PHOTOGRAMMETRY FOR VIRTUAL EXPLORATION OF UNDERWATER ARCHEOLOGICAL SITES

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ABSTRACT:

This article describes on-going developments of the VENUS European Project (Virtual ExploratioN of Underwater Sites, http://www.venus-project.eu) concerning the first mission to sea in Pianosa Island, Italy in October 2006.
The VENUS project aims at providing scientific methodologies and technological tools for the virtual exploration of deep underwater archaeological sites. The VENUS project will improve the accessibility of underwater sites by generating thorough and exhaustive 3D records for virtual exploration.
In this paper we focus on the underwater photogrammetric approach used to survey the archaeological site of Pianosa.
After a brief presentation of the archaeological context we shall see the calibration process in such a context. The next part of this paper is dedicated to the survey: it is divided into two parts: a DTM of the site (combining acoustic bathymetry and photogrammetry) and a specific artefact plotting dedicated to the amphorae present on the site.

1. VENUS, VIRTUAL EXPLORATION OF UNDERWATER SITES

The VENUS project is funded by European Commission, Information Society Technologies (IST) programme of the 6th FP for RTD [**]. It aims at providing scientific methodologies and technological tools for the virtual exploration of deep underwater archaeological sites. (Chapman et alii, 2006).
Underwater archaeological sites, for example shipwrecks, offer extraordinary opportunities for archaeologists due to factors such as darkness, low temperatures and a low oxygen rate which are favourable to preservation. On the other hand, these sites can not be experienced first hand and today are continuously jeopardised by activities such as deep trawling that destroy their surface layer.
The VENUS project will improve the accessibility of underwater sites by generating thorough and exhaustive 3D records for virtual exploration.
The project team plans to survey shipwrecks at various depths and to explore advanced methods and techniques of data acquisition through autonomous or remotely operated unmanned vehicles with innovative sonar and photogrammetry equipment. Research will also cover aspects such as data processing and storage, plotting of archaeological artefacts and information system management. This work will result in a series of best practices and procedures for collecting and storing data.

Further, VENUS will develop virtual reality and augmented reality tools for the visualisation of an immersive interaction with a digital model of an underwater site. The model will be made accessible online, both as an example of digital preservation and for demonstrating new facilities of exploration in a safe, cost-effective and pedagogical environment. The virtual underwater site will provide archaeologists with an improved insight into the data and the general public with simulated dives to the site.
The VENUS consortium, composed of eleven partners, is pooling expertise in various disciplines: archaeology and underwater exploration, knowledge representation and photogrammetry, virtual reality and digital data preservation.
This paper focuses on the first experimentation in Pianosa Island, Tuscany, Italy.
The document is structured as follows. A short description of the archaeological context, then the next section explains the survey method: calibration, collecting photographs using ROV and divers, photographs orientation and a particular way to measure amphorae with photogrammetry using archaeological knowledge. A section shows 3D results in VRML and finally we present the future planned work.

2. THE UNDERWATER ARCHAEOLOGICAL SITE OF *PIANOSA* ISLAND

The underwater archaeological site of *Pianosa*, discovered in 1989 by volunteer divers (Giuseppe Adriani, Paolo Vaccari), is located at a depth of 35 m, close to the *Scoglio della Scola*, in

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** http://cordis.europa.eu/ist/digicult/venus.htm or the project web site : http://www.venus-project.eu

front of the east coast of the island. The site is characterized by the presence of about one hundred amphorae of different origin and epoch. The various amphorae range from *Dressel* 1A (1st century B.C.) to *Beltran* 2 B and *Dressel* 20 , up to *African* models (3rd century A. D.) The site has been surveyed in 2001 by the *Nucleo Operativo Subacqueo* (MIBAC-SBAT) divers. This survey, carried out by the SBAT, proved that the site had remained untouched. And it was necessary to start a first test of excavation to know the exact nature of the archaeological site: this was one of the aims that the October 2006 underwater mission has reached.
The remarkable depth allows diving and the site was chosen to make survey using both robotic equipment and divers.
The experimental activity, under the supervision of the archaeological team of MIBAC-SBAT, has been carried out by CNRS for the photogrammetric survey, ISME with its own ROV equipped with camera from COMEX, and its georeferentiation and positioning system.
The site had to be cleaned before surveying, mainly because of the presence of dead posidonia. This first operation was made in September 2006 by SBAT including specialists from CH conservation: Roberto Bonaiuti and Emiliano Africano.

