LASER SCANNING AND CLOSE RANGE PHOTOGRAMMETRY: TOWARDS A SINGLE MEASURING TOOL DEDICATED TO ARCHITECTURE AND ARCHAEOLOGY.

Pierre Drap[a,*], Matteo Sgrenzaroli[b], Marco Canciani[c], Giacomo Cannata[c], Julien Seinturier[a]

[a] MAP-GAMSAU umr CNRS 694, Ecole díArchitecture,184 avenue de Luminy, 13288 Marseille Cedex 09, France (Pierre.Drap, Julien.Seinturier)@gamsau.archi.fr

[b] TOPOTEK Centro di Competenza per le tecniche di Rilevamento e la Geomatica via Branze 38, 25123 Brescia Italy sgrenzaroli@topotek.it

[c] Laboratorio di ì Rappresentazione Graficaî , ROMA, Universita di Roma tre. Italy (canciani,canata)@uniroma3.it

KEYWORDS: Laser Scanning, Photogrammetry, Multisensor, Archaeology, Architecture, Representation, Knowledge Base, Texture

ABSTRACT

We present here the first steps towards the development of a tool for architectural and patrimonial survey which combines the laser scanning techniques, close range photogrammetry and a fine analysis closer to the studied field, here architecture and archaeology. The present work is the result of a join cooperation between, INN.TEC.srl, an Italian Innovation Technology Consortium, with a Center of Competence (Topotek) specialized in geomatic problems and in particular in the treatment of cloud of 3D points coming from Laser scanner, a French CNRS laboratory working on close range photogrammetry in the context of architecture and archaeology and a laboratory from the university of Rome III, specialized in the representation of architecture.

We present a knowledge based survey tool which combines mixed means of Laser Scanner and photogrammetry measurement.

The statement is articulated in three phases:

- Laser scanner allows to model objects in 3D with a density of measurements that cannot be acquired within a reasonable time frame with traditional technologies. The programme used for laser data management creates a triangular 3D model (mesh) from the range information and maps 2D information on the 3D model to create the final result.
  Generally laser scanning requires to view the surveyed object from several viewpoints to resolve shadows and occlusions but displacement of the laser sensor is not always easy to achieve on site
- We developed a similar approach in photogrammetry which, using some photographs taken without too many constraints, can supplement the occlusions or lacks from the laser measurements. A survey based on an approximate geometry of the object and autocorrelation makes it possible to obtain automatically an irregular mesh with appropriate texture. The orientation phase uses the data provided by the scanner to orient the photogrammetric measurement in the same set of axes.
- The last phase involves the use of an expert system based on a knowledge representation of the object measured in order to rebuild an architectural or archaeological object while being based to the taken measures and an elaborate ideal model in collaboration with the architects or archaeologists.

The work presented here is based on an experimental study of an Etruscan amphora found on the Grand Ribaud F wreck, in HyËres, France, and studied by Dr. Luc Long, Cultural Heritage Curator, DRASSM, Marseilles, France. The survey took place at the University of Rome III in the laboratory of architectural representation directed by Prof. Diego Maestri. The laser scanning was made with the Callidus sensor gracefully lent by the company Geosystem group, Roma.

After this debugging phase on a simple object as an amphora, we project to extend this method for architectural survey.

1. INTRODUCTION

The main objective of architectural and patrimonial survey is to provide a precise documentation of the *status quo* of the surveyed objects (monuments, buildings, archaeological object and sites) for preservation and protection, for scientific studies and restoration purposes, for the presentation to the general public.

Complex object, not planar or with ornaments and decoration require high-density and high-resolution spatial data.

The laser scanning techniques and close range photogrammetry can offer two complementary sets of instruments and technologies capable to answer to the specific requirements of architectural and archaeological survey.

Laser scanner technology is based on active range sensors measuring directly the distance between the sensor and points over the surveyed object. Photogrammetric technology is generally based on processes of recording, measuring, and interpreting photographic images (passive sensor).

