Photogrammetric techniques for 3D underwater record of the Late-Imperial Torre Santa Sabina's shipwreck

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Abstract: The possibility offered nowadays by the adoption of digital photogrammetry techniques allows one to virtually reconstruct the surveyed underwater assets to make them accessible also remotely, via visualization and dissemination platforms (online or offline). To improve the study of the documented cultural heritage artefacts and sites, it is crucial to adopt the right photogrammetric principles to achieve 3D metric products that are consistent and coherent with the real object of the survey. This paper is related to the photogrammetric survey of the late imperial era Roman shipwreck, located in 'Baia dei Camerini', Torre Santa Sabina (BR), Italy, in the framework of the project UnderwaterMuse (Italia-Croatia 2014−2020 Interreg Cooperation Programme).

Keywords: underwater archaeology, underwater photogrammetry, underwater museum

1. Introduction

This paper will examine some aspects related to the photogrammetric survey techniques of the beached wreck TSS 1 (Auriemma 2014: 156–166; 2015; Auriemma *et al.* 2022a), located in 'Baia dei Camerini' of Torre Santa Sabina, Brindisi (Fig. 1). It is a late imperial Roman wreck from the late 3rd-early 4th century that lies between 2.4 m and 3.4 m deep; its investigation and enhancement was one of the three pilot actions carried out in the framework of the international project UnderwaterMuse (Italia-Croatia 2014−2020 Interreg Cooperation Programme).

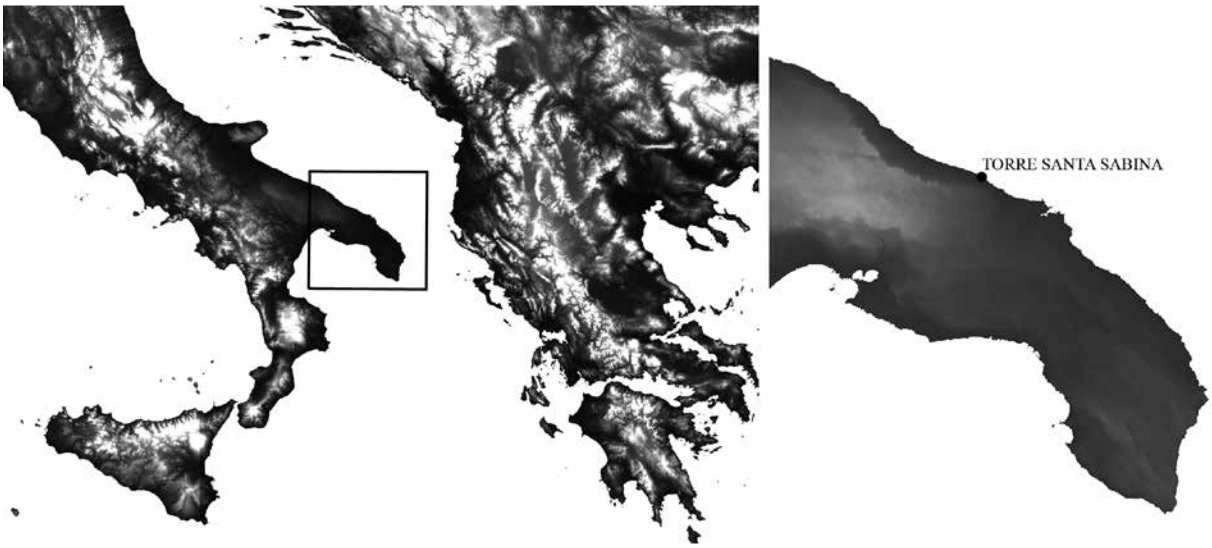

Fig. 1 Position of the site of Torre Santa Sabina

Based on our direct experience, we are fully aware that this contribution constitutes only a case study, not bringing anything new to underwater photogrammetry in general, but we nevertheless believe that it can offer some useful ideas in relation to photogrammetry in shallow depth contexts, where the ease of access suggests modifications to the appropriate intervention strategies.

In fact, contrary to what one might believe, the ease of access to a wreck at a very low depth poses a whole series of problems, mainly related to the quality of the operating conditions in the various stages of investigation development, from excavation to documentation.

