Development of a laser-scanning device for the survey of wide submerged archaeological areas

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Abstract

The need of documentation of wide archaeological submerged areas has been a stimulus for the development and implementation of a three-dimensional scanning system providing accurate information about the dimensional data and chromatic values of the artefacts.

The paper presents the work carried out on the underwater site of the "Villa con ingresso a protiro" in the Baiae Marine Protected Area, Underwater Park (Naples), in the frame of the ISCR "Restoring Underwater" Project, funded by MIBACT.

Its extension is more than 10,000 square meters and the site lies at an average depth of 4 meters.

The scanning systems currently in use offer excellent results, but in a large-scale context such as the "Villa con ingresso a protiro" they prove difficult to use.

The low depth and poor visibility of the site make the photo-based systems (ortho-photo-mosaic) almost useless, since they would require many thousands of pictures, in bad light conditions; laser-scanning systems, on the other hand, are linked to a fixed position on the seabed and work properly on small surfaces.

The development of a mixed system based on the triangulation measurements of the laser scanner and the optical structured light scanner has thus been a must.

It is free of constraints, such as the seabed fixed position, and can be moved along the whole area and close to the desired target in order to obtain further accuracy and more detailed surveys.

Introduction

In the field of underwater archaeology, there is a need to document large submerged areas, as in the case of Ancient Baiae, in the Marine Marine Protected Area-Underwater Park (MPA-UP) of Baiae. The MPA-UP is located off the north-western coasts of the bay of Puteoli (Naples), in the littoral zone between the southern limit of the port of Baiae and the dock of Lido Augusto. This site is part of the coastal region known as Campi Flegrei, that has been characterized by a periodic volcanic and hydrothermal activity and has been subjected to bradyseism, namely gradual changes in the levels of the coast with respect to the sea level. Ancient Baiae was a bathing resort for the Roman aristocracy between the 1st century BC and the 4th AD; as a result of bradyseism, it began to sink into the water around the 3rd- 4th century AD. The ancient city, now almost completely submerged, was famous for its luxurious seaside villas, public offices, baths, shops and coastal installations. The MPA-UP, which covers an area of about 176.6 hectares, not only safeguards the archaeological remains of the Roman city and the infrastructures of the roman harbor named Portus Iulius, but also represents an underwater area of great environmental value. The major environmental values of this area are related to a peculiar volcanic and deformational history. As it's known, 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 the sea level. Over the last years, the Soprintendenza Archeologica di Napoli was the Managing Authority of the MPA-UP, however recently this role moved to the Parco Archeologico dei Campi Flegrei as the new Managing Authority. Today the MPA-UP of Baiae has at least five itineraries open to the public, divers or non-divers. This last type of tourists can visit the site on board of a glass-bottomed boat. The local diving clubs areauthorized by the Managing Authority to accompany the divers wishing to visit the submerged city. The underwater itineraries are 1) the Nymphaeum of Punta dell'Epitaffio, 2) the Villa con ingresso a protiro – Villa with vestibule, 3) the Villa of the Pisoni; 4) Portus Iulius; 5) the "Secca fumosa.

Gabriele Gomez De Ayala started the development

of a three-dimensional scanning system applied to submerged cultural heritage in 2007; it was optimized through the years, and first employed by the ISCR in 2011, in the frame of the "Restaurare sott'acqua - Restoring Underwater" Project.

The Project, designed and directed by Roberto Petriaggi from 2001 to 2010, is now directed by Barbara Davidde Petriaggi and currently ongoing (http://www.iscr.beniculturali.it/pagina.cfm?usz=1&uid=69&idpro=4) and is funded by MIBACT.

A part of the Project was devoted to test tools and techniques to document the submerged archaeological remains in their real dimensions, their geographic location, and in the real aspect (color, surface characteristics, etc.).

