Virtual Environment as a Tool to Access the Marine Abysses

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Abstract— **This paper describes a virtual environment designed and developed aiming at increasing the fruition of underwater exploration. Such system is under development in the frame of ARROWS project (end August 2015, funded by the European Commission). Main objectives of ARROWS project are the development and integration of advanced technologies and tools for mapping, diagnosing, cleaning, and securing underwater and coastal archaeological sites. Along with it, an informative system, that has the role to make easier the management of the heterogeneous set of data available (such as archival and historical data; georeferenced images, sonograms, videos; texture and shape of artefacts; others), is in development. The virtual environment aims at representing all the available data in a 3D interactive and informative scene. In this way, the archaeological site is accessible both 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). Due to the high educational value of this system, it has been enriched by dedicated functionalities for the management and representation of biological information, which was beyond the original project scopes.**

Keywords— Virtual Environment; 3D reconstruction; Educational Tool; Marine Exploration; Marine Archaeology

I. INTRODUCTION

Water covers approximately 72% of the planet's surface. Marine environment, although its extension and its importance in driving weather, regulating temperature, and ultimately supporting all living organisms, is largely unexplored. Furthermore, it represents an unlimited source of discovery and knowledge in several fields, from ecology to archaeology. Since the marine environment represents an extreme setting to human being, the majority of the population cannot even access the already explored parts. Indeed, exploring these locations typically requires large amounts of funding, knowledge and expertise, and finally, it can be seriously dangerous for the explorer.

Today's information and communication technologies allow developing a system able to reduce the limitations of the exploration of the marine environment. Indeed, through the creation of a 3D virtual environment based on real data, it is possible to recreate the explored locations (such as underwater archaeological sites) and make them easily accessible and navigable. In this scenario, our activity focuses in the development of a system able to reconstruct virtual scenes as a photorealistic and informative representation of the underwater locations.

The paper is organized as follows. In Section II, we describe the state of the art in the development and exploitation of virtual environments. In Section III, the proposed Marine Virtual Environment (MVE) is presented, while in Section 4, the reconstruction pipeline adopted to obtain the 3D scene from raw data is introduced. Section V addresses several functionalities available to interact with scene objects. Section VI describes some control and visual devices integrated with the system in order to provide different approaches and ways to explore the environment. Finally, in Section VII, we discuss the obtained results and draw the conclusions.

II. STATE OF THE ART

Nowadays, thanks to the continuous evolution of ICT technologies and computing performance, the usage and exploitation of complex virtual environments is constantly increasing. In this field, graphics engines ease the development of such virtual environments. A graphics engine arises as a suite of software providing a set of high and low level functionalities. These engines also provide support for the transformations and event management typical of 3D navigation (such as viewpoint change, zoom and object collisions). The key advantage in using virtual environments for gaming, dissemination, teaching, and edutainment is the potential high level of engagement that can be offered to users.

The evidence of increasing interest in underwater world is witnesses by the massive existence of projects aiming at building systems able to offer an easy and safe exploration of many environments. The majority of them are devoted to nature, or to the scenic and architectural beauty, but only a few of them concern the marine environment. Even Google, the giant of Mountain View, has made some effort to get into the marine world; see for example the Oceans Street View [1]. More than this, archaeology and historical objects have a specific relevance in this framework (see for example the public database of shipwrecks made available by Google Map, featured on Shipwreckology [2]).

In the last two decades, there has been a boom in activities dedicated to cultural heritage, conjugated to the new technologies for modeling and rendering objects and landscapes. Such an explosion made clear to the research community the need for a regulation. The London Charter for the Computer-based Visualization of Cultural Heritage [3] was conceived in 2006, and it states a set of principles a set of principles that, once followed, ensure that digital heritage visualization reaches the same level of intellectual and technical rigor as well-established cultural heritage research and communication methods.

In this research line, we mention a sample of recent research projects developing virtual environments in the field of archaeology: Virtual Rome [4], and Aquae Patavinae. [5]. The aforementioned projects have the purpose of building an on-line three-dimensional environment, embedded into a web-browser, a contemporary approach to increase the user's engagement in cultural heritage.

On the contrary, there is no such a development for the underwater environment. This fact is due basically: i) to the scarcity of data about the underwater archaeological sites (making it difficult the reconstruction task), ii) to the presence of relevant distortions, caused by the water medium, corrupting all the available data (e.g. geometric distortions, caustics in shallow waters, prohibitive lighting conditions, reduced visibility, color absorption). Issues that do not affect any acquisition performed on the mainland. However, there exist some relevant results in underwater archaeology, like the works about the shipwreck of Mazotos, Cyprus [6, 7]. Looking ahead, the expected developments in this field include the data processing [8, 9], and both visualization and exploration (for research and dissemination) of the cultural heritage environment [10, 11].

