The Alabama Yardstick: Testing and Assessing Three-Dimensional Data Capture Techniques and Best Practices

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Abstract

Archaeological data documentation practices increasingly focuses on the use of (or incorporation of) digital, three-dimensional (3D) data capture technologies. Today, topometric scanning systems are feasible tools to implement both in terms of cost and ease of use. The capabilities and design of 3D scanning systems grow at an ever expending rate, and these provide detailed records to a degree never before achieved through photography and other illustrative techniques alone. However, with the range of technologies available today, we have yet to formulate and achieve a standard, or common, approach to 3D scanning documentation in archaeology. This then implies that an individuals approach to documentation of an archaeological object utilizing these techniques is measured only against their own achievements and their unique data set. If no 'yardstick' exists, how are we to compare data sets and assess the approach and results of other people's work in the field?

In order to create a dialogue along these lines, we developed a collaborative scanning project. The partners came from the Clemson Conservation Center, University College London, Newport Medieval Ship Project, Vasa Maritime Museum, and the Smithsonian Institution. The idea was for each partner to scan the same object, utilizing the 3D scanning technique available at their respective facility, record their approaches, and compare the results. Quantifying and understanding the variable results achieved, we believe, would start a discussion that eventually could take us down the road of achieving a standard approach and common language with regard to 3D data recording in archaeology.

***Key words**: 3D Digital Artifact Documentation, Standardization, Laser Scanning, Structured-Light Scanning, CSS Alabama*

1 HISTORICAL BACKGROUND

The CSS *Alabama* (see fig. 1) was built for the Confederate States Navy in 1862 by John Laird Sons and Company of Birkenhead, United Kingdom. During the American Civil War (1861-65), the *Alabama* served as a commerce raider, attacking Union merchant and naval ships. Over the course of a two-year period, the crew of the 1050-ton screw sloop-of-war, Captained by Captain Raphael Semmes, captured 447 vessels and succeeded in sinking the U.S.S. *Hatteras*. She was at sea for 534 of the 657 days of service, and never laid anchor in a Southern port. During this time she took 2,000 prisoners with no loss of life.

In June of 1864, in need of major repairs to both hull and machinery she put in at the harbour of Cherbourg, France. There the US Navy caught up with the ship, and on June 19, the *Alabama* went out to challenge the USS *Kearsarge*, captained by John A. Winslows. After one hour and ten minutes of intense battle at distances as close as 500 yards, the *Kearsarge* delivered a mortal blow and the *Alabama* sank. There the wreck lay undisturbed for 120 years until in November of 1984 she was discovered by Lieutenant Commander Bruno Duclos of the French Navy minesweeper *La Circe.*

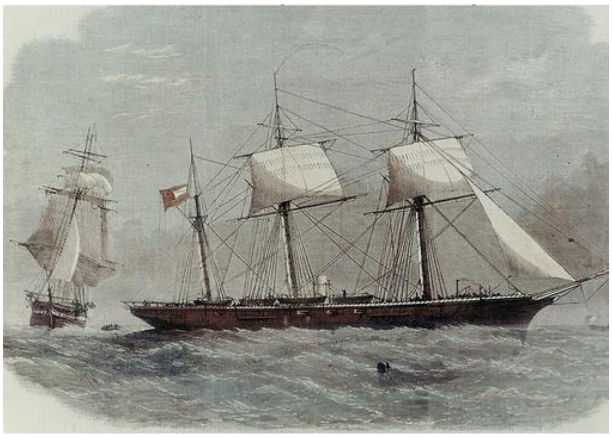

Figure 1. CSS *Alabama*. U.S. Naval Historical Center 2009

The site was partly excavated and several artifacts raised, including six cannons recovered by the French Navy and sent for conservation. In 2002 the Clemson Conservation Center received two of these cannons (fig.2) for treatment. During the process of conservation, the concretion (marine corrosion layer) covering the cannons were removed, including a fragment WL0688 utilized for this study. In 2009 the conservation of the cannons was completed.