Several aspects can be considered comparing the two technologies:

i) *Acquisition time* is generally fast with photographic cameras but longer and sometimes manual work needs do be done for extracting dense 3D measurements from stereoscopic pictures. Laser scanner acquisition time can vary from scanner type up to a maximum of c.a. 30 minutes (for a single range scan) with the advantage of providing directly 3D measurements.

ii) *Resolution* is generally limited for laser sensor depending of type of sensor and generally decreasing with the increasing of scans range and spatial coverage. With high-resolution digital or analogical photos high-accurate measurements can be obtained

iii) *Shadow and occlusion problems* during acquisition phase can be solved through photogrammetric acquisition easier than planning many laser scanning acquisitions

iv) *Light condition*s are crucial for passive photogrammetric camera while active laser is independent from external lighting.
v) *Texture mapping* with realistic colours over 3D model can be provided directly from photogrammetric picture. Nevertheless the lack of direct relation between images and object coordinates requires long process for producing 3D textured models. Laser scanner can provide black and white reflectance and realistic texture mapping can be provided with dedicates software. Few short range laser scanners can provide RGB information together with black and white reflectance.
vi) *Extraction of characteristic* feature (i.e. edges, draw, and textural information) can be obtained through manual or semi-automatic tools within photogrammetric restitution process. This process is more difficult and generally less accurate for range scans.
vii) *Costs are higher* for sophisticate laser instruments than for photogrammetric instruments.

This no-exhaustive comparison between the two technologies reveals that none of them can solve all the problems inherent to architectural and archaeological survey. Laser scanner technology and photogrammetric techniques have a lot common points; a novel technique combining intensity and range data is presented for example in [Paulo et al, 2003], further developments are anyhow required to combine these two worlds.

In this research work four major problems where using the synergy between the two technologies have been identified:

1. Completing the model derived from laser measurements where data are missing through photogrammetric measures
2. Increasing quality of the features (i.e. edges) extracted from laser scanner model through photogrammetric measures
3. Increasing registration quality between laser range scans through photogrammetric measures
4. Increasing calibration camera parameters for model texturing through photogrammetric measures

This research focuses on the first and second problems. Moreover the 2 combined technologies provide measurement that involves the use of an expert system in order to rebuild an architectural or archaeological object. With the collaboration of architects or archaeologists is possible to derive ideal model from real measurements.

In this paper the general methodological approach is presented in Section 2. Laser and photogrammetric tools adopted for testing are described respectively in Section 3 and 4. Details of the archeologically importance the case study we focused on, are detailed in Section 5. Survey, data processing and measuring object with a theoretical model are described in Section 6, 7, and 8. Combination of the different approach is faced in Section 9. Case study result and final conclusion on the general approach are reported in Section 10 and 11 respectively.

2. GENERAL METHODOLOGICAL APPROACH

The work can be divided into 4 major steps:

1. Laser scanner section
2. Photogrammetric section
3. Measuring object with a theoretical model
4. Merging the different approaches

Laser scanner section includes range scan acquisition and data processing through Reconstructor Software by Joint Research Centre ñEuropean Commission ñ (JRC, EU). Single images are also acquired and combined with range data. A textured 3D model with lacks where laser data are missing (shadows and occlusions) is the out put results of this section.

Photogrammetric section includes the acquisition of images pair with a proper base-line, camera calibration and programmatic model building.

The photogrammetric process is divided in three steps from a very general one to a specific, artefact-dependent one, described in section 4. Geometric measurements derived from the combination of laser scanner and programmatic models are inserted in an expert system. Starting from real measurements, architectural and archaeological knowledge a theoretical model of the surveyed object can be derived.Laser scanner 3D model, photogrammetric model and theoretical model are merged and compare in a single tool.