In this framework, our research represents an important step in the development of a system able to offer the user a complete and engaging experience in exploring the deep sea.

III. The Virtual environment

MVE has been developed in the framework of ARROWS (FP7-Environment-308724) and its purpose is the virtual representation of the marine seabed, explored by means of Autonomous Underwater Vehicles (AUVs).

The main idea is to provide a useful tool both for professional and general users. Aiming at fulfilling different user requirements, the system has been designed focusing on recreating environments that are both appealing and accurate. Indeed, while appeal is a crucial feature to guarantee a widely usage and distribution of the system, accuracy is strictly requested in order to ensure the professional usage. The exploitation of advanced and modern graphic engine, mixed with gestural and vision devices, ensures the environment is appealing while, on the other hand, a reconstruction workflow has been designed aiming at output accuracy

MVE has been realized exploiting Unity 3D game engine [12]. The engine manages advanced graphic features such as dynamic light effect, dynamic shadows, depth of field, dynamic textures, etc. The exploitation of the Unity 3D game engine also facilitates the development of the Marine Virtual Environment itself providing tools for the scene design and management. Unity portability capabilities also ensure the possibility of wide diffusion of the system. Indeed, the software developed through Unity is system independent and could run even on mobile devices or inside a Web page.

The designed reconstruction workflow, which will be accurately described in the next section, aims at the realization of highest accurate virtual environment starting from acquired raw data. Indeed, in the frame of ARROWS project, an Autonomous Underwater Vehicle (AUV), equipped with a set of sensors, is developed for the exploration of underwater sea [13]. In this frame, also an informative system is in development. This system is able to manage heterogeneous information: information ranges from the raw data acquired by AUVs during the campaigns, to the results of elaboration and analysis and to other information about historical interest. Exploiting the connection with such system, MVE can offer further information to the users.

Aiming at a "general purpose" educational tool, the Marine Virtual Environment and the informative system, even if conceived in the frame of ARROWS, have been expanded in order to provide support not only for cultural heritage but also for any kind of data concerning the underwater environment (Fig. 1).

IV. Reconstruction Workflow

A specific reconstruction workflow has been planned, to get the best result in our setting. Depending on specific environmental characteristics, the reconstruction workflow could change (see for example the reconstruction workflow designed for a city landscape [14]). As mentioned before, the AUVs are in charge of surveying a specific underwater area and of acquiring data. Thanks to the modular design of the vehicle, each AUV can be equipped with a different sensor suite, depending on the mission requirements, 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). Hence, off-line, the data collected are heteogeneous and need to be integrated, and analyzed in order to recognize object of interest. After this analysis, the excerpts of interesting data are processed in order to obtain 3D meshes.

The global terrain (seabed) is reconstructed mainly exploiting bathymetric sensor data. These data are low detailed but they are enough accurate for the reconstruction of the scene. Indeed, the seabed is mainly constant with few variations; thus, having high detailed seabed would be a waste of resources. From the bathymetric data, a gray scale height-map is generated. Height-map darkest regions represent deepest seabed regions.

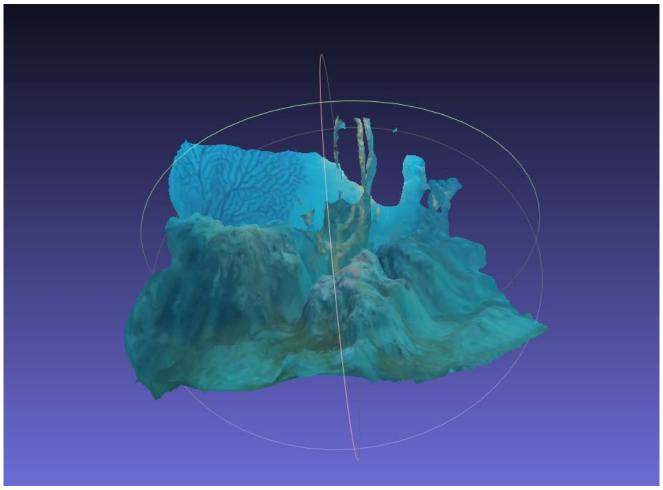

Fig. 1. 3D reconstruction of a coral and rocky structure

Aiming at obtaining high detailed meshes, the objects are reconstructed starting from optical video exploiting advanced photogrammetry techniques (Fig. 2). Some steps of this operation can require manual intervention in order to obtain a better and more accurate result. Photorealistic rendering is needed in order to provide reliability for the archeologist analysis and make the environment more immersive and captivating.