It is evident that at these depths the stay in the water can be several hours, and theoretically, a lot more work could be done compared to greater depths, but the wave motion considerably reduces this possibility. It is necessary to constantly deal with poor visibility and the undertow's movement. This applies both to excavation and documentation operations, but also and above all, to the protection and conservation of the finds and the wooden structure of the hull, which must be constantly protected and ensured. Only on days of the calm sea will it be possible to obtain the maximum profit, and, at that point, the shallow depth represents an undoubted advantage.

The possibility offered today by the adoption of digital photogrammetry techniques allows us to optimize the times in the survey phases and to make the most of the calm days of the sea, even in low visibility conditions (on the photogrammetry see Calantropio, Chiabrando 2024 with bibliography, and Costa 2022 for the applications in low visibility contexts) .

For the same reason, the recording of topographical points must also be carried out in a calm sea, but the effectiveness of the measurement can only be achieved using some practical expedients, which the shallow depth allows for implementation.

The rods with antenna or prism, depending on whether they belong to GPS instrumentation or Total Station (TS), will hardly be able to be accurately maintained on the topographic point to be recorded if the operator does not step directly on the seabed. The experimentation of some supports capable of independently supporting the poles has allowed us to obtain satisfactory results with precision comparable to that obtained in land surveys.

The topographical and photogrammetric survey was carried out in an integrated form (underwater and UAV) and the research allowed us to obtain new advances in the acquisition and processing of underwater photogrammetry data in combination with the products achievable from drone shooting.

The salient phases of the work carried out will then be presented, starting with the photogrammetric processing carried out on archive images relating to the 2007 excavation campaign. Subsequently, we will move on to the description of the 2020 experiment focused on the photogrammetric acquisition of the aft part of the Roman wreck. This allowed the calibration of the survey and survey techniques of the 2021 campaign, also through the reconstruction of the new data with those of the survey carried out 14 years before this study. In conclusion, a preview of the photogrammetric survey carried out in the 2021 campaign will be provided (Calantropio *et al.* 2021).

Another aspect offered by photogrammetry, which will only be hinted at in this document, consists of the possibility of managing 3D models to compile augmented reality reconstructions of archaeological contexts, also accessible remotely via viewing and dissemination platforms online or offline (Costa *et al.* 2020 and Auriemma *et al.* forthcoming).

2. Underwater data acquisition and processing

The collection of underwater photogrammetric data was carried out in two successive campaigns carried out in 2020 on a small portion of the wreck (stern) and in 2021 on the entire surface affected by the remains of the Roman ship.

The underwater photogrammetric acquisition was performed using two digital cameras (Fig. 2), an Olympus Tough TG-6 and a Nikon Coolpix W300 (Capra *et al.* 2015), following both different acquisition schemes (nadir and oblique) useful for obtaining complete 3D and 2D documentation.

The cameras used can operate without underwater housing at a maximum depth of 15 m the first, and 30 m the second; thus, no additional housing was used during the acquisition phase. This also reduced image residuals and systematic patterns that are usually detected when dome ports are used (Menna *et al.* 2020).

Before capturing the images, some markers were placed on the sea floor around the wreck. The same markers were subsequently measured using a 4 m long pole and prism, shot with TS from the shore. Two divers manipulated the prism to make it vertical before the TS measurements. After the first attempts conducted in the survey campaign of 2020, the difficulty of obtaining measurements with an optimal degree of precision emerged, which is why we worked to find a system that would allow obtaining an accuracy at least equal to, or if possible, less than one centimetre. Working in a shallow calm sea allowed us to use a practical expedient to achieve the desired result, a trestle stand of modular aluminium bars with plastic coupling joints, equipped with a central hole for housing the prism rod. The instrument can be adjusted by sliding two orthogonal planes on rails (Fig. 3). Once the rod was positioned inside the hole in the support and after having centred the marker with the tip, we proceeded with the levelling and orientation of the prism in the direction of the TS. The result obtained through the system described so far resulted in a deviation of less than one centimetre of tolerance. The use of trestle stands capable of autonomously supporting the prism pole allowed satisfactory results to be obtained, with an accuracy comparable to measurements taken on the ground.

Fig. 2 Image acquisition phase during the underwater photogrammetric survey 2020 of the Roman shipwreck in Torre Santa Sabina (author: University of Salento, Department of Cultural Heritage)

Fig. 3 Topographic survey operations were performed to measure the position of underwater markers, also with the adoption of a pole-holder quadripod (author: University of Salento, Department of Cultural Heritage).

