MARINE VIRTUAL ENVIRONMENT TO ACCESS UNDERWATER CULTURAL HERITAGE

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ABSTRACT

In the field of underwater cultural heritage, advanced technologies and tools are under development aiming at discovering, mapping, studying and securing archaeological sites. In this paper, we describe the system developed in order to disseminate the data collected during underwater exploration and to provide, to the archeologist, an effective tool to explore and analyze each explored underwater archaeological site. With this aim, the system exploits collected raw data together with the results of the detailed analysis and embeds them in a 3D interactive and informative scene. The scene is accessible both by the experts (for research purposes) and by general public (for dissemination of the underwater cultural heritage).

Index Terms— Underwater Cultural Heritage, Image-based Modelling and 3D Reconstruction, Underwater Optical and Acoustic Data Processing, Virtual Environment

1. INTRODUCTION

ARROWS project (FP7-Environment-308724), funded by the European Commission, aims at developing low cost technologies to detect and preserve underwater archaeological site.

With the focus of underwater mapping, diagnosis and cleaning tasks, a team of highly specialized heterogeneous Autonomous Underwater Vehicles (AUVs) have been developed [1]. These AUVs are structured with a modular conception, highly scalable according to the requirements of the different missions and scenario, in order to better support the archaeologists during the exploration phases. For instance, the AUV dedicated to the environment patrolling and mapping can be equipped with optical (digital visible light cameras, structured blue laser illuminators) as well as acoustic (Multi-beam echo-sounder) devices. The AUV also features a board dedicated to the almost real-time processing of both optical and acoustic data. Indeed, it can generate specific alerts in case encounters an area with high probability of archaeological object presence. In this scenario, the AUV starts a detailed inspection communicating with the rest of the AUVs.

A relevant activity following the acquisition campaigns is dedicated to post-process the collected data to generate two primary results: i) the detailed 3D models of the detected archaeological objects and ii) an immersive and interactive virtual environment, containing the 3D reconstruction outputs.

Heterogeneous data are collected during the survey of Autonomous Underwater Vehicles (AUVs): both acoustic (by a forward looking Multi-beam echo-sounder or a side looking sonar) and optical (by a pair of synchronized digital TV cameras with visible light as well as structured light illuminators). These data are used both for the detection of historical artefacts, both for analyzing in detail the meaningful underwater scenes and the objects detected in it.

In particular, this paper describes all the steps performed to obtain the virtual scene starting from the raw data. The MVE is also described listing different ways of fruition and provided functionalities.

2. VIRTUAL ENVIRONMENT INTO THE UNDERWATER EXPLORATION

Nowadays, the usage and exploitation of advanced virtual environment is constantly increasing and the set of fields, where it is applied, is growing. In this ambits, graphics engines play the important role of easing the development of such virtual environments. A graphics engine is a suite of software that provides a set of high and low level functionalities able to support the design of a complex 3D scene. Indeed, thanks to its functionalities, the transformations and event management typical of 3D navigation (such as viewpoint change, zoom and object collisions) are completely managed by the engine itself. The key advantage in using such virtual environments is the potential interest which can be obtained thanks to the high level of engagement that offer to users.

The increasing interest in underwater world exploration leads to the massive existence of systems able to offer an easy and safe exploration of many environments offering products which focus on: natural aspect (see for instance, Google with Oceans Street View [2]) or archaeology and historical objects which have a specific relevance in this framework (such as Shipwreckology [3]).

In the last two decades, the activities dedicated to cultural heritage have been boosted by the adoption of new technologies for modeling and rendering objects and landscapes. The expected developments in this field include the data processing [4, 5], and both visualization and exploration (for research and dissemination) of the cultural heritage environment [6, 7]. In this research line, we mention VISAS [8, 9] and ARROWS [10, 11] as a sample of recent research projects developing virtual environments in the field of underwater archaeology. The aforementioned projects have the purpose of building a three-dimensional environment completely navigable; a contemporary approach to increase the user's engagement in cultural heritage.