Figure 2. A CSS *Alabama* Cannon partly de-concreted. CCC 2009.

2 THE ARTIFACT

The triangular-shaped marine concretion (WL0688) selected for this study weighs 0.73 kg and measures 18 x 17 x 2 cm and has an overall surface area of 289 cm^3. The shape is triangular, resembling a wedge. The upper surface is rough and has a very rugged topography with numerous miniature lacunae and creviches. Evidence of macrofaunal growth is also present in the form of crustaceans and impressions of annelid worms. The underside of the concretion, where it was in contact with the surface of the cannon, on the other hand, is smoother. The artifact was chosen for the 3D scanning project because of its complex surface topography.

Figure 3. Fragment of concretion WL0688. CCC 2009.

4 SCANNING OBJECTIVES

The primary objectives of this collaborative scanning project was to test and assess the capabilities of a range 3D digital scanning systems currently utilized in the field of archaeology by comparing scan data of the same object, and to assess the individual approaches to object handling and documentation. It was hoped that this would lead into a discussion on how to formulate and achieve a standard language and common approach to 3D scanning documentation in archaeology. The accuracy in terms of metrology of the different systems was not in question. Guidelines to ensure data capture accuracy have already begun to be created, see for example VDI/VDE 2634[1]. The focus here was to understand the technical advantages and disadvantages of different systems implemented, but also, and perhaps more importantly, understanding the non-technical variable, i.e. the human element and and the different environmental factors affecting object handling, scanning quality and consistency.

5 SCANNING PARTNERS

The scanning partners were chosen primarily for the types of technologies a diverse set of systems which they employed. The differing methods of data capture both practically and technically produce differing attitudes to recording. Each scanning technology operates in fundamentally the same way; they produce a 3D image which generates a surface.

The partners of the collaborative scanning project were:

Group 1 *– Clemson University Conservation Center.*

Group 2 *– Smithsonian Museum Conservation Institute.*

Group 3 *– Vasa Maritime Museum.*

Group 4 *– University College London, Department of Civil Engineering.*

Group 5 *– Newport Medieval Ship Project.*

[2] *VDI/VDE* 2634 Technical rule, 3D Measurement Systems testing guidelines issued by Germany in 2002-2008.

6 3D SCANNING SYSTEMS

Structured Light Systems

The Clemson Conservation Center (Group 1) and the Smithsonian Museum Conservation Institute (Group 2) both utilized modular structured-light systems made by Breuckmann GmbH. Group 1 used the Opto Top-HE Scanner calibrated to a field of views (FOV) of 300mm (diagonal measurement), the Smithsonian Institute the Tritos Scanner calibrated to a 325 FOV. Structured-light technology works as a system of topometric measurement, based on the technique of photographic triangulation using Miniature Projection Technique (MPT) patented by the Breuckmann company. Both scanners consist of a small projection unit and a 1384 x 1036 pixel resolution digital camera mounted on an interchangeable bar to allow for varying field of views. The focal length and projection pattern of each system can be reconfigured by altering the lenses sets. This allows the user to configure the systems to document artifacts in range of sizes with a fixed resolution.

