Virtual Exploration of Underwater Archaeological Sites : Visualization and Interaction in Mixed Reality Environments

M. Haydar[1] and M. Maidi[1] and D. Roussel[1] and M.Mallem[1] and P. Drap[2] and K. Bale[3] and P. Chapman[3]

[1]UEVE Université d'Évry, Laboratoire Informatique, Biologie Intégrative et Systèmes Complexes, FRE CNRS 3190, Évry, France
[1]LSIS Laboratoire des Sciences de l'Information et des Systèmes UMR CNRS 6168, Marseille, France
[3]SIMVIS, Simulation and Visualization Research Group, University of Hull, Hull, UK

Abstract

This paper describes the ongoing developments in Photogrammetry and Mixed Reality for the Venus European project (Virtual ExploratioN of Underwater Sites, http://www.venus-project.eu). The main goal of the project is to provide archaeologists and the general public with virtual and augmented reality tools for exploring and studying deep underwater archaeological sites out of reach of divers. These sites have to be reconstructed in terms of environment (seabed) and content (artifacts) by performing bathymetric and photogrammetric surveys on the real site and matching points between geolocalized pictures. The base idea behind using Mixed Reality 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 which leads to the development of two parallel VR demonstrators. This paper will focus on several key points developed for the reconstruction process as well as both VR demonstrators (archaeological and general public) issues. The first developed key point concerns the densification of seabed points obtained through photogrammetry in order to obtain high quality terrain reproduction. The second point concerns the development of the Virtual and Augmented Reality (VR/AR) demonstrators for archaeologists designed to exploit the results of the photogrammetric reconstruction. And the third point concerns the development of the VR demonstrator for general public aimed at creating awareness of both the artifacts that were found and of the process with which they were discovered by recreating the dive process from ship to seabed.

Categories and Subject Descriptors (according to ACM CCS): J.2 [Computer Applications]: Physical Sciences And Engineering

1. Introduction

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 favorable 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 surface layer.

VENUS is a multidisciplinary project funded by the European Commission, Information Society Technologies (IST) programme. The main goal of the project is to provide scientific methodologies and technological tools for the virtual exploration of deep underwater archaeological sites by improving the accessibility of underwater sites and generating thorough and exhaustive 3D archives [CCD*06]. Therefore, VENUS is developing virtual and augmented reality tools for visualization and immersive interaction with a digital model of an underwater site as an example of digital preservation and for demonstrating new exploration facilities in a safe, cost-effective and pedagogical environment. 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.

Section 2 presents improvements of the seabed obtained through the photogrammetry process in terms of meshes densification and high resolution texturing. Sections 3 and 4 introduce VR application developed for archaeologists and section 5 introduces an evolution from VR to AR of this application. And finally section 6 presents the development of the VR interface for the general public recreating the dive process.

2. Virtual seabed enhancement

Getting a dense mesh for the seabed terrain have different purposes, first of all it can be useful for building an accurate orthophoto of the site on an uneven terrain, and further on it drastically enhances the realism of the reconstructed site within both VR demonstrators.

2.1. Seabed densification

The surface densification process starts from a set of points, manually measured, describing the 3D object to be surveyed in a relevant way. This cloud of point is first triangulated and then each triangle became a guide for new point generation in a regular grid. Each triangle is scanned with a given resolution and the points are projected on an image reference (a first draft version of this approach have already been published in [DFGP06]). Then we use the other projection of these points on other photographs as an approximate value for a correlation process (See [Kra97] page 354 for details on correlation). The final 3D point can then be seen on a large number of photographs and is computed with accuracy. We performed a set of tests and threshold to reject false correlation due, for example to correlation on moving algae's or fishes. This algorithm produces a high number of well organized points, but need to be processed on photographs with a correct local contrast to ensure correlation efficiency.
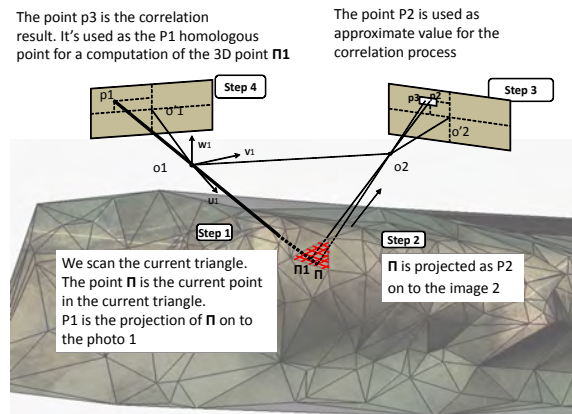