The ISCR invested important resources in the development of the three-dimensional underwater scanning systems, working with G. Gomez De Ayala to plan and document conservation works on underwater archaeological structures. In addition to the scuba laser scanning system, ISCR was interested in testing different systems of 3D documentation, such as the photogrammetry, used for the documentation of the San Pietro in Bevagna shipwreck (1).

Also, a bath of the Villa con ingresso a protiro and a portion of the wall of the *viridarium* of the Villa dei Pisoni in Baiae has been surveyed with the University of Calabria, to document and monitor the experimental cleaning operations in Baiae (2) .

The development of three-dimensional underwater Laser scanning systems in the Submerged Baiae.

The first system developed was used to document the room paved with the opus sectile floor of the bath of Punta Epitaffio and to project the restoration work of it (3). The system was based on triangulation with laser lamellar light; it was necessary that the laser emitter, the capture ccd sensors and the area to be detected were at known distances, and for this reason we created a frame with the shape of a cube, on the top of which were mounted the ccd sensors and the laser emitter and at the bottom of the cube there was the area to be detected. (fig.1)

This system provided a very good resolution because, in order to obtain a higher degree of accuracy, it was able to reduce the thickness of the laser blade to the minimum required size.

This system found its limits in some cases where areas larger of a few square meters needed to be detected. In this case it was necessary to align many single scans and to move the cube frame over the area to be detected several times.

We then developed a second scanning system that, like the first one, consisted of a system based on triangulation, but in this case the whole system was mounted on a tripod and rotated around its axis allowing the survey of a larger scan area. However, it still was necessary to move the system and repeat the scans needed for large areas (4).

In 2015, ISCR had the need to document and restore the remains of a republican Villa and the remains of a building with portico, a portion of the wider Portus Iulius.

This building is characterized by several adjacent rooms enclosed by walls in *opus reticulatum*, some of which are still standing, while others have collapsed (5;6).

Here the authors decided to test a new scuba laser scanner called WIRscann -Warm Infra Red scanner.

It was the need to scanning very large areas of the seafloor that brought to the development of this new laser, the WirScann system, which can effectively scan areas up to 1000 sqm.

We tackled and solved the problem of obtaining an accurate survey, producing many scans and their complex alignment for the lack of reference objects (just sand) by creating a system based on structured light.

We have created a pattern represented by a grid of known proportions and shape, projected through a strobe light on the surface to be detected, while at the same time a ccd sensor detects the grid deformation due to the shape of the area to be scanned; the detection is repeated 30 times per second.

This new system allows us to move freely on the area to be detected from each angle, each of the individual 30 scans carried out every second is aligned to the following automatically and subsequently simplified as it is superimposed on the next for 90%.

Many system variations have been made, such as the use of infrared laser light and the integration with a parallel acoustic system. (fig. 2)

The system made possible to realize the three-dimensional survey of a large area such as the one of the "Villa con ingress a protiro" - "Villa with protiro entrance" (Baiae), an area more than 10,000 square meters wide, characterized by walls from 2 to 150 cm high (figs. 3-4).

It was possible to measure dimensions and orientation with centimeter accuracy (even millimeters where necessary), with the ability to re-elaborate the information obtained (point cloud) to gain greater accuracy; about 80,000 pictures were used to create the texture of the three-dimensional model, and it was possible to handle this workload since the system takes only the portion of no overlap of each picture.

Conclusion

The surveys made with the laser scanners proved very useful in designing and planning conservation activities, as well as in mapping the state of decay and degradation of the archaeological structures.

The scanning systems currently in use offer excellent results, but in a large-scale context such as the "Villa con ingresso a protiro" or Portus Iulius y prove difficult to use.
The low depth and poor visibility of the site make the photo-based systems (ortho-photo-mosaic) almost useless, since they would require many thousands of pictures, in bad light conditions; laser-scanning systems, on the other hand, are linked to a fixed position on the seabed and work properly on small surfaces.
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It is free of constraints, such as the seabed fixed position, and can be moved along the whole area and close to the desired target in order to obtain further accuracy and more detailed surveys.

