employed. Different methods are available, and in the present case a photogrammetric approach has been adopted: the faces have been mapped using the external parameters of oriented photograms, derived from the photogrammetric process (Figure 16). In particular the origin and orientation of the camera (camera position and camera orientation) and the internal camera geometry (focal length, principal point position and lens distortion), were used in order to achieve correct textures of the basis. In addition to the camera position, the software texturing module is able to choose which set of triangles of the mesh have to be textured according to the visibility from each point of view.

Figure 16. The photogrammetric position of two images employed for the texture phase

In the present case, different sets of oriented images were employed, some featured by horizontal axis and some other with a tilt axis, in order to achieve the more metrical accurate textures.
In the following figure 17 the two textured faces showing the best conserved theatrical masks belonging to the block n.1 are shown.

Figure 17 Textured models of two theatrical masks (face A and B of block 1).

5. CONCLUSION AND FUTURE WORKS

The multi-sensor data fusion generating a complete textured 3D model (integrating high precision LiDAR data and digital photogrammetric products) has endowed good results. The data acquisition, processing phases and the integration issues of multi-sensor data have been analyzed and solved; this project shows the high potentialities of modern e technologies in the field of digital documentation of CH, aimed to preserve as well as sharing and managing it. 2D representations are obviously widespread and useful, but it is important to underline that rich set of information regarding the objects can be extracted from a complete 3D model, overturning traditional approach.
Considering the high accuracy achievable by more automated model generation techniques using multi image-matching (Remondino and El-Hakim, 2006, Nex and Rinaudo, 2009, our further work presented to this conference discussing very close nadiral images for quick digging survey), it's reasonable to plan a next test based on matching techniques even in a very high scale and detailed survey as the present.

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