3. OBJECT RECONSTRUCTION: FROM THE RAW DATA TO THE 3D MESHES

The planning of a dedicated reconstruction workflow is a crucial point in order to get the best 3D model starting from the raw data. Indeed, depending on specific environmental characteristics, the reconstruction workflow could significantly change (see for instance the reconstruction workflow designed for a city landscape [12]). As mentioned before, the AUVs, used to acquire data during the campaigns, are equipped with several sensors, such as Side Scan Sonar (e.g. for the survey of a large area), Forward Looking or Bathymetric Multi-beam sonar and optical cameras (e.g. to get details about textural features of interesting objects lying on the seabed). In this section we focus on the elaboration of data acquired by the optical cameras which are exploited to obtain an accurate and high detailed 3D mesh of the discovered objects of interest.

3.1. Data analysis

Once the acquisition campaign is completed, acquired data are downloaded from the AUVs internal storage. Then, the heterogeneous data are integrated and analyzed in order to recognize, in the data flow, the objects of interest.

To that purpose, the analysis highlights the regularity content in the data. In this framework, areas are considered regular both in case of containing parts of primitive curves, like lines, circles and ellipses and in case of repeating patterns in the image spatial intensity.

Based on those features, the system performs an attentive analysis of the environment by assigning to a target area a label of interest proportional to the regularity content; in details, regular areas are marked with higher ranks while chaotic and unstructured area are marked with low ranks.

The assessment of regular patterns and their segments in an image is a typical computer vision issue that has been addressed in many ways. In order to fulfil the detection requirements proper to the ARROWS project main focus, a dedicated procedure has been developed. The implemented algorithm is based on a statistical approach in order to provide the system with enough reliability keeping an eye to the computational performances. The application of the algorithm, based on the Gestalt theory [13, 14] is more thoroughly described in [15].

Moreover, analyzing the texture of the represented surface, it is possible to discern the different objects that compose the framed scene and assign them to a specific class. In this case, the texture analysis is exploited to classify the seafloor distinguishing its categories (sand, rock, seaweed). This helps into the discovery of anomalies which can be potential objects of interest. Within the many descriptors available in the literature, a method based on the Gabor filters [16] has been adopted. The result is presented as a map. Varying frequency and orientation and repeating the convolution operation allows to obtain a set of filter responses that can be clustered according to the dominant components. In this way, every pixel in the image will be assigned to a specific class.

3.2. 3D mesh reconstruction

After the analysis described in the previous subsection, the excerpts of interesting data are processed in order to obtain the 3D meshes.

The reconstruction process, composed by five steps, is completely autonomous, but each step, produces an outcome which can be manually modified and refined in order to obtain a better result.

The first step of the process is dedicated to the alignment of the frames that compose the acquired optical video. Together with the frame alignment, the system corrects the distortion generated by the camera optics. The alignment and the estimation of the camera point of views is obtained by identifying a set of markers which repeat frame to frame. The outcome of the first step can be enhanced by manually placing other markers. It helps the system in better aligning the frames. The second and the, following, third steps produce the sparse and, then, the dense point cloud. Sparse cloud is generated starting from the first step outcome; dense cloud is generated starting from the conjunction of the first and second step outcomes. Point clouds can be manually refined cleaning them from artifices and points which are wrong positioned. Fourth step is dedicated to the computation and generation of the 3D mesh. The mesh faces also possess low detailed color information inherited by the points of the point clouds. Last step takes care of the production of a highly detailed texture. The texture which will cover the 3D mesh is obtained by mosaicing the acquired frames.

Once the mesh is obtained, it can be refined exploiting advanced 3D editor tools such as Meshlab[17] (see Fig. 1).

