Virtual Immersive Environments for Underwater Archaeological Exploration

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Abstract: In this paper we describe a system designed for the fruition of underwater archaeological sites. It is under development in the ARROWS project (end August 2015, funded by the European Commission), along with other advanced technologies and tools for mapping, diagnosing, cleaning, and securing underwater and coastal archaeological sites. The main objective is to make easier the management of the heterogeneous set of data available for each underwater archaeological site (archival and historical data, 3D measurements, images, videos, sonograms, georeference, texture and shape of artefacts, others). All the data will be represented in a 3D interactive and informative scene, making the archaeological site accessible to experts (for research purposes, e.g. classification of artefacts by template matching) and to the general public (for dissemination of the underwater cultural heritage).

1 INTRODUCTION

Approximately the 72% of the Earth surface is covered by marine water. The oceans represent a rich source of discovery and knowledge in several fields, from ecology to archaeology. In spite of the huge extension and relevance in affecting the climate trends and the underwater biology, the seabed continues to be largely unexplored so far. This is mostly due to the extreme setting represented by the underwater environment, a reason why the majority of the people cannot be involved in the direct exploration. Indeed, the survey of these locations typically requires large amounts of funding and expertise, and may be a serious threat to the explorer safety. The current computer technologies allow overcoming these limitations and can extend the information enclosed in the marine environment to a wider community. In this scenario, our activity has been focused on the development of a system with the purpose of creating virtual scenes as a photorealistic and informative representation of the underwater sites. Through the virtualization of marine environments, a generic user may explore a simulated scene, realistically replicating the underwater survey experience. The virtual scene allows the archaeologists to perform offline analysis of wrecks and provides the public with a tool to visit the archeological site, without damage risk or safety danger.

The system presented in this paper has been developed in the frame of ARROWS, EU-FP7 project devoted to the development of low cost technologies for underwater archaeological site detection and preservation. In more detail, the ARROWS topics focus on the realization of tools for underwater sites mapping, diagnosis and cleaning. To those aims a team of heterogeneous Autonomous Underwater Vehicles (AUVs) is currently being developed. These vehicles sense the environment by means of proper underwater sensors like digital cameras and side scan sonar or multibeam echo-sounders. The virtual representation of the marine seabed is based on the data captured by the AUVs during the project missions, data that are exploited both for the detection of interesting sites as well as for the 3D reconstruction and virtual environment implementation. The resulting executable procedure is expected to be appealing to the generic user: the virtual diving in underwater scenarios features a wide set of possible choices in terms of exploration actions, recreating in a realistic way the survey and the discovery of relevant archaeological sites. The following sections

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of the paper contain a description of the procedure setup for the active scenario realization and the data employed to enrich the underwater scene. Finally, a case study will be presented, where the described method will be applied to the representation of an underwater archaeological site, based on a data capture campaign performed in a realistic underwater scenario.

2 THE SYSTEM, METHODS AND TECHNOLOGIES

A system designed for the research and dissemination in underwater archaeology must fulfil many requirements: it must offer an accurate reproduction of the site and of the objects lying in it; it must let the users to explore the scene at their own level of education, with an interaction as natural as possible, and possibly allow some actions (e.g. exporting 3D models). An example of a virtual reality tool devoted to the visualization of the underwater environment and to the simulation of underwater robotics is UWsim (M. Prats, 2012). Our system is a more sophisticated tool; indeed it meets the need for an easy but not simplistic visualization of the data collected and available about an underwater archaeological site.
The major features of the system, as a tool for dissemination and research in the underwater cultural heritage, are listed below:

- Different usage by user type
- Interactive, Informative and Immersive
- Accurate virtual reconstruction.

In order to realize a system able to fulfil the requirements and purposes described above, the system has been designed and developed exploiting the most advanced technologies and enriched with a set of dedicated functionalities. Indeed, the system is capable to adapt to the several needs of the user providing different functionalities to the different user approaches. By distinguishing two different kinds of users and, along with them, two different approaches, the system has been developed as a technical tool for specialized users and as a powerful disseminative tool for the public
The system provides a set of scenes that can be freely explored by the user. These scenes are the results of a processing pipeline dedicated to the 3D reconstruction starting from raw data acquired, exploiting equipped Autonomous Underwater Vehicle, during dedicated campaign.

