Development and integration of digital technologies addressed to raise awareness and access to European underwater cultural heritage. An overview of the H2020 i-MARECULTURE project

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***Abstract*—The Underwater Cultural Heritage (UCH) represents a vast historical and scientific resource that, often, is not accessible to the general public due the environment and depth where it is located. Digital technologies (Virtual Museums, Virtual Guides and Virtual Reconstruction of Cultural Heritage) provide a unique opportunity for digital accessibility to both scholars and general public, interested in having a better grasp of underwater sites and maritime archaeology. This paper presents the architecture and the first results of the Horizon 2020 i-MARECULTURE (Advanced VR, iMmersive Serious Games and Augmented REality as Tools to Raise Awareness and Access to European Underwater CULTURal heritage) project that aims to develop and integrate digital technologies for supporting the wide public in acquiring knowledge about UCH. A Virtual Reality (VR) system will be developed to allow users to visit the underwater sites through the use of Head Mounted Displays (HMDs) or digital holographic screens. Two serious games will be implemented for supporting the understanding of the ancient Mediterranean seafaring and the underwater archaeological excavations. An Augmented Reality (AR) system based on an underwater tablet will be developed to serve as virtual guide for divers that visit the underwater archaeological sites.**

Keywords— Underwater Archaeological sites, Virtual museums, Serious games, Underwater Augmented Reality system.

I. Introduction

Underwater archaeological assets represent a relevant part of the world cultural heritage and a particularly important element in the history of people, nations, and their relation with each other concerning their common heritage, especially in the European context. For this reason, the i-MARECULTURE (Advanced VR, iMmersive Serious Games and Augmented REality as Tools to Raise Awareness and Access to European Underwater CULTURal heritage) project aims to enhance the visit experience in museums and underwater parks by developing new technological solutions able to stimulate the public in increasing their knowledge about the European maritime archaeology.

The use of new technologies for improving the exploitation of Underwater Cultural Heritage (UCH) started ten years ago with the VENUS (Virtual exploration of underwater site) project [1] that strongly focused on the virtual reconstruction of underwater archeological sites and several campaigns have been conducted to acquire detailed 3D models of ancient shipwrecks. The digital models of the underwater sites have been used in a couple of Virtual Reality (VR) and Augmented Reality (AR) tools for interactive and immersive visualization [2], allowing archaeologists to study the virtual site from within. More recent works have proposed different frameworks for the collection and visualization of the underwater cultural assets by means of VR technologies, but these results limit the exploitation to a single underwater archaeological remain [3] or are more oriented to the digitization for scientific purposes [4], rather than focusing on edutainment for general audiences. Some VR based demonstrators have also been designed for the general public, but the virtual exhibit is more oriented to the presentation and visualization of archaeological data [5] rather than to edutainment purposes.

One of the few works related to the adoption of an edutainment approach for supporting the knowledge acquisition about UCH has been described by Stone [6] who has applied the serious game approach in order to raise the awareness of schoolchildren and public audiences to the importance of protecting global oceanic resources. In particular, the subsea environment, in which the wreck of the naval vessel Scylla lies, has been represented to visually simulate the life cycles of dynamic sea life forms and colonization processes in order to increase the cultural awareness about marine biology rather than underwater archaeology.

Recently, the VISAS (VIrtual and augmented exploitation of Submerged Archaeological Sites) project [7] proposed a virtual diving system based on a VR application consisting in the simulation of a real diving session from the point of view of a scuba diver. The application follows a storyline described by a virtual diving companion who guides users during the exploration of the underwater archaeological site. The virtual diving system provides general and historical-cultural contents, but also information about the flora and fauna of the specific submerged site to the users.

Compared to previous works, the i-MARECULTURE project follows an interdisciplinary approach that goes beyond the mere technological development. The challenge is to merge existing upcoming technologies, adjust them to the underwater environment, in order to bring inherently unreachable European UCH, within reach and understanding of general public. The final aim is the development of personalized experience, using several methods to provide digital content, before, during and after a visit to an archaeological park or a museum.

II. PROJECT OVERVIEW

To raise awareness and access to otherwise unreachable (or difficult to reach) European UCH, the project utilizes VR and AR technologies to prologue and personalize virtual and actual visits to submerged shipwreck and other archaeological sites. Therefore, implements a serious seafaring game to raise awareness even before public visits maritime museums or sites. In the museum, the visitor will have the opportunity to have a personalized dry visit to project's test sites, using equipment which is unavailable to wide public due to high cost, such as Holographic screens and high end VR Head Mount Displays (HMDs). During the virtual visits he will have the ability to follow his own path and acquired details about certain objects or details that he selects. If the visit is taken in a submerged site, the diver-visitor will be equipped with an AR enabled underwater tablet. After the museum visit, the visitors who wish to extend the visit, will have the ability to make an online dry visit from his home, using VR HMD, although in a reduced detail and resolution virtual world. An additional VR game, which we will be able to play from home, will provide even more information about the difficulties of the underwater documentation and excavation of such sites.

It should be mentioned that the experienced maritime archaeologists of the project, ensure the historic accuracy of every aspect of i-MARECULTURE project, both through storytelling as well as realistic representations and game scenarios.

Regarding the dry VR visits, the focus will be given to the quality of immersion into the virtual world, using as much detail as possible and high end equipment. The AR tablet will provide navigation guidance to the diver/visitor and additional information about specific exhibits based on proximity and diver's preferences. If it will be used to explore a sunken city, the AR tablet will provide the diver with conceptual designs of the underwater villas and related constructions, which are now laying in ruins. Statues that have been removed for conservation and preservation reasons will be displayed in their original position and state in the tablet's screen, overlaid on the actual video recording of the camera in real time.

The seafaring game will be used to attract and familiarize the public with ancient maritime trade and commerce, between ports and civilizations of the eastern Mediterranean during Classic and Hellenistic period. The user as a captain of an ancient ship, must sail across ports trying to increase his fortune, while staying alive and overcoming all difficulties of those trips. At the same time the user is introduced with proper storytelling to support background knowledge about ports, weather, risks, routes, cargo load, commodities, and crew, necessary to make correct decisions.