3. PHOTOGRAMMETRIC SURVEY IN PIANOSA

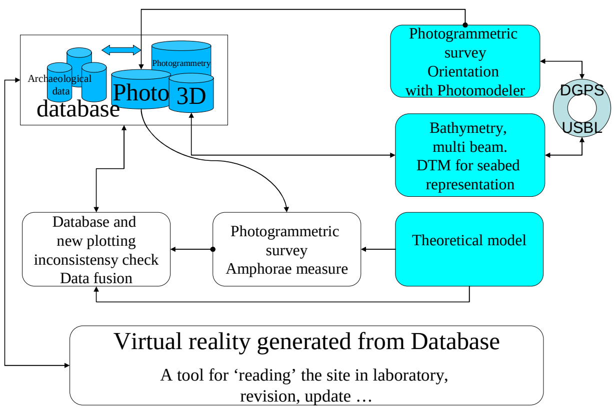

Figure 1. Synoptic schema of surveying process

The survey is done merging several kinds of information: bathymetry, DTM from photogrammetry, artefacts measure with photogrammetry and theoretical model of artefact objects. The entire survey is stored in a relational database and the geometry is exported toward tools for Virtual Reality (see fig. 1) . This approach will allow archaeologists to see the entire site, using immersive VR technologies, without diving. (Drap, Durand, Provin, Long. 2005).

3.1 Two different ways for data capture

The photogrammetric survey in Pianosa is made by a set of photographs with the right overlap (around 60%). The geometry is very similar to the technique used in aerial photogrammetry; the main difference is the distance to the seabed and the immersion in water.
As we are sure that the seabed is more or less flat, we can use a set of photographs with vertical axis to make the survey.
The photographs are taken by strips with 60% overlap for the consecutive photographs in a strip and 20% overlap from one strip to another. (See fig 3).

This first mission in Pianosa was an opportunity to test and improve several ways to perform this survey. As this site is 35m deep, we can use both a survey with divers (CNRS partner), and start a survey by ROV, managed by ISME.
The diver has a Nikon™ D70 digital camera with a 14 mm lens from Sigma™ and two flashes Subtronic™. The digital camera was embedded in a Subal™ housing with a hemispherical glass. COMEX brought its digital camera equipped for connection to the ROV: a Nikon DH2, a 14 mm lens from Sigma™ and two flashes Nikon™, SB800. The housing and connector was made by COMEX with a flat glass. (See fig.2)
A zone to be surveyed has been determined by the team and equipped with 4 scale bar (2m) and a set of 15 makers (cement block 15x15x10cm) in order to define a network for a better ROV guidance.

