Digital Applications in Archaeology and Cultural Heritage 3 (2016) 1–8

Contents lists available at ScienceDirect

Digital Applications in Archaeology and Cultural Heritage

journal homepage: www.elsevier.com/locate/daach

3D reconstruction of marble shipwreck cargoes based on underwater multi-image photogrammetry

C. Balletti [a,*], C. Beltrame [b], E. Costa [a], F. Guerra [a], P. Vernier [a]

[a] Università Iuav di Venezia, S. Croce 191, 30135 Venezia, Italy
[b] Università Ca' Foscari Venezia, Dorsoduro 3484/D, 30123 Venezia, Italy

ARTICLE INFO

Article history:
Received 30 June 2015
Received in revised form
25 September 2015
Accepted 29 November 2015
Available online 2 December 2015

Keywords:
Cultural heritage
Maritime archaeology
Underwater survey
Multi-image photogrammetry
3D modelling
GPS

ABSTRACT

Acquisition and processing of point clouds, allowing the high dimensional accuracy that is an essential prerequisite for good documentation, are widely used today for cultural heritage surveys. In recent years, manual and direct surveys in archaeological survey campaigns have been replaced by digital image processing and laser-scanning. Multi-image photogrammetry has proven to be valuable for underwater archaeology. A topographical survey is always necessary to guarantee dimensional accuracy, and is necessary for geo-referencing all the finds in the same reference system. The need for low costs and rapid solutions, combined with the necessity of producing three-dimensional surveys with the same accuracy as classical terrestrial surveying, led the researchers to test and apply image-based techniques. Ca' Foscari and IUAV University of Venice are conducting research into integrated techniques for the accurate documentation of underwater surveys. Survey design, image acquisition, topographical measurements and data processing of two Roman shipwrecks in southern Sicily are presented in this paper. Photogrammetric and topographical surveys were organized using two distinct methods, due to the different characteristics of the cargoes of huge marble blocks, their depth and their distribution on the seabed. The results of the survey are two 3D polygonal-textured models of the sites, which can be easily used for various analyses and trial reconstructions, opening new possibilities for producing documentation for both specialists and the wider public. Furthermore, 3D models are the geometrical basis for making 2D orthophotos and cross-sections. The paper illustrates all the phases of the survey's design, acquisition and preparation, and the data processing to obtain final 2D and 3D representations.

1. Introduction

Since the 1960–70's archaeologists have adapted the aerial surveying method to underwater conditions, using photogrammetry with the first stereo-pair cameras to document underwater sites (Bass, 1966; Hohle, 1971; Leatherdale and Turner, 1991; Capra, 1992). These cameras offered high accuracy in recording, measuring and interpreting photographic images, but imposed some operating constraints, such as parallel optical axes required for stereo-vision conditions. Another disadvantage was the high degree of technical knowledge required to produce relatively few measurements.

The necessity of producing accurate detailed three-dimensional mapping, a product of stereo-photogrammetry, combined with the necessity of reducing underwater work time for hyperbaric reasons, has driven researchers to look for a fast documentation technique. At the same time, this technique had to be low-cost and accessible, considering the limited budgets of the discipline. Image-based technique using digital photogrammetry is now recognized as a powerful and accessible tool for non-destructive archaeology all around the world, and also for underwater archaeological sites (Green et al., 2002; Canciani et al., 2003; Bass, 2006; Green, 2004; Drap et al., 2007, 2013).

McCarthy and Benjamin (2014) present research using standard cameras and automated processing data with special software employed to capture 3D models of underwater archaeological features. Furthermore, the possibility of checking the results in the field is certainly one of the main advantages.

In recent years, Ca' Foscari University and University IUAV of Venice have been conducting research into the application of integrated techniques to support underwater measurement documentation. Recently published papers, such as Menna et al. (2011), Skarlatos et al. (2012), Eric et al. (2013), Henderson et al. (2013) and Demesticha et al. (2014), show how multi-image

* Corresponding author.
E-mail addresses: balletti@iuav.it (C. Balletti), beltrame@unive.it (C. Beltrame), ecosta@iuav.it (E. Costa), guerra2@iuav.it (F. Guerra), vernier@iuav.it (P. Vernier).

http://dx.doi.org/10.1016/j.daach.2015.11.003
2212-0548/

photogrammetry is now an effective technique for mapping and retrieving the shape and geometry of completely submerged objects. Underwater photogrammetry has thus been transformed from a highly technical and costly process to a much more powerful and accessible tool (McCarthy and Benjamin, 2014).

The production of a precise 3D model offers many opportunities from both measurement and recording points of view, because it represents a realistic model. It is possible to verify directly many kinds of data: measurements, shapes, colours, locations, etc., without the necessity of returning to the site.

This paper describes the method employed in two underwater sites in 2014, with image acquisition, topographical measurement and data processing to produce 2D drawings and 3D models of the shipwreck cargoes.