The VR game is focusing in the challenge of underwater excavation in general and digging in particular. The player will be introduced in all phases of an ancient underwater shipwreck discovery and proper actions until he will be able to participate in a digging dive, to expose and recover artifacts. Storytelling and game plot will ensure that the game relays the proper message to players regarding all necessary actions preceding an archaeological excavation. This game will even have the option of multi-player collaboration and will also be used as training for future maritime archaeologists. The shipwreck site will be recreated procedurally each time the player starts a game, to ensure unpredictability.

In the underwater serious game, storytelling is not as evident as in Seafaring serious game. Still, will be created an intro story which will introduce the users with game topic, aim and structure. This intro should offer enough information, but has to be short and attract users to continue and play the game. An archaeologist character could be a storyteller in this game as well, because of the positive impact of such storytelling technique on users.

A by-product of i-MARECULTURE project are two libraries of 3D ship models and amphorae of that period. The 3D objects of these libraries will be used in the two serious games. Users will be given the ability to select ship and shipwreck type they wish to play with. The libraries are being designed with ontology, so that they can be useful for further archaeological archiving and will be released to public.

A. Pilot sites

Three different pilot sites have been selected for testing and demonstration activities. The selected sites are representative of different kind of UCH, of different states of environmental and geomorphologic conditions (i.e. water depth, water turbidity etc.) and of different periods, in order to present the users a wide range of the common European maritime culture.

The first site is the Underwater Archaeological Park of Baiae located off the north-western coasts of the bay of Puteoli (Naples). This site is part of the coastal region known as Campi Flegrei, that has been characterized by a periodic volcanic and hydrothermal activity and it has been subjected to bradyseism, namely gradual changes in the levels of the coast with respect to the sea level (Fig. 1).

Fig. 1. Aerial photography of the Underwater Archaeological Park of Baiae (Italy).

The Park, which has an area of about 176.6 hectares safeguards the archaeological remains of the Roman city and the infrastructures of the roman harbor named Portus Iulius. Since antiquity this coastal region has been subject to the phenomenon of bradyseism, which may be positive or negative, and in its present state, the remains of the Roman Era are submerged at a depth ranging between 1 and 14-15m below sea level. The ancient Baiae was a famous seaside town much prized in antiquity for its temperate climate, beautiful setting and the properties of its mineral waters that have been exploited since the second century BC. It was the one of the most popular resort among the Roman aristocracy and the Imperial family up until the end of the fourth century A.D., when several ground movements caused the submersion of the city. The area selected as Pilot site is the complex of the "Villa con ingresso a protiro" located at 5/6 meters' depth. The rooms which composed the Villa extend for 40 meters on the road flanked by thermae, tabernae and other villas; however, its real size could be larger. The data available for the site are digital photos, drawing and 3D models created by the Underwater Archaeology Unit of the Istituto Superiore per la Conservazione ed il Restauro directed by Barbara Davidde [8].

The second site is the Mazotos shipwreck that lies at a depth of 44 m, ca.14 nautical miles (NM) southwest of Larnaca, Cyprus, off the coast of Mazotos village, 1.5 NM from the shore (Fig. 2).

Fig. 2. Mazotos shipwreck, Cyprus.

The wreck lies on a sandy, almost flat seabed and consists of an oblong concentration of at least 800 amphorae, partly or totally visible before any excavation took place. This assemblage appears to be nearly in the form of a ship, with its south end pointed and the north one almost squared off. It measures approximately 1 m at its maximum vertical relief, 16 m on its long axes and 6.5 m on its maximum width [9, 10].

The shipwreck was reported to the Department of Antiquities in 2006. The investigation of the shipwreck is conducted jointly by the Maritime Research Laboratory (MARE Lab) of the University of Cyprus and the Department of Antiquities, under the direction of Dr. Stella Demesticha. It is the first shipwreck of the late classical period, found in the Southeast Mediterranean carrying Chian amphorae, but its significance lies mainly in its excellent state of preservation. The Department of Civil Engineering and Geomatics at the Cyprus University of Technology (CUT), under the direction of Dr. Dimitrios Skarlatos, and the MARE Lab, under the direction of Dr. Stella Demesticha, have been surveyed the Mazotos site several times thus producing a complete documentation of the site, which includes the point clouds, database, photographs of finds, 3D solid models of artefacts and the 3D Site Model [12]. A combination of computer vision and photogrammetric methods has been used as a rapid means to obtain measurements with surveying accuracy in the scale of 1-2cm.

The third site is the Xlendi shipwreck that was named after the place where it was found off the Gozo coast in Malta (Fig. 3).

Fig. 3. Xlendi shipwreck, Gozo (Malta).

The site is curated by Timmy Gambin (University of Malta) and studied by himself. The wreck was on the focus of the GROPLAN project (http://www.groplan.eu) where Timmy Gambin and Jean-Christophe Sourisseau (Aix-Marseille University) have studied this wreck. The shipwreck was detected by Aurora Trust, an American consortium expert in deep-sea detection systems, during a prospecting campaign in 2008. The inspection operation was authorized and mandated by Heritage Malta and Malta's "Superintendence of Cultural Heritage" with the aim of taking an inventory of all the underwater ruins located in Malta's territorial water at a depth between 50 and 150 meters. A preliminary expertise helped to characterize a very ancient ship, probably the oldest discovered in the western Mediterranean. An intervention group was gradually created by Timmy Gambin in order to put together a strategy adapted to the study of this shipwreck. The shipwreck is located near a coastline known for its limestone cliffs that plunge into the sea and whose foundation rests on a continental shelf at an average depth of 100 m below sea level. The shipwreck rests on a practically flat area of this submerged plateau at a depth of 94 m. Sonar images as well as the image of the entire deposit site shows that the cargo remains very closely grouped together and appears to have been very slightly disturbed.

A photogrammetric survey was done in 2014 from the submarine Remora 2000 by COMEX and LSIS CNRS - AMU in the framework of the GROPLAN project. As a first result a dense cloud of point, scaled, is available with a mesh, covering the whole site, including amphora moved far from the wreck. In addition, a very high resolution orthophoto was computed (41507 x 60377 pixels with resolution = 0.005 mm / Pixel) and accessible from a web site.

