Journal of Archaeological Science: Reports 6 (2016) 302–309

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

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

Scanning the *H.L. Hunley*: Employing a structured-light scanning system in the archaeological documentation of a unique maritime artifact

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ARTICLE INFO

Article history:
Received 23 November 2015
Received in revised form 16 February 2016
Accepted 20 February 2016
Available online 3 March 2016

Keywords:
3D data acquisition
American Civil War
H.L. Hunley submarine
Structured-light
Maritime archaeology

ABSTRACT

In 2008, the Warren Lasch Conservation Center acquired a Breuckmann Opto*TOP*-HE structured-light scanning system to begin the 3D documentation of the American Civil War submarine *H.L. Hunley*. The choice of this particular system was determined by the interests of the archaeological team and the particular research goals of the project. High resolution 3D surface topography and integrated photographic data were considered equally necessary, suggesting an optical-based scanning system. However, maritime artifacts, or artifacts from a marine environment, are necessarily stored in water or other aqueous solutions prior to completing the conservation process. Using structured-light technology on the *H.L. Hunley* submarine itself, as well as other artifacts kept in a wet condition, presented the team with some unique difficulties in terms of three-dimensional documentation. This paper will discuss the use of structured-light scanning on the *H.L. Hunley*, and highlight some of the specific problems and challenges encountered when employing this technology on maritime archaeological material. In particular, we would like to present a brief study of the effectiveness of optical scanning to record surface details, including issues of reflectivity, color, and surface darkness. Moreover, we intend to address the challenges of using the 3D data to reconstruct the submarine into an accurate, color 3D model. It is hoped that this study will both illustrate the problems associated with recording maritime artifacts and suggest further avenues for research and the development of strategies useful for better data collection.

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1. Introduction

The application of 3D scanning technology for archaeological documentation has progressed much over the last fifteen years. The development of various forms of dimensional metrology has given archaeologists many more tools to implement in the collection of three-dimensional data and the analysis and interpretation of this data. While the technologies available have been well tested and rigorously evaluated in terms of their applicability, it has also become apparent that the applicability and usefulness of certain scanning technologies varies depending on the type and nature of the archaeological material, and the kinds of information that one intends to capture (Breuckmann, 2014; Gernat et al., 2008; McPherron et al., 2009). Structured-light scanners have been particularly useful for small artifacts, where high-resolution and comparative evaluation is important (Akca et al., 2007; Karasik and Smilansky, 2008; Grosman et al., 2008; Niven et al., 2009), while laser scanners and photogrammetry have been more successfully utilized on larger area sites (Remondino, 2011; Martínez et al., 2015). Choosing the wrong technology, or being unable to utilize the data that is collected, can be a costly mistake in terms of both time and money; for high-resolution measurement, the upfront costs can be especially high. In this regard, understanding the documentation technology, the data that will be gathered, and the hardware and software necessary to process this data is equally important when choosing to apply a 3D documentation strategy in the recording of any archaeological site or material.

The recovery and excavation of the American Civil War submarine *H.L. Hunley*[1] presented the archaeological team at Clemson University's Warren Lasch Conservation Center (WLCC) with a number of specific and complex challenges for documentation that required a unique approach to the recording of provenience information. First was the dimensions and structure of the submarine itself. The *H.L. Hunley* is approximately 12.2 m. long, 1.1 m. wide, and 1.3 m. high, and initially supported by a truss and sling system along its entire length (see Fig. 1). The hull is composed of wrought iron plates, approximately 75–81 cm wide, riveted together to form an elongated cylinder, with cast-iron forming the two hatches, the bow and stern pieces, and

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[1] The *H.L. Hunley* submarine was lost several miles offshore of Charleston SC, USA, on February 17, 1864. It was recovered on August 8, 2000 and brought to the WLCC on the former Charleston Naval Base where it is currently undergoing conservation, stabilization, treatment, and analysis. For further background, see: David L. Conlin, ed., *USS Housatonic Site Assessment*, Underwater Archaeological Branch, Naval Historical Center, Washington, DC, 2005; Robert S. Neyland and Heather G. Brown, eds., *H. L. Hunley: Recovery Operations*, Naval History and Heritage Command, Department of Navy, Washington, DC, 2016, forthcoming.

http://dx.doi.org/10.1016/j.jasrep.2016.02.023
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Fig. 1. The *H.L. Hunley* submarine in its sling support system. The submarine remained in this configuration until 2011.
Photo: Friends of the Hunley, Inc.

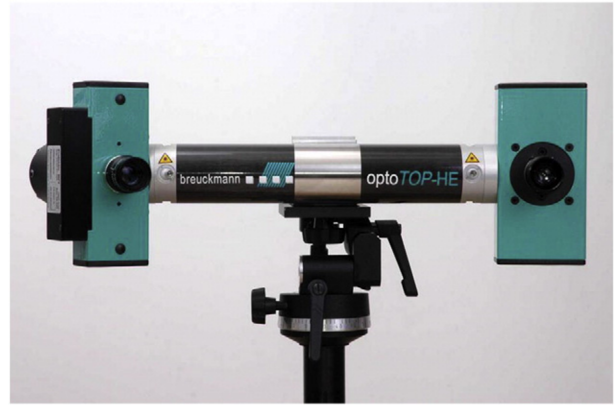

Fig. 2. The Breuckmann Opto*TOP*-HE structured-light scanner.
Photo: Breuckmann GmbH.

other complex components. The interior of the submarine was accessed through the removal of several plates and the subsequent excavation conducted via these openings.

