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VENUS (Virtual Exploration of Underwater Sites) Two years of interdisciplinary collaboration.

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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>) over its first two years of activity. The VENUS project is a collaborative venture which aims to bring together archaeological and scientific methodologies with technological tools for virtual exploration of deep underwater archaeological sites. The breadth of results produced by the project allow us to give only an overview of the key issues here.

The techniques developed through the work of the project are firmly rooted in the requirements of the archaeologists involved. The on-going relationship between archaeological requirements and technological solutions developed in response to them forms the core of the project. In this article we will describe the evolution of both the archaeological methodologies and the technical solutions that were developed to support them during the first mission of the project – at Pianosa Island, Italy in October 2006 - and in the subsequent activity, including the second mission to Sesimbra, Portugal in October 2007, and the preparation of the third one, to Marseille, France, at the end of 2008.

Realising the integration of the acoustic data stream with the optical data acquisition has formed a major component of the first two years of the project. Acoustic sensors track the position of unmanned underwater vehicles, like ROVs and AUVs, while they collect images during a site's survey. The fusion of acoustic and navigation data provides the seed for the photogrammetric process, recording cameras' position and orientation in real time within the EXIF metadata of the images.

In response to archaeological requirements the representation of the data takes two distinct forms. The first being a traditional two-dimensional representation, conforming to the illustrative norms of archaeological cartography, providing a rich interface to the extensive underlying archaeological datasets. The second representation is a three-dimensional visualization of the site. By using an augmented reality system, we are able to make available for archaeological investigation complex datasets in the accepted, traditional, two-dimensional form, as well as to produce three-dimensional interfaces which provide new insights on archaeological data.

In order to represent the archaeological information, we consider a knowledge base consisting of application ontology and observations. We constructed application ontology for underwater archaeological knowledge.

Throughout the course of data acquisition, processing and delivery, the project has addressed the need for long-term preservation and access to the dataset. By identifying specific digital preservation requirements, the aim is to produce guidelines for the archiving of material derived from future investigations.

The project will conclude with a final field mission near Marseille, France, utilising all the techniques developed to undertake a fully automated diver-less survey of a deep-water wreckage site. The culmination of the project will realise the desire of archaeologists and of the general public to make possible the interaction with an underwater site that is out of the physical reach of the common diver.

1 INTRODUCTION

The VENUS project is funded by the European Commission, Information Society Technologies (IST) program. It aims at providing scientific methodologies and technological tools for the virtual exploration of deep underwater archaeological sites [1].

Underwater archaeological sites, for example shipwrecks, offer extraordinary opportunities for archaeologists due to factors, such as darkness, low temperatures and a low percentage of oxygen, which are favourable to preservation. On the other hand, these sites cannot be

experienced firsthand and are continuously jeopardized today by activities such as deep trawling that destroy their exposed layer.

The VENUS project will improve the accessibility of underwater sites by developing tools and methodologies for constructing thorough and exhaustive 3D archives for virtual exploration.

The project team plans to survey shipwrecks at various depths and to explore advanced methods and techniques of data acquisition by means of autonomous or remotely operated vehicles (ROVs) equipped with acoustic and photogrammetric devices. VENUS research also covers

aspects such as data processing and storage, plotting of archaeological artefacts, information system management and best practices and procedures for underwater cultural heritage.

Further, VENUS will develop virtual reality and augmented reality tools for the visualization of an immersive interaction with digital models of underwater sites. Models 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. Virtual underwater sites will help archaeologists to get a better insight into the data and they will let the general public experience simulated dives to the sites.

The VENUS consortium, composed of eleven partners, is pooling expertise from various disciplines: archaeology and underwater exploration, knowledge representation and photogrammetry, virtual reality and digital data preservation.