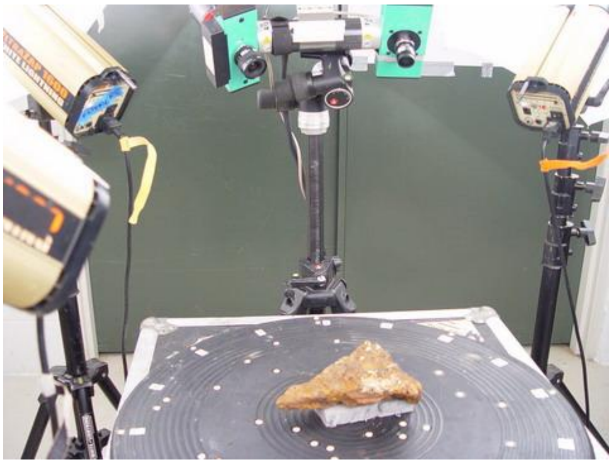

Figure 4. Recording artifact WL0688 with the Breuckmann OptoTop HE

The Vasa Ship Museum (Group 3) used the ATOS v6.1.0 3D Digitizer. This is also an optical measuring system based on photographic triangulation, the projected fringe patterns are observed with two cameras (stereo viewing), and 3D coordinates for each camera pixel are calculated with high precision. A FOV of 320mm was used. With this system 3D coordinates are computed up to a resolution of four million pixels., Geomagic v10 software employed for editing.

Laser Scanning Systems

The University of College London department of Geomatics (Group 4) used the Arius 3D scanner, a three dimensional color laser scanner that employs a motion control system for moving the camera. Each measurement point is characterized according to its color and location in space using the principles of high resolution, low-noise, three-color laser triangulation and optically-synchronized scanning. Each measurement point is described by three geometric values as XYZ and three reflectance values as RGB collected simultaneously from the target surface. Scanned data is recorded and processed by proprietary Pointstream software. Pointstream differs from the other software packages as it is raster, rather than vector based. The software builds objects from individual pixels that have six properties: red, green and blue color and X, Y, Z position, without creating polygons or applying texture maps.

The Newport Ship Project (Group 5) employed the Faro Laser ScanArm. The scanner is a non-contact measurement device with a fully integrated laser line probe. The system uses time-of-flight based using laser light to probe the subject and a laser rangefinder to calculate finds the distance of a surface by timing the round-trip time of a pulse of light. A laser is used to emit a pulse of light and the amount of time before the reflected light is seen by a detector is timed. The point data is collected and post processed using Geomagic v10.

7 Methodology and Workflow

For the project the groups were asked to record the number of scans taken and the time required to collect the data. Participants were required to scan the artifact to attain as much coverage as possible, in color if viable (with light meter readings) and to record their set ups. For post processing the groups were asked to remove erroneous data to avoid complications in 3D comparison. Similarly groups were asked not to smooth the surfaces at all or decimate the data. Finally groups were asked to create a final merged output file. The innovmetric file type .ply (Polyworks) was chosen for its universal applicability.

8 Preliminary Results and Conclusions

The purpose of the experiment described in this section was to compare in terms of global model accuracy the performance of each the scanning systems. The performances of the systems were evaluated by considering; number of scans, number of triangles, number of holes and finally a 3D comparison. Unfortunately direct comparison of UCL's (Group 3) data set could not take place as the output format does not create a mesh[4]. A .ply was considered but due the huge number of points in the dataset effective processing power was an issue.

Group	Time (mins)	Scans
Vasa	60	35
Newport	15	1 cont.
Smithsonian	145	74
Clemson	90	25

Figure 5. Time Taken to Record WL0688.

Group	Triangles
Vasa	1521890
Newport	2378450
Smithsonian	2346816
Clemson	290977

Figure 6. Number of Triangles.

Group	Holes
Vasa	70
Newport	516
Smithsonian	4810
Clemson	271

Figure 7. Number of Holes.

[4] File output is .pst a pointstream file

Differing methods of scanning meant that the number of scans collected by the various groups altered widely. Interestingly groups 1 & 2 used similar systems but the number of scans differed by almost two-thirds. Group 1 performed 25 scans whilst Group 2 performed 74. Group 3 collected 35 scans and registered data using targets located around the object's base. Group 5 collected one scan as the laser scanner collects data using one continuous beam. The conclusions that can be made regarding the amount of scans taken correspond to the type of technology used; its expected optical occlusion[5], depth of field, and, erosion of mask[6]. Overall, the number of scans and triangles vary depending upon the resolution of the scanner and the amount of scans taken. The user can therefore make their own choice for the approximate number of scans performed when recording an object as no accepted standard of recording exists by which to establish how long must be taken recording an artifact. The project guidelines required as much coverage as possible and each group created complete models. Although, every method showed some problems in collecting data in deep occlusions on the artifact. To achieve better coverage more scans need to be processed to try and cover occlusions at every possible angle.