2. The archaeological sites

The research on the photogrammetric technique began some years ago in Crotone, southern Italy, with an experiment. Using some images not intended for a final 3D representation, but only for a simple photomosaic, we evaluated the perspectives of research of a 3D representation model from point clouds (Fig. 1).

The department of Studi Umanistici of Ca' Foscari University (headed by Carlo Beltrame) and the Circe Laboratory of Photogrammetry of IUAV University of Architecture of Venice (headed by Francesco Guerra), in collaboration with the Soprintendenza del Mare of the Regione Sicilia, decided to document two shipwrecks of cargoes of marble blocks dated to the Roman period by employing software that used several cameras and sensors to obtain dense point clouds or 3D models.

Archaeometric analysis by Lorenzo Lazzarini (LAMA, University IUAV of Venice) of a few samples preliminarily identified proconnesion marble from the Sea of Marmara.

The archaeological sites differ in the distribution of the cargo on the seabed and the depth, but the integrated survey method of these shipwrecks is the same and comprises the following stages:

1. cleaning the subject from seaweed and partially from concretions;
2. manual measurements of the dimensions of the blocks and detailed photographs of the archaeological sites;
3. laying ground control points (CGP) on the upper surfaces of the marble blocks and a topographical survey of the CGP, with trilateration (Direct Survey Method) and GPS RTK measurements;
4. image acquisition for multi-image digital photogrammetry;
5. 3D modelling and hypothetical reconstruction.

2.1. First case study: Marzamemi I shipwreck

In 1958 fishermen discovered marble blocks on the seabed near

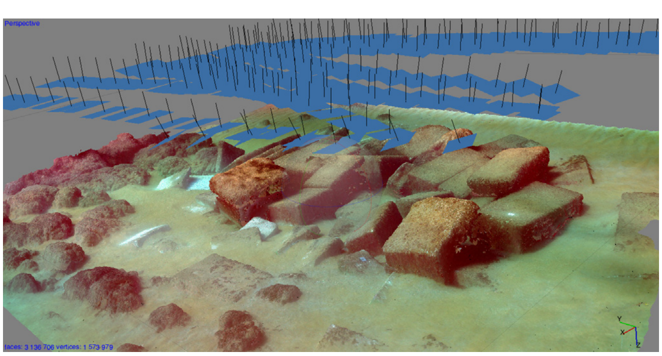

Fig. 1. Punta Scifo D shipwreck. Camera alignment and points cloud.

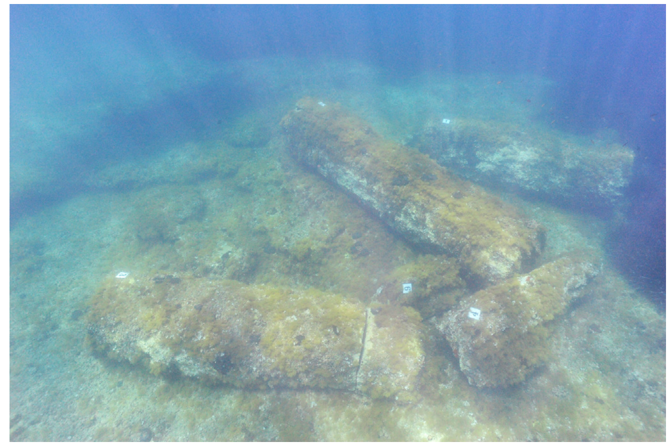

Fig. 2. Marzamemi shipwreck. Detail of the three columns (photo: D. Della Libera).

Marzamemi (Siracusa), southeastern Sicily. The following year, Kapitaen (1961), P.N. of the Gargallo Marzamemi I shipwreck, documented the shipwreck with a preliminary survey and some photographs, dating the site to the 3rd century AD, based on the study of two types of amphora found on site.

The site included 15 marble blocks scattered on the seabed; but actually the presence of *Posidonia oceanica* hid two of the more distant blocks. The cargo was semi-finished, irregular and degraded columns and squared blocks.

The principal cluster of 9 items comprised (Figs. 2 and 3):

1. 3 large columns, with a maximum length of 595 cm and a diameter of 138 cm;
2. 3 large squared blocks, the largest measuring about 4 m^3;
3. 1 large irregular block with a maximum length of 343 cm;
4. 3 small parallelepiped blocks.

The other four blocks are away from the main cluster:

1. 15 m to the south is the largest column of the site (and also the largest column found underwater in the Mediterranean), measuring 640×185 cm^2, and weighing 49 tons;
2. 15 m to the south-west are two overlapping medium-sized blocks;
3. 32 m to the west is another column.

The total tonnage, calculated on a specific gravity of 2.68 g/cm^3, is 164 tons, with a total volume of 61 m^3.

Fig. 3. Marzamemi shipwreck. Detail of the squared blocks (photo: D. Della Libera).