The user can interact with the scene objects and access to additional data concerning them. These data are:

- videos captured during the ARROWS missions or already available from pre-existing resources;
- raw data captured by different sensors (sonograms, etc.);
- the complete reconstructed 3D mesh of the objects, displayed separately from the scene and available for observations from multiple points of view;
- any supplementary information.

Moreover, the system is connected with a database that manages historical information about the objects represented in the scenes. These data describe several features concerning the object's dimensions, material and history (for the archaeologist interest) information.
The system also provides a set of functionalities dedicated to measure the model. This tool can be very useful to obtain further information about the discover artefacts and, such as in case of jar, to classify their type and/or define their functions (i.e. distinguish between funerary, wine and food jar).

2.1 From Data to the 3D Model: The Pipeline

As mentioned before, data about the underwater environment are acquired by AUVs during dedicated mission. The AUVs are equipped by several sensors (such as optical camera, side scan sonar, etc.) which data contribute to the reconstruction of the scene. The processing pipeline in charge of 3D reconstruction is described in the following.
Once the mission is completed, the data are downloaded from the AUVs internal memories. The downloaded data are then processed with algorithm devoted to the detection of artefacts (D. Moroni 2013 and D. Moroni 2013). System operators can select the most interesting scenes in order to perform further accurate analysis and to reconstruct from them the artefact 3D models. The sequences are analysed frame by frame. The system automatically calibrates the video frames, balances the colours and rectifies other aberration occurred during the acquisition phase (R. Prados, 2014). Exploiting advanced photogrammetry algorithms and tools, the system correlates each extracted frame with the others and generates a point cloud (stored as a .ply file, a standard file format of point clouds as well as meshes containing also RGB information for every point) (O.

Pizarro, 2004 and T. Nicosevici, 2013). From this point cloud, the system builds an optimized mesh (created by the triangulation of the Poisson surface that better fits the point cloud), using dedicated software such as Meshlab (Meshlab) and/or Blender (Blender). Finally the mesh is exploited to obtain the detailed 3D model of the object. Figure 1 shows the original Jar acquired and, on the right, the final output of the processing pipeline.

Figure 1: Reconstruction of a jar starting from a video capture.

Intermediate results of the data processing pipeline are made also available to perform further analysis on them: such as the processing outputs of images that are considered to be of high significance level or particularly representative of an object, as well as video excerpts to be directly displayed in 3D modality.
As a further example, the rectified and properly filtered optical data can be considered another intermediate result, computationally quite simple, of remarkable importance in terms of completeness of the overall archaeological documentation process. These intermediate output results turn out to be particularly useful for the historical experts that require an early, but at the same time "correct", visualization of the captured data, in order to review and eventually correct the automated tagging performed by the higher level object detection algorithms.

2.2 Scene Representation and Fruition

In order to realize an immersive and freely navigable environment, the generated models have to be placed into a complex 3D scene. The development of a rendering system for real-time navigation of a 3D scene has been lightened by the exploitation of graphics engines. The graphics engines are suites of software that provide a set of high and low level functionalities that also provide the support for the transformations and event management typical of the 3D navigation: viewpoint change, zoom, object collisions. The system implementation is based on the Unity game engine (Unity) since it provides optimal functionalities for an easy setup of the scene and advanced management of the interaction with the scene itself and the included objects.
Aiming at providing a useful tool for technicians and archaeologists interested into the marine exploration, the scene has to be also as relevant as possible to the real explored underwater area. Thus, the global terrain (seafloor) is reconstructed mainly exploiting bathymetric sensor data while the objects of interest, aiming at providing reliable analysis and at making the environment more immersive and captivating, are reconstructed exploiting optical data and photogrammetry techniques (R. Campos, 2015 and P. Drap, 2011).
The 3D scene navigation is an enhancing field for the study of the newest interactive technologies, generally related to videogames. Thanks to the Unity compatibility with the most advanced gestural interfaces and visors, the system integrates the support to the usage of Kinect (Kinect), Leap Motion (Leap Motion) and Oculus Rift (Oculus Rift). Kinect and Leap Motion are in charge of recognize the user gestures and to translate them into actual camera movements and scene interaction. Oculus Rift is a stereoscopic visor for the virtual reality that is able to recognize the head movements and translate them into the camera rotation inside the 3D scene.
The system exploits Kinect or Leap Motion to move the user inside the scene and to manage the interaction with the 3D models and exploits Oculus Rift as a stereoscopic visor and for camera rotation. This optional set up increases the system immersivity and captivity and, in the other hand, provides a simple and effective way to explore the scene and interact with the placed objects (Figure 2).