2 THE UNDERWATER ARCHAEOLOGICAL SITE OF PIANOSA ISLAND

This Section focuses on the first experimental sea trial in the project that has taken place in Pianosa Island, Tuscan Archipelago, Italy, on October 2006. Pianosa Island belongs to the Tuscany Archipelago, North Tyrrhenian Sea, Western Mediterranean. The underwater archaeological site of Pianosa, discovered in 1989 by volunteer divers, is located at a depth of 35 m, close to the “Scoglio della Scola”, in front of the east coast of the island. The site, mainly untouched, is characterized by the presence of about one hundred amphorae of different origin and epochs. 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 Iberian amphorae (Dressel 2-4, Pascual 1, Beltran 2 B) are predominating and they come either from northern Spain (*Tarraconensis*) or from southern Spain (*Baetica*). The site has been chosen as an operative test-bed for the VENUS project since its depth allows to survey the area using both robotic equipment and divers.

3 PHOTGRAMMETRIC SURVEY IN PIANOSA

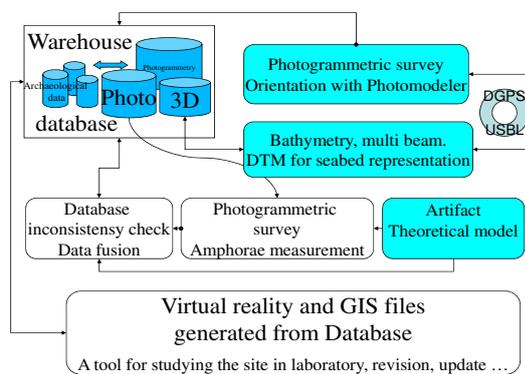


Figure 1: Synoptic scheme of surveying, data handling and rendering process.

The main goal of the experimentation at Pianosa was to provide photogrammetric data complemented by additional information (as bathymetry and seabed morphology, described by a Digital Terrain Model (DTM), obtained from acoustic and optical

measurements) and properly georeferenced by the combined use of an underwater acoustic positioning system (USBL – Ultra Short Base Line Systems) and a Differential GPS.

The material produced during the entire survey has been stored in a suitable relational database. The database structure allows comparison of the findings with theoretical models of the amphorae to remove data inconsistencies and artefacts, eventually leading to 3-D models that can be exported toward Virtual Reality environments. This approach will allow archaeologists to see the entire site, using immersive VR technologies, without diving [2], [3]. A synoptic scheme summarizing the entire process is depicted in Figure 1.

3.1 Two different ways for data capture

The photogrammetric survey in Pianosa has been planned in order to obtain a sequence of photo over a linear strip, with an appropriate forward overlap (60%) between two subsequent photographs. Once a strip has been completed, an adjacent strip is surveyed, with 20% lateral overlap with respect to the previous strip. The procedure is very similar to the one used in aerial photogrammetry; the main difference being the distance to the seabed and the presence of the water. The bathymetric variation could also be in general an important difference, but not at the Pianosa site, where the seabed in the working area is almost flat.

The Pianosa test-site offered the opportunity to test and compare different ways to conduct the survey. In particular the site was surveyed both by divers (CNRS partner) and by a ROV, a robotic vehicle linked through an umbilical cable to the surface ship, and operated in a semi-automated modality (ISME partner)[4].

The diver used a Nikon™ D70 digital camera with a 14 mm lens from Sigma™ and two flashes Subtronic™. The digital camera was embedded in Subal™ housing with a hemispherical glass. The ROV was equipped with a system provided by the COMEX partner and consisting of a Nikon DH2 digital camera, a 14 mm lens from Sigma™ and two flashes Nikon™ SB800, with custom-made housing and connectors (See Figure 2).



Figure 2: The ROV in the water with digital camera and flash lights in their housing; left: side view of the ROV; right: view from the seabed upward. The flash lights are on the side of the camera

The working area has been delimited by archaeologist, that also deployed 4 scale bars (2m each) and a set of 15 markers (concrete blocks 15x15x10cm) in order to define a grid for ROV guidance. The working area was surveyed by the ROV, strip by strip, at fixed altitude over the seabed [5]. With the ROV system, the photogrammetric data were collected in two different modalities:

- manually, through a command from the surface ship transmitted via the umbilical cable; a small video camera installed through the lenses allowed the operator to look at the scene with the same view of the camera and to activate the acquisition command.

In this modality the archaeologist on board the ship can have full control of the acquisition operation without actually diving over the site.