Through the exploitation of advanced dedicated tool, the frames, that compose the optical video, are aligned and the point of views are estimated. The alignment phase automatically produce sets of markers that repeat from frame to frame. At this point of the workflow, it is possible to identify manually some further markers.

The sparse and, then, the dense point cloud are generated once the alignment has been performed. From the point cloud, the process calculates and generates the resulting mesh.

The points possess color information, thus, also the obtained mesh possesses it. However, the obtained mesh texture is low detailed. Aiming at obtaining a good quality texture, the tool generates it starting from the optical frames. The mesh can be refined exploiting highly specialized editors such as Meshlab.

The low detailed seabed and the high detailed objects are fused together exploiting Unity game engine. The seabed mesh is obtained directly through the height-map. Indeed, Unity is able to calculate the terrain height directly from the grayscale image. The low detail terrain mesh is masked placing on it a high detailed terrain texture. In order to increase further the detail, the texture comes along with a normal map image through which Unity calculates the terrain dynamic shadows in a performing way.

Finally, the high detailed object of interest is directly placed into the scene.

Fig. 2. Reconstruction of a jar placed on the seabed starting from a video capture

V. Interactions

A crucial point to make MVE an effective and appealing educational tool consists in providing further information about the scene objects.

Meanwhile Unity manages directly and natively the representation and navigation functionalities, the object interactions have to be managed through the development of dedicated procedures.

The user can interact with the scene objects and access to additional data concerning them. Although some interactions are common to each object, there are interactions that directly rely to the data available in the informative system.

The data that can be request and obtained by the user are:

- The complete reconstructed 3D mesh of the objects, displayed separately from the scene and available for observations from multiple points of view;
- Videos captured during the ARROWS missions or already available from preexisting resources;
- Raw data captured by different sensors (sonograms, etc.);
- Any kind of supplementary information.

During the exploration, user can block the camera movements and display the mouse pointer. Through the mouse pointer, it is possible to select the objects inside the scene. For the selected object, a dedicated menu is then displayed (Fig. 3). The menu allows accessing to the available interactions.

The interactions have been designed and developed in order to provide support towards both professional and general user.

A. Reconstructured 3D mesh

Meshes of the object of interest can be viewed extrapolated from the scene. This is a significant functionality because allows user, both professional and not, observing the object details.

Any light effect (such as typical blue color of underwater environment and caustics) does not affect the object. The mesh can be freely rotated and/or zoomed in and out.

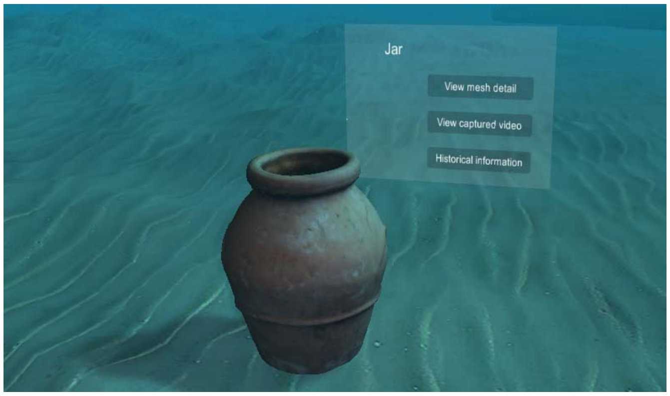

Fig. 3. A reconstructed jar with the interactive dedicated interface displayed

In addition, a dedicated menu is displayed and user can use it to access to the available interactions.

B. *Raw videos*

For each object contained in the scene, user can access to the raw video acquired during the AUVs campaign.

Raw videos can be viewed directly inside the explored scene (Fig. 4). The videos are shown on a dedicated panel that appears in the scene. User can pause the video whenever by simply clicking on the panel itself; clicking again on the panel the video will continue playing.

Videos can be accessed also when the object is extrapolated from the scene. In this case, videos will be shown directly in front of the camera.

C. *Raw data captured from different sensors*

The AUVs can be equipped with several kinds of sensors. Related to each object placed in the scene, there are several types of data acquired by different sensors (such as sonograms, magnetic images, etc.). These data can be raw format (as acquired) or the result of data processing (raw data transformed in a mesh texture, raw data analysed in order to discover object of interest, etc.). Thus, relying on raw data availability, user can access to different interactions.