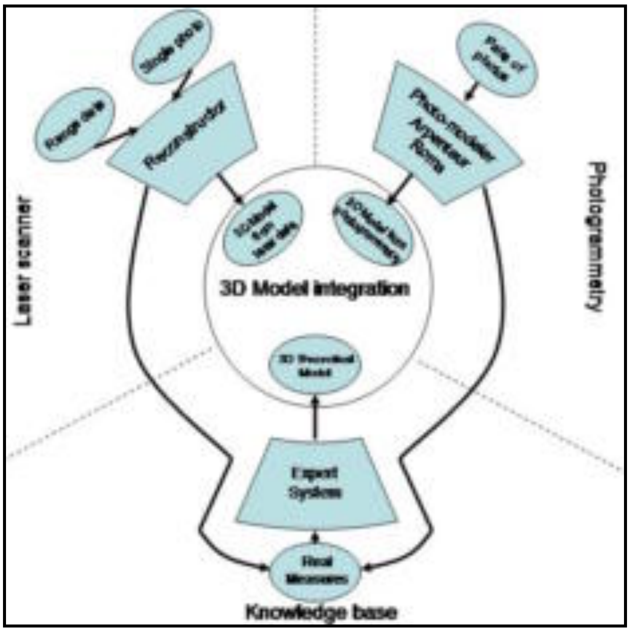

Figure 1 Method general scheme.

3. LASER SCANNER TOOLS

3.1 Laser scanner hardware

Laser range finder (LFR) can determine the distance from the systemís observation point to all points of consideration in a scene. Many LFR systems for short and long range measurements are available on the market.

LFRs can measure 3D pointís distances working with two different techniques: pulsed wave (time-of-flight) and continuous wave. [http://mortimer.jrc.it/]

For this experimental job range data were acquired using Callidus LFR [http://www.callidus.de/].

Callidus measurements system is a time-of-flight LRF; a short laser pulse is emitted at a given frequency and the time elapsed between the emission and the received echo is measured. During the measuring process Callidus measuring head can turned: i) by 360∞ along the horizontal plane (step size 0.0625∞, 0.125∞, 0.25∞, 0.5∞, 1.0∞), ii) by 180∞along the vertical plane (step size: 0.25∞, 0.5∞,1.0∞). Range distance is given up to 80 m (in radius).

3.2 Laser scanner software

Many software tools for range date processing are available on the market. Many of them has been traditionally developed for short range scan for reverse engineering purposes. Some laser scanner has property software which usually allows driving laser scanner acquisition and data storage.

The software adopted was specifically developed for the treatment of clouds of 3D points coming from laser scanner (long range) and digital images by 3DVeritas, an Italian company founded in 2000 as a spin-off from the European JRC. Actually the software development is provided by JRC where the software core originally comes from.
Reconstructor Software [Sequieira et al. 1999]; [Sgrenzaroli, Wolfart 2002] allows producing photo-realistic 3D reconstruction of real large-size object using laser scanning and still images.
The workflow for laser data acquisition phase and processing using Reconstructor can be divided in the following main steps:

viii) Data acquisition and storage; laser range data are acquire together with digital images and organized in project structure
ix) Pre-processing; range data are pre-processed for local normal computation, confidence value computation and noise reduction.
x) Data registration and geo-referencing; registration process transforms into a single reference frame, range data obtained from different viewpoints. This process can be also provided directly by laser acquisition software using external targets.
xi) Texture mapping; Reconstructor peculiarity is the possibility to use range information for external camera calibration and texture mapping over range information.
xii) Meshing; meshing tool converts the set of raw 3D points into a triangulated surface (mapped with reflectance or texture data)

The listed steps are described for the specific case study of this research in section **9**.

4. PHOTOGRAMMETRIC TOOLS

4.1 The photogrammetric way

The photogrammetric survey is driven by three constraints: a general photogrammetric survey, in order to get the camera orientation by bundle adjustment, a specific survey driven by a theoretical model, and an automatic or semi automatic measuring method in order to represent a specific surface of the measured object. The first step is made using generic and commercial photogrammetric software. In this project this first step was made using PhotoModelerV4.0. Data have been imported in Arpenteur software for the second step, Roma software was use for the third one. Arpenteur and Roma software are described in the following sections.

4.2 Arpenteur

ARPENTEUR (meaning ARchitectural PhotogrammEtry Network Tool for EdUcation and Research) is a set of software tools developed by Pierre Drap and Pierre Grussenmeyer, MAP CNRS laboratory. These tools are based on the notion network use and rely on the IP communication techniques. Examples can be consulted on the Internet site http://arpenteur.gamsau.archi.fr.
As a tool dedicated to archaeology and architecture, ARPENTEUR benefits from the expertise of two teams in the fields of close range photogrammetry and the representation of architectural information.
The main objective is founded on the idea of a process guided by the information related to the field. Concerning architecture and archaeology, the goal is to allow experts to use their knowledge to produce results which ideally meet their wishes. [BarcelÛ 2000] The results can be shown as documents, visual files, or as a body destined for a database. For this purpose the system gives to the experts a set of tools which allow them to formulate hypotheses related to their field of investigation, hypotheses that lead to easier measurement process. Between these, for example, the creation of a body representing the objects in their field of investigation.
As a benefit of those choices, the ARPENTEUR looks like a tool developed for professional architects and archaeologists with minimal intervention from the photogrammetry expert.