- In automatic mode, with a fixed frequency rate, selected taking into account the flash recharge time and the ROV speed and altitude. An example of two consecutive shots from the ROV automatic modality is reported in Figure 3.

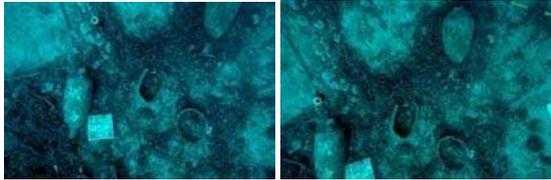


Figure 3: Two photographs from a strip made by the ROV.

3.2 Multimedia photogrammetry calibration

Camera calibration in multimedia photogrammetry is a problem identified since almost 50 years. [6], [7]. The problem has no obvious solution, since the light beam refraction through the different media (water, glass, air) introduces a refraction error which is impossible to express as a function of the image plane coordinates alone [8]. Therefore the deviation due to refraction is close to that produced by radial distortion even if radial distortion and refraction are two physical phenomena of different nature. For this reason, the approach described by Kwon [9] [10] has been adopted, consisting in the use of standard photogrammetric calibration software to perform the calibration of the set housing + digital camera. This approach can indeed correct in a large part the refraction perturbation; however, it is strongly dependent on the optical characteristics of the water/glass interface of the housing. In order to minimize the refraction error due to this last interface, a housing with a hemispherical glass (Subal™) has been selected for the divers-operated camera. The same housing, however, could not be accommodated on the COMEX developed system, due to the mechanical constraints imposed by the additional instrumentation and electronics for the automated mode operation. Hence in this latter case the housing glass was plane and the refraction action, even after calibration, is much more relevant. A specific method to compensate separately refraction and distortion has been developed, but its description is beyond the scope of this paper. The interested reader can find it as a deliverable of the VENUS project downloadable from the VENUS web site <http://www.venus-project.eu>.

3.3 The reference system

A fundamental aspect in any survey procedure is the choice of a reference system for the acquired data. The choice may be driven by the archaeological needs and by the available instrumentation. In general, two choices can be considered: a relative reference system, and an absolute georeference system. The relative reference system is the option mostly used in underwater photogrammetric work: the reference system is defined from the data themselves exploiting locally observable geometric features of which the prior orientation and dimension is known, as buoys to define the vertical axis, scale bars, etc. In most cases this approach requires preparation of the site with the deployment of appropriate

reference objects and tools by means of divers. This may be a costly, time-consuming operation, possible only at working depths for divers (about 60m).

The use of a robotic vehicle allows to obtain automatically a set of georeferenced positioning data that can be exploited in the photogrammetric process. In particular, in the Pianosa experiment ISME ROV was equipped with a USBL acoustic positioning system, consisting of an acoustic transducer, deployed from the side of the supply ship, and a transponder on the ROV frame. The acoustic pings transmitted from the surface ship are reflected by the transponder; by evaluating the time of flight and the direction of arrival of the reflected signal, the system produces an estimate of the position of the ROV with respect to the transducer. Merging this information with Differential GPS data, taking into account the displacement between the DGPS receiving antenna and the transducer position, allows to estimate the ROV position in geographical coordinates. In addition, the ROV is also equipped with inclinometers, compass and accelerometers: this allows to determine the orientation (roll, pitch, yaw) of the ROV, hence of the high resolution camera, taking into account also in this case the geometry of the system, i.e., the displacements between camera and sensors position. Additional sensors, including depthmeter (pressure gauge), altimeter (echosounder), encoders on the thrusters' shafts, are mounted on the ROV and their measurements are recorded for post-processing and validation purposes.. The Navigation, Guidance and Control (NGC) system, which governs the ROV and its sensory apparatus, associates to each photograph a set of navigation data, including in particular the georeferenced position of the camera and its orientation.. Integrated optical/navigation data are directly stored in JPEG/EXIF format. The processing flow of the system is illustrated in Figure 5. It is interesting to note that the USBL system has been employed also to track the absolute position of the divers during the "traditional" human-based acquisition test. In the photogrammetric processing, the error is taken into account by using ROV navigation data as approximate values to initialize a bundle adjustment.