Figure 1: Densification scheme

We employed four steps (see Figure 1) in this surface densification method, considering that a mesh has been measured and computed from a set of 3-D points visible on at least two images:

1. Each triangle of the mesh is scanned to get point Π. Each point Π is projected as p_1 on photograph 1;
2. Π is projected as p_2 on the second image;
3. Point p_2 is used as an approximate position to initiate the area based correlation process with p_1;
4. Point p_3 is the result of the correlation; p_1 and its homologous p_3 are used for the computation of the 3-D coordinates of Π_1.

2.2. Results on Pianosa

The first experiment on the correlation densification process was done on data from the Pianosa site [DSGG08]. The covered surface is about 20×20 meters covered by 291 photographs. The densification process start an initial set of 2816 points used to orient the photographs, then the first step is a Delaunay triangulation of the surface and then a scan of each triangle with a 1mm step.
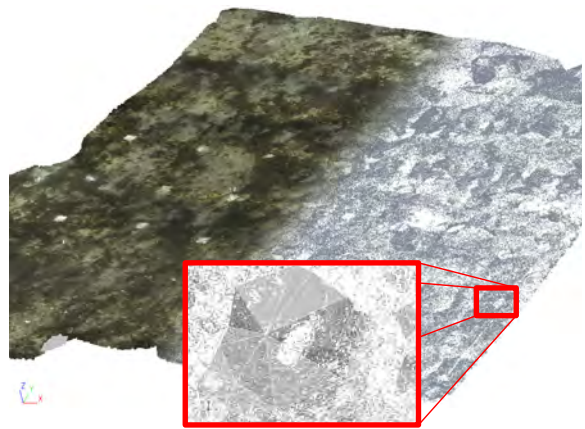

Figure 2: Densification process done on Pianosa site

The densification process (see Figure 2) produces 3586959 new 3D points and 4168954 have been rejected for correlation problem or by epipolar constraint on the third photograph. All the points have been computed on at least 3 photographs, with a minimum correlation coefficient of 0.7 and a residual error on epipolar line less than 3 pixels. We also know that final points can't be farther than 0.1 m from the original triangles which provides a mean accuracy of 5mm (the photographs have been taken by divers at 2 meters away from the seabed). The ultimate problem for the moment is performance as the process is still time consuming (around 39 hours for the entire densification) but we are currently working on to improve these aspects.

2.3. Seabed texturing

In addition to seabed densification, the resulting meshes has to feature high quality textures in order to be considered as useful as large original photos by archaeologists within the virtual environment. Besides, since textures are using these original photos, they might feature a strong vignetting effect due to insufficient lighting during shot time (see Figure 3(a))

and therefore strong luminance discontinuities might appear on the edge of each seabed part (see Figure 3(b)).
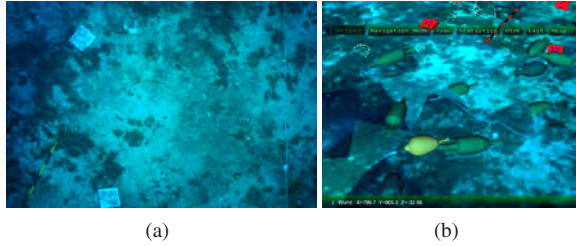