4.3 Roma: 3-D automatic Measurement Principles

ROMA, Representation of Oriented Model for Arpenteur, is a tool build on the I-MAGE method (standing for Image processing and Measure Assisted by GEometrical primitive) developed in the framework of the Arpenteur Project [Drap, Grussenmeyer, Gaillard, 2001]. Roma allows automatic measurement using a set of oriented photograph and a mesh visible on these photographs.
Two types of solutions are offered in software market: in simple software this phase is reduced to the minimum, the operator shows a point on a photograph using to the mouse pointer and the homologous point on another photograph; this solution is used for example in: Photomodeler, Rollei CDW, etc.... In more sophisticated software, based on stereoscopy, sometimes bounded with correlation, homologous pointís determination is more accurate but limited to at list two photographs and it needs the intervention of a photogrammetric restitution professional.
Roma uses simplified geometrical model, i.e. a surface mesh, image correlation and oriented photograph to determine 3D points visible on photograph and included in the mesh.

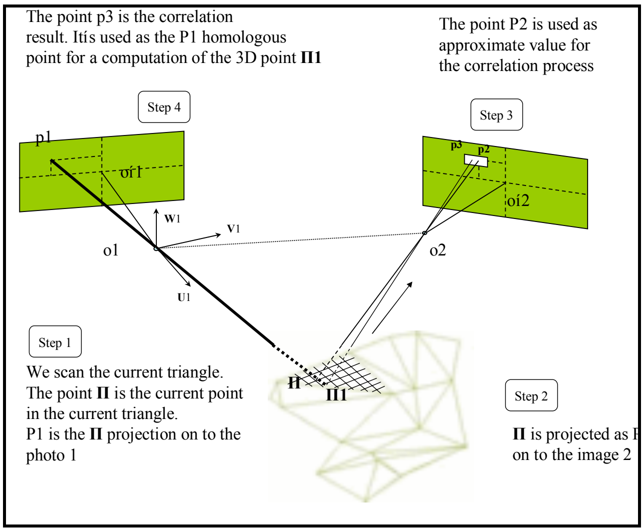

Figure 2. Roma schema of principle

We employ four steps ( ) in this Semi-automated Primitive Measurement Method, considering that a mesh has been measured and computed from a set of 3-D points visible on at least two images:

- ✓ For each triangle of the mesh we scan triangle and get point ∏. Each point ∏ is projected as p1 on to the photograph 1;
- ✓ ∏ is projected as p2 onto the second image;
- ✓ Point p2 is used as an approximate position to initiate the area based correlation process with p1;
- ✓ Point p3 is the result of the correlation; p1 and its homologous p3 are used for the computation of the 3-D co-ordinates of ∏1.

5. CASE STUDY: THE GRAND RIBAUD ESTRUSCAN WRECK

The Etruscan wreck discovered in 2000 by Mr. H.G. Delauze (COMEX, a French commercial salvage and diving company) has been dated to the between the 6th and 5th century B.C. and sits in 60 metres (197 feet) of water off the coast of Toulon, France. The archaeological interest in this wreck is considerable because only three wrecks of this type are known and all had been robbed before being studied archaeologically. A first campaign took place in October 2000 with the help of COMEX who made available their exploration vessel Minibex, their submarine RÈmora 2000 and a remotely operated vehicle (ROV).
The principal objective of the October 2000 project was to obtain digital photogrammetric coverage to record the actual state of the wreck and to allow the creation of a site plan and a 3D reconstruction using simultaneously the observed data, and archaeological sources and hypotheses.