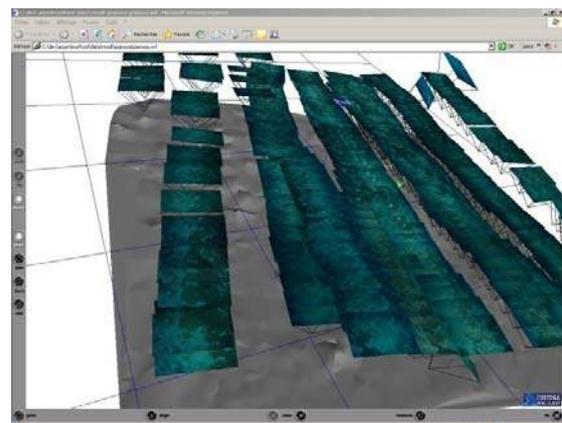


Figure 4: Oriented photographs visualised in VRML with the non textured seabed measured with photogrammetry.

The whole photogrammetric processing is conducted by means of the commercial software Photomodeler™, with user's supervision to correct the initial orientation errors. An example of the final oriented photographs, georeferenced and superimposed to georeferenced bathymetry of the area, is shown in Figure 4.

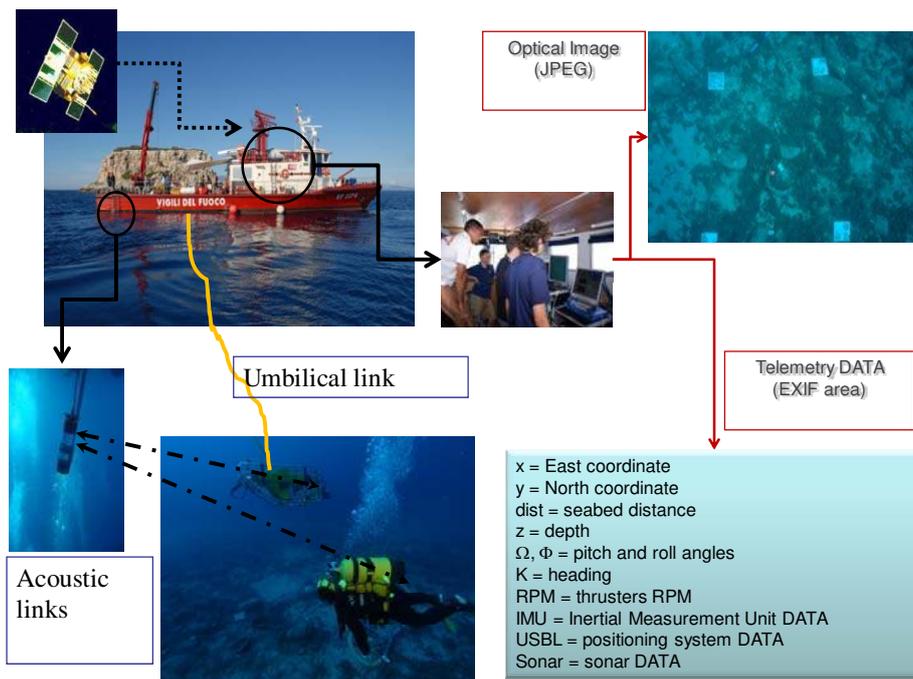


Figure 5: Pipeline for tagging photograph with navigation data.

3.4 Amphorae plotting

From the oriented photographs, a subsequent 3D geometrical modelling phase of the recorded artifacts (amphorae in our case) is started. In this phase the modelling must be driven by expert (archaeological) knowledge; the resulting models, together with the photogrammetric georeferenced data and all the survey data, is stored in a repository database for further use and interrogation.

The 3D modelling phase procedure consists in exploiting archaeological knowledge to obtain a complete representation of the measured artefact; it is articulated in two steps:

1) Development of the theoretical model: for each identified object, a geometrical description offers a set of geometrical primitives, which are the only features to be potentially measured; these are compared with the theoretical representation of the object as derived from expert knowledge. In our case archaeologists have identified six amphora typologies, and a theoretical model is produced for each of them. This theoretical model is formalized in a hybrid way, taxonomy of archaeological artefacts and XML representation for the amphora typology.

