iblueCulture – An Innovative Underwater Cultural Heritage Real-Time Streaming System In A Virtual Reality Environment

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***Abstract* – The rich and valuable Underwater Cultural Heritage present in the Mediterranean is often overlooked by most, due to the inherent difficulties in physical approach. The iblueCulture project was created to bridge that gap, by introducing a real texturing and streaming system. It captures real time video underwater and uses it to properly texture and represent the Underwater Cultural Heritage site and its immediate surroundings in a Virtual Reality environment. This system has been installed in some modern and ancient shipwrecks in the Greek archipelago, which can be viewed in situ. It can also be modified to work remotely, for example in museums or educational institutions. The system can help make such sites accessible and raise public awareness. It can potentially be used in any underwater site, both for raising awareness and educational purposes, as well as for monitoring and security.**

I. INTRODUCTION

A vast treasure trove is hidden beneath the Mediterranean sea, one of enormous cultural value. Ancient shipwrecks and even partially submerged settlements hold a cache of historical and cultural importance, that we have only just begun exploring. It has even been said that the seas hold more artefacts than all the museums of the world together [1]. Therefore, it is not surprising that the domain of Underwater Cultural Heritage (UCH) has seen such a rapid development in recent years.

One can say it all began with the Antikythera wreck, that sponge divers discovered over a century ago, which contained such a treasure that changed our view of the ancient world. The Portugueuese *nao Bom Jesus* gave valuable insights to the beginning of maritime trade between Europe and India [2]. The museum built to house the *Vasa,* the warship Gustavus Adolphus commisioned in 1626, has become Scandinavia's most visited museum [3]. Other long-lost wrecks are still being sought out. Shackleton's *Endurance* was only discovered a year ago, after lying hidden beneath the ice for more than a hundred [4]. Many more, like the nearly legendary Columbus' *Santa Maria* or the *Flor de la Mar*, still remain missing.

Underwater Archaeology (UA) and UCH encompass not just shipwrecks, but also other remains of maritime activity, such as ports, and partially submerged structures or even settlements. There are many examples, like the settlement of Helike in northern Peloponnesos [5], the town of Dunwich off the east coast of England [6] or even the remains of the famous Lightouse in the bay of Alexandria, which the UNESCO is considering adding to the list of World Heritage Sites [7].

The main issue with both shipwrecks and submerged structures is, in one word, proximity. In most cases, they can be impossible for non-divers to approach, be it to study, restore or even casually view them. Some shipwrecks have been recovered and are housed in museums, like the aforementioned *Vasa*, while in other cases parts of those UCH sites have been brought to the surface and are now in exhibitions. Still, due to the difficulty in approach, most of those sites remain out of reach for the majority of the population and, thus, relatively unknown. Since there is no way to guard them, they also remain in danger, both from natural erosion and disasters, as well as looting.

The aim of the iblueCulture project was to provide a way to monitor, study and virtually visit such sites. By offering a real time video view, the system provides stakeholders with the capability to monitor these sites, while simultaneously enabling them to protect even the most remote ones. This real time monitoring capability is also at the core of the virtual visits, which aim to raise public awareness of the cultural value of such sites, as well as assist in the scientific study of these submerged treasures.

The iblueCulture is a 3D virtual underwater exploration system, that incorporates real-time video and texturing in combination with prebuilt 3D elements. This creates the very effective illusion that the viewer is actually in situ, underwater, while he remains on dry land. The system can be used with any display type, be it a smartphone, monitor or even Augmented Reality (AR) glasses or Virtual Reality (VR) headsets.

This paper will elaborate on the iblueCulture system and operation, the benefits it can offer and the potential for future improvements.

II. STATE OF THE ART

There are many VR and AR guide applications created in the last few years. Some are focused on tourism and education, such as Archaeoguide, a mobile system installed in Olympia, Greece, that can insert and display 3D models of ancient buildings in an AR environment, on the actual location of their ruins [8]. In Galatina, Apulia, Italy, the Basilica of Saint Catherina of Alexandria was the focus of another AR application, that digitally enhanced the frescoes of the church [9]. The Aurelian Wall at Castra Praetoria in Rome was, in part, also digitally reconstructed and presented in an AR application [10]. There are many more examples, but all of those do not face the challenges that UCH applications must.

Underwater focused applications are constantly being created, though at a slower rate than land-based ones. Most look towards training divers or users, on the environment [11] or even on scientific disciplines, such as photogrammetry [12]. As an example of UCH applications in this category, users can experience the Mazotos shipwreck in a virtual dive, rich on archaeological information, with a premade 3D model and procedurally generated enviromental elements [13].