Because of the nature of the Hunley as an archaeological site, a variety of techniques and technologies were employed at different times to collect three-dimensional and spatial data from the various parts of the submarine. The selection of technologies utilized for documentation was therefore entirely dependent on the specifics of the area of the site to be recorded, and the nature of the desired data. In the early phases of the excavation of the interior of the submarine, a simple point-mapping of artifact position and provenance was the priority for the archaeological team and the focus of our documentation work. This allowed researchers to accurately reconstruct artifact positions in CAD software after removal from the site. However, as archaeological research and conservation moved forward, the focus turned to surface topography, 3D documentation, and the recording of more detailed texture/color information of the Hunley submarine and its artifact assemblage. While the implementation of surface scanning provided the archaeological team with the means to collect high resolution topography and surface details, it also presented a number of unique problems in terms of data collection associated with the nature of the *H.L. Hunley* as a maritime or marine site.

2. Documentation objectives and methods

Beginning in 2008, the archaeological team at the WLCC embarked on a plan to comprehensively map and document all of the archaeological and forensic information contained on the *H.L. Hunley's* hull, its internal components, and artifacts using a three-dimensional surface scanner. The initial impetus behind this plan was the progression of the conservation process, which involved the removal of the submarine from its cradle of slings and supporting truss, the disassembly of several structural components, and the eventual deconcretion of the entire hull. The goal of our work was therefore to begin recording all relevant archaeological information from the hull prior to the deconcretion and subsequent conservation of the submarine and its related artifacts. This would not only insure that critical archaeological data was not lost during the deconcretion process, but also allow us to capture a complete 3D representation of the submarine. In addition, we hoped to use three-dimensional scanning to document artifacts recovered from the *H.L. Hunley* before, during, and after conservation. Not only would this provide a detailed record of each artifact, but also allow for a comparative study of the conservation process through the dimensional analysis of each artifact throughout its lifetime. Lastly, the integration of our scan data with provenience information from the excavation would enable a complete three-dimensional reconstruction of the *H.L. Hunley* site, which would integrate not only the hull but also the entire artifact assemblage, sedimentary and macrofaunal information, and excavation records, into a unified, virtual site plan. This would provide the scientific team with an unprecedented level of detail about the *H.L. Hunley* submarine, and a give us an extremely powerful analytical tool for studying the submarine now and in the foreseeable future.

The scanning system chosen for the 3D documentation of the *H.L. Hunley* submarine was the Breuckmann GmbH Opto*TOP*-HE structured-light scanner (see Fig. 2).[2] The scanner consists of a two principal components: a projector and a single 1.4 Megapixel color camera. These components are separated by a carbon fiber bar and oriented at a 30° angle to each other. Each component can also be fitted with variable lens sets which, when combined with different bar lengths, allows for data collection at a number of fields-of-view and operating distances.

Structured-light scanning (SLS) technology, also referred to as "fringe-projection method" or "white-light scanning," is based on the projection of light patterns (typically grid lines or stripes) onto the surface of a target object and the subsequent interpretation and analysis of the distortion and displacement of these patterns when viewed (by one or more cameras) from different angles. The Opto*TOP*-HE scanner uses Breuckmann's Miniature-Projection-Technique (MPT) (see Fig. 3) for producing the fringe projection of patterns used to generate 3D surface data. The scanner's projector casts multi-phase slides of stripe patterns of differing widths upon the surface of an object. The digital camera then captures this pattern sequence and processes the information using a Gaussian curve algorithm to resolve a point cloud of 3D coordinates to represents the target surface (Salvi et al., 2004). Successive scans are then aligned using a least-squares, best-fit algorithm through post-processing software to build a 3D representation of the target object. All data acquisition, the initial post-processing, and preliminary alignment of scan data were accomplished using the Breuckmann OPTOCAT software package.

The Opto*TOP*-HE system was chosen for a number of specific reasons. Firstly, because SLS technology uses photographic data collection, it takes only a few seconds to capture a complete field-of-view scan. The Breuckmann Opto*TOP*-HE scanner can collect, depending on the configuration, 1–2 million points in this time period. This relatively fast collection speed was extremely important for our proposed work on the hull of the *H.L. Hunley* as it offered a potential solution to our problems of "noise" or errors that typically result from slight movements of the target object. Because the submarine rested in a cradle of slings, movement and its resulting distortion was a problem frequently encountered

[2] The Opto*TOP*-HE High-End 3D Digitizing System was purchased by the WLCC in 2008. For more information and technical details of Breuckmann scanning systems (a subsidiary of AICON 3D Systems GmbH), visit: http://aicon3d.com/products/breuckmann-scanner.html.

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