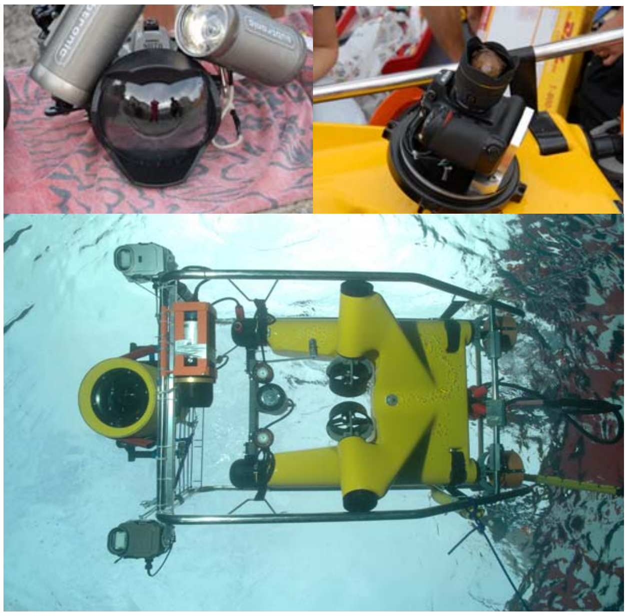

Figure 2. On the top left: the digital camera and its housing used by the diver, on the top right: the digital mounted on the housing back of the ROV, on the bottom the ROV in water with digital camera and flashes in their housing. (photo by R. Graille, CNRS)

3.2 ROV Remotely Operated Vehicle

In this mission ISME (LabMACS, Università Politecnica delle Marche - Ancona) has used the ROV unit Phantom S2. This ROV is an improved commercial ROV produced originally by Deep Oceans; it is a small class ROV DOE Phantom S2 with operating depth of 300 m. It is equipped with four thrusters (two horizontal main thrusters and two vertran ones) that actuate four degrees of freedom (surge, sway, heave and yaw): the onboard sensory system consists of a 3CCD camera, a deep meter, a compass and an inertial measuring unit (IMU) that evaluates linear accelerations and angular velocities along and around three axis. (Conte et Alii., 2004)
Mission tasks have also required the use and the integration in the control architecture of three sensor systems: a SONAR property of LabMACS, a rent SCOUT USBL and a Digital Photo Camera property of COMEX. The sonar heads is a MS 1000 produced by Kongsberg-Symrad and produces a pencil beam of conic shape, whose main lobe width is 2.7°. The second acoustic device used was the SCOUT USBL of

Sonardyne and is equipped for ROV position tracking during the mission. Finally in order to guarantee an acquisition of high definition optical image, the COMEX camera a Nikon D2Hs with a sensor of 4.26 million total pixels was integrated in the ROV system. (Conte et Alii., 2007)
The ROV has made a survey on the zone delimited by the markers. The pilot use a video camera located on the bow. He can see the markers and pilots in order to make strips. The photographs were taken in two modes:

- Manually, an operator, looking thought the lens by a small video camera to shoot the image.
- With a fixed frequency, decided according to the ROV speed and altitude.

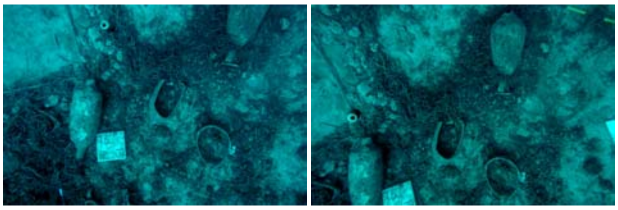

Figure 3. Two photographs from a strip made by the ROV.

3.3 Multimedia calibration

The camera calibration in multimedia photogrammetry is a problem already identified since almost 50 years. (Bass G., 1970) You can refer to Hans-Gerd Maas (Maas, 1995) to have an overview of the state of art of this field. The problem is not obvious, the light beam refraction through the different diopters (water, glass, air) introduces a refraction error witch is impossible to express as a function of the image plane coordinates alone. (Maas Hans-Gerd 1995)
Therefore the deviation due to refraction is close to those produced by radial distortion even if radial distortion and refraction are two physical phenomena of different nature.
For this reason we start to use standard photogrammetric calibration software and make a calibration of the set housing + digital camera. The distortion corrects in a large part the refraction perturbation. This was also shown by Kwon (Kwon, 1998) (Kwon & Lindley, 2000).
But this approach is strongly dependent of the ultimate dioptr water/glass of the housing. To try to minimize the refraction error we can found on the market some housing with a hemispherical glass, which is the case of Subal™ housing used with the diver. For the other one, made by COMEX the glass was plate and the refraction action is much more important.
We shall work on a method to compense separately refraction and distortion; this will be done in a future work.
For the moment and in order to validate the photogrammetric campaign, we have made the calibration using Photomodeler™ for the two housings.

