Three-dimensional Underwater Mapping: The Kizilburun Excavation

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Abstract

In the summer of 2005, the Institute of Nautical Archaeology (INA) undertook the first season of excavation at the wreck site of a Roman *navis lapidaria*, or stone carrier, off the Aegean coast of Turkey. This excavation was also one of the first INA excavations to be mapped predominantly with PhotoModeler Pro®. The software allows for the three-dimensional mapping of a site solely through the use of photographs and points of reference. As a mapping tool, it offers relatively high accuracy, maximizes time efficiency on the sea-bottom, and as far as equipment is concerned, requires only a calibrated digital camera with underwater housing, and an established system of datum points. Subsequently, mapped, referenced points may be transferred to 3D imaging software, such as Rhinoceros®, where an accurate three-dimensional model of a site may be created for study and public education purposes.

1 Introduction

The Institute of Nautical Archaeology (INA) has long experimented with efficient and accurate means of mapping underwater sites through its decades of work in the eastern Mediterranean and elsewhere. This region of the world is characterized by good underwater visibility, a fairly rugged coastline, and a sea-floor that varies between rock outcrops and sand valleys. In addition to these environmental conditions, excavation of underwater sites (predominantly shipwrecks) often entails the mapping of a large number of artifacts superimposed in a relatively small area, in addition to the mapping the surrounding seabed—something which further complicates site recording. The precision of the measurements required for interpreting site formation processes, as well as the reconstruction of the hull of a wreck, something of particular interest to nautical archaeologists, also requires a very accurate method of three-dimensional (3D) mapping of the site. Finally, the complications and restrictions imposed on archaeologists by diving require a technique that makes the best use of the limited time at depth.

2 Research Approach

As a result of the considerations noted above, during the excavation of the Tektaş Burnu wreck, the INA adopted the use of a new technique in underwater archaeological mapping, based on PhotoModeler Pro®, a photo-triangulation program. The software utilizes a calibrated camera to measure the ray paths from the principal point of the camera, through the photographic image, to various points on a site (Green et al. 2002:283). Using a series of images containing the same area/points, but shown from different angles, the software is capable of assigning X,Y,Z coordinates to particular points. The coordinates may be calibrated based on information provided by the user, such as the precise location of datum points. In the case of the INA excavations, the X,Y,Z coordinates of the datum network used to calibrate all other points were calculated through the use of Site Surveyor® (see below). All points were then be exported to three-dimensional imaging software, such as Rhinoceros®, allowing archaeologists to create a three-dimensional site map, with artifacts properly positioned and oriented. The experimental use of this mapping technique produced favorable results and thus the same method, somewhat improved by lessons learned, was adopted in the mapping of the Pabuç Burnu wreck during the 2002 and 2003 seasons. In turn, having successfully functioned as the predominant mapping technique of the Pabuc Burnu excavation, it was decided by the INA that PhotoModeler Pro® would be used as the main recording method in its latest shipwreck excavation at Kızılburun (Crimson Cape), off the Aegean coast of Turkey.

The first season of the Kızılburun excavation at the wreck site of a Roman *navis lapidaria* (stone-carrier) began in the summer of 2005 under the direction of Dr. Deborah N. Carlson of Texas A&M University. This site is of particular importance as, although there have been more than a dozen stone cargoes located in shallow waters throughout the Mediterranean, most have only been superficially studied by archaeologists. The vessel, which based on preliminary estimates is dated to the 1st century BC, appears to have carried a single monumental marble column composed of eight individual drums and what may be Doric capital. During approximately 1000 dives, members of the team successfully mapped and raised close to 800 artifacts, which are now being conserved in the conservation laboratories of the Bodrum Research Center of the Institute of Nautical Archaeology, located in Turkey.

The nature of the site posed numerous difficulties to conventional multi-tape trilateration mapping as it lies at a depth bordering 48 m (≈160 ft), on a slope surrounded by rocky outcrops. The depth drastically limits the amount of time archaeologists may spend on the site, whether excavating or mapping, while the surrounding environment makes drawing tapes to various targets on the site fairly difficult. The very size and shape of the primary cargo, the marble drums, separates the site into distinct units, further stressing the weaknesses of conventional mapping. As a result, members of the team were keen to adopt the PhotoModeler Pro® photo-triangulation technique that had proved successful with mapping deep and complex underwater sites in the past.