III. DATA GATHERING AND PREPARATION

Several underwater 3D acquisition methods are available nowadays, but for detailed archaeological documentation photogrammetry is the most prominent [13]. Except of image based only techniques, other methods exploiting active sensors are used for detailed underwater archaeological 3D recording. These methods include Time-of-Flight (ToF) or LiDAR techniques [8], triangulation scanners and structured light systems. The ToF 3D scanners obtain range information by measuring the time delay of a light signal between the system and the object. Triangulation scanners project a light beam to measure the direction of light from a known position and having a well-known geometric configuration. Regarding underwater structured light systems, in [3] is described a system consisting of two commercial optical cameras and a digital projector. Finally, acoustic systems use sound propagation properties to record underwater objects by calculating the distance to the object using the time of travel of the sound. The most common used are the Multibeam Echo sounders (MBEs), the Side Scan Sonar (SSS) and the Sub Bottom Profiler (SBP). These systems are usually mounted in a moving platform such as a Remotely Operated Vehicle (ROV) or an Autonomous Underwater Vehicle (AUV), a vessel's hull etc. Compared to optical systems, the acoustic ones provide less spatial resolution but longer range.

Since the combination of computer vision algorithm with photogrammetric techniques, image based modelling transformed from an exotic expert-only method to a trivial field task for the average archaeologist scholar. Nevertheless, although to the reach of the wide public, several limiting factor and problems in the underwater environment, pose challenges even to the experts. Given that photogrammetric accuracy depends mainly to object to camera distance, extremely detailed 3D models may be acquired underwater. This is an invaluable characteristic of photogrammetry for underwater 3D modelling.

Several examples of shipwreck documentation [11, 14] and sites [15] are to confirm this argument. All three sites involved in the i-MARECULTURE project have been detailed documented using underwater photogrammetry [10, 11, 16, 17], Structure from Motion (SfM) and Multi View Stereo (MVS) techniques. In all cases strobes and underwater lights have been used either because of the depth (Xlendi and Mazotos sites) or due to poor lighting conditions is certain areas to the shallow Baiae site. The 3D textured models have been generated from dense point clouds and are extremely detailed, appropriate to be used for virtual reality and dry visits (Fig. 4).

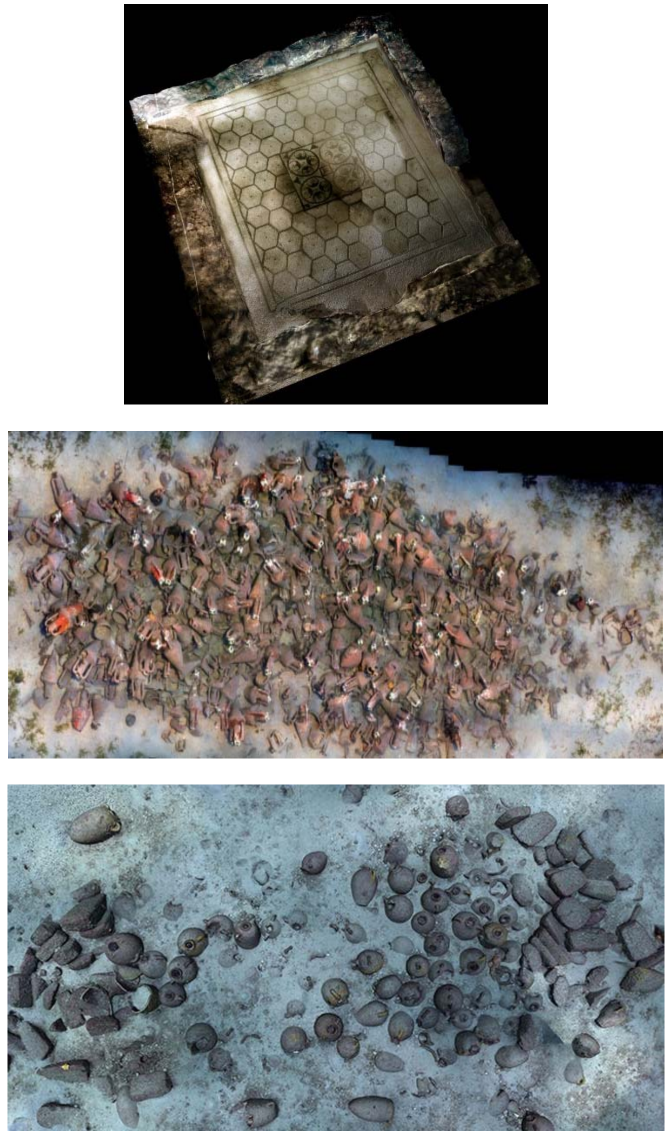

Fig. 4. 3D reconstructions of the i-MARECULTURE pilot sites: A portion of the "Villa con ingresso a protiro" at Baiae Park (top), Mazotos shipwreck (center), Xlendi shipwreck (bottom).

IV. A SERIOUS GAME FOR UNDERSTANDING ANCIENT SEAFERING IN THE MEDITERRANEAN SEA

To better understand ancient seafaring practices, we proposed the design and development of a serious seafaring game. The game's users will be able to experience the role of the ship captain/merchant. The objective of the game will be to trade goods, complete quests and face off the many perils of the high seas in a quest to uncover new sources of wealth and opportunity in distant lands based on the information we have and hypothesize for the roman-hellenistic era.

The game will make use of the probabilistic geospatial analysis of the ship routes of the Classical and Hellenistic period through the re-use and spatial analysis from open GIS maritime data, ocean and weather data. Naval engineering and sailing techniques along with the aforementioned ship routes, are used as underlying information for the seafaring game.

A game map is created as the route-plotting graph shown in Fig. 5, where each vertex represents a coastal feature, i.e. port, and the edges represent “hops” in a voyage.

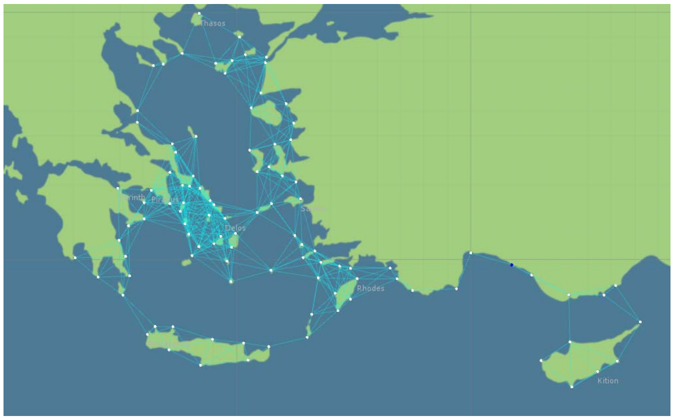

Fig. 5. Route creation algorithm in the game map.