2) As photogrammetric measurements are highly incomplete (the object is seen only partially or may be deteriorated), an Expert System determines the best strategy to 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. In our case, we are using the Jess expert system (<http://herzberg.ca.sandia.gov/jess/>).

The resulting object is thus based on a theoretical model, dimensioned by a photogrammetric measurement. The modelling procedure is revisable in time, allowing re-processing or complementing the processing as new data

may become available. The whole procedure has been implemented in Java and connected to the *Arpenteur photogrammetric toolbox*. [11], [12].

Amphorae classification in archaeological work does rely very strictly on dimension information on specific features of the object, as for instance the neck. In providing a theoretical model for a specific amphora class, it does make sense to measure these features directly on an available archaeological site. At the Pianosa site, six amphorae have been resurfaced by the divers. These amphorae are used as paradigm to define the needed theoretical model. Since they do not account for all the classes of amphorae observed at the site, the direct observation of the finds is complemented with drawings and information from archival data; for instance, type gauloise 3 is modelled accordingly to the typology presented by Archaeological Data Service, University of York, also partner in VENUS ([//ads.ahds.ac.uk/catalogue/archive/amphora_ahrb_2005/details.cfm?id=135](http://ads.ahds.ac.uk/catalogue/archive/amphora_ahrb_2005/details.cfm?id=135)).

In defining the theoretical model, 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, four measurable zones have been defined: rims, handle, belly, bottom. A set of simple geometrical primitives is fitted by least square method onto the measured points: for instance a circle on the rim or belly points, a line on bottom point, etc... This interface allows the user (generally an archaeologist) to

- Recognize the amphora type on the photographs;
- Choose the amphora type in the interface combo box;

- Measure a set of points on the zone where measure is allowed;
- Add archaeological comments and observations;
- Derive a model from the object, using the measured points to construct a new instance of amphorae;
- Insure consistency between observations and theoretical model;
- Store a new instance in the database.

4 MERGING RESULTS

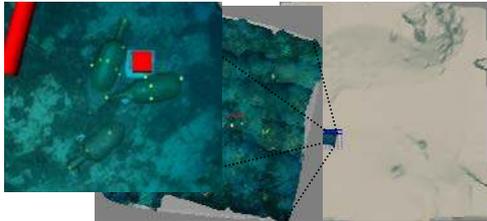


Figure 6: VRML representation of reconstructed amphorae. From right to left: general area bathymetry with the location of the archaeological site superimposed; a blow up of the experimental site; a blow up on a specific portion of the site, with amphorae entirely reconstructed using the modelling information. Also visible the measured points on amphorae, and the geometrical models of a concrete marker (red square) and two scale bars (red and white cylinders).

Bathymetric data and photogrammetric data have been merged, exploiting the georeferencing of both acquisition systems and the orientation adjustments in the photogrammetric processing, and eventually linked to the Amphorae representation in the database. The data base is organized as 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 the interface.

4.1 Accuracy

The bundle adjustment precision for all the photographs is around 0.02 m and the relative uncertainty of measurement is less than 5mm. The absolute accuracy is around 0.4 m, using four control points in which the ROV has been held at the seabed for a prolonged time acquiring a set of georeferenced data through the USBL system, averaged to improve the estimate of the absolute control point position.

The relative position of DTM coming from multibeam survey and photogrammetry is valuated in OZ: a constant error of 0.502 m with an RMS of 0.073 m. As the seabed is flat in this zone (see Figure 6, up) it is not possible to evaluate the merge accuracy in (XY), this will be estimated by the instrumental absolute accuracy.

5 CURRENT DEVELOPMENT: GIS FRAMEWORK

In the context of archaeological survey, 2D representations are well known and largely used by

archaeologists. These representations can be handmade drawing or digital maps.

Postprocessing all the data collected on the site and using the resulting information (ROV navigation data, oriented photographs, seabed DTM, 3D artefact reconstruction, and so on.) we can build automatically a GIS representation of the surveyed site.