In the case UCH applications, there are many challenges, which explains why there are so many more land-focused projects. Proximity is, as mentioned, a very limiting factor. Waterproof devices are neccessary, with cost becoming an issue the deeper one goes, due to the significant increases in pressure. In the case of seawater, corrosion is also an important factor that needs to be adderssed. Another problem is the fact that, the deeper one goes into the water, the less reliable wireless signals become, making them obsolete after a certain depth.

III. SYSTEM OVERVIEW

The iblueCulture system is a novel approach to the challenges in UCH applications. One of the case studies was the *Christophoros* shipwreck, a cargo ship originally commisioned in 1950 in Grangemouth, Scotland. It is 85m long and 13m wide. The ship sunk in 1983 and rests in 38m depth, in the bay of Panormos, Skopelos island.

The system created, and employed in this case, consists of four overall parts. These are underwater devices, the nearby supporting station, the remote processing station and the end-user's device.

A. Underwater Devices

The underwater part of the currently installed system is comprised of eight high resolution camera systems, sealed in waterproof housing and set upon stable stands, and two connector hubs, main and secondary.

The cameras are 1920x1080 resolution, 30 fps Arduino cams, with a 140° wide field of view (FOV). Each camera is connected to a Raspberry Pi4 with 8GB of RAM, that handles data capture and streaming. Four cameras connect directly to each hub, while the secondary hub also connects directly to the main. The cameras use a CAT5 Ethernet cable for data transmission and power.

The camera housing is designed to withstand pressure at a depth of 80 meters. Each housing has an 8 pin, 5A wet plug that is used to connect it to a hub, for both power and data transmission. Housings also have an automated wiper, connected to a servo motor attached to their side, that is used to remove residue from the viewport. The housings attached to stands that consist of a central modular pylon and a stability base. The central pylon can be modified to a height of 1 to 10 meters, with 1, 2.5 and 3m pieces. The extension pylons are made of aluminum, while the bases contain cement.

The hubs are in encased in similar housing, though the secondary hub possesses four wet plugs for cameras and one for the connection to the primary hub. The latter has six plugs total, four for the cameras and one for the secondary hub, and a final one on the opposite side for the cable connecting it to the supporting station. The hubs are not set upon bases, rather their housing is modified for placement on the sea floor.

All video captured by each of the cameras is processed in real time, on board, and transmitted to the connected hub, with the secondary one passing on all transmissions to the main. Finally, the main hub connects, via a 300m long Fiber optic cable and a 6 mm2 copper cable, to the supporting hub on land. All cables are protected inside a PVC housing.

Buoys are placed around the area for safety reasons.

B. Supporting Station

The supporting station can rest in any nearby land mass, be it an island or a rock islet. It incorporates four solar panels, the Sharp 445Wp, and eight batteries, the Sunlight Res sOPZs 2V-965Ah, for power generation and storage, that can keep the supporting station and underwater devices running constantly. A wind turbine serves as a backup power supply for the batteries. A weather station and surveillance camera are also part of the supporting station, for monitoring purposes. A small form factor computer, an Intel NUC with an i7 1260P with 32GB of RAM, receives the transmissions from beneath the sea and stores them in a Synology NAS with 16TB of total storage. The NUC processes the streams via ffmpeg, while simultaneously storing them, before re-streaming them out to the remote processing station. All communication, both with the underwater and remote installations are through a dual SIM modem router. A long-range Wi-Fi directional antenna is also connected to the system, connected to a local Wi-Fi network and serving as a backup, in case of service interruption due to weather or other environmental factors.

C. Processing station

The remote processing station is running the iblueCulture server application, on an Intel i9 11900KF with 64 GB of RAM. The video arriving from the supporting station is preprocessed with ffmpeg again, before being sent into the Unity server application. This video stream is used to help simulate the light conditions, by modifying color hues and matching the premade ones to the hue of the current ship textures. The application incorporates this real-time video and uses it with the pre-existing 3D model of the shipwreck, displaying the clean video on part of the model, while using color matching on the hues for both the ship and its immediate environs. The 3D model of the *Christophoros* was created using photogrammetry and approximately 5000 photos, shot by the diving team, in consecutive days with similar weather, in order to avoid significant lighting changes. A subset of these photos, as well as some previously shot ones at a different date, were used to create the immediate environs of the ship. A top side view of the ship, as a sample of these images, can be seen below in Fig. 1.

D. End-User Device

The end-user's device has a client application installed, that includes an introductory, sea level environment and navigation controls. As soon as the user decides to "dive" into the sea in this VR environment, the streaming from the processing station is initiated. The client application sends the coordinates of the user's location and FOV to the server application, which responds with the appropriate video stream.

The system was designed to be location agnostic, meaning that the user can be in any remote location, such as near the UCH site in an island or on board a vessel right above a shipwreck with a smartphone, or in a museum with a VR headset. This allows for installation in many different contexts, as discussed below.