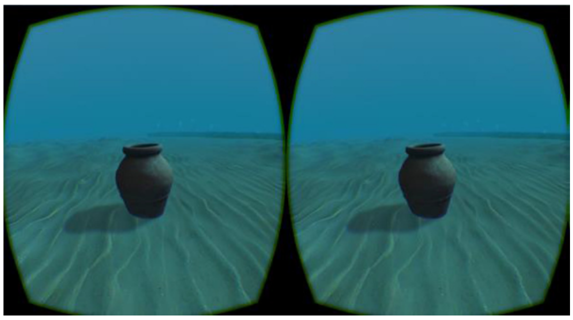

Figure 2: A jar placed into the scene viewed through Oculus Rift.

As described before, the system provides a set of dedicated functionalities that allows obtaining further information or performing analysis and measurements on the 3D models placed into the scene. A dedicated interface placed inside the scene allows the access and the usage of these functionalities. This kind of interface is available for each 3D models and can be viewed and accessed directly during the exploration of the scene (see Figure 3).

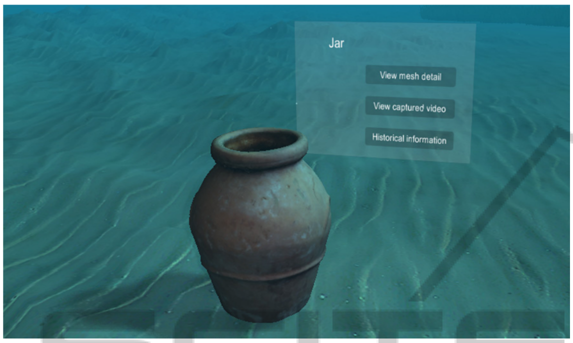

Figure 3: A reconstructed jar with the interactive dedicated interface displayed.

The system can be accessed both on a dedicated station equipped with gestural devices and Oculus Rift and via Web browser.

3 A USE CASE: A JAR LYING ON A SANDY SEABED

In this section, we will describe a generic usage case generated starting from an acquisition campaign performed in a controlled realistic scenario. The campaign has been focused into the acquisition of a jar placed on the seabed.

Figure 4: The main menu of the scene navigation system.

Figure 4 shows the main menu of the system that is displayed when user accesses to the virtual environment. Main menu contains a button for each represented scene and the button to quit from the system. The background scene is static and realized with acquired data. From the main menu, user can access to all the reconstructed scenes.

By accessing to the desired scene, the user will have the navigation control. From now on, the user can freely explore the scene and interact with the object placed in it. For instance, Figure 2 shows the interface through which it is possible to obtain further information about the jar. In this case, user can view the stream of the video acquired during the campaign, view the jar, extrapolated with the scene and without any light effects (Figure 5), and/or obtain archive information.

Figure 5: 3D model of the jar extrapolated from the scene context and without light effects.

The 3D model is observable from multi point of view and can be rotated without any restriction. Furthermore, light effects used for increase the scene immersivity, in this case, are turned off aiming at obtaining a better reliability of the 3D models.

The archive information of the jar are obtained from querying a database dedicated to manage historical data about the object recognized during the acquisition campaigns along with the sensor data collected during these campaigns.

4 DISCUSSION AND CONCLUSIONS

Our system turns out to meet all the requirements indicated in section 2. Indeed it lets the user to access both the whole scene and the raw or processed data about findings in it, at different levels of detail (depending on the user's right of access).

The system lets the user explore freely the virtual scene in a natural way (by the integration of interaction devices like Kinect or Oculus Rift) and interact with objects in the scene and to access all data linked to them (raw data like images or videos, 3D measurements, geotagging, 3D models, textures, historical or archival data, links to the web).

Generally each acquisition campaign in the seas is a high cost - high risk operation for people working in the mission. The accurate virtual reconstruction offers scholars and the public (not skilled for real diving) the possibility of frequent (and safe) visits to the desired site. Hence the archaeologist is provided with a tool to perform indirect measurements and to formulate an historical interpretation on the findings.

This system represents a first step towards a Google Street View of the Seas for archaeological sites. There already exists OCEANS Street View, which is developing the safe and easy access to seas, but our approach is quite different being more specific in content (underwater archaeology), purpose (dissemination and research), and looking for a more immersive and interactive experience.

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