Figure 3: (a) Image from real seabed. (b) Texture from digital seabed

In order to reduce textures discontinuities along the edges of seabed parts a blending algorithm have been carried out on the images used before texturing the seabed. Many related works have proposed simple linear blending methods or more complex blending methods. Clipmaps introduced by Tanner et al. in [TMJ98] provides an efficient technique for displaying very large textures. However, a large amount of texture memory is used, and a large texture must be obtained or created before use. Döllner et al. in [DBH00] present a flexible Level of Detail (LOD) technique for texturing terrain with multiple layered textures. The presented technique allows portions of different textures to be viewed selectively over different portions of terrain. However, the texture covers the entire terrain and is not built from tiles. As texture buffers in common current hardware hardly reaches 4096×4096, we have to use multiple buffers (an also images) in order to produce a high resolution texturing. We present here a static method for correcting multiple images that will be tiled on multiple meshes in order to produce a single mesh presenting multiple high resolution textures. Our method doesn't need any run time processing, and hence avoids any system's performance decrease. The main idea in our blending method is to compute on every pair of images the discontinuous line (the white line in Figures 4(a) and 4(b)) and then to merge the parts of two images around this line by applying an α-blending method.
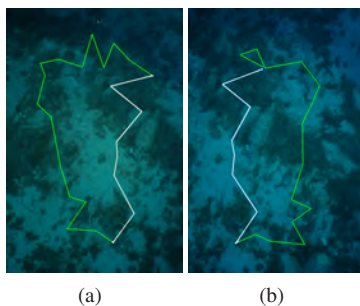

Figure 4: The white line shows the blending edge between images (a) and (b).

Seabed data is provided by an XML file registering the relationships between seabed parts and original pictures containing 3D vertices, Indexed triangles sets along with the images where these triangles are seen and also the texture coordinates of each triangle within the images (see Figure 5).

Figure 5: XML file data structure

The Seabed texture building and blending is performed in two steps by exploiting the triangles/photos relationships as follows:

- The first step of texturing consists in choosing the best image to be used as texture for a triangle in the seabed by selecting the image where the triangle center is closer to the image center in order to avoid corners where vignetting effect occurs. We construct a new XML file that contains the list of all edges of all triangles. We also add the ID of the image used to texture the triangle and the texture coordinates in the image of the edge. Then by comparing every edges couple we parse the XML file and keep only edges presenting same vertices but two different images. After applying this parser we obtained a list of segment that define the blending edges between different images (Figure 6(a)).

- In the second step an image blending process have been carried out in order to smooth the difference of pixels' values along the edge between these images. The blending process is performed as follows: Having two images img_1, img_2 and two edges $E(A,B)$, $E'(A',B')$, where A, B, A', B' are end points of the edges in the images img_1, img_2 respectively, we blend the pixels of image img_1 around the edge E with the pixels of image img_2 around the edge E' by a linear α-blending [†].

After applying this algorithm to all images, we use the images chosen in the first step to texture the seabed. The Figures 3(b) and 6(b) show the seabed before and after applying the images blending.

3. System architecture

The architecture of the VR system is composed of a database block containing all required data such as: photos, artifacts

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[†] Something is missing in there : when and where blended image are used ?
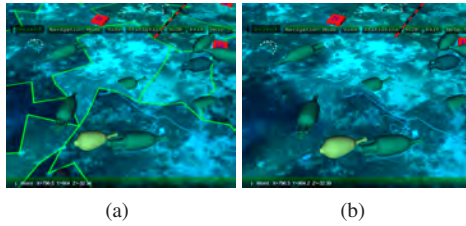
Figure 6: (a) Texture from digital seabed during processing. (b) Texture from digital seabed after image blending.

Figure 7: VE devices technology.

parameters, 2D/3D objects location, etc. The archaeological database registers the pictures taken during the survey along with 2D and 3D points of artifacts lying on the seabed measured during the photogrammetry process. When these points are labeled to belong to a recognized artifact type, an actual artifact could then be reconstructed in terms of location, orientation and size and all these parameters are also registered in the database [‡]. Therefore, such a database could be shared between the photogrammetric reconstruction process and the virtual environments designed to immersively explore the site.

In order for VE users to extract and study properties of the cargo (registered artifacts), users interaction with artifacts are translated into SQL queries to the database and results are displayed through selections or numeric data display depending on the nature of the results. Queries to the database can concern partial or complete inventory, metrology statistics (average size, similar sets,...) or spatial relationships between artifacts.