Currently, the cost function is the edge length, and the heuristic is the distance to the goal vertex. This is sufficient for estimating voyage time, but additional hazard data (piracy, weather, shallow waters, etc.) add depth to the simulated economy by exerting negative incentive along dangerous routes. This could result in high-risk destinations where certain resources are scarce, offering the player a large reward due to the correspondingly high demand. Hazard data can be defined discretely for each edge, or sampled from a heat map.

The information provided by the archaeologists has been incorporated into the game’s project data e.g. port types, commodity types.

Lastly, path-finding (A*) and spline (Catmull-Rom) tools were required to implement the route finding and route display features. We are currently in the first steps of evaluating the game with end-users.

V. VR TECHNOLOGIES FOR UNDERWATER EXPLORATION AND EXCAVATION

A. *Virtual Underwater Exploration*

The technological requirements for applying serious games to cultural heritage have been previously explored and the most characteristic case studies were presented [18]. In particular, the case studies have been categorized into three types of computer-game-like applications, namely a) prototypes and demonstrators, b) virtual museums, and c) commercial historical games. The state-of-the-art in Serious Game technology is identical to the state-of-the-art in Entertainment Games technology. Meaning gamification techniques will inform how information should be represented for the different users of the platform and adaptivity will be experimented on. Our approach will exploit the interactive characteristics of VR games.

The aim of the serious game is to raise people's archaeological knowledge and cultural awareness. It will provide immersive technologies to increase interaction time in an underwater archaeological site, both for the public, as well as, for researchers and scholars. Users can experience an immersive virtual underwater visit using off-the-shelf VR headsets (i.e. HTC Vive). Apart from their visit, they can also get some information about the archaeological artefacts (i.e. textual descriptions, videos and sounds).

The application was developed in Unity engine with support for VR Head Mounted Displays (HMD) HTC Vive. Apart from the HMD (resolution per eye 1080 x 1200, refresh rate 90 Hz, field of view 110°), HTC Vive comes bundled with two motion tracked controllers and laser based tracking system called Lighthouse providing 6 Degrees-of-Freedom (DOF) tracking in an up to 4.5 x 4.5 m area with two beacons. This setup, allows users to perceive a very immersive experience of the underwater environment. Work done for developing the immersive VR environment consists of four main parts [19]: a) graphics effects (i.e. lightning, fog), b) procedural content (i.e. placement of artefacts), c) behavior (i.e. fish movement) and d) interaction (i.e. exploring and learning). Fig. 6 provides an example of fish behavior.

Fig. 6. Fish in the underwater immersive experience.

In the virtual experience, there are two types of fish which have different sizes and speeds, spawning groups of 80 and 100 instances. Fish school simulation implementation was based on the algorithm proposed in [20]. The algorithm simulates flocking behavior boids (bird-oid objects) - birds and other living species, including fish.

The user interaction is focused on navigating inside the virtual environment and receiving information about the archaeological artefacts Fig. 7. The user can either physically walk within a space of 3x3 meters or 'teleport' in the virtual space. Using the controls of the HTC Vive device, one can select the teleporting destination. This allows the user to 'jump' from one virtual position to another without physically moving. Players can interact directly in the virtual visits with the environmental objects (i.e. game objects). If appropriate, players can pick them up and examine them using the dedicated controllers. They can also control the relevant information that they will receive. For example, they can receive textual descriptions about an artefact and then watch a relevant video (by pressing the touchpad of the right HTC Vive controller).

Fig. 7. User interaction in the underwater virtual exploration.

Another way to provide immersive experience to museum visitors is obtained by using holographic displays. In particular, we use the HoloVizio screens, developed by Holografika [21]. Using this technology, no additional gears are required and content observation depends on the user location and direction as walking in front of the display. It allows a large number of freely-moving simultaneous viewers to share the same underwater scene, viewing the 3D captured artefacts and seeing their different details with high quality. Visitors can even "look behind" the displayed objects, similarly to the real scene, having a true spatial feeling.

The approach used by HoloVizio technology is quite different from that of stereoscopic, multiview, volumetric and holographic systems. It uses a specially arranged array of projection modules and a holographic screen. The light beams generated in the projection modules hit the screen points in various angles and the holographic screen makes the necessary optical transformation to compose these beams into a perfectly continuous 3D view. With proper software control, light beams leaving the pixels propagate in multiple directions, as if they were emitted from the points of 3D objects at fixed spatial locations. In this way, viewers will perceive the points in objects behind the screen, or floating in the air in front of the screen, respectively. The HoloVizio displays generate the whole 3D light-field, not just limited numbers of views, and provide a continuous motion parallax in a wide Field of View (FOV). It is an ideal component of visualization systems to support the cooperative work of small research groups in archaeology presenting and assessing reconstruction hypothesis, or for large audiences sharing a common 3D view, as is the case of interactive installations in museums, where visual presentation can be supported without introducing wearable elements and complex management procedures.

B. *Virtual Underwater Excavation*

Another version of the underwater serious game is currently under development and will be primarily used for training maritime archaeology students. Users will be trained on the specifics of underwater excavation and familiarize themselves with the instruments in use, such as the airlift, without the constraints of the underwater environment, which, apart from the time limitations include the difficulty in verbal communication between the student and the instructor. Users will also be able to learn how to document and study wreck site formation processes. By teaming up with an expert, in this case a seasoned maritime archaeologist, students will gain valuable experience and knowledge on the methods, techniques and tools used in underwater archaeology, prior to working at the real site. The focus is not on simulating swimming but on excavating underwater following established archaeological methods and techniques.