6. THE SURVEY

An Etruscan amphora found on the Grand Ribaud F wreck, in HyËres, France, was surveyed with combines mixed means of Laser Scanner and photogrammetry measurement tools. The survey took place at the University of Rome III in the laboratory of architectural representation directed by Prof. Diego Maestri.
The survey phase can be divided in two main steps:
1) Laser scanner acquisition:
14 range scans were acquired with an horizontal step size 0,125∞ and vertical step size of 0,25∞. 13 range scans were acquired from 13 different positions around the amphora, maintaining the amphora in a fixed position through a tripod. 7 range scans were acquired using the laser scanner tripod viewing the amphora top-down. 6 range scans were acquired positioning the laser head on the ground viewing the amphora from down to top. The range scan viewing the amphora inside part was acquired positioning the object in different way. The acquisition points were positioned with a maximum distance from the amphora of about c.a. 2,7 m.
2) Photogrammetric acquisition:
A set of three photographs were taken, without too many constraints, from each laser scanner positions and from 2 right and left positions in order to guarantee a sufficient base-line. A schematic view of the acquisition scheme is reported in Figure 3.

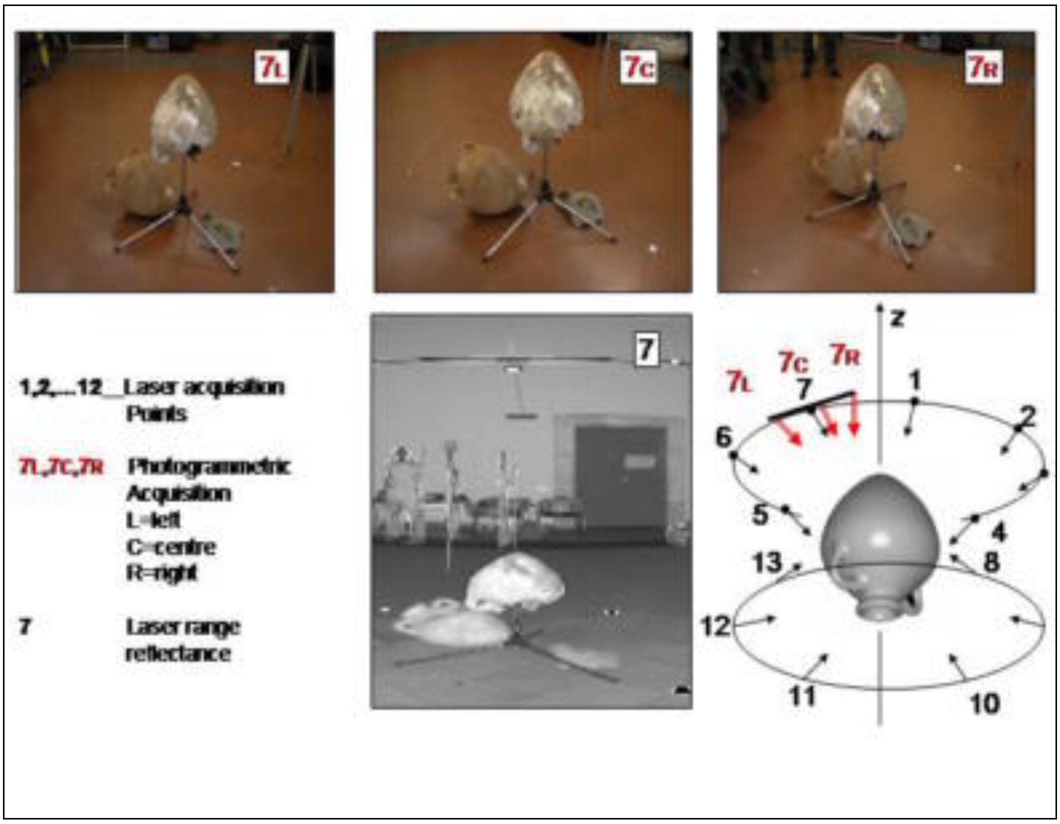

Figure 3. Survey scheme.