We developed 2 versions of the VR application for archaeologists which uses different devices technology. The first version works with simple input/output devices (mouse, keyboard, monitor) in order to easily run the demonstrator without having any specific devices that could be difficult to transport.

In the second version we employed more advanced devices to offer a semi or complete immersive navigation and more natural interaction with the environment. In this version we used 2 flysticks tracked by an A.R.T. cameras system that allows motion control and hence navigation, each flystick have 8 buttons and offers important number of choice to accomplish multiple tasks simultaneously. Display can be performed by a large screen with active stereo visualization or by a tracked Head Mounted Display (HMD) to increase immersion (see Figure 7 for tracked devices details).

3.1. Virtual Environment structure
All virtual environments for the VENUS project are developed around the "OpenScenegraph" high performance 3D graphics toolkit for VE modeling and visualization [BO04].

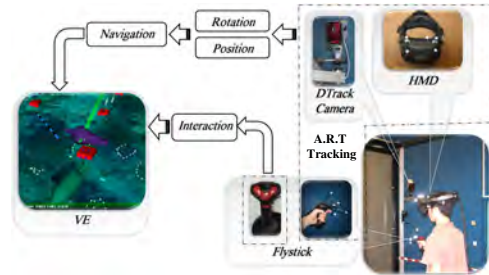---

[‡] A Reference to Arpenteur would be nice here

OpenSceneGraph provides high-level rendering features for 3D objects rendering, scene control and cameras views management. The main structure of the VE developed for archaeologists contains the various seabeds (large bathymetric seabed, and photogrammetric seabed with textures) and the various artifacts lying on the seabed and registered in the database. The construction of the VE is divided into 3 principal steps:

1. *Seabed:* Seabed meshes are loaded from an XML file containing 3D vertices and texture information.
2. *Artifacts:* An initial request to the database is performed to retrieve artifacts and markers parameters such as location, orientation, status, artifacts models. Then registered artifacts and markers 3D models are loaded.
3. *Virtual Environment:* These elements are placed in the virtual environment and navigation and interaction managers are started. When 3D interaction devices are available a connection to input devices is opened by using a VRPN server [TIHS*01]. The interaction manager handles inputs and eventually sends queries to the database.

4. User interface
The interface is composed of many classical tools: menu bar, information panel and popup message. The information panel displayed on the bottom of the VE (Figure 8) shows information about objects loading progress, user location or interaction result (e.g. amphora Id 21 was selected). A 3D popup message is displayed when the mouse passes over an object (or when the flystick selection ray casts an objects) showing the type of the objects or other information on selected objects.

4.1. Navigation Method
3D interactions with a Virtual environment can be divided into three principal tasks: Navigation, Selection and Manipulation. Navigation or viewpoint control is the most important task and most used when using the virtual environment. Bowman et al. [BKL05] recognized this task as the most common to all virtual environments. It allows users to explore, investigate and/or operate in a virtual space. They identified two main components for navigation: travel and way finding [BKH97], where they classified the different navigation techniques into three basic motion tasks: the

Figure 8: Tools in the Virtual Environment.

choice of direction or target, the choice of speed/acceleration of movement, and choice of entry conditions [BKL05][§].

We introduce here a new navigation technique using both hands to determine the direction of the motion and control its speed. A similar technique have been proposed by Mine et al. [MFPBS97], and is based on the knowledge of both hands position where speed is computed according to the distance between the two hands. This technique is cognitively difficult because the user may have difficulty in controlling the motion speed through the gap between his two hands. We used the angle between the hands rather then the distance which is more easy to control. The motion direction is then given by the orthogonal axis to the segment joining hands positions. Our method uses the positions and the orientations of both hands. Figure 9 shows the different parameters used to compute the direction and the speed by using two flysticks. Having positions P_1 and P_2 of the flysticks we can easily compute the motion direction $\overrightarrow{D}$ ($\overrightarrow{D} \perp \overrightarrow{P_1 P_2}$). The final motion is a result of a displacement Δ along the vector $\overrightarrow{D}$ and a rotation ϕ around the center of $[\overrightarrow{P_1 P_2}]$. Motion speed is inversely proportional to the angle α given by the direction of two hands whereas angle β controls rotation speed. When β reaches a $\frac{\pi}{2}$ threshold motion is turned into a pure rotation.
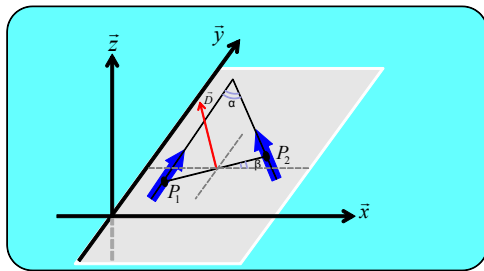