The use of a 2D GIS representation is possible since we are dealing, in the VENUS project, with the surface layer only of the explored sites and it has two advantages:

- the 2D representation is convenient for archaeologist needs;
- the GIS enables to augment simple maps by additional information

The GIS representation we consider relies on the standard formats GeoTIFF [13] and Shapefile (Shapefile is a geospatial vector file format from ESRI™ company, but an open source specification of it is available and it is used in several open source software development projects).

The Shapefile format covers simple 2D geometric representation and it is suitable for a schematic representation of the measured objects. The GeoTIFF format enables to store georeferenced images.

5.1 Archaeological database

The archaeological database registers the 2D and 3D points of artefacts lying on the seabed, measured during the photogrammetry process. When those points are labelled as belonging to a recognized artefact type, an actual artefact could be reconstructed taking into account location, orientation and size of the measured object. All the parameters involved in the process are registered in the database so to make the information available both for the photogrammetric reconstruction and the design of the virtual environment reproducing the site.

6 ARCHAEOLOGICAL ONTOLOGY

In order to represent the archaeological knowledge obtained by means of the photogrammetric process, a suitable ontological approach has been considered. The first question in its definition concerns the kind of ontology that may better represent underwater archaeological knowledge. In the context of the VENUS project, photogrammetric technologies are used for data acquisition and the knowledge provided relates to underwater archaeology but also to data the acquisition process. According to the Guarino's classification of ontologies [14], the underwater archaeological knowledge could be captured by a domain ontology that describes the vocabulary relating to amphorae, while the knowledge relating to photogrammetric data acquisition process could be captured by a task ontology. Consequently, we constructed an application ontology to represent underwater the archaeological knowledge provided by photogrammetry.

The application ontology, denoted by O, can be formalized by $O = \{C, Hc, D, R, Co\}$ where C is the set of concepts derived from the set of classes of the ARPENTEUR software, Hc is the hierarchy of concepts illustrated by Figure 1, D is the set of domains corresponding the concepts attributes. For example, a domain can be a set of numeric values for the POINT, METROLOGY, POSITION concept attributes, or an enumerated list of values for the AMPHORA ITEM

concept attributes. R denotes the set of non specialisation relations between concepts, like aggregation relations. Co denotes the set of constraints between concepts or/and between attributes and concepts, like cardinality constraints, real world constraints, conditional constraints: constraints between amphorae typology and dating or amphorae metrology and dating, for example, and spatial constraints.

A reference model, the CIDOC-CRM ontology [15], which is a domain ontology and which now is an international ISO standard (ISO 21127:2006), has been developed for traditional archaeological activities. However, when using new technologies, the construction of an application ontology taking into account a task ontology requires some extensions of the CIDOC-CRM ontology [16].

Within this framework, a knowledge base can be defined by the set $KB = \{O, I, instc, instR\}$ where O denotes the application ontology defined above representing the generic knowledge, I denotes the set of instances, i. e. the observations and instc resp. instR denote the instantiation functions on the concepts, respectively on the relations, of O. Because of errors during the acquisition process, inconsistency may result and consistency has to be restored.

The knowledge base provides a partial preorder, and we first investigated consistency handling partially ordered information, when the knowledge base is represented in propositional logic. We extended the Removed Sets approach [17], initially defined for non ordered or totally ordered knowledge base, to partially ordered propositional knowledge base and proposed an implementation stemming from answer set programming [18].

Since several observations can be performed by different actors at different times we extended the Removed Sets approach to the fusion of proposition knowledge bases. We implemented the Removed Sets Fusion with answer set programming and provided an experimental study [19].

7 VIRTUAL AND AUGMENTED REALITY

Besides the classical representation described above, the VENUS project offers new modalities for both archaeologists and general public to exploit or explore the underlying archaeological datasets through extensive use of Virtual and/or Augmented Reality.