7. DATA PROCESSING

7.1 Laser scanner data

After LFR data acquisition and storage the processing steps listed in section 3.2 were performed.
During the pre-processing phase some manual work was necessary in order to reduce noise problems especially on edge area; due to the laser beam dimension some point are wrongly measured were edges between object are present.
The standard method, based on Iterative Closest Point (ICP) algorithm (Besl, McKay, 1992), was used for aligning each scan in a single reference system (registration process) The a-priori estimation of the relative position between two scans was provided using some external reference points manually recognized in the reflectance image.
In order to project the photos acquired centrally from the same laser scanner position (see figure 3), the software needs to know the external and internal camera parameters. Internal parameters can be computed for a specific camera using standard computer

vision algorithms, which process images taken of a calibration object. The adopted Tsai camera model (Tsai, 1987) uses 5 parameters (focal length, centre of project, pixel aspect ratio and 1st degree radial distortion). Range information was used to estimate the external parameters (the translation and rotation of the camera relative to the global reference frame).
Finally per scan triangulation, based on the 2D grid provided by the scanner (Turk, 92), was created. The main problem with per scan triangulation is that the meshes from different scans need to be merged after triangulation, which can be a difficult task. nThe final result of laser data processing was a textured 3D model which can be measured and compare with model.

7.2 Photogrammetric data

The photogrammetric process, described in section 4, provides a set of geometrical data on the lacked geometry coming from laser scanner measurement. The lacked geometry has two different origins: the object is broken (a part of the lips is destroyed) and a artificial hole was simulates in the belly part to represent a physical obstacle during the laser scanning phase. The photogrammetry gave us the photograph orientation, in the same reference system, a textured mesh obtain with an automatic measurement process and data to generate theoretical model.

8. MEASURING OBJECT WITH A THEOTERICAL MODEL

8.1 Elaboration of a Specific Body

The measurement process proposed in this work is relying upon the hypothesis of the existence a theoretical model of the architectural objects studied. We can suggest a theoretical model for the amphora founded in the Etruscan wreck.
All of these amphorae are of Etruscan origin and have the same shape as amphorae individualized by A. Py in 1974 (type Py 4) in a study of the imports to Vaunage and Villevielle (Gard). Eleven years later, Gras and Slaska completed this initial classification by proposing a typology of amphora from Southern Etruria. The type Py 4 and its variants have been included in the EMD group (for detail see [Py M. et F., 1974] and the work of Sourisseau, 1997). This regularity in the production of the amphora allows us to use a modelling approach and to formalize this knowledge into a hierarchy of objects sharing the same properties and structured according to the Object paradigm. The amphorae from the wreck, for the time being, have been grouped into four sub-classes of the Py 4 type amphorae according to morphological considerations.

8.2 The use of an expert system

The objects heterogeneity handled by the archaeologist and the geometric complexity of their surfaces led us to search for stable morphological characteristics of the objects where diagnostic measurements could be taken. These diagnostic characteristics are also described in the model.
A series of simple geometric primitives are used to approximate these morphological characteristics and are used as an interface between the photogrammetric measurement and the underlying model. The measurement can have two purposes: object orientation and position and determine their intrinsic characteristics.

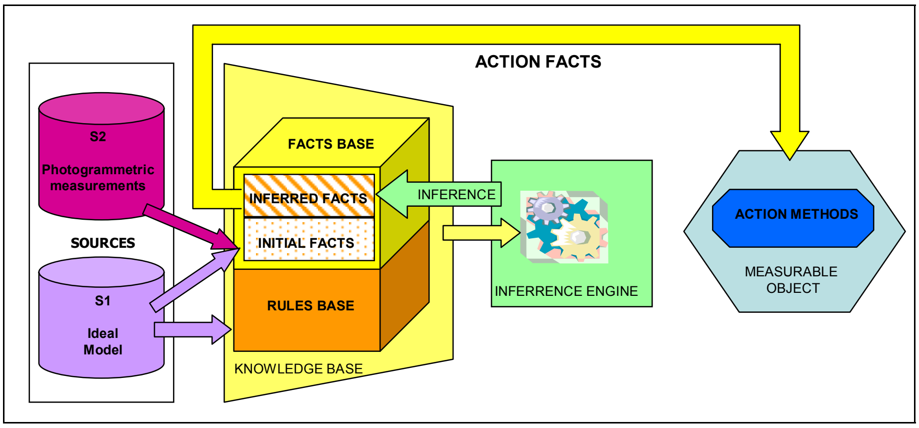

Fig. 4. The Expert System general schema.