Figure 9: Navigation with two flysticks.

On the low end demonstrator navigation inside the VE is performed using a simple mouse and mouse motions effects are conditioned by the button pressed during the motion to perform translation, rotation and zoom.

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§ Any comments on [BKL05] ?

4.2. Selection

Switching from navigation to selection is performed by using flysticks buttons. When the user selects an item lying on the seabed, the related informations extracted from the database are displayed on an overlay panel along with a view of the selected artefact type model. When the object is selected, the user can manipulate the item by moving it around, turning and zooming to get more details about the artifact. Several rendering techniques have been used to display amphorae according to their current status. A shaded rendering, a wire frame rendering, and a edge rendering enhancing the external boundaries of selected objects.

5. The AR demonstrator

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 augmented map based navigation paradigm such as the "World in Miniature" proposed by (Stoakley et al., [SCP95]) and later applied to Augmented Reality (Bell et al. [BHF02]) which provides a much more familiar interface to archaeologists. Indeed, 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. Moreover, the Augmented Reality paradigm offer the opportunity to introduce a tangible interface (Ishii and Ullmer [IU97]; Poupyrev et al. [PTB*01]) to the tools developed in the VR demonstrator for archaeologists. These elements lead to the definition of a new demonstrator for archaeologists: AR Venus.

In AR Venus, archaeologists use a real map representing the deep underwater site. AR Venus proposes to enrich this environment and complete the real-world perception by adding synthetic elements to it rather than to immerse the archaeologist in a completely simulated artificial world. AR Venus provides an easy tool to interact with the real-world using tangible interface (in our case physical objects equipped with visual targets) to select and manipulate virtual objects by using a pose estimation algorithms to display artifacts 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 map, augmented in real time with computer-generated features.

5.1. 3D map overlay

The first step in AR Venus is to project the 3D models of the seabed on the real 2D map using a system of visual markers identification and a pose estimation algorithm. For this visual tracking module, we used a simple webcam for tracking visual markers made up with printed 60×60 *mm* black and white fiducial. The tracking algorithm computes the real camera position and orientation relative to the physical markers in real time and also identify the content of the

fiducial as a unique identifier (see Figure 10). Some fiducials are stuck on the real map in order to compute the pose of the virtual environment over the real map whereas others are use to interact.

We used OSGART library [OSG] to identify targets and overlay the 3D models on the real scene. OSGART has been designed to provide an easy bi-directional transition from VR to AR [LGSB06] by integrating ARToolkit [KBBM99] within OpenSceneGraph. The tracking library finds all squares in the binary image. For each square, the pattern inside the square is captured and matched to some pre-trained pattern templates. The square size and pattern orientation are used to compute the position of the camera relative to the physical marker, hence, the pose accuracy mostly depends on the marker size. Figure 10 shows the different steps of pose estimation algorithm (also called registration).
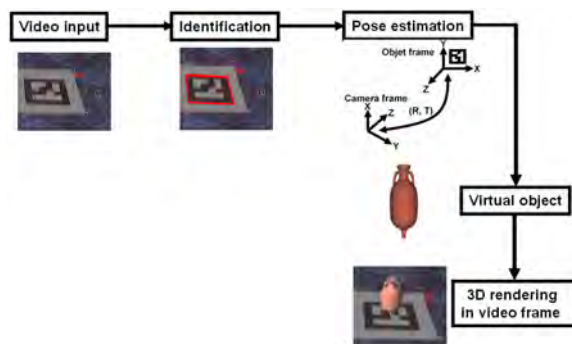

Figure 10: Pose estimation and overlay process.