3D Comparison

For evaluation of the reconstruction accuracy a 3D comparison was conducted using Geomagic Studiov8. The 3D compare tool within the software allows a detailed comparison between two models. Allowing the user to generate a three dimensional and a color coded map of the differences between the objects. The base model for comparison used was the model made by Group 1 as the artifact was scanned before and it was sent to the scanning partners. Future work however should include a calibration ball as recommended by the VDE/2364 optical measurement guidelines to aid the establishment of a known ground truth.

3D Compare	Standard Deviation	Average Distance
Clemson /Smithsonian	0.099mm	0.070mm
Clemson /Vasa	0.077mm	0.104mm
Clemson /Newport	0.090mm	0.103mm

Figure 8. 3D comparison.

3D comparison of the data collected showed an average standard deviation of 0.089mm and an overall average deviation of 0.092mm. Values for the individual comparison of the object were all higher than anticipated. Unfortunately total 3D comparison was impaired as the artifact was damaged during the project. Due to the brittle nature of the object areas around the edge became disarticulated as shown in by the dark area in Fig. 9.

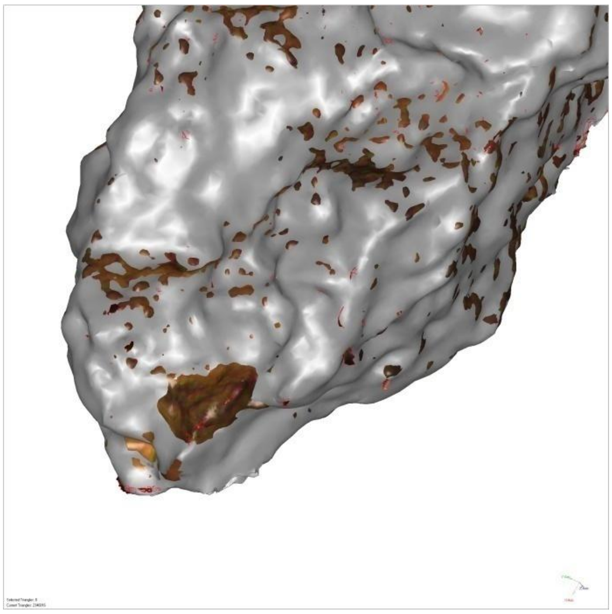

Figure 9. Large dark area showing detached piece from WL0688.

[5] If the path of the sensor is occluded by the object see William. Niem., *Robust and fast modeling of 3D natural objects from multiple views*. Proceedings of SPIE: Image and Video Processing II, Vol. 2182, 1994), 388-397.

[6] Shrinkage of resulting image to avoid bad points.

A total volume study was conducted by innovmetric using Polyworksv11 and the overall surface areas of the scans collected by Group 1 were 336033.9mm^3 and for Group 2, 329388.2mm^3. Resulting in a volumetric difference of 6645.7mm^3. In order to improve the survey a mean reduction of the spikes in the data or 'ski jumps' as they are more commonly known may have improved the 3D comparison. To further enhance accuracy of the results the filling of small holes (less than 4mm diameter) in the data sample may of improved 3D comparison results. Though this technique of 'improving' the scan data does detract from the archaeological integrity of each scan as fundamentally it would mean adding data.

Some extraneous points situated at the boundaries of the holes were also found which would of affect the 3D comparison. The heights of the points varied widely, a survey of the furthest distance in Group 1's scan showed a point distance of 0.450mm. Here the position of a single point increased the circumference of a boundary by 1.3mm. This would cause a discrepancy in the overall 3D comparison. Therefore, the minimum deletion of outliers and non manifold edges would be recommended for any future study.