Figure 7: Archaeologists (top) & General Public (bottom) VR demonstrators

The base idea behind using VR and AR techniques is to offer archaeologists and general public new insights on the reconstructed archaeological sites allowing archaeologists to study directly from within the virtual site and allowing the general public to immersively explore a realistic reconstruction of the sites. Both activities are based on the same VR engine but drastically differ in the way they present information. General public activities emphasize the visually and auditory realistic aspect of the reconstruction while archaeologists activities emphasize functional aspects focused on the cargo study rather than realism

7.1 Augmented Reality for archaeologists

Since archaeologists interest is mainly focused on the nature of the cargo, one of the first feedbacks from archaeologists concerning VR Venus was that immersive navigation didn't provide much help to archaeological tasks, in opposition to general public concerns, where immersive navigation provides a deeper experience of a site. This observation lead us to propose a map based navigation paradigm, such as the "World in Miniature" proposed by Stoakley et al [20] and later applied to Augmented Reality by Bell et al [21], which provides a much more familiar interface to archaeologists. Moreover, the Augmented Reality paradigm offers the opportunity to introduce a tangible interface proposed by Ishii & Ullmer [22] and Poupyrev et al. [23] to the tools developed in the VR demonstrator for archaeologists. These elements lead to the definition of a new demonstrator for archaeologists: AR Venus.

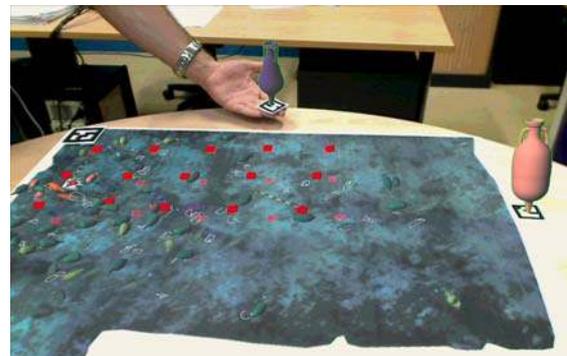


Figure 8: AR Venus

AR Venus is the Augmented Reality version of VR Venus designed to closely fit archaeological needs based on the first feedbacks from archaeologists on VR Venus. In AR Venus, archaeologists visualize a 2D map representing the site. Archaeologists have more facilities to work with maps where they can see the real world rather than a totally immersive environment in which it is difficult to be localized. Rather than to immerse the archaeologist in a completely simulated artificial world, AR Venus proposes to enrich the environment and complete the real-world perception by adding synthetic elements to it. AR Venus provides an easy tool to interact with the real-world using tangible interface to select and manipulate virtual objects with accuracy, using effective pose estimation algorithms to project synthetic models at the right location on the 2D map. Users need to wear special equipment, such as see-through head-mounted display, to see the world around them, augmented in real time with computer-generated features (see Figure 8).

7.2 Virtual Reality for the general public

The danger with a project such as VENUS is to generate large quantities of data that is relevant solely to archaeologists. With so many areas of expertise involved in VENUS it is not just the artefacts that are of interest. The final interface to our archaeological database is aimed at creating awareness of both the artefacts that were found and of the process by which they were discovered.

The general public interface recreates the dive process from ship to seabed, allowing members of the public to experience the exploratory process first hand. We allow the general public to assume the role of a virtual submarine operator, giving them the task of uncovering the archaeological sites themselves.

The vast quantities of data generated from both the initial surveys and their consequent analysis provides us with the ability to accurately model the location of the dive sites. By combining this geometry with our custom underwater render engine we are able to create an interactive and realistic reproduction of both the environments and artefacts.

We further enrich the dive simulation by linking it to additional textual and photographic records. As the interface gathers data directly from our archaeological database we also get access to the notes and interpretations made by archaeologists. By presenting this information at key points during the dive simulation we present the public with the opportunity to learn about each stage of the dive. We hope that by presenting VENUS in this way we can capture the imagination of the general public in a way that simply couldn't be achieved using traditional methods of dissemination.

8 DATA PRESERVATION

Throughout the course of data acquisition, processing and delivery, the project has addressed the need for long-term preservation and access to the dataset. By identifying specific digital preservation requirements, the aim is to produce guidelines for the archiving of material derived from future investigations.

There are four main aspects of this area that are considered in the VENUS Project. First, to refine digital preservation techniques, so that they can be readily applied to the unusual range of data formats captured during underwater archaeological investigation. In doing this we should ensure that partners within the consortium learn about digital preservation. Beyond the VENUS partnership we also aim to promote best practice in digital preservation through publication of a short practical guide based on this shared experience. And finally, during the life of the project, we hope to adopt and test those best practice and techniques.