5.1.1. Virtual objects registration

We used single and multiple targets with different scale to improve the tracking stability and accuracy. We started our tests using a single marker. The obtained results with a single marker were not accurate and we noticed a large shift between the virtual model and the real one represented on the 2D map. The size ratio between the small target and the large map didn't provide a correct registration, which led us after trying a larger target to consider a multitarget tracking approach since these targets are lying on the same map plane.

The multitarget approach provided a better registration along with stability improvements (also called jitter) (see Figure 11). Nevertheless, a misalignment persists as the projective transform used to print the map, has to be experimentally estimated.

5.2. Tangible interface

We saw in the previous section that static fiducials are used to register the virtual environment and artifacts, however, other targets can also be moved around the map and asso-
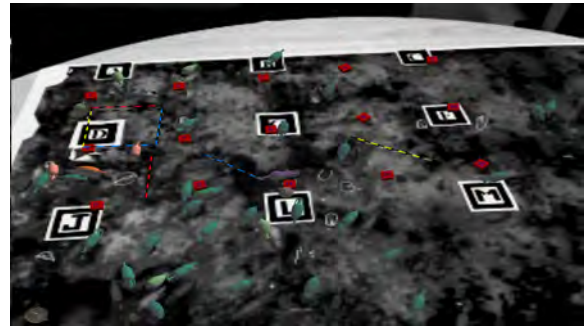

Figure 11: 3D registration using multimarker system.

ciated with virtual tools allowing the users to interact with the augmented environment[¶].

We developed a working prototype with a tracking camera. Several moving targets have been associated with virtual tools such as measuring tool and inventory tool. These tools are activated whenever the camera identifies their corresponding patterns and discarded when they aren't visible anymore. Some more tools still have to be developed, however measuring and inventory tools already represent two distinct classes: the inventory tool is attached to a single target and displays the site's artifacts inventory, whereas the measuring tool displays the distance within the VE between two attached targets (see Figure 12).

Figure 12: Tangible interface of AR Venus.

We hope that archaeologists could benefit from the merging of VR/AR environments allowing easy and natural interaction with survey data registered in the artifacts database. However, these demonstrators are currently submitted to archaeologists for evaluation and feedbacks should drive the next versions of these demonstrators.

6. VR 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

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[¶] This part lacks some references

is not just the artifacts that are of interest. The final interface to our archaeological database is aimed at creating awareness of both the artifacts that were found and of the process with which they were discovered.

Whilst both the archaeological and general public demonstrators are based upon the same core dataset, their objectives vary greatly. Up to this point our visual interfaces have been designed for archaeologists, with an emphasis on the interaction and analysis of data. The general public, however, are less specialised in their requirements. For the general public interface, we assume that the public knows very little about the datasets and aim to provide an immersive learning experience that will supply them with information about the project data and the historical context behind it. The general public interface recreates the dive process from ship to seabed allowing members of the public to experience the exploratory process firsthand. Using a virtual environment constructed from real survey data, we allow the general public to assume the role of a virtual submarine operator tasked with uncovering the archaeological sites themselves. The vast quantity of data stored on the database enables us to create accurate three dimensional representations of the dive sites topology and then build a virtual environment around it. For the purpose of the general public interface the larger, lower resolution seabed scans are used, presenting a larger area to explore, thus enhancing the sense of discovery. The artifacts themselves are represented by three dimensional replicas, generated using the photogrammetric information on the database, positioned as found on the site (see Figure 13(a)). Giving the submarine intuitive controls is another important consideration due to varied skill sets of the general public. Thus, we allow interaction with the environment using a gamepad, more commonly seen used in conjunction with computer games consoles and a familiar interaction device to many.