For the "fun" element of the game, that motivates the user to play the game - we have chosen the treasure hunt gaming approach. The main idea is that one or more players who try to find hidden objects or places by following a series of clues (i.e. finding amphorae and another archaeological artifacts). To make the game more interesting, amphorae should be placed pseudo randomly, with some degree of covering by a sandy sea bed. The amphorae placement algorithm is based on the solution presented in [19] that places the objects procedurally. The placement of objects is different with every start of the game, however, there are fixed parameters - playing area size and number of amphorae. For our game, we have chosen 25 amphorae and playing area of 20 times 20 meters. The actual placement is done using an exponential function [19] (Fig. 8).

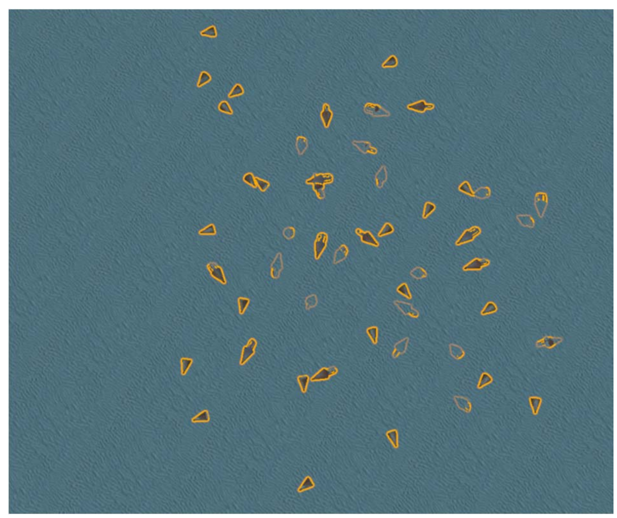

Fig. 8. Random object placement in the game scene.

An important element of the excavation game is that the objects should have different degree of coverage by the sandy terrain. Various methods for real-time modification of the terrain exists, which would allow the user to dig the objects. The methods differ on their computational difficulty and level of believability. One of the possible approaches, due to the limited amount of interaction the user is doing with the terrain (the digging is not a continuous operation done in every frame), modification of positions of the vertices of the mesh might be deployed to modify the terrain. However, more universal and correct approaches are available, e.g. the method introduced by Aquillo [22]. The method presents a real-time algorithm to modify the Dynamically Displaced Height Map (DDHM) to record vehicle tracks in sandy terrain. The height map representation also allows us to use other algorithms based on height maps, which would add slippage properties to our soil [23] (Fig. 9).

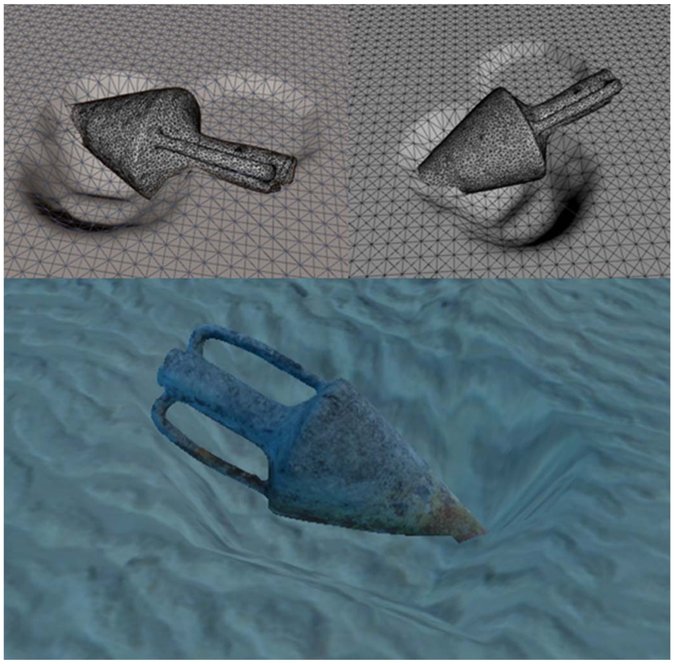

Fig. 9. Underwater digging in the serious game.

Moreover, the visual fidelity of the simulation could be increased by using a terrain-mesh blending techniques, to apply the textures of the sandy material to parts of the objects above the seabed.

VI. UDERWATER AUGMENTED REALITY

The potential of AR to enhance immediate surroundings through the projection of digital content into users' real environment has been discussed in various research contexts [24 – 26]. For the tourism industry, an increasing number of scholars recognize the potential of AR for the enhancement of the tourism experience [27]. Using marker or location based AR applications, tourists can receive instant information on unknown surroundings that contribute to provide a new learning experience.

Systems for underwater AR have been already tested and used in the last years. HMDs have been used in [28] to help divers with orientation and navigation underwater by augmenting their vision with artificial horizon and visual aids to provide a guideline and help them with their work. An underwater device for AR that allows users to play simple games underwater has been introduced in [29]. The authors, in [30], use tablets placed into a waterproof case, and develop a game for kids that helps them to improve their swimming skills in a swimming pool.

So far, the only attempt to adopt AR technology directly in the submerged environment for the exploitation of UCH is represented by the VISAS project [7, 31]. The developed AR system consists in an underwater tablet equipped with an underwater positioning and orientation system that guides the diver tourists during the diving session while providing information about the archaeological artifacts spotted during the visit.

The technologies developed during the VISAS project will be used in i-MARECULTURE project for the implementation of an underwater AR application. It consists in an underwater tablet equipped with a hybrid tracking system that guides the diver during the exploration, while visualizing an AR layer that shows labels or 3D contents representing the current or the original aspect of the artefacts. The underwater AR interface will be capable of superimposing different types of visual information (i.e. 3D, metadata, images, videos and sound) over the images captured by the tablet main camera. The divers who visit the underwater archaeological site will have the possibility to see their position over the 3D bathymetry of the site and enjoy a hypothetical virtual reconstruction of the structures to better understand their original aspect and their function.

A. Underwater Augmented Reality Interfaces

The AR software running on the tablet is the way through which the diver will be able to live an augmented experience rather than a classic immersion. Thanks to a 3D map and the hybrid localization service, the software will help the diver to understand his position and orientation during exploration. The user interface (UI) of the AR software will be designed according to a user centered design (UCD) approach in order to make it easy to use and intuitive. The AR interface will superimpose an information layer over the images captured by the tablet main camera. The AR layer can include text, images, videos and 3D models of the reconstructed underwater site, or of single artefacts. This augmented information will help divers to better understand structural information of the archaeological site especially in the case of poor visibility conditions. The UI will provide also a command button that will allow users to switch from the 3D model of the archaeological remain to the 3D model of a hypothetical reconstruction of the artefact.