Figure 1: Top side view of the Christophoros

The overall system architecture is schematically displayed below in Fig. 2. To put it simply, the cameras are placed on their bases, resting on the sea floor, and connected to their hubs, for one-way transmissions. Due to the number of cameras available and the size of this large vessel, we limited the camera view to the front and sides of the ship, as shown. We can effectively capture approximately half of the ship, with the currently available equipment. An increase in the number of cameras would mean more hubs, higher power requirements and possibly even more NUCs at the supporting station. The secondary hub passes on information to the primary, which in turn connects to the supporting station. Finally, all information is transmitted to the remote processing station. Since the system can be location agnostic, the processing station could potentially be near or within the supporting station, though that would significantly change power requirements, due to the powerful computing needs of the processing parts. The system works the same way for both mobile devices and VR equipment. The applications for each are, of course, different, with the mobile one modified with joystick controls.

IV. DISCUSSION

The matter of scale is an important issue for the iblueCulture system. For small shipwrecks, a small number of cameras will suffice. For larger ones, however, like the Christophoros, in order to have high detail we would need more cameras, perhaps of higher (2K or 4K) resolution. This increases the number of hubs required, as well as total power consumption. Bandwidth could also be problematic with 4K video streams. Overall the system can scale as is, but not infinitely, while it will have physical and technological bottlenecks.

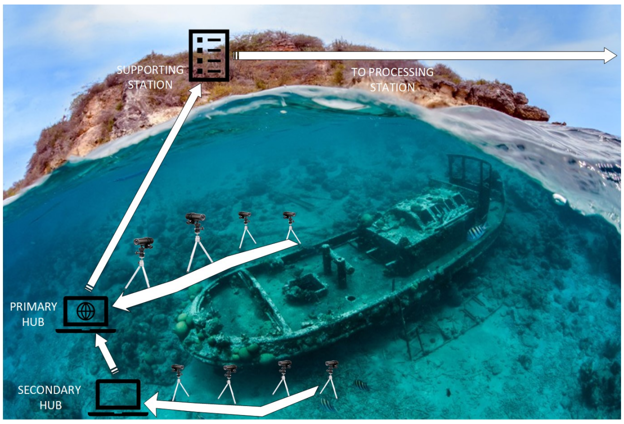

Figure 2: Overall System Architecture

As it is, the main bottleneck is purely hardware. The system can currently work with and stream a medium detail 3D model to a small number of users. In order to opt for higher detail models, we need a more powerful workstation, or more, that can work in tandem. In our tests, we tracked this issue down to the GPU and the video transcoders it supports, and in part to the CPU and RAM.

The iblueCulture system does offer a novel way to approach UCH site utilization. It can also be sustainable, especially for larger organizations, since a single system can scale to work with more than a single UCH sites. For example, a museum could setup a VR station where the shipwreck on display via iblueCulture changes every week or two. This would require only one processing station, but multiple (as many as the shipwrecks on display) underwater and supporting elements.

The benefits of having even a base system are numerous. As said before, a museum could install VR stations for iblueCulture, alongisde other VR uses. Even without this added expense for the museum, having the iblueCulture system working on the site and offering visitors access to the app per visit, with one time passwords, would be quite popular and advantageous. A single processing station could serve many users, as long as the specifications and CPU & GPU are chosen specifically for the number of client devices.

As a security implementation, the system can work even better. It can be modified to offer more detail, by not downscaling the initial video stream, since it will serve much fewer and stable clients. By having a set number of specific devices, which can be hard-coded into the system, it will become more streamlined and robust.

An ideal use for iblueCulture would also be as an archaeological research station. Again, it can be modified for fewer, specific devices, offering better video, but could be further adjusted for the exact research needs.

V. FUTURE RESERACH

The system certainly has room for improvement and expansion. One would definetely need to look into scaling and all the issues that arise. As mentioned previously, upscaling the video cameras to 4K and streaming that back to the processing station would require more NUCs and modems, which in turn would require more power. Perhaps specific video transcoders at the supporting station would help in this issue, but that usually is a GPU matter, which moves us further away from the NUC form factor.

Another avenue of improvement lies in adding various sensors to improve monitoring, such as salinity, temperature etc. Water turbidity can cause some problems as it might block the view of some, if not all, cameras. This is difficult to predict and prevent, but certainly not impossible.

Future research could also look at various AR/VR improvements. The view in VR is isolated, which enhances immersion. It is not quite the same for AR users in rooms that are not completely empty. For example, one would see a shipwreck inside a museum room that is superimposed over another exhibit. These are, of course, generic AR issues, and not project specific.

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