In order for PhotoModeler Pro® photo-triangulation mapping to properly function in underwater sites, three essential elements are required—a calibrated digital camera (calibrated by following directions provided in the software), some system of reference points whose X,Y,Z, coordinates are known, and, subsequently, targets which are used to identify points whose X,Y,Z, coordinates need to be determined. Various aids may be used to make the process more efficient and accurate, although these may vary from site to site.

The first step in mapping the site involved establishing a series of datum points/towers around the perimeter of the wreck. These datum points needed to be firmly set into place; if they unknowingly moved at any time during the excavation, the result would have been calibration errors in the mapping. Subsequent routine checks of their absolute provenience were an integral part of the data calibration process. The datum points also needed to be elevated so that one could view at least three, preferably more, datum points from anywhere on the site. The distance between all the datum points was then measured using tape trilateration and the distances were input into Site Surveyor®. This software takes the collected data into account and provides the user with calibrated X,Y,Z coordinates for each datum point. Erroneous measurements are identified, prompting the user to collect new data. Obtaining accurate X,Y,Z coordinates for each datum point was crucial in the mapping process as from that point on, all mapped points relied solely on their relation to the datum points for their X,Y,Z coordinates. Once this step was completed successfully, the next stage of the mapping process could begin.

A series of targets, ranging chiefly from what were referred to as "flags," to, on occasion, more solid "tiles," as well as small temporary targets made of perishable, high-contrast materials (neon putty), were then placed on the site. The purpose of these targets was to identify a particular point on the site, whether this was the general location of smaller artifacts or characteristic points of interest on larger ones. In the case of Kızılburun, the flags and the tiles were identified by numbers and letters, respectively. This greatly simplified the post-processing task of correlating targets in various images taken from a number of angles.

A mapping run, which involves taking a series of photographic images, was then conducted in a particular area using the calibrated camera; based on experience the same area needed to be photographed from at least six different angles in order to properly correlate the targets within each image. The images also needed to include as many datum points as possible, at the very least three, in addition to the targets that needed to be mapped. Finally, in order to provide for the most accurate results possible, the team also made use of 1m square reference frames, which were marked at 10 cm intervals. These frames were large enough to be visible in any overall photograph of the site, and small enough to act as borders in any image used for the precise mapping of individual artifacts. A single 20-minute dive tended to be sufficient for a team of two divers to photograph the entire site for mapping purposes.

The images were then uploaded into the PhotoModeler Pro® software for post-processing. The sequence followed involved identifying targets in a particular photograph, and then proceeding to identify the same targets in all other photographs of the same area (taken on the same mapping run). The process was repeated until all possible targets were identified in all photographs of a given mapping run. In addition to the targets, clearly identifiable points that are not necessarily artifacts but are visible in multiple images, were also mapped. Such was the case with the reference frames, which provided both a means of referencing detailed to overview images, as well as numerous clearly identifiable points along their marked edges. It should be mentioned that, to a certain degree, the more points that are correlated between the various images, the better the overall calibration. Using the X,Y,Z coordinates of the datum points provided by Site Surveyor®, each identified point was then assigned respective X,Y,Z coordinates. The software also provides the user with a "tightness" classification in order to make sure that each target/point lies along a calculated line of "best fit."

The final step of the mapping process involved exporting the X,Y,Z coordinates of all the artifacts (and perhaps other points of interest) into three-dimensional modeling software, such as Rhinoceros®, where an accurate, three-dimensional model of a site was created. Using the exported coordinates each artifact could be precisely placed in its position, imported to scale, and properly oriented. Following each subsequent mapping run, new points were exported to the site map, guiding the archaeologists along as new artifacts were virtually reconstructed on the digital site plan. The resulting site plan, given its three dimensions, allows for a much better understanding of a site, and aids archaeologists in interpreting wreck formation processes. It is also a much more effective in conveying information to the general public.