To increase the perception of the underwater scene, the AR application will allow to improve the vision of divers. Vision underwater is degraded by several factors, mostly by turbidity and absorption of lighting, which is different for different color channels. Concerning the turbidity in the underwater images, the problem is very similar to dehazing, i.e. to correct the effects of fog and haze in images taken above water. Many algorithms were developed to dehaze input images, for example a method described in [32], based on Dark Channel Prior, or a method presented in [33], based on color-lines. However, it is more challenging to apply them for removing turbidity because the characteristics of color images that they use are biased in the underwater images, due to uneven absorption of color channels.

To enhance the quality of underwater images, the authors in [34] use a combination of common techniques. They tested methods for color correction, white balancing, and histogram equalization. The solution described in [35] adapts Dark Channel Prior technique to work for underwater images by developing a separate method for each color channel. Some authors propose algorithms that dehaze images in real-time. A method that evaluates each pixel of the input image separately, and use CUDA to accelerate the computation is proposed in

[36]. In [37], the authors use SIMD instruction and OpenMP library to fully utilize a processor, and dehaze images in tens of milliseconds.

The workflow of the AR dehazing architecture is show in Fig. 10.

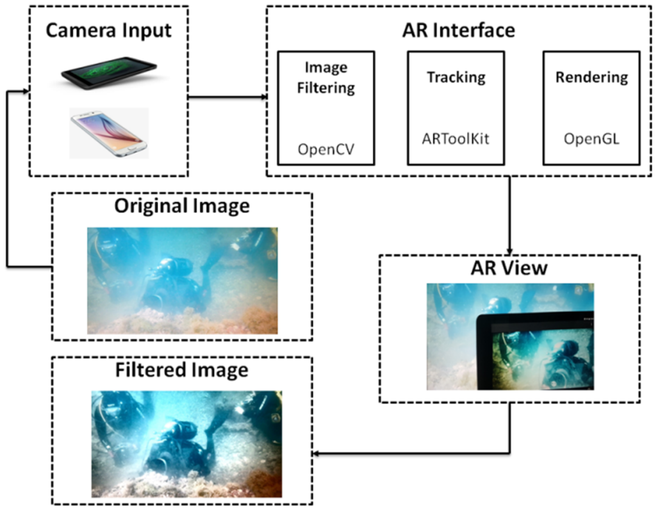

Fig. 10. Augmented reality dehazing architecture

In the first step, the input image coming from the tablet camera is filtered and improved to reduce defects and other imperfections caused by turbidity or poor lighting conditions. This preprocessed image serves in the second step as input for the detection of objects in real world that will be used by the AR tracking algorithm. In the third step, objects of augmented reality are composed together with improved preprocessed input image and rendered into output image. This image is then displayed on the screen of the tablet.

The AR dehazing architecture is implemented in Java and targets Android platforms. Input from the camera is in NV21 format, which is a variant of YUV420 format. We keep the image in this format, and in the preprocessing step, we apply Contrast Limited Adaptive Histogram Equalization (CLAHE) [38] to its Y channel, leaving U and V channels without any change. We use an implementation of CLAHE algorithm from OpenCV library [39]. The AR part is handled by ARToolKit library [40].

The AR dehazing solution was tested on several videos taken in underwater environment. The videos were played on a monitor of a PC, and a tablet was used to record, process and display the images, see Fig. 7. The resolution of input camera was 1280 x 720. We performed our tests on two devices, NVIDIA Shield K1 tablet and Samsung Galaxy S6 phone. The preprocessing step took 7.8 milliseconds on the tablet and 9.0 milliseconds on the phone, which in both cases allowed the application to present improved images in real-time.

Fig. 11. Augmented reality dehazing test results.

B. *Hybrid underwater tracking solution*

The implementation of the AR application requires the development of a solution to calculate the position and orientation of the tablet in the submerged environment. It is performed by means of a hybrid solution that merges data generated by visual tracking techniques (both marker and model based) with data from an acoustic modem, integrated with the underwater tablet, which estimates the position of the receiver by computing the distance from at least three fixed transmitters (beacons) placed on the seabed (LBL - Long Baseline technique). Moreover, data coming from an inertial platform and a depth sensor are used to improve the accuracy and increase the robustness in case of loss of signal from one or more beacons. The data coming from the various sensors are processed through data fusion and error estimation algorithms (Fig. 12).

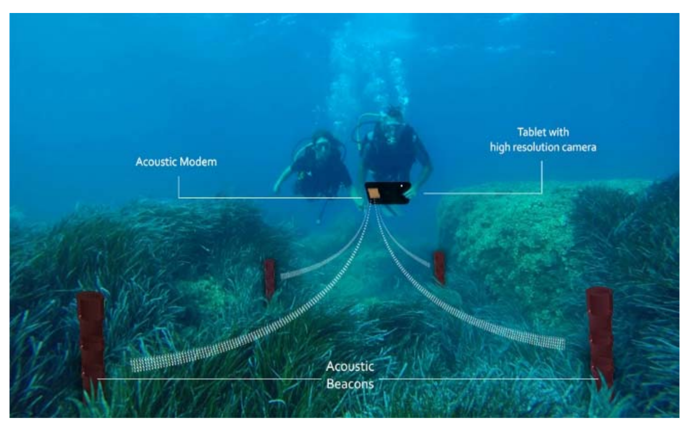

Fig. 12. Augmented Reality system.

Each beacon contains an electronic board to drive the piezoelectric transducer (Fig. 13, left). It operates at 25-30 KHz frequency band, greater than the audible band (0 - 20kHz), to avoid annoying sounds to be perceived by the divers during the immersion. The beacon is equipped with a battery pack, which enables up to five hours of use, and with anchor rings used to fix it on the buoy cable. The beacons are positioned in known geographical points using a mooring post and a surface buoy that facilitates their recovery.