3.4 The reference system

The choice of a reference system to express the measured data is very important. It's depending of the archaeological needs. Several cases can occur:

- We don't have any way to get an absolute position, or we don't need it. In this case we have to define the reference system on local, observable geometry. For example something which defines the axis of symmetry of the wreck (if there is one); buoys to define the vertical axis; scale bar.
- We need an absolute orientation and we have several ways to obtain it. For example a pipe line as DGPS – USBL can give an approximation of the ROV position, etc…

In Pianosa we will use an absolute reference given in two modes: when it will be possible ISME will associate for each photographs coming from the ROV six parameters as: x, y, z, Omega, Phi, Kappa. In the same time they will measure the absolute coordinates of a set of markers seen on the photographs and used as control points.

Figure 4. Marker on the seabed.

3.5 Orientation phase

More than three hundred photographs have been taken by the diver. They cover an area of 20 x 20 meters. The orientation was done manually using Photomodeler™.
The photographs orientation was done using points on the seabed, except on the amphorae in order to be used to define a DTM on the seabed. The oriented photographs and the diver's trajectory are visible in figure 5.
Five markers, visible in figure 4, were used as control points. The adaptation on these points was done outside of Photomodeler™ and the residuals are visible on the table below.

n	x	y	z	residual
1	297.052	112.981	-32.646	0.325
15	306.267	106.718	-32.685	0.254
5	306.757	111.633	-32.904	0.114
11	396.511	108.064	-32.438	0.400

Table 1. Residuals after adaptation photogrammetry onto acoustic survey. (The coordinate are translated for site protection reason)

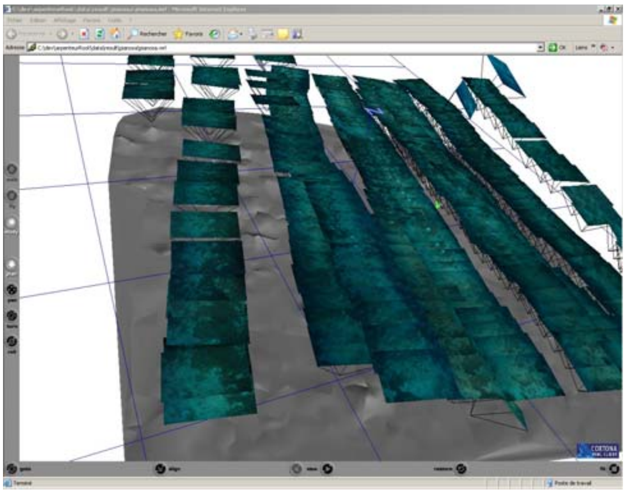

Figure 5. Oriented photographs visualised in VRML with the non textured seabed.

3.6 Amphorae plotting

Using the oriented photographw a plotting phase, driven by archaeological knowledge is processed to obtain both 3D model representing the amphorae and a database managing all the data of the project .

3.6.1 A method for measuring amphorae, After the orientation phase we shall, in the next months, start the amphorae plotting phase. This second step will use archaeological knowledge to obtain a complete representation of the measured artefact; it will be articulated in three steps:
1) Development of the theoretical model: for each identified object, a geometrical description offers a whole of geometrical primitives, which are the only objects to be potentially measured, and a theoretical representation of the object. In our case archaeologists have identified six amphora typologyies and we shall produce a theoretical model for each of them. This theoretical model is formalized in a hybrid way, taxonomy of archaeological artefacts and an XML representation for the Amphorae typology.
2) As photogrammetric measurements are highly incomplete (the object is seen only partially or may be deteriorated), an Expert System will determine the best strategy to inform provide all the geometrical parameters of the studied object, starting from the measurement process and handling the default data as defined in the archaeological model and the geometrical model. The expert System used is Jess. (http://herzberg.ca.sandia.gov/jess/)
3) The resulting object is thus based on a theoretical model, dimensioned more or less partially by a photogrammetric measurement. During the exploitation of the photographs the operator can choose the number of attributes of the object which are relevant to measure. The choice of attributes will be revisable in time, as for example during a second serie of measurements. The system can be used to position in space some objects from a catalogue after a scaling process.
All these development are done in Java and connected to the Arpenteur photogrammetric toolbox. (Drap et alii. 2003), (Drap, Long, 2005), (Drap, Long, 2006).