Of course this data alone does not create an immersive experience. In order to promote a sense of immersion in the environment we must also reproduce the underwater conditions in which the artifacts were found. The higher density of water compared to air creates a number of lighting effects rarely seen above water. As light passes through volumes of water, it refracts, producing complex lighting effects such as 'God-rays' and caustic patterns. By combing this with environmental effects such as plants and particulate matter drifting in underwater currents we are presented with a set of powerful underwater visual cues that need to be reproduced. To replicate these effects we have created an ocean rendering engine that enables us to reproduce not only the underwater cues but also create above water ocean simulations, simulating the dive process from the very start (see Figure 13(b)).

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. Whilst the main goal is to provide the general public with the ability to explore the site as it was found,

we also aim to highlight their historical context. Using the analysis provided by the archaeologists we are able to supply the public with background information about both the site and the artifacts. Presenting this information in a way that does not detract from the immersion within the environment is a difficult task. To achieve this we define a set of areas which represent points of interest. When a user encounters these points or looks at a particular item they are presented with a number of storyboards that appear within the heads-up display of the submarine cockpit (see Figure 13(c)). Each storyboard is fully configurable so as to provide the most recent information from the database.

7. Conclusions

All the tools presented here are still under development but represent a first step toward virtual access to deep underwater archaeological sites. Virtual and augmented reality can bring to archaeologists new insights on data gathered photogrammetric surveys concerning the seabed itself as well as the artifacts identified on the site by offering new and innovative ways to interact with these data.

We hope that by using these innovative methods of research and dissemination we can capture the imagination of the general public and generate interest not only in the historical aspect of archeology but also in the work and expertise that goes into supporting these archaeological surveys.

8. Acknowledgements

References

[BHF02] BELL B., HÖLLERER T., FEINER S.: An annotated situation-awareness aid for augmented reality. In *UIST '02: Proceedings of the 15th annual ACM symposium on User interface software and technology* (New York, NY, USA, 2002), ACM, pp. 213–216.

[BKH97] BOWMAN D. A., KOLLER D., HODGES L. F.: Travel in immersive virtual environments: An evaluation of viewpoint motion control techniques. In *VRAIS '97: Proceedings of the 1997 Virtual Reality Annual International Symposium (VRAIS '97)* (Washington, DC, USA, 1997), IEEE Computer Society, p. 45.

[BKL05] BOWMAN A., KRUIJFF E., LAVIOLA J. POUPYREV I.: *3D User Interfaces : Theory and Practice*. Addison Wesley Longman Publishing Co., Inc., Redwood City, CA, USA, 2005.
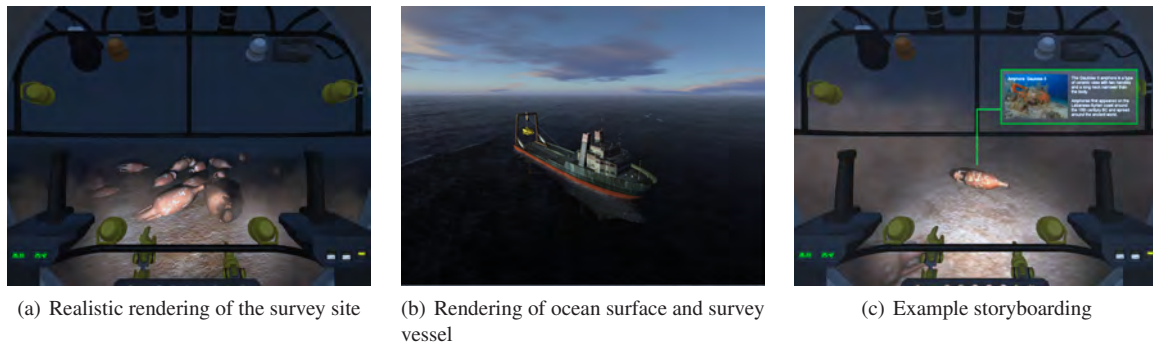
(a) Realistic rendering of the survey site

(b) Rendering of ocean surface and survey vessel

(c) Example storyboarding

Figure 13: *VR for the general public*

[BO04] BURNS D., OSFIELD R.: Open scene graph a: Introduction, b: Examples and applications. In *VR '04: Proceedings of the IEEE Virtual Reality 2004* (Washington, DC, USA, 2004), IEEE Computer Society, p. 265.