3 Conclusion

PhotoModeler Pro® is not suitable for all sites and all conditions as the software does present a few drawbacks. A prerequisite for the use of the software is good site visibility, as without it, the all-important precise identification of targets is compromised. In addition, it is important to note that the software can be taken further, as it is capable of automatically recognizing targets. The ambient light and visibility that make this function possible in terrestrial sites, however, are seldom present in underwater sites. This means that significant time needs to be devoted to post-processing. Although this may lead to the overall time devoted to mapping in this fashion to be equal to that needed for conventional mapping (if not more), it is dive time that is of utmost importance in underwater sites, and the use of this technique significantly reduced the dive time devoted to site recording. Finally, mapping through the use of PhotoModeler Pro® requires significant planning and organization. Potentially, there can be hundreds of points each related to a particular object and

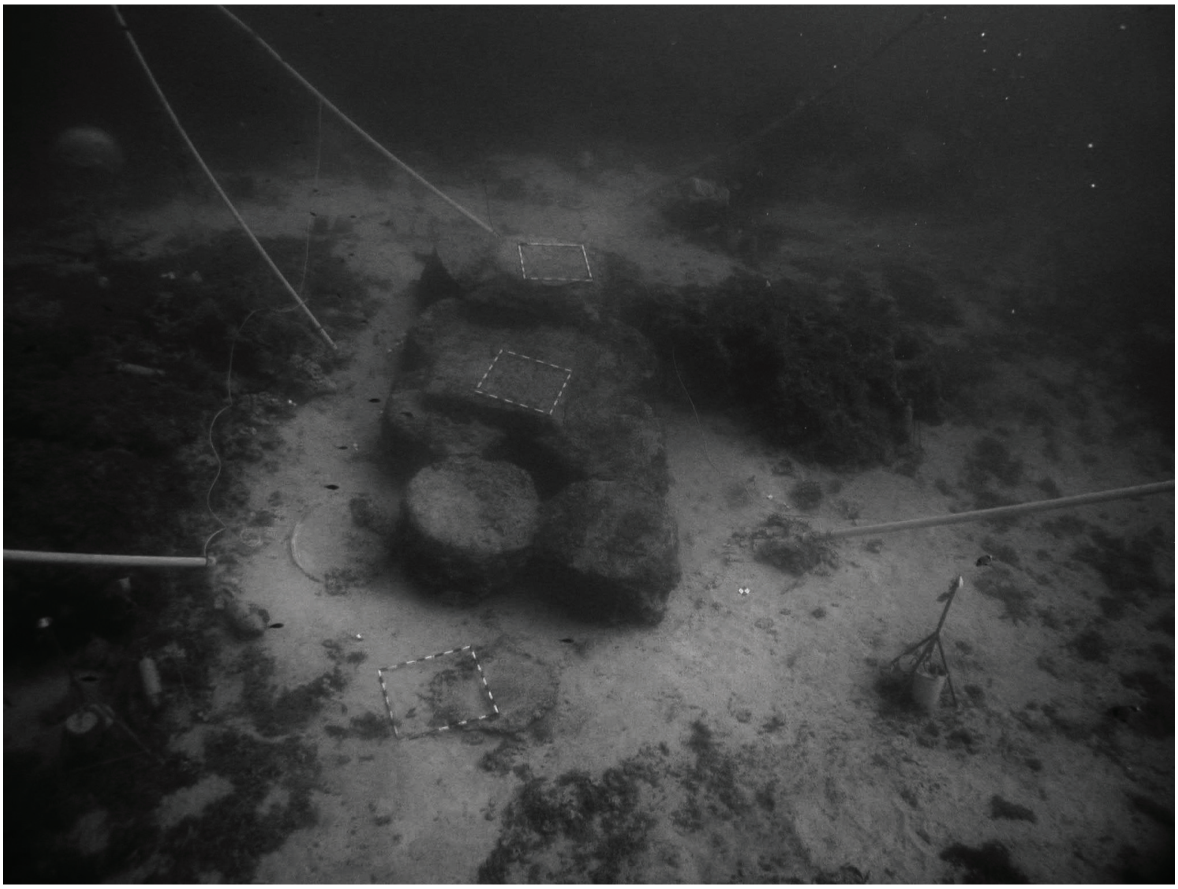

Figure 1. The site of the Roman stone-carrier wreck off the coast of Kızılburun (Turkey)