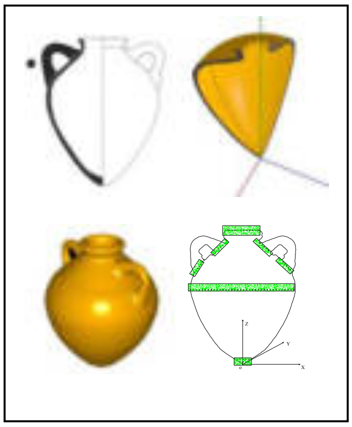

Fig.5. Ideal amphora model: from archaeologist design to digital model

The photogrammetric measurement is supported by some strategic points on the amphora (Fig. 4, on the right side). Five areas are used to redundantly define the amphora coordinate system definition parameters. If measurements to certain parts of the amphora are impossible, the coordinate system determination mechanism uses relationships between amphorae (if existent) or default values. The inference problem of values relying upon incomplete data or data that needs to be re-evaluated is frequent in archaeology.
Obtaining an amphora 3D representation requires a merge of photogrammetric measurements (S2) and theoretical model (S1). The technique that we use consists in supplementing photogrammetric measurements by the theoretical model. These two data sources give information on the remarkable zones of the amphorae, defined by an archaeologist (lip, belly, handles, back, see Fig. 4). It is obvious that the difficulty of the source merge consists in finding at which time to use a source or the other. The solution used by our system is the recourse to propositional logic to formalize the knowledge contained in the two sources and how to use it. The merging method is provided by an inference on the logic formalization of the sources which generates actions to be achieved. Finally the merge is carried out according to the actions. [Drap, Seinturier, Long, 2003].

9. EXPERIMENTAL RESULTS: MERGING SEVERAL APPROACH IN THE SAME TOOL

9.1 Combination of methodology

The Etruscan amphora was surveyed with Laser scanner and photogrammetric tolls. Textured meshes of the object were produced using: i) Reconstructor Software for LFR data and digital photos, ii) Arpenteur and ROMA Software for photogrammetric photos.
A theoretical model was produced by means of few real measures derived from real surveyed object.
The final step of merging the different approaches in the same tool was provided trough Surveyor Software (by Joint Research Centre ñEuropean Commission ñ JRC, EU). This tool allows importing wrml models, combining and comparing them, extracting linear-areas measurements, cross sections and orthographic view [Sgrenzaroli, Wolfart 2002].
An experimental test was set up in order to emphasise the potentiality of the combination between LFR and photogrammetry. An artificial hole was created in the laser range mesh using the Reconstructor mesh editor. The mesh derived from photos 7R, 7C, and 7R (see figure 3) using Arpenteur-ROMA tools was used to close the artificial hole.

9.2 Visualization and Interaction

The Surveyor Software provide different tool for managing the combined model: i) wrml models import and export, ii) model comparison, iii) linear-areas measurements extraction, iv) cross-sections and orthographic view creation. Examples of these tools used for the amphora test are show in figure 7. The photogrammetric model of the seabed surface where the Etruscan wreck was found combined with the LFR amphora model is also visualized.

10. CONCLUSION

The first steps of a common work towards building a survey tool that integrates the LFR technology and close range photogrammetry based on knowledge closer to the measured object has been presented in this article. The result is a textured mesh coming from a laser scanner software, a mesh coming from automatic photogrammetry using a geometrical approximation of the object and image correlation for the part of the object invisible by the scanner and a simple mesh for the lacked part of the measured object coming from a theoretical description. We are currently working on different aspect of this problem: i) the different data source integration in the Reconstructor Software, ii) the usage of automatic photogrammetric measurement beyond an approximation of the object geometry and image processing techniques, points of interest (as for example Harrisí points), iii) the geometrical formalization of the ideal model of the objects.