3.6.2 Measuring paradigm amphorae In order to use the method describe above, the archaeologists have taken up six amphorae from the site. These amphorae will be used as paradigm to define the theoretical model needed. The first step is to measure the amphorae and to define a geometrical model. Some amphorae have been designed in a traditional way at scale 1:1, for some others as for example the type *gauloise 3* we used the typology presented by our partner ADS Archaeological Data Service, University of York, UK. (http://ads.ahds.ac.uk/catalogue/archive/amphora_ahrb_2005/details.cfm?id=135)

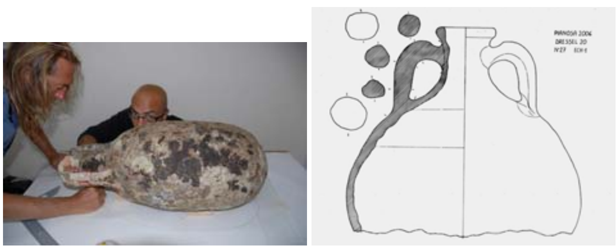

Figure 6. Direct measuring at scale 1:1 of amphorae. On the left side archeologist is measuring the amphora ; on the right a design produced at scale 1:1

3.6.3 A database to manage photographs and artifacts After the orientation phase done with Photomodeler™ all the oriented photographs are stored in the database with all the associated computed parameters. The archaeological plotting phase is done with a specific photogrammetric module, using only two images. (See a snapshot of the interface in fig 7 below).

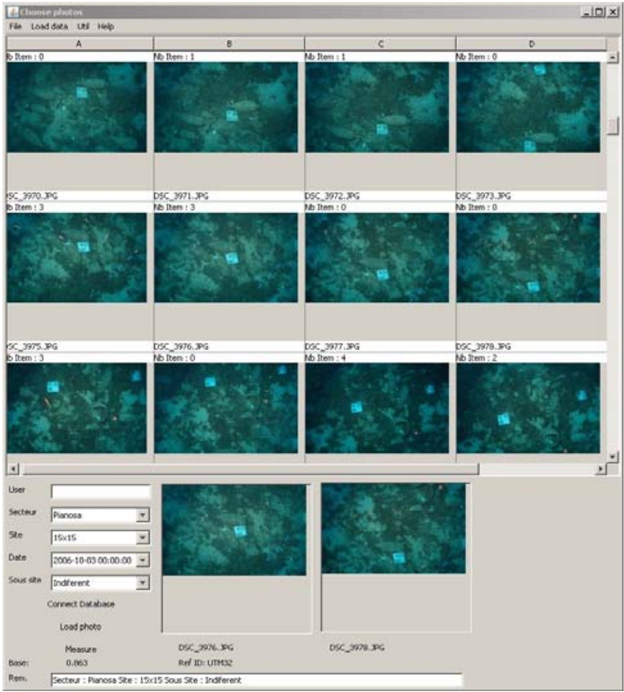

Figure 7. Choosing 2 photographs from the database and building a photogrammetric model on the fly.

At this stage the accuracy is sufficient with a measure done with two images and the interface is simpler to manage. The user has to choose two photographs, already measured amphorae are displayed and Arpenteur will generate a correspondent photogrammetric model on the fly. The application will connect to the database over the Internet to display thumbnails and to load photographs and already plotted amphorae.
In addition of the photogrammetric data all the data concerning archaeological items are stored in the database. These data are defined in the theoretical model (defined in section 3.6.1) they contain all photogrammetric data and all the archaeological data needed by archaeologists.
A direct link to the Database Php interface is available by picking the displayed amphorae in the VRML generated file.