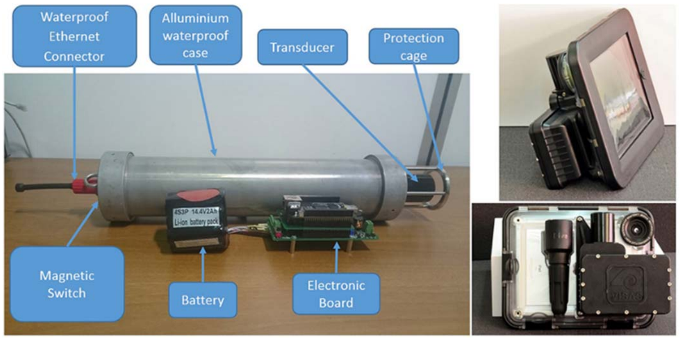

Fig. 13. VISAS beacon (left) and underwater tablet (right).

The tablet is composed of two major parts: a fully functional underwater touchscreen housing and a waterproof case for the electronics of the tracking system (Fig. 13, right). The two devices are connected using a Wi-Fi interface.

The tablet updates the diver's position and orientation on the 3D map at a frequency of 50 Hz. The current position is estimated through an Extended Kalman Filter that uses the distances from each beacon, the depth provided by a pressure sensor, the accelerations along the three axes (x, y, z), the orientations provided by an inertial platform and the position and orientation data provided by the visual odometry algorithm. The distance between the tablet and a beacon is computed using the time-of-fly of the acoustic wave. To this end, the acoustic modem on the tablet sends a two-way range (TWR) command to the remote beacon and starts an internal timer. When the tablet receives the response message sent by the beacon, the timer is stopped. The tracking system sends cyclically a TWR to all beacons. shows the localization algorithm.

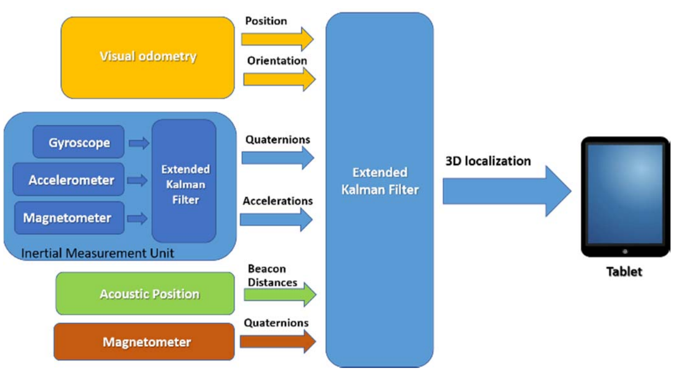

Fig. 14. Schematic of the localization algorithm.

VII. Conclusions

This paper has presented the i-MARECULTURE project and the partial results achieved so far. The project is characterized by the integration of different research activities in the areas of 3D acquisition, Virtual and Augmented reality, serious games, GIS, marine archaeology and storytelling. This synergy aims at creating innovative applications and digital experiences in the area of Virtual Museums in order to empower different types of users to engage with European underwater cultural heritage digital resources.

In particular, the paper has presented a VR application for underwater exploration and the first steps in the development of two serious games: the first one devoted to the simulation of ancient seafaring practice through the Mediterranean Sea and the second one for the simulation of underwater archaeological excavation. Moreover, the development of an underwater AR system has been presented. The system is based on an underwater tablet coupled with an acoustic localization device. The AR software will manage the image enhancement issue and will perform a hybrid localization by combining data generated by the acoustic device and by an optical tracking algorithm that is currently under development.

The tools will be validated and tested across real-world application coming from maritime archaeology research so as to achieve a great mixture between entertainment, informal educational, and underwater/maritime CH understanding.

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References

[1] P. Chapman, D. Roussel, P. Drap and M. Haydar, "Virtual Exploration of Underwater Archaeological Sites: Visualization and Interaction in Mixed Reality Environments", in *9th International Symposium on Virtual Reality, Archaeology and Cultural Heritage (VAST)*, pp. 141-148, 2008.

[2] P. Chapman et al., "Venus, virtual exploration of underwater sites", *Proceeding of joint event CIPA/VAST/EG/Euro-Med,* 2006.

[3] G. Varinlioğlu, "Data Collection for a Virtual Museum on the Underwater Survey at Kaş, Turkey", *International Journal of Nautical Archaeology,* vol. 40(1), pp. 182-188, 2011.

[4] I. Katsouri, A. Tzanavari, K. Herakleous, and C. Poullis, "Visualizing and assessing hypotheses for marine archaeology in a VR CAVE environment", *Journal on Computing and Cultural Heritage (JOCCH*), vol. 8(2), p. 10. 2015.

[5] M. Haydar, D. Roussel, M. Maïdi, S. Otmane, and M. Mallem, "Virtual and augmented reality for cultural computing and heritage: a case study of virtual exploration of underwater archaeological site", *Virtual reality*, vol. 15(4), pp. 311-327, 2011.

[6] R. Stone, D. White, R. Guest, and B. Francis, "The Virtual Scylla: an exploration of serious games, artificial life and simulation complexity", *Virtual reality*, vol. 13(1), pp. 13-25, 2009.

[7] F. Bruno et al., "Project VISAS – Virtual and augmented exploitation of Submerged Archaeological Sites: overview and first results", *Marine Technology Society (MTS) Journal*, vol. 50(4), pp.119-129, 2016.

[8] B.D. Petriaggi, and G.G. de Ayala, "Laser scanner reliefs of selected archaeological structures in the submerged Baiae (Naples)", in *Intl. Arch. Photogramm. Remote Sens. Spatial Inf. Sci*., vol. 5, pp. 79–83, 2015.

[9] S. Demesticha, "The 4th‐Century‐BC Mazotos Shipwreck, Cyprus: a preliminary report", *International Journal of Nautical Archaeology*, vol. 40(1), pp. 39-59, 2011.

[10] S. Demesticha, D. Skarlatos, and A. Neophytou, "The 4th-century BC shipwreck at Mazotos, Cyprus: new techniques and methodologies in the 3D mapping of shipwreck excavations", *J. Field Archaeol*, vol. 39(2), pp. 134–150, 2014.