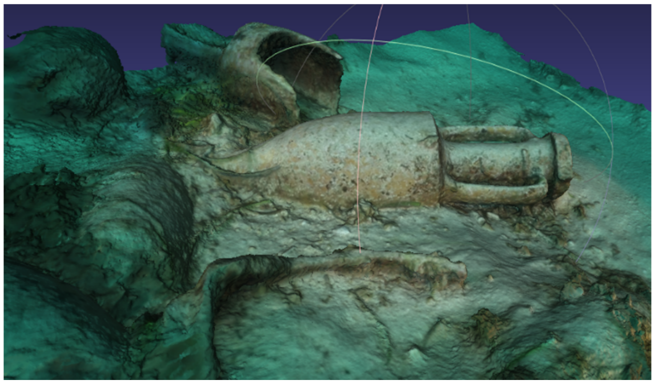

Fig. 1: From raw data to 3D

4. MARINE VIRTUAL ENVIRONMENT

MVE aims at supporting specialized users into the analysis of the explored archeological sites and at offering to the general public a captivating experience in the field of underwater exploration.

Aiming at fulfilling the requirements of both aspect, the MVE has been designed and developed able to recreate and manage accurate and appealing scenes, to offer different kind of interaction and to be accessed and experienced in several different ways. Indeed, accuracy is a necessary parameter in order to provide a valid tool that supports archeologist into the analysis of underwater archaeological site and, in the other hand, the overall appealing is needed to ensure the system distribution and usage.

The 3D reconstruction workflow described in section 3, in conjunction with the reconstruction of the seabed, ensures the high quality and accuracy of the reconstructed scene. Moreover, the developed interactions guarantee the validity of the tool used for professional aims. In the other hand, MVE appealing is obtained by adopting a visually pleasing graphics and by offering different ways to approach and exploit the system itself.

MVE has been realized exploiting Unity 3D game engine [18]. The engine provides advanced graphic features such as dynamic light effect, dynamic shadows, depth of field, dynamic textures, etc. As discussed before, the exploitation of a game engine such as Unity 3D facilitates the development of the scenes, that compose the Marine Virtual Environment itself, providing tools for the design and management. Moreover, Unity is supported by most of the actual informatics system and platforms (Windows, Mac, Linux, Android, iOS, etc.), feature that ensures the wide diffusion of the system. Indeed, the software developed through Unity can be executed on the different operating systems and even on mobile devices or inside a Web page by specifying some options during the project build phase.

The Marine Virtual Environment is connected with an information system which manages heterogeneous information which ranges from raw acquired data to the elaboration results and other kind of information such as historical data. Connection with the information system is exploited to provide to the user further information about the objects contained into the scene.

4.1. Seafloor reconstruction

As mentioned in Section 1, the AUVs are equipped with several kind of sensors. Optical data are good for high detailed reconstruction of the objects of interest and they could be also used to reconstruct the entire scene explored by the AUVs. However, this solution requires a big computational effort both during reconstruction phase and, mainly, during exploration phase: the MVE will be an elitist system that could be run only on most performing computer.

Thus, aiming at lightening the MVE, the seafloor is reconstructed stating from bathymetric sensor data. The seafloor is represented as a grey-scale height map that is natively accepted by Unity. The reconstruction is low detailed but it is enough because the seafloor is mainly constant. The seafloor texture will be obtained by mosaicking the optical data.

4.1. Scene reconstruction

The scene reconstruction is performed exploiting Unity game engine.

The seafloor mesh is obtained directly through the height-map; as mentioned in the previous section, Unity is able to calculate the terrain height directly from the grayscale image. Seafloor texture comes along with a normal map image exploited by Unity to calculate the terrain dynamic shadows.

The 3D meshes are then placed into the scene through the Unity GUI with some simple drag and drop operations and, thanks to the functionalities provided by Unity, each mesh is then scaled and rotated in order to be placed into the correct position.

5. FRUITION POSSIBILITIES

Aiming at increasing the general captivity of the system, MVE exploits the most advanced technologies developed in the game industry.