[CCD*06] CHAPMAN P., CONTE G., DRAP P., GAMBOGI P., GAUCH F., HANKE K., LONG L., LOUREIRO V., PAPINI O., PASCOAL A., RICHARDS J., ROUSSEL D.: Venus, virtual exploration of underwater sites. In *The 7th International Symposium on Virtual Reality, Archaeology and Cultural Heritage, (VAST 2006)* (Nicosia, Cyprus, Oct. 2006), Ioannides M., Arnold D., Niccolucci F., Mania K., (Eds.).

[DBH00] DÖLLNER J., BAUMMAN K., HINRICHS K.: Texturing techniques for terrain visualization. In *VIS '00: Proceedings of the IEEE conference on Visualization '00* (Salt Lake City, Utah, United States, 2000), IEEE Computer Society Press, pp. 227–234.

[DFGP06] DRAP P., FRANCHI R., GABRIELLI R., PELOSO D.: Integrated application of laser scanning techniques and close range photogrammetry. the case study of the ancient water supply system of petra. *ACN - Archaeological Computing Newsletter 64* (2006), 12–18.

[DSGG08] DRAP P., SCARADOZZI D., GAMBOGI P., GAUCH F.: Underwater photogrammetry for archaeology, the venus project framework. In *GRAPP 2008, Third International Conference on Computer Graphics Theory and Applications* (Funchal, Madeira, Portugal, Jan. 2008), Nunes J. B. N. J., Pereira J. M., (Eds.), pp. 485–491.

[IU97] ISHII H., ULLMER B.: Tangible bits: towards seamless interfaces between people, bits and atoms. In *CHI '97: Proceedings of the SIGCHI conference on Human factors in computing systems* (New York, NY, USA, 1997), ACM Press, pp. 234–241.

[KBBM99] KATO H., BILLINGHURST M., BLANDING B., MAY. R.: *ARToolKit (Technical Report)*. Tech. rep., Hiroshima City University, 1999.

[Kra97] KRAUS K.: *Photogrammetry Fundamentals and standard Processes*, vol. 1. Ferd. Dummlers Verlag, Bonn, 1997.

[LGSB06] LOOSER J., GRASSET R., SEICHTER H., BILLINGHURST M.: Osgart - a pragmatic approach to mr. In *International Symposium of Mixed and Augmented Reality (ISMAR 2006)* (Santa Barbara, CA, USA, 2006).

[MFPBS97] MINE M. R., FREDERICK P. BROOKS J., SEQUIN C. H.: Moving objects in space: exploiting proprioception in virtual-environment interaction. In *SIGGRAPH '97: Proceedings of the 24th annual conference on Computer graphics and interactive techniques* (1997), vol. 31, ACM Press/Addison-Wesley Publishing Co., pp. 19–26.

[OSG] http://www.artoolworks.com/community/osgart/.

[PTB*01] POUPYREV I., TAN D. S., BILLINGHURST M., KATO H., REGENBRECHT H., TETSUTANI N.: Tiles: A mixed reality authoring interface. In *INTERACT 2001 Conference on Human Computer Interaction* (Tokyo, Japan, 2001), pp. 334–341.

[SCP95] STOAKLEY R., CONWAY M. J., PAUSCH R.: Virtual reality on a wim: interactive worlds in miniature. In *CHI '95: Proceedings of the SIGCHI conference on Human factors in computing systems* (New York, NY, USA, 1995), ACM Press/Addison-Wesley Publishing Co., pp. 265–272.

[TIHS*01] TAYLOR II R. M., HUDSON T. C., SEEGER A., WEBER H., JULIANO J., HELSER A. T.: Vrpn: a device-independent, network-transparent vr peripheral system. In *VRST '01: Proceedings of the ACM symposium on Virtual reality software and technology* (New York, NY, USA, 2001), ACM, pp. 55–61.

[TMJ98] TANNER C. C., MIGDAL C. J., JONES M. T.: The clipmap: a virtual mipmap. In *SIGGRAPH '98: Proceedings of the 25th annual conference on Computer graphics and interactive techniques* (New York, NY, USA, 1998), ACM, pp. 151–158.