[11] D. Skarlatos, S. Demestiha, and S. Kiparissi, "An 'open' method for 3D modelling and mapping in underwater archaeological sites", *International Journal of Heritage in the digital era*, vol. 1(1), pp. 1-24, 2012.

[12] P. Drap, Underwater photogrammetry for archaeology, INTECH Open Access Publisher.

[13] F. Bruno, G. Bianco, M. Muzzupappa, S. Barone, and A.V. Razionale, “Experimentation of structured light and stereo vision for underwater 3D reconstruction”, *Journal of Photogrammetry and Remote Sensing*, ISPRS, vol. 66(4), pp. 508-518, 2011.

[14] P. Drap et al., “Underwater cartography for archaeology in the VENUS project”, *Geomatica*, vol. 62(4), pp. 419-427, 2008.

[15] J. Henderson, O. Pizarro, M. Johnson - Roberson, and I. Mahon, “Mapping Submerged Archaeological Sites using Stereo - Vision Photogrammetry”, *International Journal of Nautical Archaeology*, vol. 42(2), pp. 243-256, 2013.

[16] F. Bruno et al., “3D documentation of archeological remains in the underwater park of Baiae”, *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 40(5), p. 41, 2015.

[17] P. Drap et al., “Underwater photogrammetry and object modeling: a case study of Xlendi Wreck in Malta”, *Sensors*, vol. 15(12), pp. 30351-30384, 2015.

[18] E.F. Anderson et al. “Developing serious games for cultural heritage: a state-of-the-art review”, *Virtual reality*, vol. 14(4), pp. 255-275, 2010.

[19] F. Liarokapis et al., “3D Modelling and Mapping For Virtual Exploration of Underwater Archaeology Assets”, *Proc. of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* (ISPRS), XLII-2/W3, Napflio, Greece, pp. 425-431, 2017.

[20] C.W. Reynolds, “Flocks, herds and schools: A distributed behavioral model”, *SIGGRAPH Comput. Graph.,* vol. 21(4), pp. 25–34, 1987.

[21] T. Balogh, P.T. Kovács, and Z. Megyesi, “Holovizio 3D display system”, in *Proceedings of the First International Conference on Immersive Telecommunications*, p. 19, ICST, October 2007.

[22] A. Aquilio, J. Brooks, Y. Zhu, and G. Owen, “Real-time GPU-based simulation of dynamic terrain”, *Advances in Visual Computing*, pp. 891-900, 2006.

[23] H. Prautzsch, A. Schmitt, J. Bender, and M. Teschner, “Soil deformation models for real-time simulation: a hybrid approach”, *Workshop on Virtual Reality Interaction and Physical Simulation VRIPHYS*, 2009.

[24] D.I. Han, T. Jung, and A. Gibson, “Dublin AR: Implementing Augmented Reality (AR) in Tourism”, In *Z. Xiang, & I. Tussyadiah (Eds), Information and Communication Technologies in Tourism*, pp. 511-523, Springer Computer Science: New York, 2013.

[25] M. Bordegoni et al. “Environment based on Augmented Reality and Interactive Simulation for Product Design Review”, in *Eurographics Italian Chapter Conference*, pp. 27-34, 2008.

[26] R. Hammady, M. Ma, and N. Temple N., “Augmented Reality and Gamification in Heritage Museums”, in *Joint International Conference on Serious Games*, Springer International Publishing, pp. 181-187, 2016.

[27] Leue M. C., Jung T., tom Dieck D. (2015) Google Glass Augmented Reality: Generic Learning Outcomes for Art Galleries. In I. Tussyadiah & A. Inversini (Eds.), Information and Communication Technologies in Tourism 2015 (pp. 463-476). Vienna:Springer.

[28] R. Morales, P. Keitler, P. Maier, and G. Klinker, "An Underwater Augmented Reality System for Commercial Diving Operations," in OCEANS 2009, MTS/IEEE Biloxi - Marine Technology for Our Future: Global and Local Challenges, 2009, pp. 1–8.

[29] A. Bellarbi, C. Domingues, S. Otmane, S. Benbelkacem, and A. Dinis, "Augmented reality for underwater activities with the use of the DOLPHYN," in 10th IEEE International Conference on Networking, Sensing and Control (ICNSC 2013), Evry, 2013, pp. 409-412.

[30] L. Oppermann, L. Blum, and M. Shekow, "Playing on AREEF: evaluation of an underwater augmented reality game for kids”, in Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI '16). ACM, New York, NY, USA, pp. 330-340.

[31] F. Bruno et al., “Virtual and Augmented Reality Tools to Improve the Exploitation of Underwater Archaeological Sites by Diver and Non-diver Tourists”, in *Euro-Mediterranean Conference*, Springer International Publishing, pp. 269-280, October 2016.

[32] K. He, J. Sun, and X. Tang, "Single Image Haze Removal Using Dark Channel Prior," in IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 33 (12), pp. 2341-2353, 2011.

[33] R. Fattal, "Dehazing Using Color-Lines," in *ACM Transactions on Graphics*, vol. 34, pp. 1-14, 2014.

[34] C. Ancuti, C. O. Ancuti, T. Haber, and P. Bekaert, "Enhancing underwater images and videos by fusion," in *IEEE Conference on Computer Vision and Pattern Recognition*, pp. 81-88, 2012.

[35] Y. Gao, H. Li, and S. Wen, "Restoration and Enhancement of Underwater Images Based on Bright Channel Prior," in *Mathematical Problems in Engineering*, p. 15, 2016.

[36] J. Zhang, and S. Hu, "A GPU-accelerated real-time single image de-hazing method using pixel-level optimal de-hazing criterion," in *Journal of Real-Time Image Processing*, vol. 9, pp. 661-672, 2014.

[37] J.-H. Kim, W.-D. Jang, J.-Y. Sim, and C.-S. Kim, "Optimized contrast enhancement for real-time image and video dehazing," in *Journal of Visual Communication and Image Representation*, vol. 24, pp. 410-425, 2013.

[38] S. M. Pizer et al., "Adaptive Histogram Equalization and Its Variations" in *Computer Vision, Graphics, and Image Processing*, vol. 39, pp. 355-368, 1987.

[39] Open Source Computer Vision Library. [Online]. Available: http://opencv.org.

[40] ARToolKit. [Online]. Available: https://artoolkit.org.