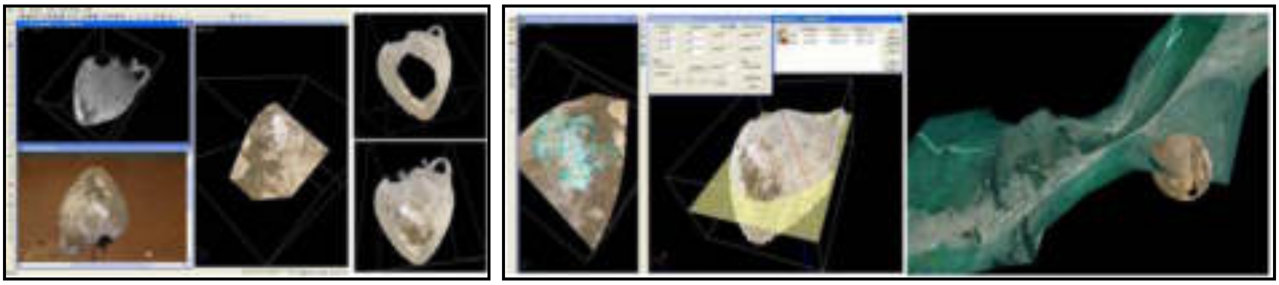

Fig. 6. On the left: Synoptic view of method combination; on the left laser range and programmatic photo, the mesh derived from photogrammetry in the central icon, and on the right the artificial hole in the laser- derived mesh close through the mesh derived from photogrammetry

11. REFERENCES

[BarcelÛ, 2000] Juan A. BarcelÛ Visualizing what might be. An introduction to virtual reality techniques in archaeology. VIRTUAL REALITY IN ARCHAEOLOGY, Edited by Juan A. BarcelÛ, Donald Sanders, Maurizio Forte. Published by ArchÈopress PO Box 920 Oxforf OX27YH, 2000.

[Besl, McKay, 1992] Besl, P. J. and McKay, N. D., 1992. A method for registration of3-D shapes. IEEE Trans. Pattern Analysis and Machine Intelligence, 14(2): 239-256, 1999

[Drap, Seinturier, Long, 2003] Pierre Drap, Julien Seinturier, Luc Long, *A photogrammetric process driven by an Expert System: A new approach for underwater archaeological surveying applied to the ëGrand Ribaud Fí Etruscan wreck,* ACVA'03, Applications of Computer Vision in Archaeology, Madison, Wisconsin, USA, June 17, 2003.

[Drap, Grussenmeyer, Gaillard, 2001] Pierre Drap, Pierre Grussenmeyer, Gilles Gaillard. *Simple photogrammetric methods with arpenteur. 3-d plotting and orthoimage generation : the I-MAGE process*. CIPA 2001 International Symposium, Potsdam University (Germany) September 18 - 21, 2001. The ISPRS International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIV ñ 5/C7, ISSN 1682-1750, p. 47, 54.

[Paulo et al, 2003] D. Paulo, S. Sequeira and F.Vaz , 2003, Registration and Fusion of Intensity and Range Data for 3D Modelling of Real World Scenes, 3Dim (to be published)

[Py M. et F., 1974] Py F. et Py M. *Les amphores Ètrusques de Vaunage et de Villevielle (Gard)*, in : MEFRA 86, 1974, 1.

[Sequieira et al., 1999] V. Sequeira, K. Ng, E. Wolfart, J.G.M. GonÁalves, D. Hogg,1999.,"Automated Reconstruction of 3D Models from Real Environments", ISPRS Journal of Photogrammetry and Remote Sensing (Elsevier), vol. 54, pp. 1-22.

[Sgrenzaroli, Wolfart 2002] M. Sgrenzaroli, E. Wolfart 2002, Accurate texture-mapped 3D models for documentation, surveying and presentation purposes, CIPA-Corfu 2002

[Sourisseau, 1997] Sourisseau J.-Chr. Recherches sur les amphores de Provence et de la Basse VallÈe du RhÙne aux Èpoques archaÔque et Classique (fin VIIË-dÈbut IVË s. av. J.-C.), thËse de doctorat, Aix-en-Provence, 1997

[Tsai, 1987] Tsai, R.Y.,A versatile camera calibration technique for high-accuracy 3D machine vision metrology using off-theshelf TV cameras and lenses. IEEE J. Robotics and Automation, 3(4): 323-344, 1987