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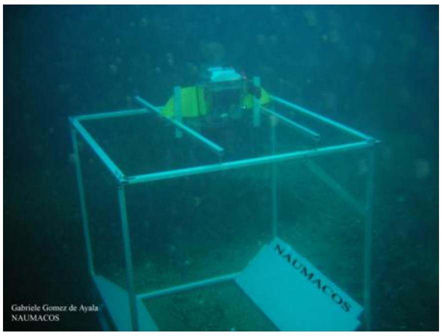
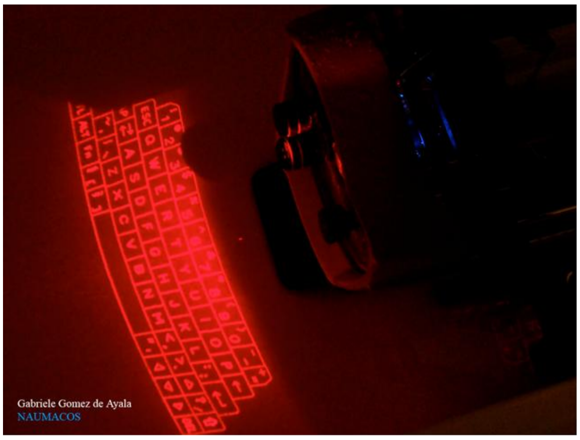


Fig. 1. Cube frame of the first scanning system



Ffig. 2. Acoustic optical system

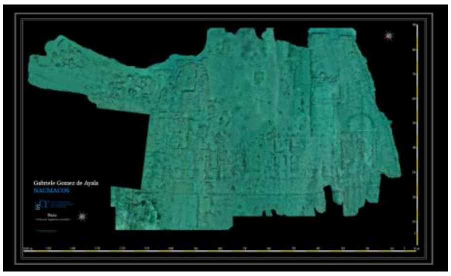


Fig. 3. Orthogonal view of "Villa con ingresso a protiro" (Data capture and elaboration: Gabriele Gomez de Ayala). Copyright ISCR

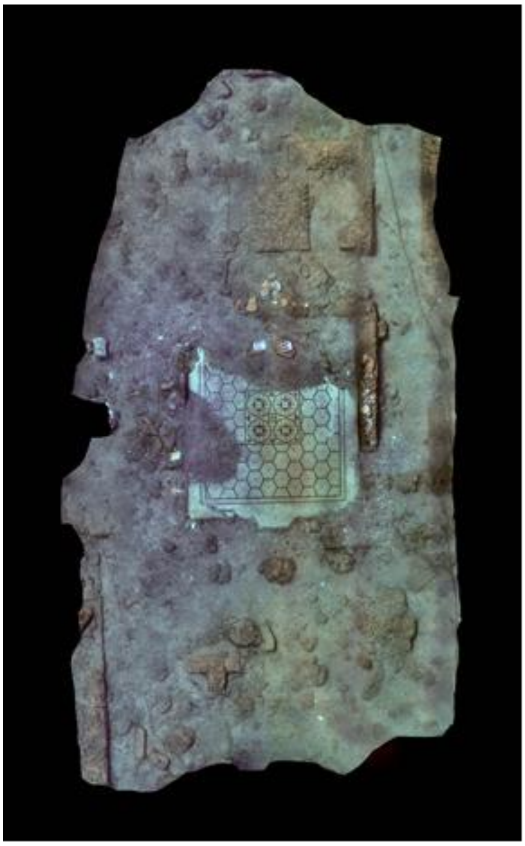


Fig. 4. A sector of the Villa con ingresso a protiro, with the black and white mosaic floor during restoration. (Data capture and elaboration: Gabriele Gomez de Ayala). Copyright ISCR

Fig. 5. 3D model of a room of the bath of the "Villa con ingresso a protiro". (Data capture and elaboration: Gabriele Gomez de Ayala). Copyright ISCR