3.6.4 The plotting interface The diversity of the objects handled by the archaeologists and the geometric complexity of their surfaces led us to search for stable morphological characteristics of the objects where diagnostic measurements could be taken. 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.
In the case of amphorae we define four measurable zones, rims, handle, belly, bottom, and we use a set of geometrical primitives computed by least square method onto the measured points. For example a circle on the rim or belly points, a line on bottom point and center of these two circles.

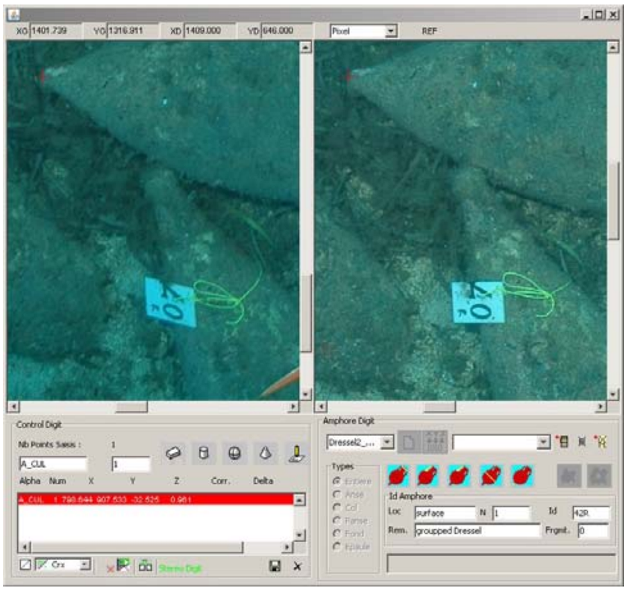

Figure 8. Plotting amphorae according to the theoretical model.

This interface (fig 8) allows the user (generally an archaeologist) to

- Recognize the amphora type on the photographs,
- Choose the amphora type in the interface combo box (The site was already studied in collaboration with archaeologists to define the typology),
- Measure a set of points on the zone where measure is allowed,
- Add archaeological comments and observations,
- Compute the object, using the measured points to construct a new instance of amphorae,
- Insure consistency between observations and theoretical model,
- Store this new instance in the remote database.

4. MERGING RESULTS

We have merged the data coming from the bathymetry mission, conducted by *Geosystem Parma*, Italy, the photogrammetric campaign ie, a survey of the seabed at large scale with a good quality texture and a survey, driven by archaeological knowledge of all the amphorae and fragments of the site with a direct link from the Amphorae representation to the database. (see fig 9 to 11).

All these data now are stored in a relational database (MySql) and a set of java tools allows to wrap objects from the database and to produce a VRML representation.

The VRML file produced contains a link for every amphora to the database via a PhP interface. This interface allows the user to see, check and modify the archaeological values regarding the amphorae. Of course the user has access to all the data, i.e. measuring points, photos and photo orientation used to measure the artefact, but these data are read only through this interface.

At this stage we use another tool to check inconstancy in the site: an extension of the arpenteur project: Ametist, for **A**rpenteur **M**anag**E**ment **T**ool for **I**nteractive **S**urvey **T**reatment. This is a new part of the project which provides an easy to use system of survey management. The application can perform various post-processing on data issued from Arpenteur's interface. Operations can be data verification, merging different data sources or export data in various formats (such as XML, VRML ...). (Seinturier J., Drap P., & Papini O. 2006)