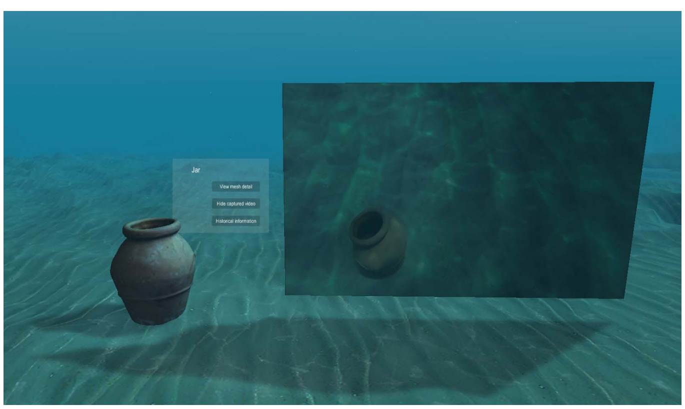

Fig. 4. Jar placed on the seabed with the acquired raw video displayed on a panel

For instance, during the exploration, a user observes a jar. Assuming the informative systems has stored a sonogram related to that jar; user will be able to view the sonogram as a texture of the jar itself.

D. *Other kind of information*

The informative system, which the Marine Virtual Environment is connected with, manages not only data acquired during the AUVs campaign but also data concerning the object's dimensions and material, historical (for the archaeologist interest) or biological details (for the biologist interest).

Information will be shown in a dedicated panel that will appear once the user chooses this functionality.

VI. INTEGRATION WITH GESTURAL AND VISION DEVICES

MVE can inherit advanced technologies from the videogame industry that provide alternative approaches and ways to navigate and experience the scene. Their exploitation allows making the system more appealing and enhances its immersive features.

Unity distribution and its active community facilitate this task. Indeed, Unity natively supports and integrates most recent 3D interaction devices, like Oculus Rift, and gestural interfaces, like Leap Motion.

A. *Oculus Rift*

Oculus Rift is a head mounted display. Thanks to two OLED displays placed in front of user eyes, it provides one of the most accurate stereoscopic vision. It is also equipped with a set of accelerometers that are able to recognize head movements.

The integration with the Marine Virtual Environment involves these device features.

The head movements are recognized and translated into the camera movements in the scene, so that it is possible to change the scene point of view simply moving the head, as in real world. This, coupled with the accurate stereoscopic vision, contributes to increase the engagement of the user (Fig. 5).

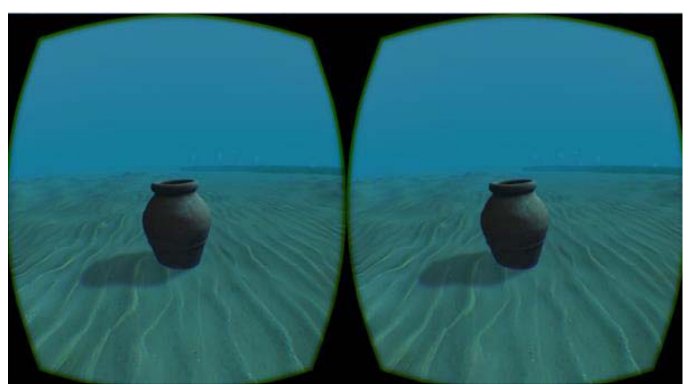

Fig. 5. A jar placed into the scene viewed through Oculus Rift

B. *Leap Motion*

Leap Motion is a touchless controller (https://www.leapmotion.com/). It is able to recognize the hands, the fingers and their position and orientation.

The integration of the Leap Motion with MVE makes possible to navigate the scene exploiting the gestural control and making the interaction more intuitive and natural. In more detail, the user can change camera orientation by turning the orientation of their hands. By widening the hands it is possible to go backward and by closing the right hand it is possible to stop.

VII. CONCLUSIONS

The proposed Marine Virtual Environment owns all the features required to be 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 provides a set of functionalities dedicated to the observation of the scene and the objects placed in it. Archaeologist can exploit these functionalities in order to perform analysis of the site. The analysis can regard the measurements of interesting objects, the observation of details and the possibility of making deductions starting from object displacement on the seafloor. This kind of support is obtained by realizing a most accurate environment as possible. Thus, the technologies exploited for the reconstruction of the scene starting from the raw data, acquired during the campaign, aim at this. Thus, these features coupled with the possibility to access directly the raw acquired data offer to professional user a valid system to perform the exploration of underwater environment.

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.

Exploiting the connection with a dedicated information system makes MVE an interesting tool in the educational field about marine environment. The informative system has been extended in order to manage biological information about corals, fishes and underwater living beings. This extension enables the Marine Virtual Environment to cover each aspect of underwater environment providing an alternative and captivating way to educate general user about the underwater environment itself and its exploration.

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