Recently the instrument market has introduced a new generation of more highly performing machines for GCP (Ground Control Point) detection of topographic markers. This GPS (Global Positioning System) is also waterproof and can make measurements with a tilt compensation of up to 30 degrees and more from vertical. However, for depths like the one encountered in TSS 1, characterized by strong disturbances caused by currents and waves, it is always preferable to measure with TS and rely on a stand for fixing the rod which certainly allows work with greater precision. This was taken into account when assessing the accuracy of the survey and part of this work focused on assessing the quality of a photogrammetric 3D model generated via a free-mesh adjustment approach (followed by assigning a scale based on known distances). The 3D model developed following this method was compared with those generated using the previously collected data set.

The underwater photogrammetric datasets were processed using the software Agisoft Metashape 1.6.5. Following the software's operative workflow, images were oriented. A set of 5 previously measured points was used to provide correct georeferencing to the survey; in the end, dense point clouds, DEMs (Digital Elevation Model), and orthoimages were generated.

In both the 2020 and 2021 campaigns, before the photogrammetric survey a necessary archaeological procedure was applied for the characterization of the shipwreck via an operation that marked the most significant elements of the wreck using small portions of coloured electrical cables, some 'push-pin' thumbtacks, and plastic cards. Push-pins were also used to indicate where wooden nails were previously located. The same operative workflow of the first dataset was used. However, this time the 3D model was generated via a free-net adjustment, assigning a scale to the model via a least-squares adjustment on two scale bars placed in the surveyed scene. In this case, the camera calibration certificate of the previous dataset was used to provide an initial estimation of the camera's internal parameters.

To evaluate the quality of the two 3D models, the same portion (1 m^2) of the two models was compared, performing a rigid roto-translation without changing the scale of the models. For point cloud management and analysis, the commercial software Leica Cyclone 3DR[1] was used; the two clouds were aligned using the best-fit option of the above-mentioned software, allowing for a registration using the ICP (Iterative Closest Point) algorithm. This resulted in an average error of 2.8 mm and a standard deviation of 3.5 mm, measured via a C2C (Cloud to Cloud) comparison. The max value of detectable deviation was imposed at 2 cm.