The first stage in addressing these aspects was to undertake a comprehensive desk-based study of the data lifecycle of the project, from data acquisition, through post-processing (including photogrammetry) to dissemination via various VR techniques, and ultimately to its long-term storage and accessibility to future scholars. This study was started prior to the first VENUS mission (Pianosa, Italy) as it concerned generic technologies and their data outputs and formats. Elements of the study were significantly informed by the work carried out by the partner ADS, relating to formats and metadata for large scale bathymetric survey, as part of the

English Heritage funded *Preservation and Management Strategies for Exceptionally Large Data Formats: 'Big Data'* project (<http://ads.ahds.ac.uk/project/bigdata/>).

Close collaboration between the ADS and other VENUS partners was required to develop a comprehensive picture of the data lifecycle of the project. To this end the ADS undertook a data audit of the digital outputs of the first underwater mission, working with partners at ISME, looking in detail at the processes of data acquisition and the immediate processing and sampling that is carried out as the survey is undertaken. The breadth of the potential dissemination modes for the project were considered in collaboration with colleagues at the University of Hull – assessing incoming and outgoing file formats and the variety of VR dissemination hardware and solutions available.

What became clear from this work is that both the level and scope of the metadata generated during data capture are high, and that much of this metadata is critical to the later stages of the lifecycle (photogrammetric modeling and VR model generation). Devising a comprehensive archive and dissemination strategy to encompass the complexity of this dataset presents a distinct challenge.

It is apparent that the VENUS Project data lifecycle (and therefore other, similar, complex data acquisition and processing cycles) represents a series of sophisticated data transitions. The data preceding and following each transition stands, with its associated metadata, as a coherent dataset, embodying the previous transitions and the techniques employed during those transitions. Each of these points represents an opportunity to archive the data. We have termed these 'candidate Preservation Intervention Points'. If the data at these points is to be included in a digital archive, and it become a true Preservation Intervention Point (PIP), a number of criteria must be met: the accompanying metadata must be sufficient for preservation purposes (allowing any anticipated reuse of the data in the future); there must be suitable resource discovery metadata associated with the data; the data at this point should have either a known re-use case, or a strong potential re-use case; and the repeatability and value of the previous data transitions must be assessed.

Measuring concordance with the metadata requirements is relatively straightforward, but understanding the re-use potential, repeatability and inherent value of the processed data is most appropriately left to those with particular expertise in handling the data at each stage. To guide this process the project is developing a decision tree which will act as a tool for VENUS data managers to use in determining the most suitable stages at which to archive the dataset.

These Preservation Intervention Points are non-exclusive and the archival process should be non-proscriptive in the selection of data for inclusion. It is hoped that this will increase the engagement of the data producers in the archival process, helping to ensure the future usefulness and value of the archived material.

9 CONCLUSIONS AND FUTURE WORK

Archaeologists need to explore and make an inventory of deep wreck sites, which are unreachable by divers, since those sites are jeopardized by deep trawling and other off-shore activities and they risk to be destroyed in the very next few years. The digital preservation aspect is one of the main goals of this project.

A methodology for underwater survey and data processing - involving the complete processing flow: from georeferenced data acquisition in semi-automatic mode to merging acoustic/optical data with a theoretical model including archaeological knowledge and to site reconstruction in virtual and augmented reality - has been developed in the framework of VENUS and presented here.

A first draft of a 2D GIS application has been proposed and used for testing. The geometric-database link and an automatic transfer from 3D representations to 2D standard GIS formats have been implemented. Enhancements of the GIS capabilities are planned..

The second VENUS mission has taken place in Sesimbra, Portugal on a wreck at about 60m depth, on October 2007. The survey was made both by divers and ROV. The next VENUS mission is scheduled in October 2008. It will take place in Marseille, France, over a shipwreck lying at a depth of about 100m. That mission will not involve divers and it will serve to test a fully automatic procedure to gather and process submarine navigation data with photogrammetry.

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