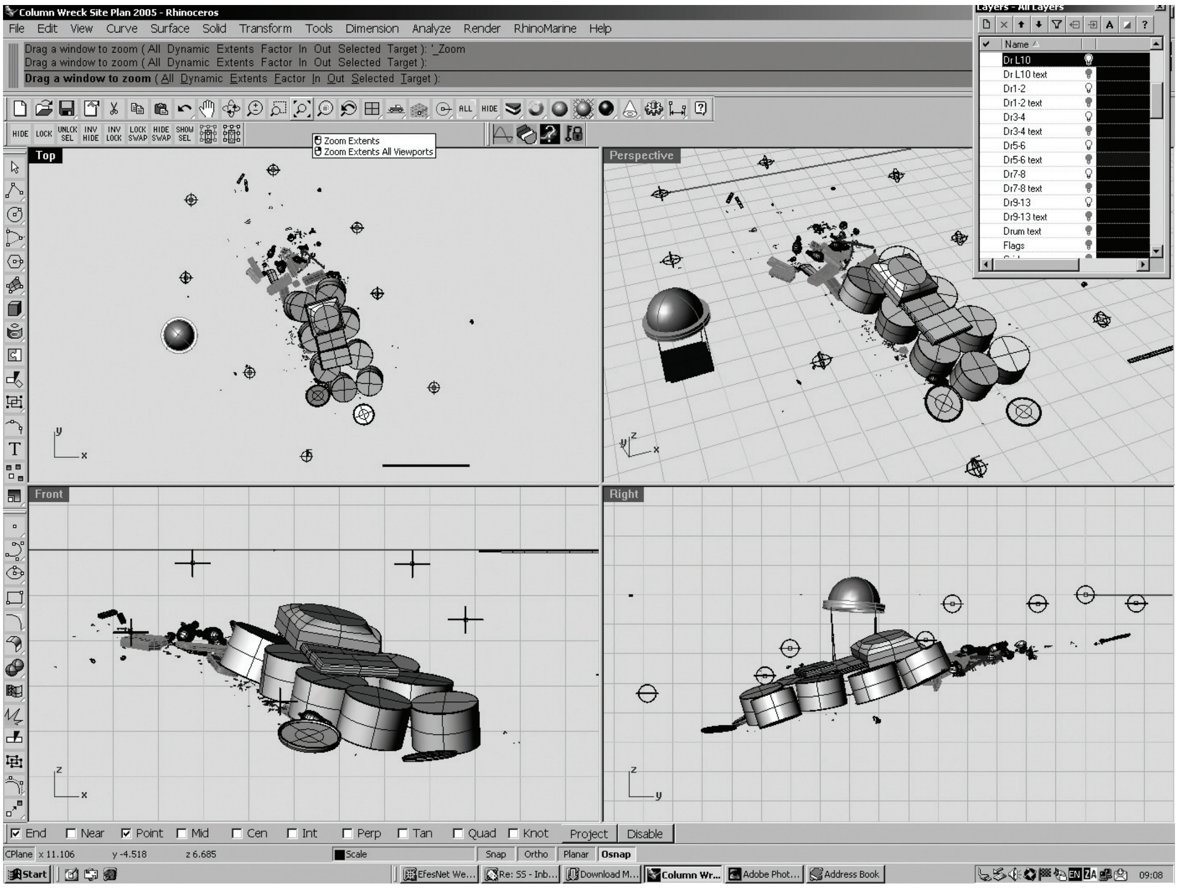

Figure 2. Photomodeler Pro® site mapping in progress.