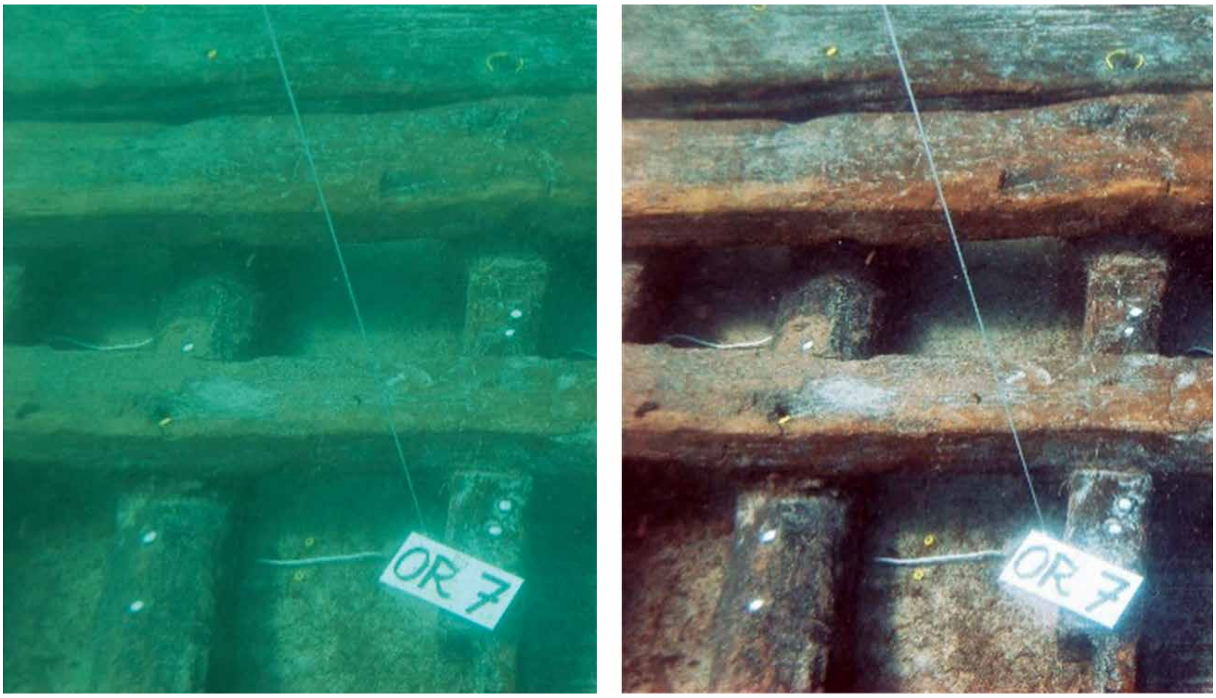

Fig. 4 Left: an image of the 2007 dataset before the radiometric correction; Right: the same image after applying the ACE (Automatic Colour Enhancement) filter (author: Calantropio 2023)

1 https://leica-geosystems.com/en-us/products/laser-scanners/software/leica-cyclone/leica-cyclone-3dr.

3. Comparison with the 2007 survey

Given the importance of legacy data, it was interesting to compare data obtained and processing techniques followed in the 2020 acquisition campaign with a previous survey campaign performed in 2007 (Alfonso 2014). Images of the 2007 excavation campaign dataset were captured using a Nikon D50 (3008 × 2000 pixels) with underwater housing.

Since the acquired images suffered a severe chromatic aberration (Agrafiotis *et al.* 2017), a radiometric pre-processing was performed (Fig. 4) using the adaptation of the C code of the ACE (Automatic Colour Enhancement) image colour enhancement filter (Getreurer 2012), integrated into the Image Enhancement process tool of the i-MARECULTURE project.[2]

Because absolute georeferentiation data was not available, the operative workflow previously described (generation of a 3D model via a free-net adjustment) was followed, assigning a scale to the model via a least-squares adjustment on six measures obtained exploiting the metric rulers attached to the archaeological grid (Barker 1993), placed in the scene for performing the direct survey. To compare and relate the 2007 and the 2020 surveys, it was necessary to manually connect the two orthoimages on the same reference system, exploiting a small overlapping part. This made it possible to produce a complete orthomosaic and DEM to facilitate the understanding of the shape and extent of the wreck and plan future investigations (Fig. 5).

Fig. 5 Ortho imagery of the 2007 excavation georeferenced by the 2020 survey (author: Calantropio 2023)

4. Discussion and conclusions

Concerning the photogrammetric survey performed using UAS (Unmanned Aerial System), it was possible to document the wreck thanks to the generation of metric products (orthophotos, digital surface models and 3D models) obtained through photogrammetric techniques based on SfM (Structure from Motion) algorithms (Calantropio *et al.* 2021; Calantropio, Chiabrando 2024).

During the processing of the UAS data, an accurate assessment of the quality of the direct photogrammetric approach was carried out, using the two platforms. The proposed georeferencing method has shown that good results can be achieved with an autonomous PPK (Post Processed Kinematic) approach, even without measured GCPs.

In the first campaign of 2020, an essential part of the activities carried out in the underwater environment focused on the photogrammetric acquisition of the aft part of the Roman wreck, allowing both the understanding of the survey techniques to be used in the 2021 survey and the possibility of relating the new data to those from a survey carried out 14 years before this study. The results presented show that modern photogrammetric algorithms can provide a valid alternative to direct surveys in the documentation of the excavation phases of archaeological sites (Fig. 6).

[2] https://imareculture.eu/downloads/project-tools/image-enhancement-process-tool/.