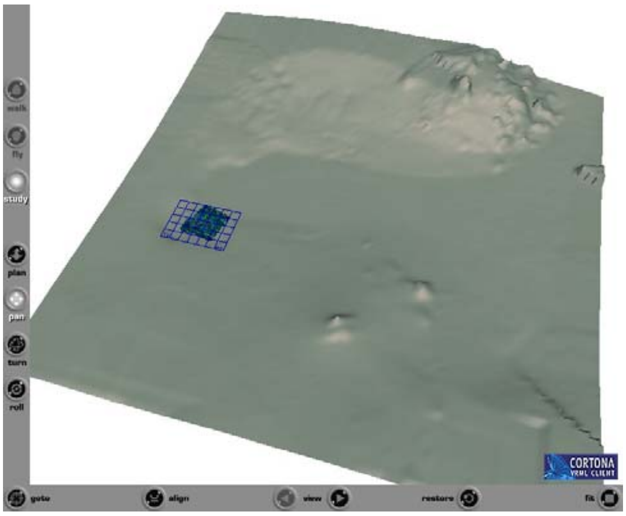

Figure 9. Bathymetry (without texturing) and 20x20m zone surveyed by photogrammetry.

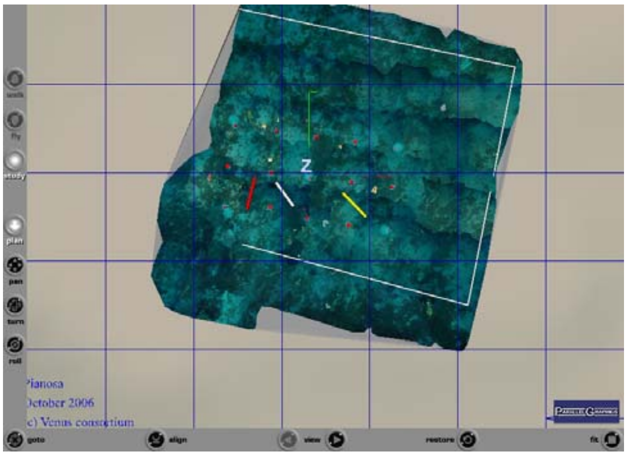

Figure 10. The 20x20m surveyed by photogrammetry. The VRML file representing seabed and amphorae is generated automatically by interpretation of data from the database.

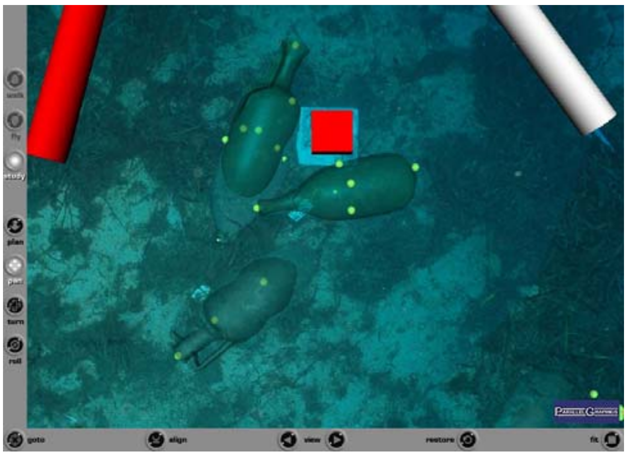

Figure 11. VRML representation of reconstructed amphorae. Also visible the measured points on amphorae, a marker and two scale bars. The seabed is textured using the oriented photographs.

5. CONCLUSIONS AND FUTURE WORK

Archaeologists need to explore and make an inventory of deep wreck sites unreachable by divers as these sites may be jeopardized by deep trawling in the very next few years . The digital preservation aspect is one of the main goals of this project.

We have presented here the underwater survey process from taking photographs to the site reconstruction, merging acoustic and optical data, and a theoretical model based on archaeological knowledge for amphorae. In the framework of the VENUS project a work is in progress to define ontologies for underwater archaeology and more precisely for amphorae present on the site. (Jeansoulin R., Papini O., 2007)

The measured object are stored in a database and wrapped in Java Objects able to generate their morphology in VRML.

In addition of the site survey presented here we plan to immerse archaeologists inside a virtual universe depicting a reconstructed archaeological site, for example a shipwreck, and allow them to work on this site as naturally as possible. The digital model generated by the survey will then be used, with the help of virtual reality and mixed reality, for constructing immersive, virtual environments that enable archaeologists and general public to experience an accurate and fully immersive visualization of the site.

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