Color Settings

Due to types of systems used a direct comparison of the color calibration methods used by each group was not possible as Group's 4 & 5 do not have color capture capabilities. Group 3 using the Arius color laser system collects data through RGB lasers. The system does not use ambient light to illuminate the object being scanned, so the resulting images are free of deficiencies such as glare and shadow and color cast[7]. The most suitable for close comparison were Group's 1 & 2. Both systems used OptoCAT 2007r2 for data capture and color calibration.

Setting	Group 1	Group 2
White Balance (vr)	84	76
White Balance (ub)	247	232
Shutter	11.62	9.58
Gain	1.00	1.00
Offset	0.6	0.6

Figure 10. OptoCAT Color Calibration Setting

The aim of color calibration is to adjust levels of a device in order to establish a known relationship to a measured color space. The OptoCAT color calibration setting provides five options; white balance (vr), white balance (ub), shutter, gain and offset. Both groups used white balance cards and Macbeth ColorChecker charts. The color checker is used for precise color balance in a range of professional photographic industries. An array of 24 printed color squares, which include spectral simulations of light and dark, skin and foliage, etc. The color checker charts are ideal as a source for calibration as all the colors have been measured and precisely produced to conform to the Munsell scale[8].

There are discernible differences in color between the two scans do exist. The artifact to the eye has a generally orange and brown hue, in comparison the scan performed by Group 1 is lighter than that of Group 2. The white balance (vr) setting of Group 1 was 84 and Group 2 was 76 (see fig.10). Calibration problems may have been caused by a scene balance issue caused by differing light source intensities and a color interpolation problem[9] as the number of targets that are measured using the color checker target (24) are comparatively small considering the range of colors in the spectrum that can be selected by the input device. Therefore the user's approximation of color being even just fractionally different can cause differing end products.

Color variations may also be attributed to the light source. Group 1 used four studio lights (Paul Bluff UltraZap 1500) with 300W bulb and 1m diameter umbrellas. Lights were set up with a stand-off distance of 1.2 meters from the center of the modeling wheel. The lights were set to model mode, this mode constantly emits a light over the object and the light switches were controlled manually by the user. Group 2 used overhead lighting (fluorescent and tungsten halogen) operated in switched groups from a 12' high ceiling. To limit color casting the room was painted flat grey. Variations in lighting and positioning result in slight but discernible variations adjusting the light source intensities can also be a reason for a color difference as the sources may not be identical. The radiance from individual bulbs of the same type will vary slightly depending upon their age and overall strength. The light source spectrum can also vary from bulb to bulb, with time and with level of power input.

[7] A color cast is a tint of a particular color, usually unwanted, which affects the whole of a photographic image evenly.

[8] Kuehni Rolf, "The early development of the Munsell system". *Color Research & Application* 27 (2002): 20–27

[9] Hsien-Che Lee, *Introduction to color imaging science* (Cambridge: Cambridge University Press, 2005), 35.

Artifact Color Change

The artifact also seemed to change color during its time with scanning partners. The color of the artifact was recorded under controlled conditions before it was sent out. A significant color change may of occurred due to the fact that the artifact is not fully stabilized and could still be oxidizing. During oxidization the surface would be expected to lighten and orange rust spots would be expected to appear. This took place over varying parts especially on the upper surface.

The center of the object also darkened dramatically. Here the color change is thought to be due fact that the artifact may have been handled without using gloves and oils from the skin may have altered of the Breuckmann system the object. However, it should be noted that guidelines on object handling were never made to any of the participants.

9 FUTURE WORK

From the experiment it is clear that the the establishment of methodological guidelines for assessing 'best practice' is a difficult target to achieve. The experiments performed in this work do not lead to the conclusion that one unique technique is recommendable. As future work increasing the number of objects, scanners and calibration tools will give a better overview of the current state of the 3D reconstruction. The known guidelines must be extended to establish more complete methods for ensuring effective comparison of the 3D models.

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