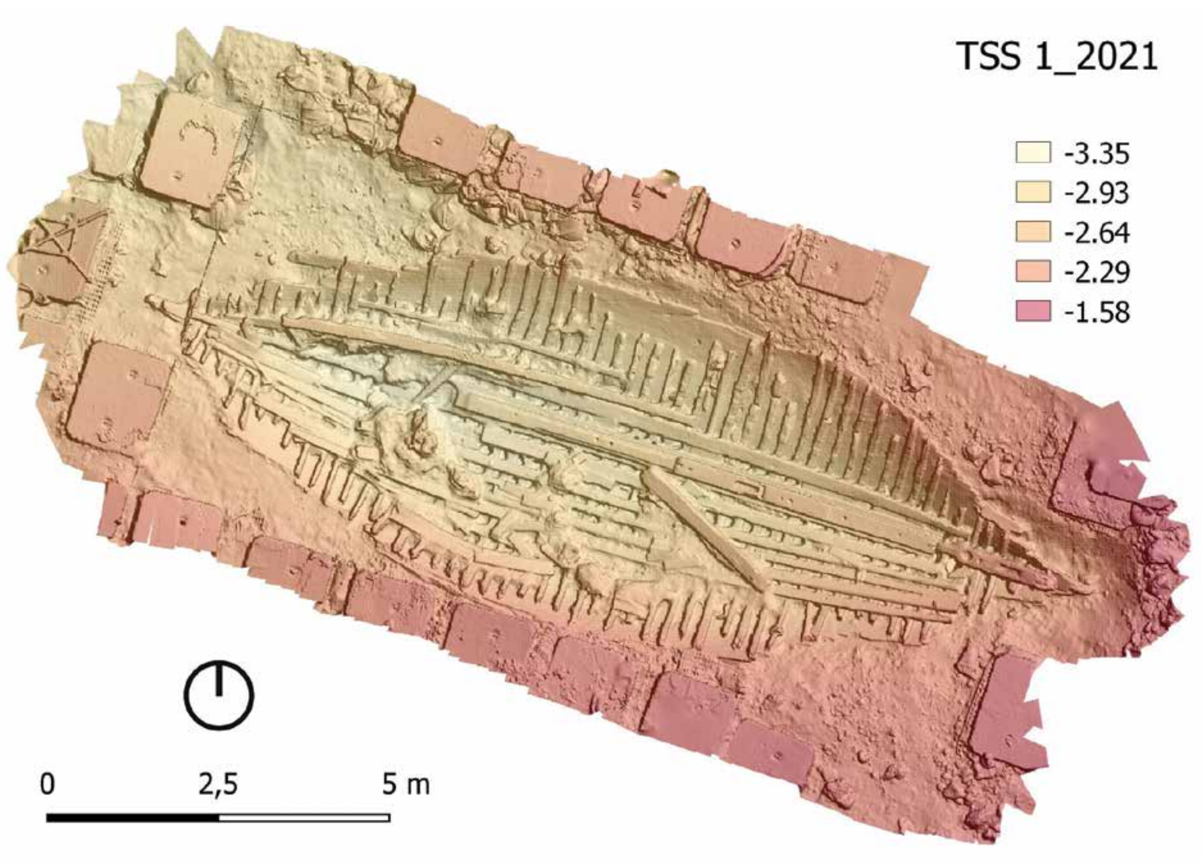

Fig. 6 DEM (Digital Elevation Model) of the TSS 1 shipwreck being processed (author: Polytechnic of Turin - DAD, Laboratory of Geomatics for Cultural Heritage)

The use of digital photogrammetry techniques applied to the archaeological survey of underwater sites can constantly speed up survey operations without neglecting the quality and reliability of the data collected (Calantropio, Chiabrando 2024). The implementation of these procedures also offers better conditions for the operator involved thanks to the reduction of the overall dive time. The critical aspects of the application of this methodology are mainly related to the preliminary assessment of the camera calibration.

The execution of the survey in very shallow waters offers both advantages from the logistical point of view and some drawbacks in measuring the GCPs with traditional topographic methods. These aspects can be overcome by adopting simple fixing systems for the prism holder or GPS antenna rods. These are ballasted mobile stand trestles that can be locked in the desired positions when the operator is on the vertical of the topographic point with the pole.

As anticipated in the introduction, the 3D document base created can be used for virtual reality and augmented reality applications.

The three-dimensional reconstructions can be used for the study of naval architecture and to verify the hypothesis of restoration projects, recovery operations and enhancement of the wreck in the museum. It will also be possible to create immersive virtual tours able to allow the virtual use of the heritage (both naturalistic and cultural). These reconstructions can be exploited in museums, in underwater archaeological parks, in marine protected areas visitor centres and all regional networks of places of culture but also directly *in situ*, through interactive systems for the use of the underwater archaeological heritage, based on simple underwater tablets, connected to an antenna for reading the data recorded on tags placed near the archaeological finds. In this regard, we can cite the Italian realities of the Submerged Archaeological Park of Baia (see Gallo *et al.* 2012; Bruno *et al.* 2019; Davidde 2022) or the case of Grado 2 shipwreck (see Auriemma *et al.* 2022b; Auriemma forthcoming).

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