Thus, MVE offers three main ways to be experienced:

i) Classic approach which exploits mouse and keyboard to navigate into the scene. This approach is the less captivating in terms of fruition but it provides a set of interaction that enhance the overall experience. The interaction has been designed for both professional and disseminative usage and will be described into the next section.

ii) Second approach exploits Oculus Rift (OR). OR is the most diffused head mounted display. The head mounted display, thanks to the double displays placed directly in front of the eyes, offers the most accurate stereoscopic vision. Moreover, they mount a set of accelerometers that are able to recognize the head movements. This approach to the MVE exploits both these features. The stereoscopic vision is guaranteed by Unity by placing two cameras in the scene at the same distance of the people eyes; the head movements are mapped into the camera movements.

iii) Third approach exploits Leap Motion which is a touchless controller able to recognize the hands and finger movements. Using Leap Motion, users can access to the MVE and explore the scene only moving their hands. The controller will recognize the hands and finger position and will translate them into camera movement. Indeed, it is possible to change both camera orientation and position with simple hand rotation or widening.

6. INTERACTION

Interaction is a crucial point for providing further information about the object contained into the scene and for offering support to both professional and disseminative users.

Meanwhile Unity manages the scene and its navigation, the interactions have been realized through the development of dedicated procedures.

The interactions available for an object of interest directly depends on which kind of data are stored into the informative system for that object.

User, during scene exploration, can, by pressing “E”, block the camera and use the mouse to select the objects. For the selected object a panel with the list of interaction will be displayed (see Fig 2).

Most common available interaction are:

i) User can observe the object extrapolated from the scene. The object can be freely rotated and zoomed and its texture is not afflicted by any light effect (such as light blue colored and caustics). Here user can perform also measurement operation.

ii) Selecting “View captured video” user can view the raw video acquired during the AUVs campaign. The video is displayed in a panel that appears in the scene (see fig. 3). User can stop the video by clicking on it.

iii) If available, as well as for the raw video, user can access to the raw data captured during acquisition campaign. For instance, user can view the acoustic data placed as a texture of the object.

iv) Finally, user can view a dedicated panel containing all the historical and morphological information collected for the object.

7. CONCLUSION

The Marine Virtual Environment is accessible by all kind of users without any restriction. Thanks to Unity capabilities, MVE is Operative System independent and can be used both on Windows, Linux or MacOS; a mobile version is in development. MVE can be downloaded at [19].

Marine Virtual Environment is a valid, useful and charming tool for underwater exploration. The system is able to provide support both for professional (such as archaeologist) and general user.

To the professional users, it is a useful tool dedicated to the study of the scene and the objects placed in it. Archaeologist can perform analysis of the site directly exploring the scene. To this, MVE offers a set of interaction with facilitates the analysis of the object itself; by accessing raw data users can also confirm the deductions obtained exploring the scene. The accurate positioning of the object inside the scene helps the archeologist to discover the causes behind the sink and the generation of the site itself.

On the other hand, the Marine Virtual Environment is able to attract the general user interest thanks to a captivating graphics and by exploiting advanced gestural and vision devices that offer different approaches and alternative experience for the scene exploration. The virtual diving in underwater scenarios, thoroughly reconstructed and modeled by processing the data taken by the AUV multi-sensor platforms, features a large series of possible choices in terms of exploration actions, thus recreating in a strongly realistic way the survey of underwater locations and the discovery of interesting archaeological sites.

Fig. 2**:** Interactive panel relative to an amphora

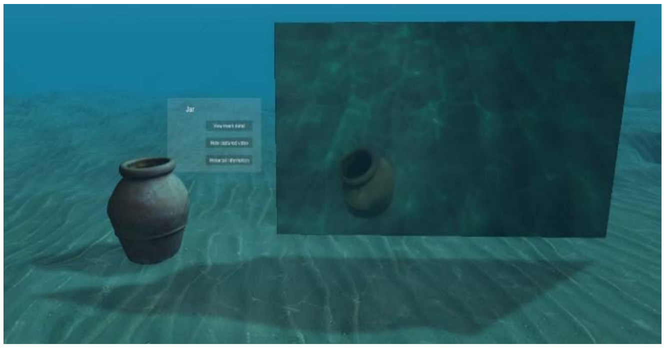

Fig. 3: Acquired raw video of a reconstructed amphora

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