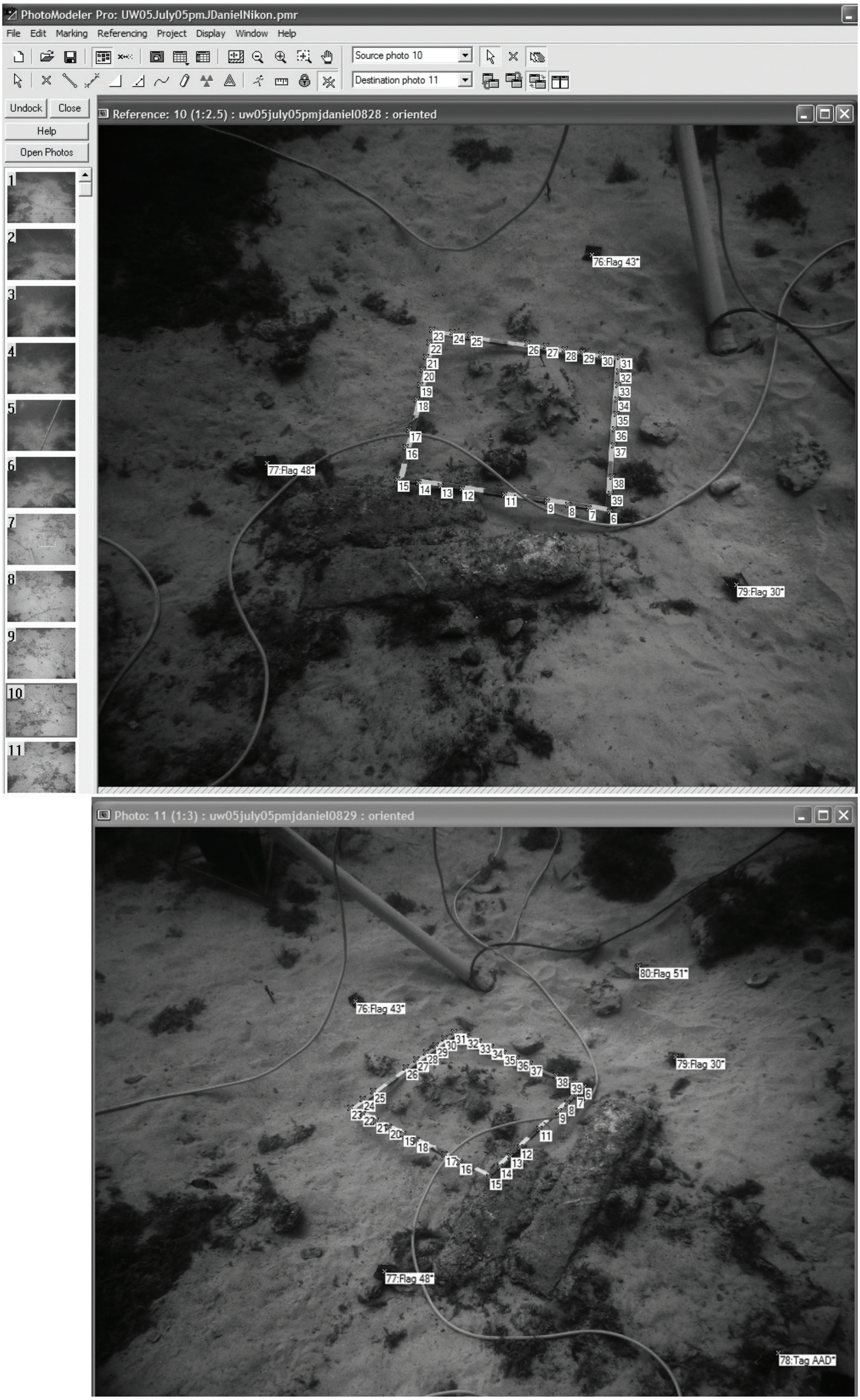

Figure 3. Three-dimensional site reconstruction as modeled in Rhinoceros®.

cross-referenced to various files and images, from different mapping runs, and different dates. Complicating the situation is that in an excavation setting, the same flag (identified by its number) may potentially be re-used to identify a different target, as it may be at times unreasonable to create hundreds of uniquely numbered flags. Thus, a clear flag to mapping run to date correlation must be established and maintained throughout the duration of the excavation. It is recommended that images are saved in duplicates so that originals are never modified, something which often results in loss of image quality. Finally, it is clear that all precautions need to be taken in order to avoid loss of critical data once the decision is made to rely (solely) on digital data for mapping.

Taking all these characteristics of the software into consideration, the use of PhotoModeler Pro® as the basis of three-dimensional underwater mapping for the Kızılburun excavation proved to be an effective means of balancing the issues under consideration. Based on current estimates, all mapped points of interest had a degree of error of no more than 2-3 cm, an acceptable discrepancy for underwater sites. Most importantly, this was accomplished without expending large amounts of valuable dive-time. A group of two divers was assigned to mapping each day, allowing all other divers to focus on other aspects of the excavation such as airlifting, removing marine concretion, drafting, etc. In a single dive, the divers were able to plot the location of tens of artifacts, if not more. In this manner, excavators did not have to constantly reach for a measuring tape or interrupt the work of fellow divers in order to map the position of artifacts. As the excavation is ongoing, and slated for completion in 2008, the ability to add information to an existing site-map is a further desirable characteristic of this mapping method. Having decided upon the creation of a three-dimensional site model prior to the beginning of the excavation, the exporting of target X,Y,Z coordinates from PhotoModeler Pro® to the modeling software was a smooth process. As a result, an accurate, editable, informative, and visually appealing site-plan can be created in three dimensions.

Acknowledgements

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